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The impact of Open Source Software and Hardware on technological independence, competitiveness and innovation in the EU economy

FINAL STUDY REPORT

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Abstract

This study analyses the economic impact of Open Source Software (OSS) and Hardware (OSH) on the European economy. It was commissioned by the European Commission's DG CONNECT.

It is estimated that companies located in the EU invested around €1 billion in OSS in 2018, which resulted in an impact on the European economy of between €65 and €95 billion. The analysis estimates a cost-benefit ratio of above 1:4 and predicts that an increase of 10% of OSS contributions would annually generate an additional 0.4% to 0.6% GDP as well as more than 600 additional ICT start-ups in the EU. Case studies reveal that by procuring OSS instead of proprietary software, the public sector could reduce the total cost of ownership, avoid vendor lock-in and thus increase its digital autonomy. The study also contains an analysis of existing public policy actions in Europe and around the world.

The scale of Europe's institutional capacity related to OSS, however, is disproportionately smaller than the scale of the value created by OSS. The study therefore gives a number of specific public policy recommendations aimed at achieving a digitally autonomous public sector, open R&D enabling European growth and a digitised and internally competitive industry.

Executive Summary

a. Introduction

This study was commissioned by the European Commission's DG CONNECT to analyse the economic impact of Open Source Software and Hardware on the European economy. It provides a comprehensive picture of the current commercial uses, costs and benefits of Open Source Software (OSS), and global policy efforts to utilise and magnify the benefits of using OSS. On the basis of this information, the study assesses the potential for the European Union (EU) to achieve its policy goals (including economic growth, greater competitiveness, innovation, and job creation) through the use, promotion and support of OSS and of Open Source Hardware (OSH).

The study involved the review of relevant literature, the performance of several case studies and statistical analyses, and a detailed survey among a representative sample of companies and developers. A strong consistency was observed between the data provided by the various sources consulted, and the data collected specifically for the study.

b. Econometric Analysis Insights

EU OSS developers (solo developers, academics, government personnel and employees) contribute significantly to the global OSS ecosystem. In the EU, it is employees of small and very small businesses that are most likely to contribute OSS code ("commits") whereas in the US commits are mostly made by large ICT companies, which base their relevant business models successfully on the large body of freely available and continuously improving OSS code.

Based on public domain information, companies located in the EU invested some €1 billion in OSS in 2018. The study concludes that the OSS pool contributes significantly to the EU's GDP, and that an increase of 10% in contributions would generate between 0.4% and 0.6% additional EU GDP per year. The study also concludes that an increase of 10% would generate more than 600 additional ICT start-ups per year in the EU. Case studies revealed that by procuring OSS instead of proprietary software, the public sector could not only reduce the total cost of ownership but could also reduce or prevent vendor lock-in. Overall, the benefits of Open Source greatly outweigh the costs associated with it. These benefits relate mainly to openness (including standards and independence) and labour cost savings rather than to additional revenue generation.

Econometric time series analysis of EU Member State GDP data indicates that in 2018, across all Member States, the economic impact of OSS was between €65 and €95 billion. Individual contributors numbered at least 260,000, representing 8% of the almost 3.1 million EU employees in the computer programming sector in 2018. In total, the more than 30 million commits in 2018 from EU Member States represent a personnel investment (based on full-time equivalents) equal to almost €1 billion, and the results of this investment are available in the public domain and therefore do not have to be developed by others again.

The data indicate that the smaller the company, the greater the relative investment in OSS (companies with 50 or fewer employees made almost half of the commits in our sample of the most active companies in OSS). Although more than 50% of contributors are from the ICT industry (8% of all employees participated in OSS development EU-wide), there was also strong involvement from professional, scientific and technical companies and, to a lesser extent, from wholesale, retail and financial companies.

On a cumulative basis, the study estimates that, up to 2018, the contribution of OSS to EU GDP, and contributions of EU employees to OSS, yield a cost-benefit ratio of slightly above 1:10. After taking into account hardware and other capital costs of the 260,000 EU contributors to OSS, the cost-benefit ratio is still slightly above 1:4.

c. Survey Insights

More than 900 companies and developers responded and approximately 100 replied to all the questions, which focussed on information about cost and benefits in areas not well covered in previous OSS research. Almost 25% of respondents were software development companies, and another 10% individual developers. A further 40% of company respondents produced components, final goods or services, or were platform providers, systems integrators or network operators. Only a small number of respondents meaningfully participated in OSH development. Start-up companies were strongly represented. Among the survey respondents, micro companies including start-ups make disproportionately significant contributions to, and investments in, OSS, both in absolute terms and relative to their size. Several small and micro companies reported that more than half of their revenues were attributable to OSS, and particularly OSS related services. Respondents (and particularly small and micro respondents) also reported a high percentage of innovation-related expenses, and almost 50% of their OSS contributions related to internal product development and another 40% to already existing OSS. Respondents rarely filed patents in relation to their public code contributions, but did find alternative ways to protect their intellectual property.

Motivations to participate in OSS, in order of priority, were: Finding technical solutions, avoiding vendor lock-in, carrying forward the state of the art of technology, developing high quality code, knowledge seeking, and knowledge creation. Personal interests of individual participants were also important. Accessing new markets and customers via contributions to OSS were not significant incentives. However, cost saving was an important motivation, through lowering internal maintenance efforts, gaining access to royalty-free code, and increasing returns on R&D investment. Other above-average motivations included: the establishment of networks, development of non-differentiating features (e.g., commonly used libraries) and enhancing reputation. Respondents using OSS and contributing code to OSS projects identified supporting open standards and interoperability as generating the highest benefits, with the benefits being indirect and arising through network externalities rather than from direct revenues. Respondents also assigned above medium importance to: access to source code, reduced expenditure, avoidance of vendor lock-in, access to an active community for knowledge exchange, the innovation fostering effect of participation, and enhancement of security and quality.

In terms of their own assessment of overall cost-benefit ratios, one third of respondents perceived very high benefits and low costs, and more than another third either very high benefits and medium costs or at least high benefits and low costs, with the most cited value being 1:10, followed by 1:5. For comparison, taking non-personnel costs (e.g., hardware) into account, the study estimates a cost-benefit ratio of 1:4 based on econometric based benefits.

d. Case Study Insights

To address the lack of data, in particular on OSH, from both the literature and our survey, five case studies were conducted on community development of Open Source Software and Hardware (OSSH), which can lower barriers to participation, enable experimentation and contribute to development of de facto standards. Foundations are a significant driver in the OSS and OSH ecosystems, providing a number of important services, such as standardisation, knowledge transfer and project management. Businesses participate in foundations to engage deeper with the OSSH community, not merely as technology consumers but also as key contributors and stewards. However, while several OSS and OSH projects (some with public funding) are headquartered in the EU, participation is not limited to EU individuals or companies. Participation correlates with company size and thus many participating companies are large US-based enterprises using OSS for their platform based business models. Thus it is difficult clearly to distinguish European OSS or OSH projects. It is also too early in most cases to assess benefits, as the OSH discipline is still emerging, with product development yet to come. However, the cases did reveal that both OSS and OSH ecosystems are highly and efficiently integrated with some overlaps, e.g., software support for OSH. The qualitative insights from case studies are used as a basis for the analysis of the strengths, weaknesses, opportunities and threats (SWOT) for the EU.

e. Policy Analysis

The study reviewed the scope, effectiveness and impact of governments' public and private sector policies relating to OSS in a number of EU Member States (Bulgaria, France, Germany, Italy, Poland and Spain) and other countries, in Europe (the UK), the Americas (the US and Brazil) and Asia (China, Japan, India and South Korea). The study used both qualitative and quantitative methods. The review revealed significant differences of scope and purpose between geographies. Finally, creating and implementing effective OSS and OSH policies remains challenging.

Overall, four main motivations were found, with changing emphasis over time: (i) cost savings; (ii) switching costs and network effects; (iii) underproduction of public goods; and (iv) market competition and technology neutrality. The study also identified two main waves of OSS government support, the first starting in the early 2000s and the second in the mid-2010s. Both these waves were driven by different narratives.

Public sector policies aim either to improve competence regarding Open Source and optimise results within the public sector, or to favour OSS over proprietary software in public procurement. Such policies have different scopes, implementation mechanisms and levels of prescriptiveness, ranging from binding laws to simple norms. Private sector policy actions are more varied. They include guidance and support for OSS. Some governments impose or influence industrial policy to produce innovation through OSS, while others work with universities to foster OSS training and development, or reach out directly to support the creation, or support, of OSS communities. Governments can also directly fund or certify Open Source projects to achieve policy goals.

Broadly speaking, government policies in Europe and the Americas focus on the public sector, while governments in Asia tend to focus on the private sector. A majority of surveyed EU Member States and other countries in Europe have formal policies on OS at the national level - in most cases, an OSS public procurement policy. Overall, the study found that public sector OSS policies were often not successful, even in the case of public procurement. The only truly convincing implementations occurred where Open Source has become a core component of a digital shift and thus ingrained in the digital culture of the administration. Laws requiring the development and reuse of OSS within the public sector were also generally not successful, often due to the absence of concrete implementation guidance. In the countries which today have increased software capabilities in the private sector (i.e., South Korea and China), Open Source has played an important role in industrial policy. European governments have taken a more laissez-faire approach and today, the EU is on the back foot when it comes to capabilities in this area. The success in the private sector is related to economic incentives associated with Open Source playing a smaller role in the public sector.

With respect to OSH, there are significant differences from OSS, because: the potential market for OSS solutions is far broader than for OSH, funding OSS-based start-ups may often be less expensive than for those based on OSH, and a greater degree of management sophistication is needed to launch many OSH businesses. And it remains to be seen whether industry will find an open approach to hardware to be as appealing as it has in the case of software. The return on investment of public funds with respect to OSH is therefore both more speculative and likely to be narrower than would be the case with OSS.

Finally, current events provide a window of opportunity for EU leadership and commitment to yield disproportionate results. OSS foundations and standards developers have relocated to the EU as a result of recent trade conflicts. The history of neutrality represented by non-governmental entities headquartered in the EU therefore provides an appealing solution to a problem that is likely to persist regardless of policy changes elsewhere.

f. Policy Recommendations

Based on the results of our empirical analyses, the following recommendations are derived.

A digitally autonomous public sector

Building Institutional Capacity

- It is recommended to create a Commission-funded network of up to 20 OSPOs (Open Source Project Offices) intended to support and accelerate the consumption, creation, and application of open technologies.

Creation of Legitimacy

- It is recommended to promote digital autonomy and technological sovereignty via Open Source.
- It is recommended to integrate OSS and its communities not only into European research and innovation policies, but also into general policy frameworks, such as the European Green Deal and European industrial strategy. Engaging with OSSH foundations in research and innovation programmes may offer a suitable approach to manage funding and support.
- It is recommended to evaluate options for direct contributions to OSS.
- It is recommended to reference the Open Source Initiative’s Open Source Definition when legislating on Open Source.

Strategic Intelligence

- It is recommended to integrate Open Source in Eurostat’s data collection activities and into EU benchmarking activities.

- It is recommended to expand the Open Source Observatory by components of strategic intelligence.

Open R&D enabling European growth

Knowledge Creation

- It is recommended to provide more R&D funding related to OSS and OSH projects through existing programmes, such as Horizon Europe, and new initiatives, in particular targeting SMEs or even microenterprises and start-ups, as well as individual developers; this funding should focus on EU-specific goals, such as the European Green Deal and European industrial strategy.
- It is recommended to launch research awards and prizes for OSS and OSH communities, students, and professors.

Knowledge Diffusion and Networking

- It is recommended to provide strong incentives for uploading code generated in publicly funded R&D projects in publicly accessible EU-based OSSH repositories.
- It is recommended to support the development and maintenance of platforms and depositories, as well as networks hosted in the EU. Expanding the remit of the current Open Source Observatory could be a starting point.

Entrepreneurial Activities

- It is recommended that the Higher Education Institutions in the Member States should provide entrepreneurial skills facilitating OSSH based start-ups, e.g., in the various Master programmes on entrepreneurship, as well as in ICT studies.
- It is recommended to support OSS and OSH foundations by providing financial support, e.g., for their education programmes and for their collaborations with companies, in particular SMEs and start-ups.

Human Capital Development

- It is recommended to include OSS and OSH as topics into the European Qualifications Framework (EQF).
- It is recommended that national organisations which are responsible for education should promote the inclusion of Open Source (development, business models and licensing) in the programmes of their HEIs.
- It is recommended to provide incentives for Higher Education Institutions (HEIs) and Public Research Organisations (PROs) and business schools to offer specific OSSH-focused management courses, e.g., as mini MBAs.
- It is recommended to develop an EU Certification Scheme for individuals who have developed Open Source skills in particular fields.
- It is recommended that the EU should increase the diversity of Open Source contributors, starting with a research project.

A digitised and internationally competitive industry

Financial Capital Development

- It is recommended that OSSH contributions from both individuals and corporations should be treated as charitable donations for tax purposes.
- It is recommended to continue the Enhanced European Innovation Council (EIC) (including the EIC Accelerator) programme and explicitly open it to applications

from young, high-risk, R&D-intensive OSSH-based entrepreneurs, in order to address the lack of venture capital in the European small business ecosystem.

- It is recommended to launch financing instruments, like focused Venture Capital funds, that help newly funded OSSH-based start-ups to team up with established companies.
- It is recommended to fully exploit the potential synergies between pre-commercial procurement and OSSH in a more strategic and systemic way.

Regulatory Environment

- It is recommended to clarify the liability for individual developers of OSSH.
- It is recommended to fund security audits of critical OSS projects requiring specific security-improving changes with public resources.
- It is recommended to promote OSS in addition to standardisation as a further channel of knowledge and technology transfer, e.g., as an explicit dissemination channel for Horizon Europe projects.
- It is recommended to improve the inclusion of OSS in public procurement, e.g., in directives or strategies, taking into account the needs of OSS-based SMEs.
- It is recommended to consider Open Source in future revisions of European copyright and patent legislation.
- It is recommended to consider the interrelationship between OSS (as well as OSH and open data) in related policy initiatives.

Market Creation

- It is recommended to consider Open Source explicitly in competition and platform policies, e.g., relating to the governance of Open Source communities.
- It is recommended to consider Open Source explicitly in SME policies.

Open Source Hardware specific recommendations

- It is recommended to fund a project to develop innovative regulatory mechanisms for Open Source Hardware, such as the approaches being considered in relation to white space spectrum deployment.
- It is recommended to fund the development of centres of excellence in the area of Open Source Hardware consisting of partnerships between academia, research institutions and the private sector.

Domain specific recommendations

- It is recommended to provide funding opportunities for OSS developers and companies related to Artificial Intelligence.
- It is recommended to consider OSS explicitly in the EU's future AI strategies.
- It is recommended to launch a standard request (mandate) to the European standardisation bodies to develop a European standard for a bitstream format for Field Programmable Gate Arrays (FPGAs).

Sustainability

- It is recommended to establish a right to repair, including the right to software changes once the manufacturer ends device support, because OSSH contributes to sustainability by extending the life cycle of devices, enabling reuse of components and reducing duplicate development effort.
- It is recommended that additional funding or incentives be applied in support of OSS and OSH projects, if they provide supplemental green benefits.

Résumé

Cette étude analyse l'impact économique des logiciels libres (OSS) et matériels libres (OSH) sur l'économie européenne. Elle a été commandée par la DG CONNECT de la Commission européenne.

Les entreprises dans l'UE ont investi environ 1 milliard d'euros dans les logiciels libres en 2018, avec un impact sur l'économie européenne entre 65 et 95 milliards d'euros. L'analyse estime un rapport coûts-bénéfices supérieur à 1:4 et prédit qu'une augmentation de 10 % des contributions aux logiciels libres créerait annuellement 0,4 % à 0,6 % de PIB en plus ainsi que plus de 600 start-ups technologiques supplémentaires dans l'UE. Des études de cas révèlent qu'en privilégiant les logiciels libres, le secteur public pourrait réduire le coût total de possession, éviter un effet de dépendance à l'égard des fournisseurs et accroître ainsi son autonomie numérique. L'étude analyse également les actions de politique publique en Europe et dans le monde.

Cependant, l'échelle des capacités institutionnelles de l'Europe liées aux logiciels libres est disproportionnellement inférieure à l'échelle de la valeur créée par les logiciels libres. L'étude présente donc quelques recommandations spécifiques de politique publique pour obtenir un secteur public numériquement autonome, une R&D ouverte favorisant la croissance européenne, et une industrie numérisée et compétitive à l'international.

Résumé de l'analyse

a. Introduction

Cette étude a été commandée par la DG CONNECT de la Commission européenne afin d'analyser l'impact économique des logiciels libres et des matériels libres sur l'économie européenne. Elle dresse un tableau complet des utilisations commerciales actuelles des logiciels libres (ou logiciels Open Source), de leurs coûts et avantages, ainsi que des efforts politiques déployés à l'échelle mondiale en vue d'utiliser et d'amplifier les avantages liés à l'utilisation des logiciels libres. Sur la base de ces informations, l'étude évalue la capacité de l'Union européenne (UE) à atteindre ses objectifs politiques (notamment en termes de croissance économique, de renforcement de la compétitivité, d'innovation et de création d'emplois) grâce à l'utilisation, à la promotion et au soutien des logiciels libres et des matériel libres (ou matériels Open Source).

L'étude comprenait l'examen de la documentation pertinente, la réalisation de plusieurs études de cas et analyses statistiques, ainsi qu'une enquête détaillée réalisée auprès d'un échantillon représentatif d'entreprises et de développeurs. Une forte cohérence a été observée entre les données fournies par les différentes sources consultées et les données collectées spécifiquement pour l'étude.

b. Aperçu de l'analyse économétrique

Les développeurs européens de logiciels libres (développeurs indépendants, universitaires, fonctionnaires et salariés du privé) contribuent de manière significative à l'écosystème mondial des logiciels libres. Dans l'UE, ce sont les employés des petites et très petites entreprises qui sont le plus susceptibles de contribuer à la production de codes de logiciels libres (on parle de « commits »), tandis qu'aux États-Unis les commits sont principalement produits par les grandes entreprises du secteur des TIC, qui fondent avec succès leurs modèles commerciaux pertinents sur le vaste corpus de codes de logiciels libres disponibles gratuitement et en constante amélioration.

Sur la base des informations du domaine public, les entreprises situées dans l'UE ont investi quelque 1 milliard d'euros dans les logiciels libres en 2018. L'étude conclut que le bassin de logiciels libres contribue de manière significative au PIB de l'UE, et qu'une augmentation de 10 % des contributions générerait chaque année entre 0,4 % et 0,6 % de PIB supplémentaire pour l'UE. L'étude conclut également qu'une augmentation de 10 % entraînerait la création de plus de 600 start-ups technologiques supplémentaires par an dans l'UE. Des études de cas ont révélé qu'en achetant des logiciels libres plutôt que des logiciels propriétaires, le secteur public pourrait non seulement réduire le coût total de possession, mais aussi réduire ou empêcher l'effet de dépendance à l'égard des fournisseurs. Dans l'ensemble, les avantages de l'Open Source l'emportent largement sur les coûts qui y sont associés. Ces avantages concernent principalement l'ouverture (notamment en termes de normes et d'indépendance) et les économies de coûts de main-d'œuvre plutôt que la génération de revenus supplémentaires.

L'analyse des séries chronologiques économétriques des données relatives au PIB des États membres de l'UE indique qu'en 2018, dans tous les États membres, l'impact économique des logiciels libres était compris entre 65 et 95 milliards d'euros. Le nombre de contributeurs individuels se chiffrait à au moins 260 000, soit 8 % des près de 3,1 millions d'employés de l'UE travaillant dans le secteur de la programmation informatique en 2018. Au total, les plus de 30 millions de commits provenant des États membres de l'UE en 2018 représentent un investissement en personnel (sur la base d'équivalents temps plein) égal à près d'un milliard d'euros, et les résultats de cet investissement étant disponibles dans le domaine public, ils n'ont pas besoin, par conséquent, d'être à nouveau développés par d'autres personnes.

Les données indiquent que plus l'entreprise est petite, plus l'investissement relatif dans les logiciels libres est important (les entreprises de 50 employés ou moins ont produit près de la moitié des commits dans notre échantillon des entreprises les plus actives en matière de logiciels libres). Bien que plus de 50 % des contributeurs soient issus de l'industrie des TIC (8 % de tous les employés ont participé au développement des logiciels libres à l'échelle de l'UE), il a également été constaté une forte implication des entreprises professionnelles, scientifiques et techniques et, dans une moindre mesure, des entreprises du commerce de gros, du commerce de détail et des sociétés financières.

Sur une base cumulée, l'étude estime que jusqu'en 2018 la contribution des logiciels libres au PIB de l'UE et les contributions des employés de l'UE aux logiciels libres ont généré un rapport coûts-bénéfices légèrement supérieur à 1:10. Après avoir pris en compte les coûts liés au matériel et les autres coûts d'investissement des 260 000 contributeurs de l'UE aux logiciels libres, le rapport coûts-bénéfices est encore légèrement supérieur à 1:4.

c. Aperçu de l'enquête

Plus de 900 entreprises et développeurs ont répondu à l'enquête et environ 100 d'entre eux ont répondu à la totalité des questions, qui portaient sur des informations concernant les coûts et les avantages dans des domaines qui n'étaient pas couverts adéquatement dans les précédentes recherches menées sur les logiciels libres. Près de 25 % des répondants étaient des sociétés de développement de logiciels et 10 % des développeurs individuels. 40 % des entreprises interrogées produisaient des composants, des biens ou des services finaux, ou étaient des fournisseurs de plateformes, des intégrateurs de systèmes ou des opérateurs de réseaux. Seul un petit nombre de répondants ont participé de manière significative au développement de matériels Open Source. Les start-ups étaient fortement représentées. Parmi les répondants à l'enquête, les microentreprises, et notamment les start-ups, apportent des contributions et effectuent des investissements disproportionnés dans les logiciels libres, à la fois en termes absolus et par rapport à leur taille. Plusieurs petites et microentreprises ont indiqué que plus de la moitié de leurs revenus étaient attribuables aux logiciels libres, et notamment aux services liés aux logiciels libres. Les répondants (et en particulier les petites et microentreprises interrogées) ont également signalé un pourcentage élevé de dépenses liées à l'innovation, et près de 50 % de leurs contributions aux logiciels libres étaient liées au développement de produits internes et 40 % aux logiciels libres déjà existants. Les répondants ont rarement déposé des brevets en lien avec leurs contributions au code source public, mais ont trouvé d'autres moyens de protéger leur propriété intellectuelle.

Les motivations des répondants pour participer aux logiciels libres étaient, par ordre de priorité : trouver des solutions techniques, éviter la dépendance à l'égard des fournisseurs, faire avancer l'état de développement de la technologie, développer un code source de haute qualité, la recherche de connaissances et la création de connaissances. Les intérêts personnels des participants individuels étaient également importants. L'accès à de nouveaux marchés et clients par le biais de contributions aux logiciels libres ne représentait pas une incitation significative. Cependant, la réduction des coûts constituait une motivation importante, en réduisant les efforts de maintenance interne, en accédant à des codes sources libres de droits et en améliorant les retours sur investissement en R&D. Parmi d'autres motivations supérieures à la moyenne, on peut mentionner : la création de réseaux, le développement de fonctionnalités non différenciantes (par ex. : des bibliothèques couramment utilisées) et l'amélioration de la réputation. Les répondants utilisant des logiciels libres et contribuant au code source des projets de logiciels libres ont identifié le soutien aux normes ouvertes et à l'interopérabilité comme générant les avantages les plus élevés, les avantages étant indirects et résultant d'externalités de réseau plutôt que de revenus directs. Les répondants ont également attribué une importance supérieure à la moyenne à : l'accès au code source, la réduction des dépenses, l'évitement de la dépendance à l'égard des fournisseurs, l'accès à une communauté active pour l'échange de connaissances, l'effet favorable de leur participation sur l'innovation, ainsi que l'amélioration de la sécurité et de la qualité.

S'agissant de leur propre évaluation des rapports coûts-avantages globaux, un tiers des répondants ont perçu des avantages très élevés et des coûts faibles, et plus d'un autre tiers a perçu soit des avantages très élevés et des coûts moyens, soit au moins des avantages élevés et des coûts faibles, la valeur la plus citée étant 1:10, suivie de 1:5. À titre de comparaison, en tenant compte des coûts non liés au personnel (par ex. : matériel), l'étude estime le rapport coûts-avantages à 1:4 sur la base des avantages économétriques.

d. Aperçu des études de cas

Afin de pallier le manque de données, notamment sur le matériel libre, provenant à la fois de la documentation et de notre enquête, cinq études de cas ont été menées sur le développement communautaire de logiciels et de matériels libres (OSSH) qui peuvent réduire les obstacles à la participation, permettre l'expérimentation et contribuer ainsi à l'élaboration de normes de facto. Les fondations constituent un facteur important dans les écosystèmes de logiciels et matériels libres, en fournissant un certain nombre de services importants, tels que la normalisation, le transfert de connaissances et la gestion de projet. Les entreprises participent à des fondations afin de s'engager plus étroitement auprès de la communauté des OSSH, non seulement en tant que consommateurs de technologies, mais également en tant que contributeurs et administrateurs clés. Cependant, alors que plusieurs projets de logiciels et matériels libres (dont certains bénéficient d'un financement public) ont leur siège dans l'UE, la participation n'est pas limitée aux particuliers ou aux entreprises de l'UE. La participation est corrélée à la taille de l'entreprise et, par conséquent, de nombreuses entreprises participantes sont de grandes entreprises basées aux États-Unis qui utilisent les logiciels libres pour leurs modèles commerciaux basés sur le principe des plateformes. Il est donc difficile de distinguer clairement les projets européens de logiciels libres ou de matériels libres. Il est également trop tôt dans la plupart des cas pour évaluer les avantages, car la discipline des matériels libres est encore naissante, le développement des produits correspondants restant encore à venir. Cependant, les cas étudiés ont révélé que les écosystèmes de logiciels libres et de matériels libres sont intégrés de manière forte et efficace avec certains chevauchements, par exemple, en termes de support logiciel pour les matériels libres. Les informations qualitatives issues des études de cas sont utilisées comme base d'analyse des forces, faiblesses, opportunités et menaces (SWOT) pour l'UE.

e. Analyse des politiques

L'étude a examiné la portée, l'efficacité et l'impact des politiques gouvernementales des secteurs public et privé relatives aux logiciels libres dans un certain nombre d'États membres de l'UE (Bulgarie, France, Allemagne, Italie, Pologne et Espagne) et d'autres pays, en Europe (Royaume-Uni), dans les Amériques (États-Unis et Brésil) et en Asie (Chine, Japon, Inde et Corée du Sud). L'étude a utilisé des méthodes à la fois qualitatives et quantitatives. L'examen a révélé des différences significatives en termes de portée et d'objectif entre les zones géographiques concernées. Enfin, la création et la mise en œuvre de politiques efficaces en matière de logiciels libres et de matériels libres restent un défi.

Dans l'ensemble, quatre motivations principales ont été identifiées, avec une variation au fil du temps de l'importance accordée : (i) économies de coûts ; (ii)coûts de transition et effets de réseau ; (iii) sous-production de biens publics ; et (iv) concurrence sur le marché et neutralité technologique. L'étude a également identifié deux vagues principales de soutien gouvernemental aux logiciels libres, la première commençant au début des années 2000 et la seconde au milieu des années 2010. Ces deux vagues ont été motivées par des approches différentes.

Les politiques du secteur public visent soit à améliorer les compétences en matière d'Open Source et à optimiser les résultats au sein du secteur public, soit à privilégier les logiciels libres par rapport aux logiciels propriétaires dans les marchés publics. Ces politiques présentent des portées, des mécanismes de mise en œuvre et des caractères normatifs différents, allant de lois contraignantes à de simples normes. Les actions politiques du secteur privé sont plus variées. Elles comprennent des actions de conseil et de soutien pour les logiciels libres. Certains gouvernements imposent ou influencent la politique industrielle en vue de générer de l'innovation par le biais des logiciels libres, tandis que d'autres collaborent avec les universités afin de favoriser la formation aux logiciels libres et le développement de ces derniers, ou s'efforcent directement de soutenir la création ou le soutien des communautés de logiciels libres. Les gouvernements peuvent aussi directement financer ou certifier des projets Open Source afin d'atteindre leurs objectifs politiques.

D'une manière générale, les politiques gouvernementales en Europe et dans les Amériques se concentrent sur le secteur public, tandis que les gouvernements asiatiques ont tendance à se concentrer sur le secteur privé. La majorité des États membres de l'UE et d'autres pays européens étudiés ont des politiques formelles sur l'Open Source au niveau national – incluant dans la plupart des cas une politique de marchés publics pour les logiciels libres. Dans l'ensemble, l'étude a révélé que les politiques de logiciels libres du secteur public ont souvent été infructueuses, même dans le cas des marchés publics. Les seules mises en œuvre véritablement convaincantes ont eu lieu dans les cas où l'Open Source est devenu un élément central d'un virage numérique et s'est par conséquent ancré dans la culture numérique de l'administration concernée. Les lois exigeant le développement et la réutilisation des logiciels libres dans le secteur public n'ont généralement pas été couronnées de succès, souvent en raison de l'absence de directives de mise en œuvre concrètes. Dans les pays qui ont aujourd'hui augmenté les capacités logicielles dans le secteur privé (c'est-à-dire la Corée du Sud et la Chine), l'Open Source a joué un rôle important dans la politique industrielle. Les gouvernements européens ayant adopté une approche plus libérale, l'UE est aujourd'hui en retrait en ce qui concerne les capacités dans ce domaine. Le succès observé dans le secteur privé est lié aux incitations économiques associées à l'Open Source, lesquelles jouent un rôle moins important dans le secteur public.

En ce qui concerne les matériels libres, il existe des différences significatives par rapport aux logiciels libres, car : le marché potentiel des solutions de logiciels libres est bien plus large que celui des solutions de matériels libres, le financement des start-ups basées sur les logiciels libres peut souvent s'avérer moins onéreux que dans le cas des start-ups basées sur les matériels libres, et un niveau de complexité de gestion plus élevé est nécessaire pour lancer de nombreuses entreprises de matériels libres. De plus, il reste à voir si l'industrie trouvera une approche du matériel libre ouverte et susceptible d'être aussi attrayante qu'elle l'a été dans le cas du logiciel libre. Le retour sur investissement des fonds publics en matière de matériels libres est donc à la fois plus spéculatif et susceptible d'être davantage limité que ce ne serait le cas avec les logiciels libres.

Enfin, les événements actuels offrent une fenêtre d'opportunité permettant au leadership et à l'engagement de l'UE de produire des résultats disproportionnés. Les fondations de logiciels libres et les développeurs de normes se sont réinstallés dans l'UE à la suite de récents conflits commerciaux. La tradition de neutralité représentée par les entités non gouvernementales dont le siège est situé dans l'UE fournit donc une solution attrayante à un problème qui est susceptible de persister indépendamment de l'évolution des politiques dans d'autres régions du monde.

f. Analyse des politiques

Les recommandations suivantes sont formulées sur la base des résultats de nos analyses empiriques.

Un secteur public numériquement autonome

Renforcement des capacités institutionnelles

- Il est recommandé de créer un réseau financé par la Commission et comprenant un maximum de 20 OSPO (« Open Source Project Offices », ou bureaux de projets Open Source) dans le but de soutenir et d'accélérer la consommation, la création et l'application de technologies ouvertes.

Création de légitimité

- Il est recommandé de promouvoir l'autonomie numérique et la souveraineté technologique via l'Open Source.
- Il est recommandé d'intégrer le logiciel libre et ses communautés non seulement dans les politiques européennes de recherche et d'innovation, mais aussi dans les cadres politiques généraux, tels que le pacte vert pour l'Europe et la stratégie industrielle européenne. La collaboration avec les fondations de l'OSSH dans le cadre de programmes de recherche et d'innovation peut offrir une approche appropriée pour la gestion du financement et du soutien.
- Il est recommandé d'évaluer les options de contribution directe aux logiciels libres.
- Il est recommandé de se référer à l'Open Source Definition (définition de l'Open Source) telle que formulée par l'Open Source Initiative lorsqu'il s'agit de légiférer sur l'Open Source.

Veille stratégique

- Il est recommandé d'intégrer l'Open Source dans les activités de collecte de données d'Eurostat et dans les activités d'analyse comparative de l'UE.
- Il est recommandé d'élargir les attributions de l'Open Source Observatory (Observatoire du logiciel libre) en y intégrant des composantes de veille stratégique.

Une R&D ouverte au service de la croissance européenne

Création de connaissances

- Il est recommandé de fournir davantage de financements de R&D liés aux projets de logiciels libres et de matériels libres via les programmes existants, tels qu'Horizon Europe, et de nouvelles initiatives, en ciblant notamment les PME ou même les microentreprises et les start-ups, ainsi que les développeurs individuels; ce financement devrait se concentrer sur des objectifs spécifiques à l'UE, tels que le pacte vert européen et la stratégie industrielle européenne.
- Il est recommandé de lancer des bourses et des prix de recherche pour les communautés, les étudiants et les professeurs spécialisés dans les logiciels libres et les matériels libres.

Diffusion des connaissances et réseautage

- Il est recommandé de fournir de fortes incitations au téléchargement du code généré dans le cadre des projets de R&D financés par des fonds publics dans des référentiels OSSH basés dans l'UE et accessibles au public.
- Il est recommandé de soutenir le développement et la maintenance des plateformes et des référentiels, ainsi que des réseaux hébergés dans l'UE.

L'élargissement des attributions de l'actuel Open Source Observatory (Observatoire du logiciel libre) pourrait constituer un point de départ.

Activités entrepreneuriales

- Il est recommandé que les établissements d'enseignement supérieur des États membres fournissent des compétences entrepreneuriales facilitant l'émergence des start-ups basées sur l'OSSH, par exemple dans le cadre des différents programmes de master axés sur l'entrepreneuriat, ainsi que dans le cadre des études consacrées aux TIC.
- Il est recommandé de soutenir les fondations de développement du logiciel libre et du matériel libre en apportant un soutien financier, par exemple, à leurs programmes de formation et à leurs collaborations avec des entreprises, et notamment avec des PME et des start-ups.

Développement du capital humain

- Il est recommandé d'inclure le logiciel libre et le matériel libre en tant que sujets à part entière dans le cadre européen des certifications (CEC).
- Il est recommandé aux organismes nationaux en charge de l'enseignement de promouvoir l'inclusion de l'Open Source (développement, modèles commerciaux et octroi de licences) dans les programmes de leurs établissements d'enseignement supérieur (EES).
- Il est recommandé de fournir des incitations aux EES, aux organismes de recherche publics (ORP) et aux écoles de commerce pour qu'ils proposent des cours de gestion spécifiques axés sur l'OSSH, par exemple sous forme de mini MBA.
- Il est recommandé de développer un programme européen de certification pour les personnes qui ont développé des compétences Open Source dans des domaines particuliers.
- Il est recommandé que l'UE renforce la diversité des contributeurs Open Source, en commençant par un projet de recherche.

Une industrie numérisée et compétitive à l'international

Développement du capital financier

- Il est recommandé que les contributions des personnes physiques ou morales à l'OSSH soient traitées comme des dons de bienfaisance à des fins fiscales.
- Il est recommandé de poursuivre le programme Enhanced European Innovation Council (EIC) (y compris l'EIC Accelerator) et de l'ouvrir explicitement aux candidatures de jeunes entrepreneurs OSSH à haut risque et à forte intensité de R&D, afin de remédier au manque de capital-risque dans l'écosystème européen des petites entreprises.
- Il est recommandé de lancer des instruments de financement, tels que des fonds de capital-risque ciblés, qui aident les start-ups basées sur l'OSSH et nouvellement financées à s'associer à des entreprises établies.
- Il est recommandé d'exploiter pleinement les synergies potentielles entre les achats publics avant commercialisation et l'OSSH d'une manière plus stratégique et systémique.

Environnement réglementaire

- Il est recommandé de clarifier la responsabilité des développeurs individuels d'OSSH.

- Il est recommandé d'assurer, à l'aide de ressources publiques, le financement des audits de sécurité des projets critiques de logiciels libres nécessitant des modifications spécifiques liées à l'amélioration de la sécurité.
- Il est recommandé de promouvoir les logiciels libres en plus de la normalisation en tant que canal supplémentaire de transfert de connaissances et de technologies, par exemple en tant que canal de diffusion explicite pour les projets du programme Horizon Europe.
- Il est recommandé d'améliorer l'inclusion des logiciels libres dans les marchés publics, par exemple par le biais des directives ou stratégies y afférentes, en tenant compte des besoins des PME basées sur les logiciels libres.
- Il est recommandé de prendre en compte l'Open Source dans les futures révisions de la législation européenne sur le droit d'auteur et les brevets.
- Il est recommandé de prendre en compte les interactions existant entre les logiciels libres (ainsi qu'entre les matériels libres et les données ouvertes) dans les initiatives politiques connexes.

Création de marché

- • Il est recommandé de prendre en compte l'Open Source de manière explicite dans les politiques relatives à la concurrence et aux plateformes, par exemple, en ce qui concerne la gouvernance des communautés Open Source.
- • Il est recommandé de prendre en compte l'Open Source de manière explicite dans les politiques relatives aux PME.

Recommandations spécifiques au matériel libre

- Il est recommandé de financer un projet visant à développer des mécanismes de régulation innovants pour le matériel libre, tels que les approches envisagées dans le cadre du déploiement du spectre des espaces blancs.
- Il est recommandé de financer le développement de centres d'excellence dans le domaine du matériel libre constitués de partenariats entre les universités, les instituts de recherche et le secteur privé.

Recommandations spécifiques au domaine

- Il est recommandé de fournir des opportunités de financement aux développeurs de logiciels libres et aux entreprises liées à l'intelligence artificielle.
- Il est recommandé de prendre en compte de manière explicite les logiciels libres dans les futures stratégies de l'UE en matière d'IA.
- Il est recommandé de lancer une demande standard (mandat) auprès des organismes européens de normalisation en vue de développer une norme européenne pour un format de flux binaire pour les FPGA (réseau de portes programmables).

Durabilité

- Il est recommandé d'établir un droit de réparation, y compris le droit aux modifications logicielles une fois que le fabricant met fin à la prise en charge des appareils, car l'OSSH contribue à la durabilité en prolongeant le cycle de vie des appareils, en permettant la réutilisation des composants et en réduisant les doublons en matière d'efforts de développement.
- Il est recommandé que des financements ou des incitations supplémentaires soient mis en œuvre à l'appui des projets de logiciels libres et de matériels libres, s'ils offrent des avantages écologiques supplémentaires.

1. Introduction

The increasing relevance of Open Source (OS) during the last two decades requires an update of an in-depth analysis of its current role, position and its potential for the European economy. In particular, in the last few years, several significant investments and acquisitions related to Open Source based companies have taken place.

Whereas Open Source Software (OSS) has become mainstream across all sectors of the software industry during the past 20 years, Open Source Hardware (OSH) is still in an emerging phase. However, the business ecosystem for OSH is developing. This includes areas such as 3D printing, electronics (exemplified by the success of Arduino, a European-based Open Source electronic microcontroller and prototyping platform enabling users to create interactive electronic objects), and open source silicon. Open principles have also been applied in the datacentre, through initiatives such as the Open Compute Project. OSH shares several features with OSS, but also has distinct characteristics. This report defines Open Source Software (OSS) as software which has been released under a licence complying with the Open Source Initiative’s Open Source Definition, and Open Source Hardware and Open Hardware (OSH) as hardware (any physical thing) the design for which has been made public, and which has been released under a licence complying with the definition of Open Source Hardware published by the Open Source Hardware Association. Because OSS and OSH have connotations which go beyond the licensing model, it should be beared in mind that the blanket term OSSH is a broad concept that subsumes aspects of source code or design licensing, the governance of collaboration as well the provision of the means of and the production process itself.

One generic objective of the study is to investigate the different dimensions of the economic impact of Open Source Software and Hardware (OSSH) on the European economy both at the macroeconomic and company level, but also with the help of case studies, in particular in the area of Open Source Hardware. These insights are the basis to identify strengths, weaknesses, opportunities and challenges of Open Source in different domains. Furthermore, policies to support Open Source initiated both within Europe and worldwide have to be analysed. Finally, based on the different types of analyses, policy recommendations have to be derived that can maximise the benefit of Open Source in support of a competitive EU software and hardware industry and an eco-friendly transformation of the whole EU economy.

The aim of the Final Study Report is to provide the final results of the analysis and the policy recommendations for the project “Study on the impact of open source software and hardware on technological independence, competitiveness and innovation in the EU (SMART 2019/0011)”, which is being carried out by a consortium of Fraunhofer ISI and OpenForum Europe.

This report covers the following topics that are briefly described below. In order to elucidate the state of the art regarding the significant body of research in particular related to Open Source Software a comprehensive review of the literature published in the last two decades has been conducted including contacting leading scholars in the field. The result is summarised in the second chapter. Based on the findings of the literature including taking the existing data limitations into account methodologies have been developed to address the different tasks. The proposed methodological approach is consequently elaborated in the third chapter. Since there are a number of taxonomies and business models applicable to Open Source Software, some of which also apply to Open Source Hardware, and some of which are distinct, case studies including success stories are presented from different industry domains in the fourth chapter followed by an SWOT analysis of the European economy and quantitative investigations of business models both in Open Source Software and Open Source Hardware. The fifth chapter presents first the economic analysis of the impacts in particular of Open Source Software, but also existing alternative approaches and highlighting the limitations. Secondly, the economic analysis is complemented by a cost-based impact analysis both at the country and the company level in order to present eventually cost-benefit ratios. The results of the stakeholder survey are presented in the sixth chapter followed by a comprehensive summary and condensed triangulated analysis of the results resulting from the different methodological approaches in the seventh chapter. The insights from the analysis of the different policies to support Open Source Software and Open Source Hardware based on an analytical framework are displayed in the eighth chapter before the policy recommendations are presented based on the different insights gained from the various analyses.

2. Literature Review

a. Approach

The review of the literature about the impact of Open Source in general and both Open Source Software and Open Source Hardware in particular is based on searches in the three databases Google Scholar, Scopus and Web of Science. These searches have been performed stepwise applying a very broad approach, which has then been narrowed down to publications addressing the various impacts of Open Source Software (OSS) and Open Source Hardware (OSH).

Overall, the de facto open literature database Google Scholar, which includes on the one hand peer reviewed journals and books, but on the other hand also to an even larger extent unreviewed publications including policy documents, generates more than 2 million sources looking for “Open Source” in general. The two databases SCOPUS and Web of Science including only peer reviewed journal articles, books and conference proceedings reveal more than 70,000 respective 30,000 publications. Overall, the annual number of publications is still increasing but reaching a level of consolidation in these two databases.

Narrowing the search down to a combination of “Open Source” and “impact” still leads to more than one million publications in Google Scholar, but only around 4,500 publications in SCOPUS and 3,000 publications in the Web of Science. The latter database is more restrictive in the inclusion of journals and conference proceedings regarding both the peer review process and the scientific quality compared to SCOPUS. Overall, the annual number of this subset of publications is only slightly increasing and is trending to a consolidation.

The abstracts of the 3,000 publications have been screened and the further subset of publications has been structured according to the following headings.

b. Open Source Software in the context of other concepts

Open Source Software (OSS) has in particular not been discussed in the management literature in isolation, but in the context of much broader concepts starting with Open Innovation introduced by Chesbrough (2003) two decades ago. Following the change of paradigms from closed to open innovation the concept of user innovation in particular (as developed by von Hippel) has been introduced. In that model, software developers can be categorised as a specific type of user innovators. In parallel, Open Source has been meanwhile integrated even in the Oslo Manual for the first time in its 4th edition released in 2018.

The term “Open Source” is often applied to innovations that are jointly developed by different contributors. Although Open Source outputs such as software code can be included in products that are sold, royalty fees are seldom paid to contributors and there are usually no significant restrictions on how these outputs are used. Indeed, open source licences (as that term is defined by the Open Source Initiative) may not provide for any royalty payments or any restriction on how the outputs may be deployed. Follow-on additions to Open Source outputs may also need to be provided on an “Open Source” basis (OECD/Eurostat 2019, p. 133).

More recently, OSS is discussed in the context of crowdsourcing, a specific approach in the context of Open Innovation. In addition, the joint development of source code belongs to a kind of co-production. Finally, OSS generated new business models, which have been discussed in the literature. In the following sections, OSS is put in the context of these concepts of innovation.

OSS in the context of open innovation

Following the seminal publication by Chesbrough (2003) on open innovation, several scholars developed different taxonomies, into which also Open Source has been integrated. Consequently, a significant number of papers addressing both Open Innovation and Open Source has been published.

One option to categorise Open Innovation is proposed by Huizingh (2011), who differentiates between the openness of the innovation process and the innovation outcome. The category characterised by openness both of the process and the outcome of innovation is labeled as Open Source innovation. For him, OSS is the best-known example of this category without further elaboration.

Table 2.1: Various ways of innovation based on the openness of both the process and the outcome of innovation (Huizingh 2011, S.3)

Innovation Process:	Innovation Outcome:	
	Closed	Open
Closed	1. Closed innovation	3. Public Innovation
Open	2. Private Open Innovation	4. Open Source Innovation

Dahlander and Gann (2010) use on the one hand inbound (sourcing) and outbound (revealing) innovation and pecuniary and non-pecuniary interactions on the other hand to differentiate four forms of openness. Within this taxonomy, OSS is categorised as non-pecuniary outbound innovation. As examples Linux (Henkel 2006) and proprietary platforms, like Apple or IBM, supporting OSS as part of their platform strategies are mentioned (West 2003). Here, it is mentioned that in the absence of a strong IPR regime, there are greater chances of cumulative advancements, like in the development of OSS (West and Gallagher 2006).

Table 2.2: Structure of different forms of openness (Dahlander and Gann 2010)

	Inbound innovation	Outbound innovation
Pecuniary	Acquiring	Selling
Non-pecuniary	Sourcing	Revealing

West and Bogers (2014) focus on the leveraging of external sources in the context of open innovation by differentiating between the four phases of obtaining, integrating, commercialisation and eventually interaction. OSS can be considered as user innovation (see the following section). However, firms use OSS communities to, e.g., provide commodity technology (West, 2003), to engage in informal knowledge sharing (Henkel, 2006), and to develop potential improvements to existing products (Dahlander and Magnusson, 2008). Although “free riding” might be at first glance a rational economic strategy for firms, they authorise employee contributions to the community’s innovation efforts to gain legitimacy and access to community innovations (e.g., Dahlander and Wallin, 2006; Henkel, 2006). According to West and Lakhani (2008), open innovation communities are defined as an ongoing voluntary association of individuals or organisations that are organised or leveraged by for-profit actors. They are different from networks in having membership, identity, and group loyalty (von Hippel, 2007). OSS communities are perceived by West and Gallagher (2006) as firm-to-firm collaboration in order to pool innovation resources, while Dahlander and Wallin (2006) focus on the interactions between hobbyists and firm employees. Furthermore, the trade-offs for firms between the resources invested in and the innovations obtained from OSS communities has been analysed e.g. by Spaeth et al. (2010) and Stam (2009). In addition, firms have to balance the benefits from sharing code and other knowledge in OSS against the potential loss of information, control, and differentiation to the OSS community and potential competitors (Stuermer et al. 2009).

West and Gallagher (2006) are the authors, who explicitly connect open innovation and OSS by presenting specific OSS strategies as solutions to open innovation challenges, like finding creative ways to exploit internal innovation, incorporating external innovation into internal development, and motivating outsiders to supply an ongoing stream of external innovations. First, OSS can help to pool R&D and even product development, like Linux. Second, internal development projects can become externally visible OSS projects via spinouts, as in the case of Eclipse. Third, selling complements to a free core product, like the Apache server, but also training and support services related to Linux, is another option. Fourth, complements cannot only be sold but even donated, like user toolkits, but also games, like Half-Life, to technically proficient private or commercial buyers, who are able to generate their own modifications and improvements of OSS.

In addition, von Hippel and Krogh (2003) introduce OSS as a compound “private collective” model of innovation based on their perception of a mainly private user driven development of OSS at the beginning of the century. Their model contains elements of both the “private investment” and the “collective action” models. The first model assumes returns to the innovators from private goods based on effective and efficient regimes of intellectual property protection. The latter model assumes that under market failure, e.g. due to knowledge spillovers, innovators collaborate in order to contribute to a public good. Despite free revealing of code, OSS can generate private benefits for innovators by pushing their diffusion of innovation. Complementary, they question that free riders are able to obtain all the benefits from OSS as a public good, which active contributors can obtain inherently to its development. Consequently, they claim that OSS can offer society the “best of both worlds”.

Table 2.3: Open Source strategies as solutions to open innovation challenges (West and Gallagher 2006)

Open Source Strategy	Example	Maximizing Returns of Internal Innovation	Role of External Innovation	Motivating External Innovation
Pooled R&D /Product Development	Linux	Participants jointly contribute to shared effort	Pooled contributions available to all	Ongoing institutions establish legitimacy and continuity
Spinouts	Eclipse	Seed non-commercial technology to support other goals	Supplants internal innovation as basis of ongoing innovation	Free access to valuable technology
Selling Complements	Apache	Target highest value part of whole product solution	External components provide basis for internal development	Firms coordinate ongoing supply of components
Donating Complements	Half-Life	Provide an extensible platform for external contributors	Adding variety and novelty to established products	Recognition and other non-monetary rewards

OSS vs user innovation vs crowdsourcing vs co-creation

Whereas OSS is meanwhile integrated in the discussion on open innovation, the starting point has been von Hippel's work on user innovation communities, which he has linked to OSS projects already in 2001 (von Hippel 2001). Here, the focus is on consumers or users developing, producing, distributing and consuming products together with other users without the involvement of manufacturers. Later von Hippel (2007) introduces innovation networks with OSS as a prominent example. Here, users of OSS simply “use the code” relying on interested volunteers to write new code, debug others’ code, answer requests for help posted on Internet help sites, and help coordinate the project. First, he states, that there is no commercial market for OSS, but he already observes that as user innovation networks grow and mature, commercial enterprises attach to or assume complementary roles to user innovation networks, like Red Hat distributing and providing support services or IBM selling complementary proprietary software or hardware.

Following von Hippel (2007), Bogers et al. (2010) point in particular to the opportunity that OSS users can develop products even with the involvement of producers, which has already been highlighted by Benkler (2006). In addition, to company-driven development of OSS, West and O’Mahony (2008) identify user innovator start-ups in university-developed OSS.

In addition to the classification of OSS as user communities, they can also be perceived as self-governing groups of individuals (West & Lakhani 2008; Lerner & Tirole, 2002; O’Mahony, 2003).

More recently, OSS is also categorised as a form of co-creation (Zwass 2010) or joint cumulative production of shared information goods (West & Lakhani 2008). It was originally defined as co-creation of value by a firm’s customers, but then gradually extended toward autonomous individual initiatives. Based on new technological opportunities OSS development methods elaborated by communities of volunteer developers enabled their integration along with their products into productive activities for organisations, in particular companies. Zwass (2010) also points to the two-sided network effects of OSS, because the more individuals use an OSS based product, the more valuable is the recognition its creators gain, and the higher the likelihood that the product will be well maintained for future use by these motivated developers. It is possible that users of OSS can become co-creators with its developers by co-creating new OSS, but also testing and improving existing OSS. In addition, sharing data, information, and knowledge in the digital platforms by individuals contribute further to the growth of co-creation activities, like OSS.

In addition to co-creation, OSS is meanwhile also linked to the newer approach of crowdsourcing, an approach companies use to support the development and implementation of better processes and products. OSS can be categorised as crowdsourcing applied to software development (Olson & Rosacker 2013). However, it is also different, because in OSS development there is learning and reciprocity, but also the free software ideology as drivers in addition to the fact that the majority of developers are paid by their companies or organisations (see also Geiger (2017) or the recent survey by Nagle et al. 2020). These characteristics are, in general, not given for crowdsourcing, which follows more a top-down approach (Battistella & Nonino 2012), whereas reputation and recognition are similar drivers.

A last important relation to be mentioned is the one to research or science. Whereas, there are important differences between OSS development and crowd science (Franzoni & Sauermann 2014), like the degree of self-organisation and the role of the community, the innovation process in OSS resembles knowledge production in science (von Krogh & Spaeth 2007). First, like OSS, science has the objective of creating a public good. Second, OSS development can be perceived as a special type of academic research (Bezroukov 1999) carried out by virtual teams around the world, as can science. Furthermore, changes in OSS code are driven by peers similar to the peer review process scientific papers have to go through. Although, both contributors to OSS and to scientific work are more intrinsically motivated and by peer recognition than by financial incentives (Bezroukov 1999), researchers are in contrast to OSS developers in general not using the output of their work (von Krogh & Spaeth 2007). Meanwhile, the funding of OSS activities comes from companies paying their programmers, which resembles their funding in particular of basic research activities.

Finally, the outcome of applied science can be OSS code, which, in the context of the promotion of open science, including open access and open data, is becoming even more popular (McKiernan et al. 2016).

OSS and business model innovation

Although there has been an intensive discussion among practitioners about business models based on OSS, there is only a limited body of literature addressing these business models explicitly. For example, West and Gallagher (2006) elaborate four Open Source strategies, which partly represent new business models. However, they do not put them explicitly into the context of business model innovation. Research on business model innovation only became properly established in the period starting in 2010 with the highly cited contribution by Chesbrough (2010). Obviously, the scholars working on Open Source and open innovation have been forerunners on business model innovation with their work without explicitly elaborating this link. It has to be noted that Chesbrough (2010) neither mentions software nor Open Source in discussing drivers and barriers of business model innovations. Obviously, there is no explicit focus of the business model innovation scholars on OSS. This is also underlined by the extensive review of Shahrivar et al. (2018) on business models based on commercial Open Source, which is eventually based only on around 30 studies. In contrast, Jin and Ji (2018) find that “Open Source” belongs to the main hotspots of the literature on business model innovation without providing a list of relevant publications.

Even so, there is still a limited number of papers on business models and Open Source with very few publications in the last few years. Okoli and Nguyen (2016) can be seen as the most recent study available which identifies the most relevant business models (obtained by relying on expert interviews in the field of OSS). New business models arise through technological developments (such as Software as a Service), but they are in general not addressed by the business model scholars. Although an in-depth review of the literature does not reveal a significant body of literature linking Open Source and business models, there are a few exceptions. However, Ebert (2007) does indeed identify new business models, including distribution models and new services such as liability support, driven by Open Source in addition to process innovations, new technologies, higher quality and new architectures and standards as other types of innovations. Recently, Riehle (2019) confirms business model innovations differentiated into for-profit models and Open Source foundations as one type in addition to legal innovations, i.e. licences, tools and processes. In summary, it can still be postulated that a significant research gap exists between the increasing literature on business model innovation and the body of literature on Open Source.

c. Economics of OSS

Eventually, the economics of OSS is addressed. Early studies characterise the development of OSS as the dynamic provision of a public good, like Johnson (2002) focusing on the example of the GNU-Linux operating system. In their model, individual user-programmers decide whether to invest their own effort to develop a software enhancement that will become a public good if so developed. However, it also shows that free riding may prevent the development of valuable Open Source code. Hawkins (2004) defines OSS as quasi-public good in contrast to a true public good, in which the cost of production is small compared to the social benefit, but large compared to the private benefit. Taking Apache as example, Hawkins (2004) argues that for IBM it is profitable to invest into the OSS code than to keep and maintain its own proprietary solution, because IBM is not bearing the entire cost of providing this quasi-public good. Bitzer et al. (2007) perceive OSS also as a public good, but they understand the development of OSS the private provision of a public good, which is driven by play value or homo ludens payoff, user-programmers' and gift culture benefits. Kubiszewski et al. (2010) perceive OSS as information good being a subcategory of a public good, which is enhanced with increased use. For them the status driven incentive structures based on individuals' reputation derived from their contributions are the main drivers for the development of OSS.

A slightly different approach is proposed by Lee and Cole (2003), who perceive OSS, in particular the Linux kernel development project, as a model of community-based knowledge creation in contrast to the firm-based models. It is characterised by an evolutionary process of learning driven by criticism and error correction.

Following Raymond (1999), Bergquist and Ljungberg (2001) understand the development of OSS code as a result of the gift economy, which creates openness and relationships between people. OSS gift giving transforms these relationships to interdependencies based on the idea of reputation. The giver gets power from releasing the code he or she develops, but this is also a way of guaranteeing the quality of the code due to the possible inspection and correction by peers.

Demil and Lecocq (2006) inspired by Raymond (1999) introduce the bazaar governance model to describe the governance structure of OSS projects based on transaction cost economics. Since low levels of control and weak incentive intensity are distinctive features of this bazaar economy, there is a high uncertainty of transactions. However, bazaar governance promotes the openness of OSS communities, which generate strong positive network externalities and subsequent efficiency in cumulative transactions. Also inspired by the bazaar model introduced by Raymond (1999), Fitzgerald (2006) highlights that the focus has shifted from the development of OSS code to the OSS product delivery and support services.

The labour economics of OSS have been analysed by Lerner and Tirole (2002, 2005). They argue that career concerns are important drivers for OSS developers due to better future job offers in addition to the already mentioned ego gratification incentives stemming from a desire for peer recognition. Without in-depth elaboration, Lerner and Tirole (2002, 2005) mention also the relevance of OSS for assuring compatibility and setting open standards, which includes its role in battles against dominant firms. This is in line with the finding by Bonaccorsi and Rossi (2003), who observe that OSS diffused in environments dominated by proprietary standards. With characterising contribution to OSS code as selective revealing of knowledge, in particular solutions to create new development paths, Alexy et al. (2013) derive several propositions about its use. First, revealing OSS code might be used to induce collaborative behaviour with firms providing complementary assets and services. Second, this approach is used if companies have the capacity in extracting value from external knowledge provided by other companies or organisations. Third, the perceived strength of a substitutive threat by competitors puts pressure on the own company or organisation to contribute to OSS code.

d. Framework conditions for OSS

Before moving to the literature on the impacts of OSS, it has to be mentioned a set of framework conditions, which have to be taken into account.

The framework conditions are divided into four categories. First, the motivations both of individuals and of companies to contribute to OSS are summarised. Then, the business models and eventually the governance of OSS are considered.

Motivations of individuals

According to the comprehensive review article by von Krogh et al. (2012) based on previous work by von Krogh and von Hippel (2006) and complemented by the survey by Battistella and Nonino (2012) on open innovation platforms including OSS, the following categories of developers' motivations to contribute to OSS are found. According to Nagle et al. (2020) still dominating intrinsic motivations ideology, altruism and fun are differentiated from reputation, reciprocity, learning and own-use as internalised extrinsic motivations and career and pay as purely extrinsic drivers. They further propose to distinguish between short and long term motivations. Differences can be observed depending on the type of contribution (Oreg and Nov 2008), the payments developers receive, but also the type of application, e.g. Bosu et al. (2019) about OSS developers' motivations in the area of blockchain. Complementary to the above-presented distinction between internal and external motivations, Bagozzi and Dholakia (2006) find cognitive (attitudes, perceived behavioral control, identification with the Open Source movement), affective (positive and negative anticipated emotions), and social (social identity) determinants for participation in OSS in Linux user groups (Bagozzi & Dholakia 2006). Furthermore, motivations might change over time (Shah 2006). Context factors have a strong influence of the contributors motivations, e.g. the governance (Shah 2006), including the community-based credibility and openness of the sponsoring firm (Spaeth et al. 2015), but also the satisfaction with the management (Iskoujin & Roberts 2015) of OSS projects. In particular, the degree of openness of the project license is important for intrinsic motivation, reputation, and labour market signaling, but has a more limited role for reciprocity (Belenzon & Schankerman 2015). Finally, the acceptance of payments by developers is influenced by their different types of motivation (Krishnamurthy et al. 2014), but the payments change their motivations (Roberts et al. 2006).

Motivations of companies

Whereas the motivations of developers have been in the focus of research at the early stages of OSS research, focus has shifted to consideration of companies' motivations and strategies. The strategy of selective disclosure of code has already been mentioned in the section about the economics of OSS. However, it has been highlighted as a specific company strategy (Henkel 2006), which is strongly dependent on companies' overall characteristics and strategies. In particular, companies seek access to OSS code and to influence the direction of its development (Dahlander and Wallin 2006) applying different approaches of accessibility and transparency (West & O'Mahony 2008). The approaches depend on the companies' objective to either foster greater growth, which requires a more open strategy, or secure greater control, which favors a more proprietary strategy. These choices shift over market life cycle and depend on competencies amassed by organisation (Appleyard & Chesbrough 2017). In introducing OSS in the context of open innovation, four strategies have already been presented to explain why companies make investments in OSS which is shared with real and potential rivals. These are pooled R&D or product development, spinouts, selling complements and attracting donated complements (West & Gallagher 2006). In this context, Dahlander and Magnusson (2005) introduce a typology of symbiotic, commensalistic and parasitic approaches to handle the relationship between companies and the OSS community. OSS can also play an important role in companies' branding strategy with OSS representing a final phase in the evolution of corporate open (Pitt et al. 2006).

There are several factors which influence companies' strategies and motives. As already mentioned, general company characteristics play an important role (e.g. Henkel 2006). In addition, companies vary significantly in their attitudes towards, and the strategies they adopt towards intellectual property rights, and this, together with the size and strength of the intellectual property portfolios they hold, primarily in terms of patents and trademarks, goes some way towards determining which firms release OSS, but also incorporate OSS into their commercial products (Fosfuri et al. 2008), as do technological, organisational and environmental determinants (Chauhan et al. 2018). There is even the option to offer dual licensing models (Välimäki 2003). However, not only company characteristics matter, but also their mode of communication with the OSS community, i.e. if firms seek to generate new strategic opportunities, they should create an open communication environment (Foss et al. 2016). The diversification of contributions to OSS projects also correlates positively with the diversity of their software product portfolio. This within-industry diversification is even further promoted by authorising their software developers to contribute autonomously to OSS projects of their own choice during working hours (Colombo et al. 2013).

Overall, whereas at the early stages of OSS already 40 percent of contributors to OSS projects are ‘‘paid’’ to participate (Lakhani and Wolf 2005), which is higher than reported by Ghosh (2006), company contributions have been increased in some projects to 90% (Zhang et al. 2019). As a company specific example, IBM’s adoption of OSS has been investigated, e.g. by Campbell-Kelly and Garcia-Swartz (2009).

Business models

In the section about innovation, the literature on business model innovation has already been addressed, which is not really linked to the OSS related business model research.

As already indicated in the section on companies’ motives, companies’ activities related to their contributions to and use of OSS depend on their possession of complementary assets, in particular intellectual property rights. Therefore, Bonaccorsi et al. (2006) speak about hybrid business models. In particular in the early stages of OSS, firms have adapted their strategies and business models to markets dominated by incumbents and their proprietary standards. Consequently, they offer both proprietary and OSS under different licensing schemes. The traditional vendors of proprietary platforms introduced hybrid strategies in order to combine the advantages of OSS, while trying to retain control of their proprietary software and to differentiate themselves from their competitors (West 2003).

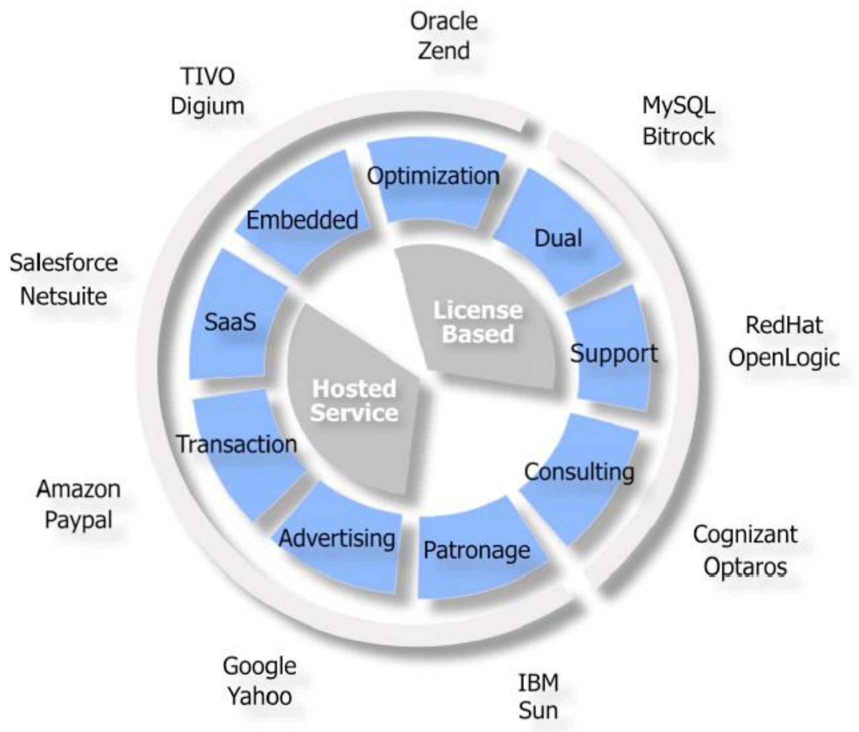
Later in the development stage of OSS, more user-centric OSS business models have been introduced. Companies access OSS communities to extend their resource base, aligning their strategies with the community and even assimilate the OSS communities in order to integrate and share results (Dahlander and Magnusson 2008). These comprehensive approaches need to include an appropriate social software design, a transparent intellectual property strategy, an adequate incentive system and an evolutionary learning and nurturing approach accompanied by employee empowerment (Hienerth et al. 2011).

In the context of open innovation, Rajala et al. (2012) propose an ambidextrous approach, which combines market orientation with the principles of open innovation. Such approaches increase companies’ profitability, shorten time to market through effective market access, and enhances innovation capability (Rajala et al. 2012).

Koenig (2004) already identifies seven business models based upon OSS:

1. optimisation
2. dual licensing
3. consulting
4. subscription
5. patronage
6. hosted applications
7. embedded applications.

Figure 2.1: OSS Business Models and Examples (Koenig 2004)



Business models based on Open Source follow the principles of Open Source Software development patterns. OSS development can be highly collaborative and does not restrict access to the code. Thus, it is unusual that the developer asks for an upfront payment for purchasing a license to use the software. The value of the OSS model is that developers pool resources and work together to collaboratively develop a solution that benefits all involved. The special aspect of OSS is that after pooling resources, the developers make the result available to everyone for re-use without charge. Thus, different models to finance development of Open Source Software had to be found.

An exhaustive, clearly delineated list of business models based on OSS is difficult to establish and there is only limited research available on this topic (see the review by Shahrivar et al. 2018). New models come up through technological developments (such as Software as a Service) and many models have overlap. Okoli and Nguyen (2016) can be seen as the most expansive study available, relying on expert interviews to identify the most relevant business models relying on OSS. They identified a total of 27 business models, with 10 of them being considered “most noteworthy” by experts.

Of these ten business models, there are eight established business models where a common understanding of how they work has already been reached. Additionally, there are two business models which are still emerging and are therefore currently in flux.

The eight established business models for OSS:

- Auxiliary services
- Corporate development and distribution
- SaaS with distribution of server software
- Dual-licensing/Selling exceptions

- Membership and donations
- Crowdfunding
- Advertising
- Update subscriptions

The two emerging business models for OSS are:

- Selling user data
- Software certification

Governance principles of OSS

Literature on the governance of OSS is limited. The wider OSS community has evolved beyond the earlier understanding of individual volunteer driven communities reflected in Benkler (2002), Lerner and Tirole (2002) or O'Mahony and Ferraro (2007) towards a model of collaboration shaped by industry driven continuous research and development cooperation. This development is not in contradiction to these earlier observations, it marks a change in community composition that represents the adoption of OSS products and processes across the industry. It also represents a more marked distinction between copyright licensing under the terms of OSS licenses and OSS governance covering the norms of how communities organize themselves. In particular, business models emerged that combine the use of OSS licensing with closed governance that is not conducive to community participation, as for example the Android Open Source Project, or single-vendor OSS products where copyright ownership is centralized with a single entity.

Closely based on Böhm (2019) and Blind and Böhm (2019) the following recent observations on the governance of OSS can be summarised.

The governance in OSS communities is still shaped by voluntary participation of all contributors. Individuals and organisations contribute to a community's development process only if it is in their self-interest. While some communities have decision making and conflict resolution procedures and functions in place, they cannot force a contributor to implement a community decision. A participant always has the choice not to contribute to the implementation of the decision or to leave the community altogether. Because of that, OSS communities generally aim for consensus when making decisions and are considerate towards minority opinions. The role of steering committees and boards is primarily to moderate the process of finding consensus and to facilitate contributions.

The ultimate decision maker in an OSS community is the whole of all contributors, with each vote possibly weighted by the contributor's merit in the meritocratic organisation. Different approaches exist with regard to the weight of the vote of specific contributors, leading to a spectrum of governance models with for example founder-led, corporate or egalitarian characteristics.[1] While, in the past, concepts like a "benevolent dictator" veiled the fact that without voluntary participation there are no contributors and no community, in recent years governance norms of communities have increasingly been formalised and common expectations established. Representative boards, either elected by the contributors or appointed based on financial contributions of organisations to the community, are tasked with day-to-day management, but can rarely take decisions even against an influential minority of contributors. There is also a common understanding that community

[1] https://www.redhat.com/en/blog/understanding-open-source-governance-models

management and technical leadership are separate concerns. Many community organisations separate between a governing board and a technical steering committee.

The voting rules reflect this ambivalent nature of leadership under voluntary participation. Votes are typically assigned in a one-contributor-per-vote scheme or based on a tiered model where organisations that pay a higher membership fee gain additional votes and committee seats based on that status. However, the composition of the representative committees only rarely translates to concrete influence over technical decisions. Technical leadership emerges from concrete product contributions which often only partially overlaps with administrative project leadership.

This means that the election process is based on a mix of meritocracy and organisational status within the project. The election process is also much less impactful. Since administration in OSS communities plays a subdued role as an enabler of product contributions, serving on a governing board or a technical steering committee translates more to responsibility than to privilege. If OSS projects elect representative functions, voting is performed either based on one-contributor-per-vote schemes or on tiered membership status.

The individual duties of the participants are focused on the overall goal of the community to enable and attract contributions. They require for all participating organisations to collaborate with other contributors in the interest of the project, regardless of competitive interest. Once communities grow to a size where formal organisation is necessary, details of these behavioural expectations are often laid out in a “code of conduct” adopted by the project that aims at creating an inviting, non-discriminating, productive community conducive to attracting contributors and contributions. Beyond explicit policies like a code of conduct, solidified implicit community norms reinforce professionality, acting in good faith and integration with parent umbrella organisations and the wider Open Source community.

The organisational form of OSS communities varies from small, self-organised groups to formalised structure with appointed governing and technical representatives. Voluntary participation dictates that these project representatives do not enjoy executive power over project contributors and have only limited influence on the concrete technical output.

Some projects, however, employ technical and/ or administrative staff. In such setups, the community organisations act similar to companies in carrying out the mission of the project. Only a small number of OSS communities are set up as independent legal entities. Most of the larger collaborations established in recent years are established under an umbrella organisation, such as the Eclipse Foundation, the Apache Foundation or the Linux Foundation that are legal entities, which provide administrative support, technical infrastructure and other functions like marketing and fundraising coordination (Izquierdo & Cabot 2018).

The role of staff cannot easily be generalised, since the project setups vary significantly. In industry-driven communities staff typically focuses on community management and project representation. Key technical contributors, like release managers, are employed as staff in some projects to enable them to work on their projects fulltime. Overall, staff headcount of OSS projects is typically small compared to the number of engaged contributors and focuses on enabling and supportive roles. OSS community staff is usually not in a position to dictate governance, legal or technical decisions.

Similarly, the OSS ecosystem has evolved into the global upstream/downstream network that integrates the work of the various individual communities into a technology stack suitable for end-users and as software platforms for commercial products. The term wider OSS community describes this global network of individual projects, developers, research institutions, business and any other entities that participate in the creation of Open Source Software. No central decision-making body exists to steer the work of the wider OSS community in the global upstream/downstream network. The work of the wider OSS community is coordinated by way of competition between alternative solutions for downstream integration and adoption. Collaboration between the communities within the upstream/downstream network may emerge organically, with the support of companies acting as distributors of integrated products, like Red Hat, SUSE or Canonical, or facilitated by umbrella organisations.

The presented governance principles of OSS are important to understand both the development of OSS communities, but also the impacts of OSS.

e. Impacts of OSS

Although the study is focusing on the economic impact of OSS, the literature review has been differentiated into different subdimensions in order to generate a comprehensive picture. First, it is concentrated on the economy as such, but then it is focused on companies, but also on the individual OSS contributors, the OSS projects. Finally, the impact of OSS on society as such and eventually policies are considered, which are linked to to the policy analysis.

Impact on the economy

Lerner and Schankerman (2010) put software in general and OSS in particular in the context of the new growth theory. In principle, it could provide on the one hand the best available software at essentially zero cost exploiting the full advantage of its non-rivalry property. On the other hand, the incentive problem could be solved by the fact that developers (either as individuals or as firms) contribute voluntarily to OSS development. Potentially, OSS could have a large impact on economic development. Drawing on a large-scale company survey database, Lerner and Schankerman (2010) reveal that OSS and proprietary software interact, i.e. firms sell proprietary software while contributing to Open Source, and users extensively mix and match the two. Therefore, they assume that there are substantial cost synergies, whether in product development or marketing, between OSS and proprietary software. However, they do not show empirically the economic impact of OSS derived from their theoretical considerations.

Ghafele and Gilbert (2014) conceptualise OSS as a prototype of open innovation characterised by a process of learning and imitation. Based on shifts in the structure of US employment, they postulate that OSS might have a positive impact on employment growth in well-paid jobs. However, their findings are just based on the extrapolation of historical employment data. Ghosh (2006) integrate OSS in a simulation model to explain labour productivity and derive from a hypothesised duplication of OSS investment a 0.1% increase in GDP. However, this finding is not validated by empirical data.

The main argument by Ghosh (2006) explores the significant savings related to the development of software, which is beneficial for economic development. For example, Mockus (2007) finds that 50% of popular OSS code is reused often in several projects. This economic rationale of this cost saving effect is elaborated by Riehle (2007) in a microeconomic model. In addition, Ghosh (2006) argues that OSS potentially saves industry investments in software R&D, which can result in increased profits or be more usefully spent in further innovation activities. Robbins et al. (2018) analyse the impact of OSS as intangible capital. With lines of code to estimate effort, they use a modification of a national economic accounts method to estimate the resource cost for some popular OSS packages. In addition, they estimate the resource costs of the OSS shared by the US Federal Government on Code.gov. Most recently, Wright et al. (2020) find a robust positive impact of commits to GitHub on the number of IT start-ups for a panel of over 180 countries.

More recently, OSS characterised as a kind of open innovation is also discussed in the context of national innovation systems. And it is argued that OSS is reinforcing the importance of the national systems of innovation, but also improving its effectiveness and diversifying their networks (Wang et al. 2012). Eventually, due to the ecosystems and platforms around OSS, it is more inclusive and, therefore, proposed as a possible strategy for social entrepreneurs (Waitzer & Paul 2011).

Competition effects of OSS can have impacts on price and quality of proprietary software (e.g. Jaisingh et al. 2008). Whereas some quality impacts are ambivalent (Choudhary & Zhou 2007), although OSS vendors show more immediate patch releases related to vulnerabilities (Arora et al. 2010), OSS pushes pressure on the price of proprietary software (Xing 2015). However, network externalities are also important for the competition between OSS and proprietary software (Cheng et al. 2011) as well as of users' expertise related to OSS (Lin 2006). Recently, August et al. (2020) expand the analysis to a three player game and examine how OSS licensing affects competition among an OSS originator, OSS contributor, and a proprietor competing in an enterprise software market. Here, the role of OSS licenses has a strong influence on the market outcome and social welfare. There is even empirical evidence of the specific enforcement of intellectual property rights on OSS project success (Wen et al. 2013). Recently, the related impact of M&A on contributions to OSS projects has been analysed by Chen et al. (2018).

Impact on companies

There are several studies, which focus on the impact of OSS on individual software producing and buying companies (Krishnamurthy 2003) or on SMEs in particular (Hendrickson et al. 2012). For example, Cereola et al. (2012) analyse the impact of Open Source enterprise resource planning (ERP) software for SMEs.

In contrast to the above-mentioned papers, which are of more qualitative nature, there is only a limited number of quantitative studies. Aksoy-Yurdagul (2015) analyses the impact of OSS commercialisation on firm value considering complementary assets of software patents and trademarks. The impact of both OSS utilisation and contribution of growth on Japanese IT companies has been investigated by Noda & Tansho (2014). The impact of OSS usage and of contribution on company productivity using a panel of companies has been analysed by Nagle (2018, 2019b). A qualitative approach on the impact of OSS on telecommunication software development is presented by Theunissen et al. (2004).

Whereas the rather theoretical economic studies postulate a cost-saving impact of OSS adoption, according to Kumar and Krishnan (2005), it is positively associated with overall firm IT expenditure, in particular on IT labour expenditure.

As introduced above, OSS can be put into the context of open innovation (Chesbrough et al. 2006). Consequently, the impact of outside-in open innovation (Inauen & Schenker-Wicki 2011) and inbound open innovation (Parida et al. 2012) on innovation performance have been analysed. However, the role of OSS has not been explicitly addressed in this context so far. One exception is the study by Piva et al. (2012), who find that entrepreneurial ventures collaborating with the OSS community exhibit superior innovation performance compared with their non-collaborating peers.

Impact on projects

A further impact dimension, which has to be at least to be considered, is the project level, because OSS projects are shared by different organisations, i.e. individuals, companies and even foundations.

A first challenge is the definition and the measurement of OSS project success (Crowston et al. 2003; Sen et al. 2012; Ghapanchi & Aurum 2012). Secondly, it is crucial to find the factors being responsible for the success of OSS projects (Stewart 2004, Wray et al. 2009; Koch 2007; Ahuja 2018).

Obviously, the project initiators themselves are important (Wang & Wang 2020), but so is the leadership in running the projects (Neufeld & Gu 2019). Since the OSS projects are developed by networks of developers, the network embeddedness (Grewal et al. 2006), their collaboration networks (Singh 2010; Singh et al. 2011; Koo et al. 2017; Sowe et al. 2006), social networking (Barbagallo et al. 2008) including their communication (Chent et al. 2013) and feedback patterns (Kavaler et al. 2019) are important for projects' success. OSS projects are in general global. Therefore, the global dispersion of the involved developers has an impact on their coordination and performance, including software quality (Anh et al. 2015, Bird et al. 2012; Daniel et al. 2013). In particular, design (Zazworka et al. 2011, D'Ambros & Bacchelli 2010; Fontana et al. 2012; Palomba et al. 2018), code review (McIntosh et al. 2016; Herzig & Zeller 2013, Rigby et al. 2012; Zanjan et al. 2014, Baysal et al 2013, Hu et al. 2019), code reuse (Haefliger et al. 2008; Jiang et al. 2019c), have an impact on OSS quality and eventually success, e.g. of security by design (Chehrazi et al. 2016). In addition, comment statements influence code stability in OSS (Aman & Okazaki 2008). Finally, the work division and timing in OSS projects is relevant for their success (Howison & Crowston 2014).

The involvement of users has also an influence on the success of projects (Ghanpanchi et al. 2012) as well as the mix between exploration and exploitation (Lee et al. 2019).

As framework conditions, different types of licenses are certainly important (Subramaniam et al. 2009, Ghapanchi & Aurum 2011), but also the financial compensations (Atiq & Tripathi 2016, Liao et al. 2019).

Impact on individuals

Although, companies are meanwhile the main drivers in OSS projects due to the majority of contributors paid by their companies (Geiger 2017 and Nagle et al. 2020), the individual developer still plays an important role for the quality of OSS code and consequently for its final impact.

Consequently, it has been revealed that social ties and collaboration have a strong influence on OSS project team formation (Hahn et al. 2006; Hahn et al. 2008, Qureshi & Fang 2011). This is complemented by the high relevance of the initial environment on the work of the developers (Zhou & Mockus 2011, 2015). In further stages, social capital influences sustained participation in OSS (Qiu et al. 2019) as well as contributions on developer turnover in OSS projects (Lin et al. 2017). Developers' reputation has an influence on code review outcomes (Bosu & Carver 2014). However, even peripheral developers have an impact (Setia et al. 2012). In general, OSS developers are learning from their peers and their own experiences (Singh et al. 2011). In summary, leadership, team member's identification and the perception of the public benefit influence the satisfaction of OSS developers (Chang 2018).

Also individual developers experience tensions between proprietary and OSS development (Rolandsson et al. 2011), which is complemented by the significant impact of ideology misfit on OSS communities and the involved companies (Daniel et al. 2018).

Impact on society

In addition to the impacts on the whole economy and the companies, in particular active in the software sector, OSS also has an influence on other areas. However, the scientific literature is limited and mentions fields, like journalism and printing (Berry 2008), library and information science (Adhikari 2017), translation services (Désilets 2007) and education (Brown 2008). In addition, there is some literature about the influence of OSS on security in general (Hepman & Jacobs 2007), but also cloud security (Riquet t al. 2012), security by design (Chehrazi et al. 2016) and eventually safety (Dobberstein et al. 2017).

In addition to security and safety as public goods, OSS is perceived to become relevant in environmental science (Blower 2019), but also disaster impact assessment (Olyazadeh et al. 2016), energy efficiency (Capra et al. 2012) and eventually on sustainability in general (Fitzgerald et al. 2019). However, there is little recent scientific literature on the role of OSS in the public sector (Mergel 2015).

f. Literature on Open Source Hardware

In contrast to the large body of scientific literature on OSS, the publications on Open Source Hardware are quite limited, not only related to innovation, but to business and economic impacts. One exception is the significant literature on 3D printing or additive manufacturing e.g. on small manufacturing (Laplume et al. 2016), drones (Ebeid et al. 2018) or bio-printing (Lee et al. 2017). Further topics in mostly very specific technical case-based papers are the role of OSH for teaching (Herger & Bodarky 2015; Rodriguez-Sanchez et al. 2015, Schelly et al. 2015) and research, e.g. for microscopes (Wijnen et al. 2016), for the prototyping of robots, for sensor networks and IoT and finally for applications in health, meanwhile including medical devices related to solve the consequences of Covid-19, and environmental protection. Prominent examples of OSH hardware platforms are for example Arduino (Nayyar & Puri 2016). However, the economic and financial aspects have not been analysed yet.

Some studies investigate the participation in OSH (Bonvoisin et al. 2018), the motivation (Hausberg & Spaeth 2020) and the motivations of entrepreneurs of OSH based companies (Li et al. 2017) Since OSH is based on the platform principle (Kim & Hong 2018), openness is an important aspect (Bonvoisin & Mies 2018). OSH is used for product development and design (Bonvoisin 2017), characterised by iterative processes of design, involving several professionals and employing OSH and OSS (Spallazzo & Ceconello 2018). These open design projects pursue complex strategies. It turns out that Open Source communities value openness of software more highly than openness of hardware. For example, Balka et al. (2010) find that open design companies can successfully implement strategies of partial openness to safeguard value capture without alienating their developer community. The communities and partners in the OSH ecosystem are centered around design or production with a mix of complimentary services to create values (Moritz et al. 2018). Kim and Shin (2016) put OSH in the context of social platform innovation and find that content, consumer support, user interface, and reward are important factors that trigger the contributions to a social OSH platform.

In contrast to the more sophisticated and diversified OSS business models, the literature on OSH business models is very limited. Pearce (2017) presents the following list of OSH business models, which is, however, focused on serving the scientific community.

- OSH Makers (Type 1)
    - Kit Suppliers
    - Specialty Component Suppliers
    - Calibration and Validation Services
- OSH Buyers (Type 2)
    - Selling OSH
    - Selling OSH Services
    - Outsourcers of experiments (Type 3)

Li and Seering (2019) expand the work by Pearce (2017) by analysing the business models of OSH based companies in general.

Finally, there are only a few studies on the impact of OSH. One example is a method for determining a Return on Investment (ROI) for the development of scientific free and Open Source Hardware (FOSH) by Pearce (2016), which in particular is focused on the cost-cutting impact of OSH (Pearce 2014). However, the examples are mainly focused on Open Source scientific hardware development. Further, the cost-oriented Open Source automation potential in industrial control applications has been investigated (Hoxha et al. 2016). In a complementary manner, Kwak et al. (2018) expand the perspective from single 3D innovations to innovation eco-systems and platforms in the area of 3D printing technologies, which might kick-off a broader discussion of the link between OSH and innovation including business models.

In summary, the literature on OSH is quite limited or focusing on very case specific examples and technologies, i.e. the case study on OSH has to provide new insights on its economic impact.

g. Summary of literature review

The review of the literature reveals a large body of scientific publications for OSS. In a first step, OSS is put in the context of open innovation and related approaches, because this shows the wider framework, within which its impacts have eventually be analysed. In a second step, the framework conditions are considered for OSS, i.e. the motivations of companies and individuals, but also the available business models and governance mechanisms of OSS. Eventually, the literature on impacts of OSS is summarised starting with the studies on the economy level. Since these are limited the impacts on companies, projects, an important level, and even the individual developers have to be considered. Finally, it is concluded with a brief review of the few studies on OSH, which address economic or business aspects.

Overall, the literature review provides the base for the empirical analyses and the review of the policies to be conducted within this project.

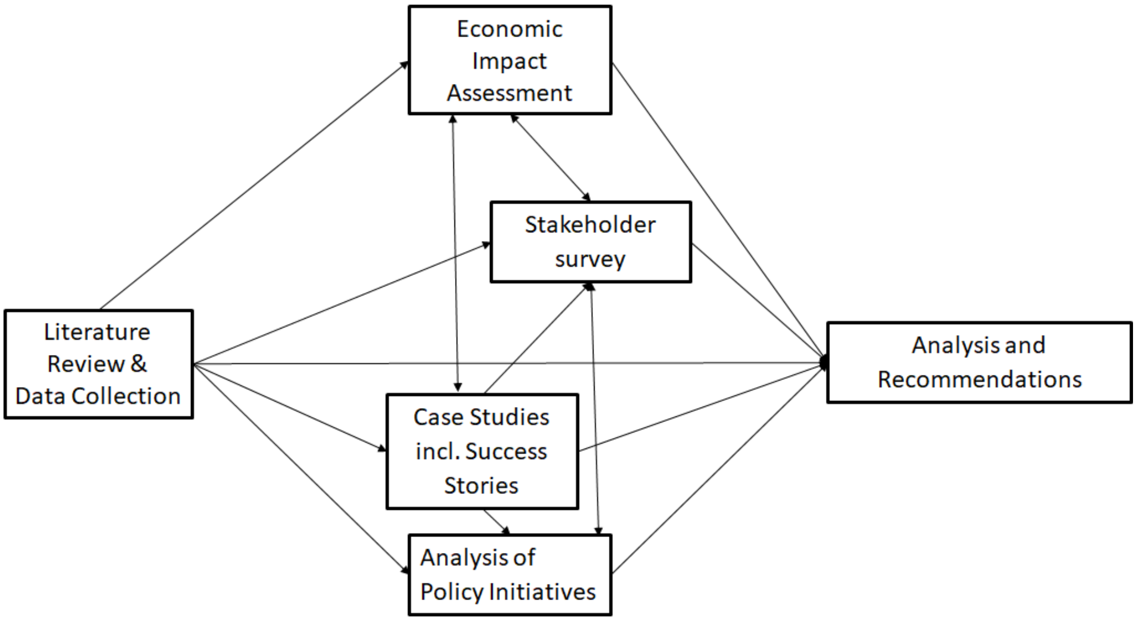
3. Overview of Methodological Approach

a. Introduction

Since there has been no well-established methodology to measure the impact of Open Source Software (OSS) despite recognition of its relevance since almost two decades (see review of the literature), a methodology has been developed, which is based on several pillars. The challenge to develop such a methodology is even higher for Open Source Hardware (OSH), because of the missing previous research and the lack of empirical evidence, in particular data. Therefore, a separate approach has been followed for OSH, which is mainly based on the case studies.

In the following figure, the overview of our different methodological approaches is displayed to analyse OSS and OSH and its various impacts, which are based on the comprehensive review of the existing literature. The approaches are explained in detail in the following sections. In addition, several workshops have been performed with more than one hundred experts representing different stakeholder groups and conducted interviews in addition those related to the case studies and the policy analyses.

Figure 3.1: Overview of methodological approaches



b. Case studies, business models and taxonomies

From the literature review and discussion with experts, a number of taxonomies, including taxonomies of business models, potentially relevant to the analysis phase of the study have been identified. The adoption of a meaningful set of taxonomies fulfils two purposes. The major purpose is to ensure that research is carried out in a consistent way, so that valid comparisons can be made between different projects, both for data obtained during research for the study and for data which are available from existing sources. The second purpose is to suggest a framework to facilitate the data collection in particular of the case studies in a way which minimises conversion errors and assumptions.

It is noted that, especially in relation to OSH, there is a limited number of datasets already available. Although the taxonomies which have been used to collate those existing datasets may not have been ideal for our purposes, nonetheless, in some cases it is possible to translate between taxonomies, either directly, or with a relatively small amount of additional research, with minimal loss of information. In some cases, there were no existing taxonomies available, so it was required to develop our own. In other cases, there were competing taxonomies, so it had to be selected or adapted an appropriate taxonomy for use in the study.

During our initial experts' conference call, some experts questioned whether the inclusion within the study of organisations focused on commercialising proprietary designs was appropriate, given that the study focuses on OSS and OSH. It seemed that to answer the underlying research question on the impact of OSSH also includes consideration of organisations which ingest and make use of Open Source, even if the products they are commercialising are not (wholly or predominantly) Open Source. This led to the consideration of whether 'openness' should be considered in a more nuanced way. Precisely how nuanced is a question which was discussed at the workshop. Similarly, the introduction of "hardwareness" suggests that there is more value in data collection and analysis involving OSS, where possible, using the same set of taxonomies as used for open hardware.

Other taxonomies are more straightforward (such as those relating to geography) or ones which have been imported wholesale to facilitate integration with pre-existing datasets (for example the categorisation used by the Open Source Hardware Association for their certified products database).

These taxonomies and business model categorisations have been used in collecting and analysing data both during the desktop research phase, but also during the interview and survey phase.

Using the data obtained through desktop research and expert input, several significant projects have been identified and selected for the five case studies. From those projects, the suitable ones have been identified as input for case studies, and have performed a series of interviews. Within the five case studies five related success cases have been identified and elaborated. Based on the case studies, a SWOT analysis of the European economy based on the industry domain case studies has been performed.

The analysis of business models within the case studies is complemented by an overview of organisations with successful OSS based business models and an analysis of the description of a larger sample of start-ups provided by CrunchBase showing the diversity of sectors and technologies affected. Finally, for a smaller sample of OSH-based start-ups a more in-depth analysis of business models has been conducted.

c. Economic impact analysis: macro and micro level

Since the literature review revealed various impact dimensions of OSS, different approaches have been applied to address the different impact dimensions at various levels.

The starting point is the database provided by GitHub, which is the most important Open Source repository. The OSS data obtained from the GitHub developer platform is provided by TU Delft in the context of the GHTorrent project (https://ghtorrent.org/). This source is particularly promising and, therefore, the main database of our methodological approach to assess the economic impact of OSS. As the largest repository for OSS projects, GitHub provides unique systematised data on the prevalence of OSS across countries and organisations. Other databases, like GitLab and Software Heritage, do not currently provide adequate data. The relevance and soundness of GitHub as a database is supported by the increasing number of publications mentioning GitHub. Our economic analyses cover only data until 2018. Consequently, the implications of the takeover of GitHub by Microsoft for our analyses are marginal.

Unfortunately, data about the diffusion of OSS code is, in general, not available. However, as outlined in the literature review OSS can be considered as user innovation or a form of co-creation between developers and users. Consequently, contributions to OSS code at GitHub also reflect their use. Therefore, it is proposed to rely on the contributions of code to GitHub following Nagle (2019a) and others assuming that contributing leads also to implementing OSS. In a second step, it also promotes the learning of the contributors as they receive feedback from the crowd of more experienced users and are, therefore, able to better capture value from using the goods (Nagle 2018).

The data provided by GitHub is going to be used for different purposes. The large number of more than one billion commits and more than 30 million users allows the generation of sufficient long and robust time series for all Member States of the EU, but also important other countries contributing to OSS. These time series are used as input into macroeconomic panel regressions, which allow to determine the impact of OSS on the GDP in the EU and labour productivity, but also on competitiveness, innovation and market entry. Based on the contribution of commits to or on users active at GitHub, it is possible to calculate the macroeconomic impact of OSS integrating all direct and indirect impacts. However, since the macroeconomic variables available, e.g. from Eurostat, OECD and other well recognised organisations, are not focused on OSS, but on the economy in general, some of the macroeconomic models do not generate significant results. Nevertheless, at the level of the Member States of the EU it is possible to identify the number of contributors and commits, which allows us to calculate the necessary investments as a baseline of cost for producing OSS in the EU. These cost figures are put in relation to the GDP created based on these investment and lead eventually to the determination of cost-benefit ratios.

In addition, the data provided by GitHub also on a more disaggregated level, i.e. the organisational level, is used. Of the more than 32 million users, 600.000 are linked to an organisation, i.e. both companies and other organisations, like foundations, but also projects. However, the project level is not appropriate for an analysis of the economic impact of OSS, because they cannot be attributed to specific countries or the EU and there is no external financial data available on the project level. Therefore, it has been decided to focus on organisations or better on companies for the analysis at the microlevel. It has been concentrated on the 10.000 organisations with the highest numbers of users or contributors. They attract more than one third of all users in GitHub revealing a link to an organisation. The matching of these organisations with the company database Amadeus generated almost 2.000 European companies or companies with an affiliation in a Member State of the EU.

Eventually, for more than 1.000 of these companies information about their turnover and the number of employees in the year 2018 is available. This information is matched with the number of users, i.e. employees, and their commits. Therefore, it possible to differentiate these companies by sector, employee and turnover category. Eventually, the investment of these companies into OSS is calculated and compared with their revenues as a kind of cost-benefit analysis.

Finally, the stakeholder survey has also a section for determining cost-benefit ratios. These ratios are linked back to the findings of the macro- and microeconomic cost assessment and therefore contribute to validate the so far determined cost-benefit ratios.

d. Stakeholder survey

As already indicated, a further important element of our methodological approach is the performance of a comprehensive stakeholder survey. The aim of the stakeholder survey is to gather and analyse the views of a broad set of stakeholders on the topic of the impact of OSS and OSH, hereby creating a robust empirical representation of the opinions and issues at stake. In addition, the insights from the literature, data base and case study driven approaches to assess the impact of OSS and OSH are complemented with input from the respondents of the stakeholder survey.

The following steps have been conducted:

1. start with the design of a questionnaire based on research done beforehand (such as literature search, case study design and survey of existing data)
2. programming the questionnaire with web-based tools
3. test the survey in the field
4. prepare the delivery of the survey to the survey participants by setting up a database of contacts
5. execute the survey by sending out the questionnaires to different communities and target groups incl. two reminders
6. analyse the results using state-of-the-art software and statistical techniques.

The structure of the survey is the following:

- Position of the person answering the questionnaire
- Basic information about organisation (incl. position on software-hardware scale and business model, innovation activities)
- Strategies for the protection of organisation's or business unit's know how
- Involvement in OSSH
- Type of participation of organisation's in OSSH
- Relevance of incentives to join OSSH development
- Role of copyright licenses
- Differentiation of areas, in which OSSH is used, integrated, developed or participated
- Benefits and costs of OSSH
- Additional comments including suggestions for potential support to Open Source by the European Commission.

e. Final analysis

The insights of all different analysis approaches are used to triangulate and validate the final findings. Therefore, the mainly quantitative findings from the economic analyses, which is mainly top down in particular from the macroeconomic level, is triangulated with the mainly qualitative insights from the stakeholder survey and eventually the case studies, which are generated bottom-up.

Consequently, first the results of the economic analyses are summarised and then complemented in the following sections with the summaries of the stakeholder survey and eventually the case studies. Finally, the findings are structured by the stakeholders involved into OSS or OSH, the subject matters and eventually the impact dimensions.

These findings based on different sources of evidence are the basis for the derivation of general and topic-specific policy recommendations.

f. Public policy analysis

The main aim of the policy analysis is to identify relevant public policy actions and factors therein that impact Open Source in the target countries. When defining the final indicators for the public policy analysis, the need to derive policy recommendations has been already taken into account. The target countries of the public policy analysis are spread all over the world and thus reveal different approaches to Open Source.

First, to identify the relevant actions, it is necessary to rely on different sources for information. Open Source is not a mainstream public policy area and thus, information is often not widely available, especially on a per-country level. To gather the necessary information a mix of academic sources, expert interviews, government resources and professional research is used. This is adjusted on a per-country level.

While in some countries academic sources are available and relatively in-depth research has been performed, in other countries, or for that matter most countries, academic sources are unavailable. Still, about 150 relevant academic publications have been screened for the purpose of the policy analysis. Expert interviews have been the second important sources of information.

Experts can provide information in a more informal setting, providing context and background, information on the successes and failures of policy actions and are thus very important to understand the unwritten laws and cultural specificities and bridge the language-gap that play into public policy in the different countries. Experts also provide an important head start in research, act as multipliers and provide information important academic and government sources. For the purposes of the public policy analysis, over 50 expert interviews have been conducted. These interviews are based on a semi-structured questionnaire.

Governments, especially in democratic countries, usually provide themselves with a significant amount of information on policy actions in the form of governmental reports, strategy documents and laws. This is an important tool for the content analysis of policy actions. In addition, consultancies and other professional services commonly also provide important information on policy actions.

Besides the identification of policy actions and their contents, to be able to draw conclusions from the analysis and use these for the formulation of public policy recommendations, a comparison of policy actions is performed.

Such a comparison necessitates that comparable information is collected. Thus, the data gathering is based on a common analytical framework across all cases which is outlined below and detailed further in the public policy analysis chapter. The analysis is structured around two dimensions – one around public policy actions aimed at the public sector and one aimed at the private sector.

Based on this framework, data is gathered and analysed. The comparison marks the expansiveness of public policy actions based on indicators which derive from the above dimensions and criteria. Thus, each analysed country has a detailed country report and a comparative score based on the expansiveness of its policies.

Table 3.1: Framework of public policy analysis

Dimension	Criteria
Public sector aimed policies referring to how the public authority in question implements OSS & OSH in their own organisation.	• The level of prescriptiveness of a policy throughout the jurisdiction. • The degree to which public procurement policies take OSSH into account. • How effectively the policy is being executed. • The degree of competence with regard to OSS and OSH within the public authority.
Private sector aimed policies referring to how the public authority in question engages with other actors, specifically in the private sector.	• To what degree the jurisdiction supports private actors in adopting and developing OSS and OSH. • To what degree the jurisdiction makes guidance available for private actors. • Whether the jurisdiction's administration takes on a role (and if so, what role) with regard to OSS and OSH communities. • To what degree OSS and OSH is being taken into account in neighbouring policy fields.

g. Policy recommendations

Throughout the work, there was a constant exchange among core team members on possible observations and ideas regarding recommendations and conclusions. Core team staff have also been engaged to a large degree in field work, ensuring that all team members got the 'full picture', rather than working only in an isolated manner on specific tasks without knowledge of the wider context. The results from the policy analysis and comparison played a major role in deriving policy recommendations. During regular team meetings new ideas, conclusions and options for recommendations were discussed. Once the first results from the different approaches were available, they were triangulated based on the different evidence bases so as to counter the advantages and disadvantages of each method. In all relevant stages the sounding board members have been involved as sparring partners for our ideas and recommendations. In particular, the five workshops provided valuable input for the derivation of policy recommendations. Finally, the progress reports and the meetings with the EC allowed for an exchange on the development process towards the recommendations.

The limited, but well-defined set of recommendations have been derived based on the outputs of the previous work reflecting the request for evidence based recommendations. In particular, the analysis of impact reveals insights first about the justification of public policy measures and second about the stakeholders involved in OSS and OSH as target groups for these policy measures, e.g. micro companies and SMEs. The case studies, the SWOT analysis and the stakeholder survey provide insights on specific areas on which policy measures should be focused, as well as which instruments the EC should concentrate on.

The analysis of the public policies provides a structured, indicator-based overview not only of currently existing policy measures, which might need to be expanded or adapted, but also of best practices from other countries to be considered by the EC.

Overall, the need has been identified both for OSSH specific policy initiatives and for integrating OSSH policy aspects into other policy initiatives, like education, competition or public procurement. Where possible, the analysis is performed separately in emerging technologies, e.g. Artificial Intelligence, as well as in sectoral applications. Since OSS has a high importance for IT security, recommendations are derived related to the joint contribution of OSS and OSH towards the provision of secure and trustworthy ICT solutions. Finally, OSS has a large potential for the public sector and recommendations have been derived on strengthening the role of OSS in the development of interoperable solutions and public services.

4. Case Study Analysis, Business Models and Taxonomies

a. Introduction

This section of the final report aims to provide a qualitative analysis of key OSSH projects using taxonomies listed in the Annex that define the key variables and metrics describing relevant characteristics of OSSH at the individual, organisational, sectoral and societal level. Insights from the case studies complement the quantitative assessment of the impact of OSS and eventually are the basis for the derivation of policy recommendations.

OSSH is a broad concept that subsumes aspects of source code or design licensing, the governance of collaboration as well the provision of the means of and the production process itself. To understand the impact of OSSH along each of these dimensions, this report aims to develop a system of taxonomies and to suggest a relationship to business models and economic impact.

b. Case study methodology

The cases have been researched in the form of embedded multi-case studies (Yin 2003). Data is gathered using semi-structured, open-ended interviews based on a standardised interview guideline. The individual cases are assessed using a common structure of criteria, making them horizontally comparable. The cases are then aggregated in a SWOT analysis focusing on the perspective of a policy decision maker. The cases have been selected based on their influence on technological independence, competitiveness and innovation in the European economy as indicated by the interview results as well as by input provided in an expert workshop.

Selection of case studies and interviewees

The five case studies represent a diverse set of industry domains related to the OSSH field. They are based on interviews with key individuals from thirteen relevant projects (in come cases, with more than one interview per project). All of the interviewees are prominent individuals in their various fields and all have been keen to participate and have provided valuable insights. Their involvement and co-operation is highly appreciated. It is also worth noting that it is in the nature of OSSH that individuals tend to be involved in multiple projects, so each individual interviewee has been asked to answer in respect of the specific project which they felt was most pertinent to the study. The criteria for selection of the interview candidates include:

Geographical diversity: although the bulk of the candidates are based in the EU, interviewees come also from North America and the UK.

Sectoral diversity: it was ensured to have representation from projects representing commerce, the public sector and academia.

Hardware and software: interviewees represent projects in hardware (additive manufacturing, electronics and silicon) and software (foundational technologies and end-user technologies).

Openness diversity: interviewees represent projects which are fully open (as assessed using the models set out below), through to those which provide proprietary products which are based on open technologies, but which are themselves closed.

Diversity of organisational structure: interviewees represent foundations, project leads, venture-capital funded corporations, privately-funded corporations, academic institutions, and government-sponsored entities.

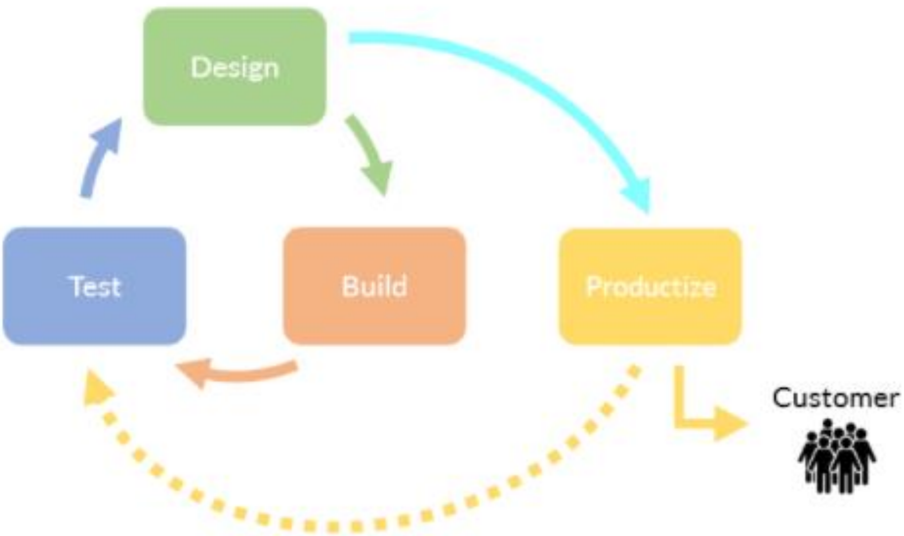
Structure of the interviews

The interviews were timetabled to take one hour, with slack for up to an additional 30 minutes of overrun. They all took place using videoconferencing, owing to the impact of Covid-19, and the calls were recorded for internal use only. Prior to each call, the interviewee was provided with an interview template and a set of explanatory notes (see Annex). The interviews consist of a mixture of quantitative questions (where the interviewee is asked to give a subjective numerical assessment of the impact of OSSH on various factors, and the impact of various factors on OSSH), and a series of qualitative questions to which more discursive answers could be given.

c. Dimensions of openness and hardwareness of software and hardware

Development of software and hardware typically consists of a cycle that spans design, build, test, and then re-design, based on outputs of the test. When ready, the build phase of the cycle switches to productization. For software, all phases take place in the digital domain.

Figure 4.1: Design-build-test cycle and productization



Productization may be as straightforward as removing some debug code and placing the binary in a place where it can be downloaded. It might involve packaging the product electronically (e.g. in a Linux container image), or might involve flashing the binary into a device's nonvolatile memory. For something like a car, although much of the design may occur digitally, many parts cannot be effectively tested until they are physically built, and whereas a one-off suspension component can be individually machined, preparing the car for manufacture will involve a vast amount of activity in the physical domain such as creating jigs etc. Thus much more of the cycle will take place in the analogue/physical domain.

Hardwareness

At each stage, the activity will occur somewhere on a spectrum between the digital (informational) domain and the physical domain. For example, in relation to software, design and build will occur in the digital domain, and testing will likely also occur in the digital domain, although software intended for use in devices will involve loading into the device. Productizing will likely also be in the digital domain.

Field programmable gate arrays (FPGAs) are designed and built using a hardware description language (HDL). Much of the testing will occur in the digital domain. Some testing as well as productising will involve some activity in the physical domain (loading the bit stream onto the FPGA mounted on a circuit board). For application-specific integrated circuits (ASICs), design and build (using simulation) happens digitally, testing may involve some physical activity (if an FPGA is used for testing), but productization will require significant activity in the physical domain.

For printed circuit boards (PCBs), much of the design and testing takes place in the digital domain, but productizing is largely physical.

Much activity regarded as artisanal or craft is likely to happen largely at the hardware end of the scale. It may help to think of “software” as “informational”: for example, even if a design for something is sketched out on paper and mailed to someone else for comment, this would still be somewhere towards the software end of the scale as information is being transferred. If the product spans two domains (for example a PCB which also contains firmware), there may be different levels of hardwareness for each component. . Bearing this in mind, for the design, build, test and productize stages in the cycle, hardwareness can be assessed on a scale.

Degrees of openness

The debate on the meaning of openness is older than Open Source itself. It is widely accepted that there is no binary distinction between open and proprietary technologies. The most defined aspect is that of licensing, since there is an accepted definition of what is and what is not an Open Source licence. The wider context of openness however is that of collaboration, (re-)distribution and reuse of the results in the form of derivative works. Here it has become obvious that stakeholders can still maintain a firm control over a technology even if it is freely licensed. This illustrates the need to answer the question of how open a technology effort is considered to be.

To assess degrees of openness, a number of existing approaches have been evaluated including the open by rule model and the Waugh-Metcalfe model. The open by rule model postulates that open, meritocratic governance, a rule-based system, collaborative roadmap planning, a healthy community of independent contributors, the possibility of forks and overall transparency are key dimensions of openness. The Waugh-Metcalfe model differentiates between legal, standards, knowledge, governance and market openness.

The different aspects of openness are difficult to assess directly by asking participants to rate their openness on a scale. Instead, indicators based on the open by rule model and the Waugh-Metcalfe model are evaluated indirectly and separately in the interview questions and case study structure. With this approach, an overall assessment of openness for each case is achieved by aggregating the results. The interviewee is never asked directly to assess the openness metrics of a domain.

Positioning in the productive process

Related to the design, build, test and productize stages in the hardwareness taxonomy, the process of introducing a product based on a combination of software and hardware into the market involves the creation of information goods such as software and hardware designs as well as the manufacturing of physical products like boards, components and devices. Based on that, the question of what is open about a technology can be separately answered for the design process and the means of design in contrast to the manufacturing process and the means of production. It has be found that there is a relationship between openness and hardwareness.

Approaches to both openness and hardwareness regularly change along the productive process. For example, freely licensed chip designs which are information goods resulting from the design phase may be used to manufacture chips that are physical goods and sold at market prices. Similarly, proprietary software development tools may be used as means of design to create freely licensed software products. By separately assessing openness of the design process, the means of design, the manufacturing process and the means of manufacturing separately, the question of what is open can be answered systematically, and a relationship between openness and hardwareness can be determined .

An interesting perspective offered by this breakdown is that software development processes can be considered a special case of this overall productive process that ends after the design phase. As an information good, software usually does not incur a manufacturing phase. During the design phase however, it is similar to the development of hardware designs, especially those which are developed mostly in the digital domain.

This description of the productive process is generic. The current perspective differs from before the introduction of the concept of OSSH in that openness in any of the four aspects is now a possibility. This offers a potential theoretical approach that considers proprietary and open products and processes on a spectrum of openness and a spectrum of hardwareness instead of making a binary distinction.

Positioning in market sectors, technology areas and industrial domains

The European economy comprises multiple industrial domains that are expected to the especially affected by OSSH. These domains include energy, health, home automation, aerospace, consumer electronics, entertainment, automotive, manufacturing and logistics. Technical developments that are expected to drive change in these domains include advances in cybersecurity, computing, networking and software infrastructure, artificial intelligence, high performance computing as well as testing and tooling. The cases qualitatively explore these combinations of domains and technical developments further to potentially identify specific areas of interest.

Aspects of collaboration on technical development

The development of OSSH technologies for the most part depends on productive collaboration in a healthy community. Cases where single entities develop OSSH technology exist, however they are not common and do not represent major areas of innovation, even though they do represent relevant domains of venture capital funding. Usually, community collaboration out-innovates single competitors while reducing the cost for the individual participants through the pooling of R&D spending. The cases studied for this report focus on community-developed technologies.

Many participants grow into the community by gradually extending their participation. This journey from a consumer to a strategic engagement of individual participants and the extent of the organisation’s involvement in communities indicate the impact OSSH is able to achieve.

Communities as well mature from loosely organised groups with no formal structure to potentially complex ecosystems with effective governance and influence on informal and formal standards. Assessing the maturity of a community helps to understand the impact the community may have on the respective industry sector or domain.

Foundations play an important role by facilitating projects, providing administrative support, organising events and raising funding. Foundations here are understood as umbrella organisations that host multiple individual OSSH projects within a larger organisation. Domains that developed effective foundations can be assumed to have larger impact on technical development.

d. Business models and value propositions

Software and hardware modules are aggregated and combined into systems of systems until they eventually form consumer facing products. Every market actor in this supply chain offers their customers a value proposition. The customers compare those with the propositions of competitors and choose the one that they perceive offers the best value. This simple concept illustrates that in an economic context, the development of OSSH must provide tangible market value to justify investments. This puts the focus on the approaches of commercialisation and knowledge transfer from community development to businesses.

Product and service classifications

The applied approach of business model analysis classifies value propositions into products and services. Products are defined as items which the seller has the right to sell and in some way exclude others. This includes physical items and proprietary software. Services can be offered on items or products not owned by the entity providing the service. They represent value in relation to products either by complementing products or by vertical integration. They are usually offered on a billable-hours or subscription basis. Products are classified based on their revenue model, the type of good and their differentiating aspects. This approach assesses how products generate value and how their characteristics impact the viability of business and governance model choices of companies.

Related to the development of OSSH, the type of good is modeled on a spectrum from foundational technology or unfinished products to consumer-oriented technology or finished products. The same idea is represented in the technical concept of the software stack. Placing a product in this type of good spectrum illustrates R&D priorities including the choice of an open or proprietary development model.

Differentiation is modeled on a spectrum from non-differentiating product features that are expected by consumers but rarely noticed unless they are absent to differentiating product features that determine buying decisions. Market actors make decisions for in-house development (differentiation) or collaboration and allocate R&D spending based on the differentiating aspects of their products.

The analysis of revenue models often focuses on the generation of revenue for the business. In the context of OSSH, the question can be asked more generically as how businesses realise the benefit from using and developing it. These benefits can be placed on a spectrum from cost savings as in pooled R&D spending to revenue-generating consumer-focused value propositions. This variable influences decisions about openness or exclusivity applied to the development process, the applicable intellectual property rights (IPR) models, as well as the viability of business models as such.

The revenue-differentiation-product type space

The combination of the three dimensions representing the revenue model, the approach to differentiation and the product type creates a three-dimensional space with eight octants. Each octant represents an area with common product characteristics and a set of viable business strategies. For example, the octant of cost-saving, non-differentiating and foundational technologies provides the space for Linux distributions and modules under weak-copyleft licenses. Other octants like the revenue-generating, non-differentiating and consumer-oriented one are not commonly suitable for OSSH based business strategies.

A special case is represented by value propositions that focus neither on revenue generation nor on cost savings, and are instead indifferent to revenue generation. These cases represent businesses generating indirect benefits for example by marketing commercial services facilitated by the offered OSSH technologies. This poses a specific regulatory challenge of balancing innovation and market competition.

Relationship to public infrastructure

A key aspect of the overall impact of OSSH is its utility as reusable foundational or building blocks of various complex technologies. OSSH innovations create positive spillover effects from a “soup of innovations”. They facilitate means for specific ends like communicating or learning without prescribing the exact use. They do not discriminate by use or user. They unlock access where it would otherwise not be economically feasible, like in the provisioning of software to underdeveloped or economically poor areas. This means OSSH exhibits attributes commonly associate with infrastructure.

On the one hand, this means that the economic impact of the infrastructure-type spillovers may outweigh, but be obscured by the direct benefits. On the other hand, it indicates a public interest in the viability of OSSH development and of safeguarding key OSSH products.

The openness debate

The different variables and metrics described in these various taxonomies try to offer a more systematic answer to the question on the meaning of openness by separately assessing how the openness of the licensing and development models of goods at the point they are licensed and those of the next good they become the input for. This discussion is complicated by the fact that combinations of free and proprietary inputs are common. For example, proprietary tools are commonly used to author OSS. Similarly, freely licensed 3D printers can be applied to create commercially sold items. This means that taxonomies of openness applied at different points of the value chain are necessary to isolate the impact of OSSH.

e. Industrial domain case studies and success stories

Maker to manufacturer - process innovations

Introduction, positioning and domain description

Open source hardware (OSH) enables the development of technologies which bring together sectors such as academia and the maker movement and provide a bridge between citizen manufacturing and the industrial domain, enabling each to benefit from the other. This case study includes input from the projects Arduino, WhiteRabbit, MyriadRF and RepRap.

Arduino is a family of microcontrollers. These are small, simple, single-board computers which can be configured in multiple ways to undertake a variety of tasks including sensor logging, device control, IoT interfacing. Both the hardware and the firmware are Open Source. WhiteRabbit is a project of CERN, originally intended to provide high precision timing of events taking place in the particle physics domain by extending the Ethernet networking standard and protocols, this family of electronic devices is now used in other academic fields, as well as areas as diverse as seismology and high-frequency financial trading. MyriadRF is a family of software defined radio technologies, combining Open Source electronics, gateware, firmware and software. RepRap is a 3D printer technology, originally emerging from academia, notable in that many of the components in a RepRap printer are themselves printable using a RepRap printer. To this extent it is partially self-replicable.

These technologies typically facilitate or enable other technologies. They can emerge from a diverse set of fields: academia, manufacturing, electronics and research. By providing a stable implementation of the technology, they provide a low friction platform for development and frequently provide benefits which the original instigators never envisaged. There is no dominant market or organisational sector which is represented: both the development of the original project and their exploitation can arise across a broad range of sectors.

Technologies in this category are characterised by their flexibility. In each case, the initial developers of the technology anticipate that this flexibility is best exploited by opening the technology freely to others. The drivers are diverse. White Rabbit, a project of CERN, was opened primarily because the project instigators felt strongly that public money should result in technologies which are equally available to the public. They also felt that with appropriate licensing, any improvements to the designs they employed would also themselves be opened up to the public, and ultimately they could feed back to the initial project. Each of the projects mentioned is a combination of hardware and software (and, in the case of White Rabbit and MyriadRF, software-like technologies including HDL code). Even within each project, different communities coalesced around each sub-project.

There is a broad range of funding models behind the actors in this sector. The initial project instigators have benefited from academic and research funding, as well as private sector investment and government grants. The structure and ecosystem behind each project varies and this means that, as a whole, each project ecosystem has different funding models. Care needs to be taken, in most cases, to separate the project instigator from the commercial models which have emerged around the project. For example, RepRap itself has minimal funding, but does have a thriving ecosystem of commercial operators who take and commercialise the design.

In each case the perceived reduction in vendor lock-in which arises from the open licensing model is a key factor in the adoption of the technology. This gives adopters comfort both that the underlying technology is not going to disappear, or be radically changed, and that there is no one manufacturer who will suddenly increase prices. In particular, researchers and academics who have both operated under budgetary constraints, and also themselves have the curiosity, and in many cases the skills and expertise necessary, to wonder whether they cannot produce the product themselves, more efficiently and effectively than the existing proprietary market. In every case, new use cases have been found for the projects than were anticipated by the project initiators. Openness facilitates the repurposing of the design for different use cases. For example, hardening a circuit board for use in high temperature or high humidity environments becomes significantly simpler and cheaper when applied to an open design, than requesting that a proprietary producer develop a one-off variant for that specific use case.

In many cases, the market for the products themselves has diversified, by being catered for by a number of actors. In each case, it is (theoretically, at least) possible for a consumer to make the product themselves. This is true, in practice, for most components of the RepRap and many end users choose to ask a friend with an existing RepRap to fabricate many of the components themselves. They can also engage a third party 3D printing company to print those parts, use an existing 3D printer at a maker-space, or they can purchase a complete RepRap printer from a company like Prusa. These options create a diversity in the marketplace, and potentially lead to resilience in supply. Likewise, with Arduino, although many purchasers opt to buy a complete board from Arduino themselves, and whilst many home users might find it challenging to fabricate an Arduino circuit board themselves, it is theoretically possible for them to take the board designs and have them produced quickly, cheaply and efficiently by one of the increasing number of companies which provide on-off circuit board fabrication facilities. There is also a thriving ecosystem of Arduino-compatible boards manufactured and sold by companies other than Arduino. This suggests that a key differentiator is that consumers buy genuine Arduino boards because they perceive that a genuine board has higher quality standards than those of an unknown manufacturer. Another factor might be that consumers want to recognise the value that Arduino has added to the open ecosystem (a form of “thank you”). It is notable that it is possible to engage Arduino to develop and produce custom board designs at volume, and in those circumstances, consumers choose Arduino both because of the amassed skills and experience, but also because Arduino itself is developing the ability to negotiate keen prices with its own subcontractors. These all suggest that, in contrast to the open nature of the Arduino licensing model, Arduino relies on tight control of the intellectual property in its trademark to sustain the commercial model.

What is particularly interesting is that it is possible for different ecosystems to coalesce around the same project. Where a project consists of hardware and software, for example RepRap, then different ecosystems, with different dynamics, can develop around the hardware portion and the software portion. For MyriadRF, there are three distinct communities: hardware, software and gateware. Each different ecosystem presents different dynamics, and different opportunities for differentiation. One commonality is that "Open Source development model", where participants can change the underlying design to address a particular issue or desire, and which can then be fed back into the main designs, functions in the software and gateware domains, but less so in the pure hardware domain. In other words, the "harder" the hardware, the more likely it is that the design and development work is ultimately carried out in the same way as it is carried out by proprietary developers by a centralised research and development operation as opposed to a community of collaborators.

The technologies in this sector can be used in a broad range of use cases. They are not turnkey consumer products, but are generally used as components of more complex systems, or in research and academia.

Tooling was considered to be a significant issue. In each case, the relative lack of Open Source Software tools to design, manufacture and test the product was noted as an inhibitor to development. This issue applies both to "hard" hardware (mechanical components, and electronics) and "softer" hardware such as the tools to develop, test, simulate and instantiate gateware. In each case, participants noted that this situation was improving, but needed to improve still further to lower the barrier to entry for participation.

None of the participants viewed cybersecurity as being of particular importance during research and development. However, for any project using silicon, there remains a concern that the underlying chips could be internally compromised. This was a particular concern for projects which could be incorporated into communications (such as MyriadRF). In theory, a chip could be manufactured with a hidden backdoor which could facilitate the decryption of messages, or allow a malicious third party with knowledge of the backdoor to have access to the equipment. This is potentially a more significant problem for application-specific integrated circuits (where it is notoriously difficult to trace the complete manufacturing supply and development chain) than for FPGAs, which are general purpose chips that can be configured using gateware. Open gateware, therefore, potentially provides a route to increased security by permitting scrutiny of the code, as well as allowing the incorporation of code which can monitor anomalous behaviour, and also permitting vulnerabilities to be patched while the device is in the field. Computing infrastructure is, therefore, potentially also impacted by this area of open hardware. Artificial intelligence was not regarded as particularly impacted by this sector. However, the relevance and impact of these factors are expected to increase in the future.

The technologies in this sector currently have a low or minimal impact on research and development in most sectors, with the most development likely to be seen in the corporate sector. This is true, to a lesser extent in the public academic and research sectors. This will grow over time, especially for companies. The same is true of the impact on these sectors in the production phase.

Success case: Arduino

The Arduino project demonstrates how a need generated by the hobbyist, maker and manufacturer movement in Europe can expand to a successful manufacturing business which has developed its own ecosystem with international impact.

Arduino consists of a family of microcontrollers, which can be used in multiple applications from maker projects to academia to industry, both in the research and development domain and manufacturing at scale. The hardware itself is licensed under a creative commons share-alike licence (CC-BY-SA 4.0) and the software under an equivalent reciprocal licence (GPL). This means that the designs of the hardware can be (and are) copied, both commercially and non-commercially, so control over the Arduino trade mark and associated licensing model is critical to retaining value for the business, and associating the name with quality and the origin of official Arduino products.

Arduino sells its range of boards in the commercial marketplace. It also provides consultancy around the use and development of the boards, and has recently launched a paid-for SaaS model to facilitate the development of IoT technologies using Arduino hardware.

Arduino’s very low barrier to entry for hobbyists and makers means that there is a large number of people with experience of the platform. This in turn means that many of the makers become teachers and educators, and the ecosystem becomes self-sustaining. When people with this experience move into industry, they continue to use the platform they are familiar with, and this becomes very attractive because of the avoidance of lock-in that the platform provides. Although there are third party providers of the hardware, in practice, this is not a large threat, as the price differential is minimal, and customers are more comfortable purchasing genuine Arduino products. The main differentiating factors are there for the existing ecosystem of knowledgeable individuals, and compatible hardware and software, and the security of supply caused by the absence of lock-in.

Arduino boards can be used in many cases where simple processing and connectivity are required, including academia, research and manufacturing. An increasing field of use is Internet of Things where a small, low-power device with flexible processing ability and RF (radio frequency) connectivity using a variety of protocols and frequencies are critical.

Significant factor impacts exist in the physical domain, and open hardware projects, including Arduino, are affected by these as well as impacts applicable to the digital domain. Thus the existence of software tooling for research and development of circuitry still lags behind the equivalent for software. Open source alternatives (such as KiCad) are being developed, but the availability of Open Source Hardware tooling still lags behind the availability of similar tools in the software world. This means a higher barrier to entry, which means that the hobbyist/maker market finds these tools inaccessible, meaning there is a smaller pool of engineers skilled in these products. Physical items are also impacted by issues around shipping (for small devices such as circuit boards, this is not so much transportation costs, but issues relating to shipping the devices across borders, and import regulations in some countries. Regulation and certification can also have an impact, which is disproportionate for short runs, and therefore particularly impacts SMEs. Examples are CE marking (in the EU) and FCC certification (in the USA).

Cybersecurity is a significant factor, and becoming more important over time. It is also likely that Arduino devices will become an increasingly important component of the digital infrastructure, particularly in the area of IoT.

Arduino is unlikely to have a disproportionate impact in any one industry or societal sector, although overall it is expected that there may be significant positive effects on all sectors overall, owing the use of Arduino in infrastructure, and particularly the domain of IoT. This may be of particular benefit to SMEs who will see their access to this market enhanced by the lower barriers to entry presented by Arduino.

Arduino demonstrates how providing a simple hardware platform on an Open Source basis can democratise access to the technology (leading to increased public participation from hobbyists and makers, as well academics, researchers and, ultimately, industry). Adoption by industry is spurred both by the availability of a pool of individuals who are knowledgeable about the technology and also, crucially, the comfort that the Open Source nature of the technology provides a guard against lock-in, enabling Arduino, as a relatively small organisation, to effectively compete against much larger businesses.

Integration into the Open Source Software and Hardware community

The ecosystem covers a diverse range of activities. Vertically the ecosystem can be divided into segments covering the “hard” hardware, gateware and firmware/software. Although interdependent, each ecosystem has its own characteristics and dynamics.

In parallel to the establishment of multiple interdependent ecosystems, there is also the establishment of interdependent communities. The most well established are those operating at the software end of the hardware projects, with deep integration into other relevant communities, such as Linux.

The contribution mechanism varies significantly from organisation to organisation and from project to project within organisations. The key observation is that the harder the hardware, the more likely it is that the development is undertaken by organisations using a traditional development methodology.

The ecosystem is diverse, consisting of manufacturers, designers, hobbyists and makers, academics, and commercial manufacturers.

Arduino, RepRap and White Rabbit adopt copyleft licensing models for both hardware and software, although each of the projects recognise that there may be use-cases where more permissive licensing models may be more appropriate (for example, to facilitate interfacing with proprietary technologies). Arduino may also apply non-open-source licences such as licences with non-commercial conditions, in use cases such as education. In each case, the copyleft licence is employed to encourage entities using the technologies to release the design materials for any improvements or modifications they make to the underlying technologies. Arduino, in particular, uses its trademark rights as a mechanism to differentiate itself, and promote clarity within the ecosystem. Thus using the term “Compatible with Arduino” is encouraged (where this is true), whereas describing a non-Arduino product as “Arduino” is prohibited.

There tends to be a differentiation between those contributing to the software and gateware, who may be makers, hobbyists and individuals, and those involved in the development of harder hardware, such as electronic circuits, and physical items, who tend to be more corporate led. Individual developers are more likely to be retained when they are in an active community, so in each case, community outreach is important.

A wide variety of approaches is deployed, from making material available online, to more interactive and interpersonal approaches such as running workshops, and presenting at conferences in a wide variety of countries worldwide. Arduino also has a programme to donate materials to disadvantaged individuals.

Arduino sells direct to customers, and as such is an integrated entity which handles IP development, community development and outreach, and sales. White Rabbit designs, by contrast, are sold by independent commercial entities. CERN is in itself more interested in knowledge transfer, and giving commercial entities freedom to use that knowledge, with the objective that where possible (through use of reciprocal licensing, for example), knowledge which is further generated should be required itself to be made available. RepRap is available through a number of commercial entities who make and sell the machines: for example, Prusa. There is also a growing market for farms of 3D printers which can produce materials on a volume basis as the point at which it becomes cost-effective to switch to mass manufacture techniques (for example, injection moulding) increases.

Arduino as a commercial organisation sees revenue and profitability as significant, but is also keen to see that the technology is not stagnating and continues to be deployed in new and innovative ways. This latter factor is probably more of interest to RepRap and White Rabbit. RepRap and CERN (White Rabbit) are keen to see the deployment of the technology by commercial entities like Prusa (in RepRap's case). MyriadRF is keen to see growth of the community, and an increasing number of diverse projects emerging from the technology.

Conclusion

The EU possesses enviable projects which demonstrate the power of open licensing and open development methodologies in bringing together a diverse ecosystem from hobbyists to researchers to academics and manufacturers and sellers. However, regulation and lack of clarity in IP can be an inhibitor. Removal of those barriers presents a significant opportunity, provided that a balanced approach is taken, and threats from the USA and the Far East are appropriately responded to.

Open Hardware computing and infrastructure

Introduction, positioning and domain description

These projects were initiated with the aim of leveraging open and quasi-open hardware technologies to provide a platform for innovation and commercial exploitation. The case study considers the projects Open Compute Project, RISC-V and SiFive.

The Open Compute Project was initiated by Facebook to reduce the cost and improve the efficiency of datacentres, by developing components ranging from servers to data storage to racks and other physical infrastructure. It encompasses the spectrum of hardware and software, from the hardest (racks and furniture), to intermediate (network switches incorporating FPGAs configured with HDL bitstreams) and software (firmware, interface and monitoring, for example). Its licensing model (for hardware) is not fully open. RISC-V is an instruction set architecture for microprocessor cores developed at the University of California at Berkeley which is released under an Open Source licence, and which has been implemented in a number of microprocessor core designs which can be implemented in FPGAs and ASICs. Some of these designs are available under open licences (for example, SWERV (developed by Western Digital) and the Freedom platform from SiFive. SiFive is the third case study in this sector, and is an aggressively commercial company founded by the individuals who developed the RISC-V ISA, and based in Silicon Valley. It has attracted funding of $125m as of the end of 2020, and produces a range of processor cores and associated products on both Open Source and proprietary licences.

These technologies leverage the cost-savings inherent in sharing research and development using Open Source licensing. However, emergent benefits have arisen, which extend further than cost savings. Open hardware computing and infrastructure projects seek to leverage the power of standardisation and collaborative research and development. The de-proprietarisation of technologies has revealed a tension between the customers for infrastructure technology who are pushing for commoditisation and standardisation (because the traditional providers extract value by differentiating their own products higher up the value chain) and the traditional infrastructure technology providers who continue to try to differentiate their own products. RISC-V and SiFive are major players in an ecosystem (with much overlap between the two organisations in terms of influential individuals), and demonstrate how a not-for-profit and a for-profit VC-funded entity can interoperate for their own benefit, for the benefit of the ecosystem and for the benefit of the wider economy.

The Open Compute Project is funded largely by subscriptions from its members, predominantly large players in the technology industry. The funds are spent on administration and outreach. RISC-V is mainly funded by member subscriptions and to a limited degree by event sponsorship fees. Si-V is a commercial trading entity with sizable capital investment. Its day-to-day revenue derives mainly from the sale of IP (e.g. core designs) and silicon.

The common thread of these projects is that they differentiate from proprietary technologies by reducing lock-in. In the case of the Open Compute Project, the designs are available to be implemented by multiple manufacturers, so in each case, the customer has a potential choice of vendor for their chosen hardware, or, in extremis, can arrange to have the hardware manufactured to those specifications themselves. The RISC-V foundation acts as the governing body for the RISC-V instruction set. This means that the instruction set consists of a consistent core, with optional (official) extensions. Broadly, this means that anyone writing software to run on a RISC-V core using that instruction set (and, if they wish) official extensions), can feel comfortable that their software will continue to run on a variety of chips from different vendors. Although there is nothing to stop a core developer from developing a core which implements their own proprietary extensions, the fear of lock-in can disincentivise the use of these extensions, which in turn incentivises the extension developer to submit their extension for incorporation into the official specification. This synergy is exemplified by SiFive which itself participates extensively in the development of the RISC-V instruction set. This participation gives customers of SiFive, even those using SiFive's proprietary technology, comfort that the risk of lock-in is reduced.

OCP projects are typically used in datacentres, but can also be used in contexts outside the datacentre where similar hardware characteristics (the ability to be centrally managed and monitored; the ability for the hardware to be reconfigured dynamically; low environmental impact and energy costs and easy replacement and repair of defective hardware with equivalent hardware from multiple vendors) can be used (for example, cell towers). RISC-V processors are used in an increasing number of contexts. Western Digital makes use of them in multiple storage products (embedded systems are a popular use case), but instruction set extensions allow for use in vector processing supercomputers, and general purpose operating systems such as Linux (as in, for example, the BeagleV). In particular, automotive technologies are on the roadmap.

The Open Compute Project does not adopt a classic open-source style development model for its hardware. It is not developed in the open, and the designs are generally presented as completed designs, although improvements may be fed back to the original designers. In contrast, software developed by OCP is developed on GitHub in a more participatory fashion (and under a fully Open Source licence). For this reason, although tooling was noted by OCP as a significant factor, its openness was not. Transportation is an important factor for the success of large pieces of physical hardware, like server racks, but minimally important for very small items of hardware such as silicon chips, and irrelevant for software and gateware. OCP noted that human factors such as design thinking (i.e. developing designs from the perspective of the user, not the vendor) was critical, and all projects noted the significance of community. OCP noted that the increasing prevalence of environmental thinking coupled with the circular economy (including reuse and repurposing of components) was critical for the success of the project, and aligned with both the business needs of the member companies, and their desire to be seen as good corporate citizens. Currently, a barrier to the development of silicon is access to foundries and costs involved in preparing an ASIC for manufacture. To be cost-effective, it's necessary to work at high volumes, and this presents a barrier to accessing that marketplace for SMEs.

Cybersecurity was of significant importance to all respondents in this sector. A particular concern related to the security of silicon, and the ability of chips to incorporate backdoors or malware embedded by a bad actor in the supply chain. The ability to develop and maintain a root of trust, through the supply chain is facilitated by open hardware and software. This impact will increase over time.

It is expected that the technologies will all impact infrastructure significantly, and increasingly so.

Artificial intelligence will be impacted significantly by the technologies in this sector, and increasingly so, for different reasons. OCP tends to concentrate on the technologies necessary to build the datacentres which will provide the data and compute power necessary for the advanced deployment of AI technologies, whereas RISC-V, with possible extensions, may provide the core processing capability. It is likely to have a significant and increasing impact over time. The responses were similar for high performance computing, and for similar reasons.

The environment was already being positively impacted by developments in these technologies, and the assumption was that this would increase significantly.

All sectors are impacted by these technologies both in relation to research and development, and production, and it is likely that this impact will increase significantly in the future. All sectors are represented either directly or indirectly, and potentially had a significant role to play.

Success case: RISC-V and SiFive

The combination of RISC-V and SiFive demonstrates the power of combining an Open Source Hardware foundation, based on technology emerging from academic research, with a commercial entity positioned to access funding from capital markets. Further, the RISC-V foundation has shifted its seat to an EFTA country, Switzerland.

All microprocessors (CPUs) require a set of instructions which determine how they operate and function. The RISC-V instruction set is freely available under the liberal BSD license, making it implementable with minimal friction by any type of organisation, whether commercial or non-commercial. This means that implementers are free to choose their own licensing models, and a variety of models are employed. Some of the implementations are themselves Open Source, such as the Western Digital SweRV cores and SiFive's freedom cores, all released under permissive Open Source licences. SiFive also produces proprietary technologies using the Risc-V ISA. Its revenue model involves licensing this proprietary IP, selling silicon, and selling consultancy.

RISC-V and SiFive are two key players in an ecosystem, which is primed by SiFive (and others) actively contributing to the development of the RISC-V ISA and its extensions, to provide a stable standard platform, while at the same time, SiFive uses those standards to develop and commercialise IP, both directly and indirectly. SiFive also actively participates in the Open Source community around RISC-V core technology (as opposed to the ISA specification), which makes it easier for people to get to grips with RISC-V technology in practice, which then provides a base of trained and knowledgeable individuals who can continue to work in the RISC-V ecosystem.

RISC-V is funded 92% by member subscriptions, and 8% by event sponsorship fees. Its expenditure covers admin, outreach (marketing and event management and promotion), and development of RISC-V technical work. Si-V is a commercial trading entity with sizable capital investment. Its day-to-day revenue derives mainly from the sale of IP (e.g. core designs) and silicon. The majority of its expenditure is on research and development, and in particular engineering.

SiFive and RISC-V differentiate themselves by providing a technology platform which is perceived to be free from dangerous lock-in effects. In common with many other Open Source projects in both the worlds of hardware and software, they lower the barrier to entry to the technology and at the same time provide comfort for those using the technology in a commercial context that their implementation will continue to exist and be supported, because, in extremis, the customer is able to take the open designs and either continue the support themselves, or seek it from another commercial partner.

SiFive cores can be found in multiple applications across a broad range of sectors, from IoT devices, to system-on-a-chip designs, through to the recent emergence of processors which are capable of running desktop operating systems.

Tooling remains an issue both in the R&D and development phases, as does the availability and quality of the implementations of the designs. Logistics is of less importance (the products are either IP or consultancy - where is irrelevant, or silicon chips, which are physically small). IP constraints, and particularly patents, may be an issue. RISC-V is intended to be as free from IP impingement as possible, and the choice of a permissive licence for the Freedom cores reflects that. Human and design factors are important: the RISC-V ISA is designed to be reasonably straightforward and align with the structure of other ISAs that students and others may already be familiar with, so even if they have not been exposed to RISC-V, the learning process is likely to be fairly rapid. A particularly important factor in this regard is the interplay between the RISC-V foundation as a not-for-profit and SiFive as the commercial entity.

Cybersecurity is significant from the perspective of both hardware and software, and the impact of the technologies on infrastructure is important and increasingly so.

Artificial intelligence may be an area where the flexibility and replicability of the RISC-V ISA and hence SiFive silicon increases in relevance. This will likely increase with the adoption of domain specific extensions to the ISA in areas like vector mathematics and tensor instructions. However, one inhibitor in the adoption of the technology in the context of high performance computing is that much of the existing IP is heavily protected, and therefore not amenable to implementation in Open Source.

There are a number of initiatives around RISC-V both to produce low power chips, but also to maximise efficiency for high performance computing so that the maximum amount of TFLOPS per watt can be attained.

RISC-V and SiFive products are likely to have a significant impact on individuals, especially those involved in research. Currently, the impact in companies revolves more around FPGAs rather than ASICs, and this trend is likely to continue as FPGAs get more important. Standardisation of interfaces and instructions is an important factor for the adoption of RISC-V technology, and this is likely to continue to be so. The impact on the public sector may be of particular interest in relation to digital sovereignty and autonomy. An example is the Shakti core developed at the Indian Institute of Technology in Madras. This is an Open Source core based on RISC-V technology, an aim of which is to ensure that Indian computing capability, including that used in the military for nuclear development, continues to be available and capable of further development should other countries restrict supplies of their technology.

SiFive demonstrates that a company can successfully raise finance in the $100m range to develop Open Source Hardware technologies, and that the success of that activity is dependent to a significant degree on the synergistic relationship between SiFive and the RISC-V foundation, as well as with the wider world.

Although the RISC-V foundation itself has moved with the EFTA (Switzerland), SiFive remains based in Silicon Valley in the USA, for reasons including the capital-raising environment.

Integration into the Open Source Software and Hardware community

The two core ecosystems studied have, at present, little overlap. The Open Compute Project consists of organisations who have an interest in developing and standardising components for datacentres, to reduce costs overall, and those who wish to implement the designs. The RISC-V ecosystem consists of implementers of the RISC-V ISA, coupled with the RISC-V foundation, as well as other organisations, such as the Open Hardware Group which exist to leverage the technology, as well as CHIPS Alliance (a project of the Linux Foundation). There are also other related ecosystems which coalesce around the development of Open Source toolchains, for example, covering hardware description languages.

SIFive itself and the RISC-V foundation are deeply integrated, with many of those involved in the initial development of the RISC-V ISA being, and remaining, involved in both organisations. Both organisations are heavily involved in outreach and development, and SiFive is a member of organisations like CHIPS Alliance.

SiFive is a core contributor to the RISC-V ISA and also to its own chip designs. The Open Compute Project rarely undertakes collaborative design so far as hardware is concerned, and to that extent, the designs are submitted to the OCP largely as completed designs, which may then go out to beta testing with a select group of testers, and then have their comments fed back to the original designing organisation. The software, alternatively, is developed very much on an Open Source Software development methodology, and takes place on GitHub.

In each case, the hub of the ecosystem is an organisation (The RISC-V Foundation or the Open Compute Project Foundation) which acts fundamentally, as a custodian of the core IPR for each project. In the case of RISC-V, this is the Instruction Set Architecture, and in the case of OCP the various hardware, software and interface designs. In addition to the custodian role, they each provide co-ordination, outreach and a central hub for governance. The stability of the core IPR is critical to the success of each of the projects, and to this extent, the foundations fulfil a de facto role as a standardisation body and allows openness in the governance structure.

The RISC-V ISA is made available under a minimally-restrictive BSD license, but the cores implemented using that ISA are released under a wide range of different licences, from permissive through to proprietary. It is notable that Open Source RISC-V cores intended for a volume implementation are most likely released under a permissive licence. This is because of the (perceived) complexities of applying a copyleft/reciprocal licence to gateware, and perceived incompatibilities with the proprietary licences under which many of the IP blocks and other components introduced by proprietary toolchains are released. Hardware and software released by the Open Compute Project are released under a variety of licences, with the hardware being released under one of two licences drafted by the OCP itself (permissive and reciprocal/copyleft). These are notable in that they are probably better described as standards licences than Open Source licences, given that the only fully licensed implementations are those which faithfully follow the original Licensor's designs.

OCP and RISC-V rely on the contributions of the corporate members. Particularly, so far as the hardware is concerned, there is little individual input. The communities which have coalesced around software, however, do tend to be more diverse. RISC-V seeks to lead by example and by encouraging its members to become involved in other projects, i.e. it seeks to establish project contribution as an industry norm. RISC-V also believes that the human factor behind a desire to contribute is that their projects are compelling and rewarding. Some engineers like to use their contributions as a platform to show off their engineering prowess, but this is most evident in software, or the more software-like areas of hardware such as gateware (cores).

A significant amount of effort and expenditure in each case is deployed in education and making the relevant designs and materials available and usable. These include wikis, member portals, GitHub, discussion forums, tutorials, text books, professional training partners, online learning, workshops, meet-ups and so-on.

OCP's primary aim is to make its designs function in a commercial context, in a way which offers cost reduction and efficient improvements to users of the technology. Use of OCP technologies is intended to impact users' bottom lines, but by means of reduced expenditure, not increased income. This is true (to an extent) of RISC-V as well, but as a rapidly-moving technology area, RISC-V is more likely to find itself deployed in new applications which are themselves profit generators.

SiFive's core metric is adding shareholder value, but within that, metrics such as design wins and adoption rates are significant. Overall, the number of SiFive cores it sees as a proportion of cores deployed overall is significant. Another factor is seeing the emergence of the core in technologies as an enabler, and of the emergence of new technologies from academia making use of it. These latter metric are also of relevance to the RISC-V foundation with respect to RISC-V cores of all flavours.

Conclusion

The existence of several centres of academic excellence in the EU/EFTA (University of Bologna, The Spanish National Supercomputing Center in Barcelona, ETH Zurich) coupled with small and medium sized business developing and exploiting this sector is a huge positive. However, and despite the positive step of the RISC-V foundation relocating to Switzerland and the existence of the mainly EU-based FOSSi Foundation, most of co-ordination in open hardware is driven from the USA. The move to software defined infrastructure presents a great opportunity for the EU to consolidate its skills and commercial activities in this area, provided that it can develop a business environment which is less risk averse so that it can retain businesses and entrepreneurs tempted to seek capital in jurisdictions which have a deeper understanding of the businesses around open technologies, and have the access to capital to promote them. In addition to looking at the USA (mainly Silicon Valley, the greater Boston area and the North Carolina Research Triangle), the EU should be cognisant of competition coming from the UK and the Far East, particularly China.

End-user applications

Introduction, positioning and domain description

Consumer-focused or end-user applications represent an area where, because of the inherent conflict between the general freedom of the software and the need for businesses to differentiate, the development of viable business models is particularly challenging. The case study builds upon input from CentOS, LibreOffice, Nextcloud and OW2.

The community-driven CentOS project delivers a Red Hat derived Linux platform that is widely used as the basis for embedded systems. LibreOffice is an office suite developed by The Document Foundation. Nextcloud is an on-premise content collaboration platform focused on security and privacy. OW2 develops infrastructure software for enterprise information systems.

The needs of consumers are served by a mix of product-focused SMEs, service providers as well as community-managed not-for-profit organisations. Large European companies rarely represent major Open Source projects. Actors often combine business self-interest with community or political engagement.

A broad range of Open Source at least partially targets consumers or end-users, including most of the software included in common Linux distributions. The primary interest of developers is to seek adoption of their products. Besides profit motives, it may be encouraged by a drive to build on open standards, the ability to cater to diverse needs like minority languages or to reduce barriers to technology adoption. This results in a broad diversity of actors from community organisations to start-up companies.

European Open Source business catering to consumers is characterised by SMEs self-funded from revenue. They may be embedded in product-specific contributor communities, with the business providing the planning and stability that enables the community to innovate. Personnel costs are the biggest share of spending. Cloud computing and marketing cost are also important. Not-for-profit organisations are funded from membership fees, donations and revenue from conferences or merchandise. In-kind contributions, for example donations of hardware or cloud infrastructure are also common. Community organisations sometimes fund types of activities like user experience design or documentation that are not well-served in peer-production processes.

The fact that the software is free under an Open Source license is a key differentiator. It facilitates the exploration of unanticipated use-cases and reduces vendor lock-in in the case of embedded systems or keeps consumers in control of their data and privacy. Some consumers decide on technologies based on mandates from their own stakeholders, for example if they demand data to be kept in openly standardised formats. Open governance serves as a differentiator as well, with Open Source products developed at a recognised community organisation in a peer-reviewed fashion preferred over simply the availability of source code on a development platform. This in particular enables industry collaboration where open governance may also be a requirement for reasons of pro-competitiveness.

Consumers range on a wide spectrum of willingness to pay. Open Source products facilitate adoption by users with little financial means, but are also used in combination with service subscriptions. They also cater to consumer needs driven by non-financial reasons, for example makers or educational institutions who prefer open technology for teaching.

Research and development of Open Source products are most impacted by the availability of human and design factors as well as tooling and components. In production, component and tooling availability remain a concern, together with human factors.

Participants rate computing infrastructure and cybersecurity as important during research and development today and expect environmental aspects and computing infrastructure to increase in importance in the future. In production, computing infrastructure and cybersecurity are considered important as well, with environmental concerns increasing in importance in the future.

During research and development, the impact of individuals, companies or organisations, public sector bodies, industry representatives and the EU are considered fairly balanced today. The relative impact of companies or organisations is expected to grow. The productive use of Open Source is seen as driven by companies or organisations and public sector bodies, with the importance of companies or organisations increasing in the future.

Success case: Nextcloud

Nextcloud is a particular success story in the Open Source end-user applications domain. It enables users to synchronise data between computers, mobile devices and with the cloud. As of 2020, Nextcloud is the most widely deployed Open Source content collaboration platform. It was concepted and incubated as ownCloud by the also European-centered KDE community with the goal to improve the control users have over their cloud-stored data. After ownCloud received venture capital investments, conflicts arose between the developer community and the investors. In the resulting split, Nextcloud was created with a governance model that is oriented more closely on the viability of both the commercial and volunteer community. Nextcloud is licensed under the AGPL-3.0 and does not require a contributor license agreement.

Since being founded in 2016, Nextcloud exhibited steady year-on-year growth of enterprise customer subscriptions, employees and revenue. In 2020 it crossed €8 million in revenue. Nextcloud received funding from the European Commission to develop privacy respecting search functionality as part of the Next Generation Internet programme.

Nextcloud is a content collaboration platform that is deployed either on-premise, as a preconfigured application by vertical integrators or on user-operated cloud hardware. Unlike competing offerings, Nextcloud does not operate an analytics or advertising platform based on the hosted user data. Users appreciate the increased control over privacy and security of their data.

This security and privacy focus enables a number of use cases that are otherwise not well-served. Large universities use it to provide collaboration platforms to their students. Public broadcasting stations and government ministries in France and Germany deploy it. Businesses use it to share sensitive data or to implement policies to keep company information off public cloud platforms. The availability of the complete source code under an OS license facilitates security and compliance auditing and ensures long-term freedom to operate for organisations investing into larger Nextcloud deployments.

Most factor inputs for the development of Nextcloud as a product are readily available. The company emphasises the importance of human factors, in particular engineering skills and creativity, and also the legal and regulatory environment.

Cybersecurity, including data privacy, is of key interest. The regulatory environment is crucial for the balance between the protection of user privacy and the interests in user data analytics by businesses or the public. The availability of general-purpose computing infrastructure that operates as a neutral platform is considered an important foundation.

The innovations provided by Nextcloud affect stakeholders across the board. Enterprises are currently the biggest group of users. It also sees adoption by hobbyists and individuals as a self-hosted platform for home use. Governments and public institutions increasingly adopt it because of the match between the privacy focus and the public mandate to protect citizen data.

Nextcloud is a prototypical European Open Source business - a self-funded SME that emerged from the creative fabric of the European Open Source community and aligns itself with community and user values. The sustainability of its community governance model that builds on symmetry between contributors and a supportive role of the company for the developer community is a role model for Open Source businesses.

Integration into the Open Source Software and Hardware community

The development of consumer-facing Open Source is considered a comparatively sustainable way of driving technology innovation. In particular it allows it to cater to minority interests as well as non-financial incentives and counteracts the centralising tendency of IT platforms.

Overall the various actors are deeply integrated with the Open Source ecosystem. Projects build on each other's solutions as part of the global upstream-downstream network. Some projects aim explicitly at building a European sub-ecosystem with an emphasis on open governance and enabling market entry. While not directly aimed at them, this is considered one way to be able to compete with dominant Internet companies based in the USA.

Most projects are built around an SME or a small group of core contributors surrounded and supported by a network of occasional contributors jointly forming the project community. The good reputation that not-for-profit organisations enjoy in this environment is based on the close match of the governance of the organisations with the incentives of the community to participate.

For projects that require governance beyond simple collaboration on the code, the governance and administrative home of an OS project is typically either a foundation or a business. Foundations, including European ones, host projects and provide administrative, legal and financial support. This promotes a portfolio of Open Source with good credibility and open governance. Many projects at European foundations are driven by SME. Businesses build or adopt communities around products, managing a delicate balance to generate business value based on community work. Successful models have emerged in both the foundation and the business driven scenarios.

The concepts of Open Source licensing separate copyright-based ownership of the code from stewardship over the project by the community of current contributors. This separation is a feature for service providers that offer customisation, operation and other complementary services for Open Source products. Offering such services does not require permission by the copyright holders or negotiations with them, encouraging competition in the Open Source services sub-sector. For Open Source vendors, the separation of ownership and stewardship poses the particular problem of how to differentiate themselves in the eyes of the customer. Since there is otherwise no intrinsic relationship between the producer and consumer of Open Source, the software itself tends to quickly commoditise. Especially vertical integration by cloud service providers allocates most added value at service operators that do not necessarily contribute to the product. Licenses like the GNU Affero General Public License address this topic by treating cloud hosting as software distribution, which triggers license obligations.

All projects reported difficulties in attracting and retaining contributors and generating community contributions. Most indicate that only a small fraction of contributors stick around for a longer period of time. Businesses react by employing core contributors. Today the majority of contributions come from paid developers and the commercial ecosystem. Communities tend to value diversity and inclusiveness to be as attractive and welcoming as possible, maintaining a reputation of fairness, transparency and sustainability.

There is a steep learning curve in becoming an Open Source contributor. Projects recognise this and offer mentoring, guidance and even summer programmes for high school students. This focus on knowledge transfer highlights the need for more Open Source based teaching leading up to tertiary education. While not primarily focused on job-related skills, it teaches technology basics and enables future inventors.

Commercialisation is not a major concern in end-user focused applications. Business-driven projects leave commercialisation to them. Community organisations encourage and rely on complementary service providers.

Projects measure success on tangible criteria. They particularly look at the size of the community and the number of contributions to the code base as indicators or community health. Next to these tangible criteria, most participants mention additional aims like aligning the ecosystem to the expectations of the users or contributing to progress in society. It is obvious that without these idealistic goals, the Open Source ecosystem would be less innovative and inclusive.

Conclusion

Developing applications targeting consumers or end-users poses a particular challenge to the Open Source community because of the underlying mix of altruistic and self-interested concerns. It is served by a viable, diverse and innovative SME ecosystem that is well-integrated into the global upstream/downstream network. However, especially large enterprises still often innovate in other fields than software. This limits the potential investments into and thus the market impact of Open Source consumer applications.

Embedded systems and the Internet of Things

Introduction, positioning and domain description

Physical devices that embed general purpose computers have become prevalent, from smartphones to lawnmowers to cars. Many of them are created using Open Source components. The increased price competition by off-the-shelf hardware combined with freely licensed software leads to reduced prices for consumers, but also threatens the market position of bespoke hardware and software solutions and encroaches on technology areas where IPR are guarded, like in telecommunications. The case study uses input from CentOS, the OpenCompute project, SiFive and Yocto.

The community-driven CentOS project delivers a Red Hat derived Linux platform that is widely used as the basis for embedded systems. The OpenCompute project develops efficient, flexible, and scalable standardised hardware components. SiFive is a company that develops domain-specific chips based on Open Hardware designs.

Innovation in various types of physical devices is increasingly driven by software. This is highlighted by the trend towards autonomous driving where the vehicle looks familiar but gains new functionality from updates to the embedded computer systems and the application of artificial intelligence. Because of that, the task of embedding a computer with a general purpose or real-time operating system into a device is becoming oblivious. This makes embedded OSSH systems essential to the ICT sector.

Inputs to embedded systems are the choice of computing device and the choice of software platform. Both together enable the user-visible functionality of the device. CentOS and Yocto offer ways to configure customised Linux-based software platforms for the underlying hardware. The availability of such configurable software platforms allows device developers to focus on differentiating functionality as opposed to fundamentals. Linux has become the dominant operating system for general computing purposes. Proprietary operating systems are still used for example for real-time use cases.

Hardware components are also increasingly standardised and considered a commodity. Participants expect a growing interest in open hardware designs with the motivation to reduce cost, including by reducing the obsolescence of components and increasing their lifetime. At the same time, the availability of open hardware chip designs and instruction sets simplifies the development of bespoke silicon, reducing cost and energy consumption. Besides cost, the combination of Open Source Software platforms and open hardware is also considered a more efficient approach to innovate in the embedded systems market.

The embedded software platforms are funded and governed in ways that ensure that no single party is able to wield undue influence over the project. Yocto is hosted at the Linux Foundation. CentOS maintains a close partnership with Red Hat from which products it is derived. Many contributions are in kind in the form of hosting the software development infrastructure or donating network bandwidth, provided by universities or businesses. This corresponds to the spending structure, where computing infrastructure costs dominate. Personnel expenses are kept low as the projects rarely pay for direct contributions or staff, instead relying on the community to supply them.

Open hardware projects are driven mostly by industry since they promise concrete benefits in cost reduction and supplier competition. OpenCompute was launched by Facebook in 2009 to reduce cost and improve efficiency for their own data centers. SiFive is a business that relies on the RISC V instruction sets.

Users decide to use open hardware designs and Open Source embedded software platforms because the combination reduces cost and the overhead of implementing basic functionality before being able to focus on the features of their products. They benefit from best practices in software configuration and license management. Most of these aspects are repetitive and non-differentiating. Standardising software and hardware components simplifies hiring and contract management.

The commoditisation of open hardware components is pushed by large industrial consumers. After developing a specification for a standardised component, suppliers are able to engage in price competition. This reduces gratuitous differentiation and enhances the life time of individual components. The combination with standardised software platforms provides the necessary building blocks for embedded systems.

Human factors, the legal and regulatory environment and the availability of tooling are primary concerns during research and development. Especially Open Source tools for open hardware design are lacking compared to commercial offerings. In production, tooling and human factors remain concerns. For the embedded software platform projects, productive use is mostly the responsibility of the user.

Cybersecurity, computing infrastructure and artificial intelligence are areas of specific interest when building embedded systems. Artificial intelligence applications have imposed harder performance requirements for embedded computers. These aspects are expected to increase in importance in the future.

Stakeholders' impact is strongest for individuals because of the pervasiveness of embedded devices, businesses because of market impact and specific industry subsectors, where incumbent bespoke hardware and software systems are replaced by general purpose devices. This particularly changes the nature of supply chains where innovation shifts from suppliers delivering black-box solutions to where the open hardware specifications and software platforms are being developed.

Success case: Yocto

The Yocto project develops an environment that is used to build custom Linux distributions for devices, especially embedded systems. It is used to create environments for a wide spectrum of devices, from Raspberry Pis used by hobbyists to cube satellites.

Yocto is a non-profit Linux Foundation collaborative project announced in 2010. It originates from the London-based startup OpenedHand that was acquired by Intel in 2008. It provides developers of embedded and IoT devices with development tools and a reference platform. It is widely adopted as a base platform for embedded systems, including Automotive Grade Linux which builds upon it.

Being organised as a typical industry-led Open Source community, Yocto is funded from membership fees. It provides the collaboration platform with the main expenses being system administration, computing infrastructure and very thin staff. The project does not generate direct revenue. Direct contributions to the project code are funded by the contributing entities.

Being a neutral collaboration platform is essential to enable participation of otherwise competing device manufacturers. This extends to providing independent development and integration platforms. Contributing to and participating in Yocto is considered a best practice. In turn, Yocto offers participating companies critical mass, state of the art technical quality, license management and efficiencies of scale.

Users build products based on Yocto. This is supported by a layered approach that incrementally adds functionality. Some silicon vendors contribute hardware support layers directly to the Yocto project. The device configurations are versioned and to a large extend reproducible, which is crucial for systems engineering.

The Yocto project focuses on development of the operating system platform and leaves the adaptation of it for concrete use cases to the platform users. This is supported by the layered development approach. Important factor inputs for the development process are tooling, human factors and the IPR framework. Tooling provides the characteristic automation of the process to build system images specific devices. Participating in this development process is highly demanding, which makes human factors essential. The project warns users that “you need to be a pretty good coder or be willing to become one”.[2] Since the Yocto build process assembles numerous common Open Source packages into an integrated system, it heavily relies on the overall Open Source licensing and license compliance mechanisms.

As a platform used widely across the industry, Yocto has a potential to amplify cybersecurity issues, making cybersecurity concerns particularly important. The availability of computing infrastructure is of key importance to the operations of the project. In the future, the project expects environmental concerns to become highly significant, also considering the explosively growing overall number of embedded and internet of things devices.

The project expects to impact various stakeholders in the future. Individuals rely on it to deliver stable and secure underlying platforms for the hobbyist and commercial devices. Businesses build their products with it and depend on it. As some computing and internetworking functions acquire utility character, the Yocto project will also start to influence the public sector. It increasingly runs critical software and networking infrastructure.

The Yocto project showcases the potential of Open Source innovation by demonstrating the consequent collaborative development of non-differentiating functionality at a vendor-neutral organisation. It also offers opportunities for engagement by all stakeholders. It considers it important not to drown developer creativity in too much red tape and not to be too prescriptive. With that, it bridges the interest of private enterprise that created the project with societal interests of security and sustainability.

Integration into the Open Source Software and Hardware community

An important change perceived by the interviewees of the OSSH ecosystem on the embedded systems market is the segregation of product ownership and functionality. It limits planned obsolescence and the addition of features for marketing needs. Also it creates the possibility for devices to be updated by the consumer after the manufacturer ends support. This reduces the impact on the environment and enhances sustainability. Even previously more specialised data center hardware is becoming commoditised.

Hardware and software often develop in lockstep, especially at the operating system level. The combination of Open Hardware and Open Source Software reduces the cost of customising both components for a specific application. The barriers to collaboration in the embedded systems market are higher than average compared to the wider Open Source community. Operating system software is complex to develop and often requires access to

[2] https://www.yoctoproject.org/is-yocto-project-for-you/

pre-production hardware. Nevertheless, CentOS and Yocto are tightly integrated in the Open Source ecosystem.

For open hardware projects, the investment required for participation is even higher. Development is performed by industry stakeholders or academia in association with community foundations and relies more on standards, like instruction sets.

The contribution processes reflect this complexity. Unlike Open Source Software development, the idea of building upon underlying works to create derivatives that are individually licensed is not very common for hardware.

Even though their contribution processes are tailored to the low-level type of programming activities they focus on, the operating system platforms still operate as regular Open Source communities.

The Yocto project is hosted by the Linux Foundation. It is assumed that the two organisations contribute to each other's credibility and that governance independent from any individual actor is necessary. CentOS operates as an independent project in a close relationship with Red Hat. Governance and collaboration processes in the open hardware area are less developed, however, the Linux Foundation also hosts the Risc-V project on which's instruction sets SiFive's designs are based.

Since the operating system platforms ship a multitude of packages developed by diverse upstream communities, their licensing model follows the upstream license choices. For own code, the Apache-2 license is commonly used. License management is growing increasingly complex because of the growing number of packages typically included. Emerging industry standards like SPDX mitigate this issue.[3] Coverage of operating system level software functionality by patents is considered antithetic to innovation.

Open hardware licenses are less standardised than Open Source licenses. Since workable concepts for copyleft open hardware licenses have not yet emerged, permissive license models are preferred for open hardware.

The Open Source Software communities experience a high contributor attrition rate. Only a small number, estimated by one interviewee at about 5%, of contributors, participate for a longer period of time. While one-off contributions are generally common in Open Source, this reflects the higher technical complexity. The concept of release-early-release often, that is common to Open Source Software, is difficult to apply in open hardware communities. Instead, presenting progress and innovations at events is a common way to advertise for new contributors. Those participants that are able to get over the barriers to entry enjoy a comparatively high market value and good career prospects.

Knowledge transfer is considered a problem which also reflects the overall technical complexity of the subject. Onboarding new contributors depends on prior knowledge which is not always transferable. This limits the ability of businesses to assign staff to tasks according to their own priorities. Opportunities to communicate achievements, for example by publishing Open Source Software contributions, are appreciated by employees.

Approaches to commercialisation reflect a delicate balance to encourage consumers to build on top of the community products, while preventing that the project itself is commercialised. Separation of the governance of the project from the activities of the participating businesses is essential. This effort is sometimes supported by trademark

3 https://spdx.org/

registration processes, recognising the separate value of community trademarks from the copyright on the source code or hardware designs.

Success is commonly assessed based on the ability to curate an ecosystem of adopters and contributors that is aligned with the goals of the project. It is often measured by the value consumers add on top of the platform. Other than that, common community health metrics remain the number of contributing entities or member companies, contribution count, but also mindshare expressed in the number of job posts that require prior experience with the project technologies. All of these reflect reputation and adoption of the technology in the market. Similar to other domains, interviewees also express satisfaction with the enabling character of the OSSH community, for example by facilitating students to study and further develop “the real thing”, not abstract concepts.

Conclusion

The embedded system and Internet of Things subsector exhibits a massive impact in the ICT sector as an enabling technology for a variety of applications. It creates the possibility to cover basic hardware and software functionality using OSSH and immediately start at the point of innovation. There is a strong European footprint on key innovations and core projects. This, however, does not yet not fully translate into market leading positions for European companies. Europe boasts a healthy, tightly integrated OSSH community that brought forward key innovations in the software and hardware space. It lacks, however, in commercialisation and adoption of the technological potential in concrete marketable products.

The public sector

Introduction, positioning and domain description

The interaction of the public sector with OSSH primarily involves three key aspects: The public procurement as one of the biggest users of software and hardware for use in the public sector, the relationship of the public sector with the OSSH ecosystem as a participant, stakeholder and contributor, and the public policy framework provided by government for the OSSH communities. This case study focuses on the public procurement aspect as well as the relationship between the public sector and the OSSH ecosystem. It is based on input from OW2, Software Heritage, White Rabbit and X-Road. The public policy framework is handled in more detail in the policy analysis and eventually the policy recommendations of the study report.

OW2 develops infrastructure software for enterprise information systems. Software Heritage collects and preserves software source code as part of our cultural heritage. It is a non-profit multi-stakeholder established by Inria and supported by UNESCO. White Rabbit is a fully deterministic Ethernet-based network for general purpose data transfer and synchronisation developed at CERN. X-Road is a data exchange layer developed by the Nordic Institute for Interoperability Solutions and used across the world to manage access to sensitive data across distributed information systems.

Relevant actors are typically industry fouX-Road is a centrally managed distributed data exchange layer between information systems developed by the Nordic Institute for Interoperability Solutions.

Relevant actors are typically industry foundations, multi-stakeholder platforms, public-private partnerships or public agencies implementing their own technology needs. They see themselves as part of or closely related to the wider Open Source community. Some maintain additional relationships, for example to academia or by employing active Open Source contributors. For-profit enterprises are not very visible, even though they are the traditional providers of ICT products and services for the public sector. Some actors develop backbone solutions that are used to offer digital public services, for example in the Nordic countries. Others work towards implementing public responsibilities like the preservation of cultural heritage.

Because of the need for auditability, accountability and transparency for public software services, Open Source middleware and data exchange layers are considered a natural fit, especially when built on open standards. Activities where information is provided publicly funded in the first place, as for example in academia, enjoy special attention. At the same time, service providers that offer software solutions at the scale that matches public sector needs usually build on proprietary software. An environment where service providers either develop Open Source licensed solutions or offer services for them at scale is not yet fully developed.

Various funding structures are evident in the public OSSH domain. Industry foundations are usually funded by membership fees, but also from publicly funded research projects as for example within the EU funded H2020 programme. Others combine public funding, for example through academia, with sponsorship by or cooperation with private enterprise. Some projects are specifically to develop OSSH solutions for public needs. Besides direct funding, most projects have little direct revenue. A conflict is typically perceived between serving public needs and differentiating for customer revenue. The two activities are often clearly separated, sometimes in cooperation with businesses covering the revenue-generating activities. Personnel expenses consume the largest share of overall spending.

Quality, open governance and transparency are key differentiators for OSSH activities in the public domain. There is a noticeable focus on topics of seriousity, like middleware or managing citizen data, as opposed to gaming or entertainment. Reputation and credibility is built on peer review, but also public recognition. Participants are additionally motivated by the virtuous character of the activities provided. There is broad public interest towards OSSH and open governance once such issues gain attraction in public debate. Public institutions, especially in academia and basic research, enjoy public goodwill if they produce OSSH technologies that find adoption. There is a strong sense that the results of publicly funded research should be generally available both by the involved academics as well as by the public.

Use cases can be grouped in three main areas: Industry associations developing OSSH solutions and offering commercial services around them, publicly guided development of essential infrastructure-like software that enables other uses or public digital services, and developing solutions that service public responsibilities, like archiving or enabling access to services for citizens.

During research and development, human factors, tooling and components are a main concern. It seems to be particularly difficult to hire highly qualified innovators in this domain in competition with the private sector. In production, tooling is less of an issue, while components and human factors remain relevant.

Computing infrastructure and environmental aspects are mentioned as of particular interest during research and development, with environmental aspects becoming more important in the future. In production, computing infrastructure, cybersecurity, applications of artificial intelligence and environmental aspects are expected to be highly important in the future.

R&D in the public OSSH domain is expected to mostly affect companies or organisations as well as public sector bodies. In the future, a higher impact of R&D activities on individuals and industry subsectors is expected. There is no relevant difference between R&D and production in this context.

Success case: X-Road

X-Road is the Open Source data exchange layer that is the backbone of the Estonian and Finnish data exchange layer ecosystems. It has been developed since 2001 and continues to be actively developed by an international community of mostly government stakeholders. X-Road serves as a foundation of the government e-services in Estonia, Finland and Iceland.

Coordinated, strictly managed, secure and privacy-enabled data exchange is at the heart of digital government services. It enables citizens to provide their data once when required by the government and then that data to be shared where necessary and appropriate with other e-services. X-Road is the data exchange solution that drives government e-services in Estonia, considered a world-leader in public services digitalisation, as well as about 20 other countries including Finland, Iceland, Argentina and Germany. X-Road is licensed under the MIT license. Participation requires acceptance of a contributor agreement.

X-Road is developed by the Nordic Institute for Interoperability Solutions (NIIS)[4]. NIIS operates as a not-for-profit organisation. Stakeholders in NIIS are usually government ministries. NIIS and X-Road are primarily publicly funded with funding needs established by NIIS and shared between stakeholder countries.

X-Road differentiates by enabling the decentralised storage of data at the agencies that originally acquire it from citizens. Instead of being duplicated, data is shared with the authorities that are allowed to use it in a secure fashion, while maintaining the integrity and confidentiality of the data in transit as well as protecting it from access by unauthorised third parties. The managed sharing of data between agencies reduces administrative overhead and eliminates traditional duplicate filing of information while maintaining the expected level of privacy, resulting in a high level of acceptance and approval from citizens. In particular, the elimination of menial bureaucratic work allows government employees to focus on tasks where citizens really require their attention.

Estonia uses X-Road to manage citizen identity, the land registry, healthcare access including prescription administration, education and tax information and other services. It estimates that 99% of all state services are online and that the X-Road based systems save citizens 844 years of working time every year.[5]

Handling personal citizen data means that the legal and regulatory frameworks, including data protection regulations, are the most important factor when operating X-Road in production. Additional complexity is added by cross-border data exchange that requires a harmonised regulatory environment. In development, the availability of tooling and human factors are also important.

Because of the sensitivity of the managed data and the potential impact of privacy violations or data breaches, cybersecurity and suitable computing infrastructure are of specific concern for operators of X-Road based services. Additionally, governments are held to high standards regarding sustainability and the impact on the environment. X-Road aims to be the most environmentally friendly data exchange solution. In general, the same areas of interest and emerging technologies impact X-Road that also impact the private sector. Public scrutiny and the political need for accountability result in a perceived need to hold public sector e-services to higher standards than private sector internet platforms.

Well-managed and efficient public e-services have the potential to significantly improve the efficiency of the interactions of citizens and enterprises with government. The Estonian X-

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[4] https://www.niis.org/

[5] https://e-estonia.com/solutions/interoperability-services/x-road/

Road based X-tee system demonstrates this by processing almost one billion data requests per year. At the same time, comparably efficient government e-services are not yet common in most EU Member States. This indicates an enormous potential for the further development of online services provided by the Member States, as well as improved integration of e-services within the EU Single Market based on the federation features of X-Road. Estonia and Finland started federating their data exchanges in 2018. The resulting efficiency gains in cross-border trade will be maximised for the EU if such a federation is extended to the complete Single Market.

X-Road demonstrates the potential of Open Source based e-services provided by the public sector. The combination of Open Source licensing of the source code with an open and transparent governance model overseen by the participating countries establishes trust, reduces cost and enables wide-spread adoption. It serves as an example of the public sector not just consuming, but actively developing Open Source Software infrastructure.

Integration into the Open Source Software and Hardware community

The private businesses potentially offering OSSH related services to the European public sector are mostly SMEs. Large ICT enterprises usually build upon proprietary solutions. This leaves public sector actors with a choice between less than optimal solutions.

Industry associations and academic projects are usually well-integrated into the wider OSSH community. Public actors regularly struggle with community integration, similar to incumbent large European enterprises. However, a small number of successful examples exist and are represented in this case study, indicating that the remaining issues can be overcome, for example by a European framework for participation of public actors in the Open Source ecosystem and more stringent guidelines for open licensing of publicly funded information goods.

Contribution processes reflect the specific public sector stakeholders and community composition. Academically driven projects typically follow the norms of the OSSH community. However, some projects implement more managed bureaucratic participation, reflecting the needs of their stakeholders for transparency and accountability. The examples show that such a combination of OSSH licensed development with public sector managed governance can be successful.

Key stakeholders are public agencies usually in a consumer role or that of a provider of a digital public service, SMEs anchored in the OSSH community as well as academic and research institutions. Many projects maintain good relationships with important umbrella OSSH organisations. Some projects adapt to the stakeholder composition by considering Member States represented by ministries as their ecosystem. This clearly shows that there is a chance to model OSSH development by public service actors with adapted forms of governance.

Aspects of licensing do not play a significant role in the public OSSH domain. Most actors choose existing well-known Open Source Software or Open Source Hardware licenses. Some require customised contributor license agreements.

Attracting contributors is done based on open governance, in particular fairness, transparency and sustainability of the community, as well as acquiring a reputation of being a state-of-the-art project. It is recognised that barriers to entry should be kept as low as possible. However it is also recognised that some barriers, like mandatory Copyright Licensing Agreements, may be necessary in the public OSSH domain context.

Knowledge transfer relies on common practices like newsletters and conferences. There is a profound understanding that results should be made freely available for both pragmatic as well as idealistic reasons.

Commercialisation is not always a primary concern. Where appropriate, actors create relationships with commercial product manufacturers or service providers. Project engage in community building and stewardship over the OSSH product.

Projects measures their success similar to other actors in the OSSH ecosystem. The influx of contributions and acquisition of new contributors are considered essential metrics. Where possible, this is combined with productivity metrics aligned with the project goals like the amount of code archived. Non-quantitative metrics like developer mindshare or technical recommendations play an important role because of their relationship to the intrinsic motivation of the individual contributors.

Conclusion

The relationship between the public sector and the OSSH ecosystem still develops. Even though there are few success stories operating at the Member States, they clearly show the enormous potential of public Open Source collaboration. To realise this potential requires both public sector actors to shift towards more open collaboration and less locally developed solutions as well as a change in the role of private sector service providers from offering bespoke proprietary solutions to servicing software infrastructure built on Open Source components. The preference for public e-services to be based on Open Source Software should be considered a matter of principle, not just cost, since the freedom to operate that it affords state actors may come at the cost of public investment in the development of Open Source Software infrastructure.

Summary of the results of the case studies

Based on the analysis of the insights from all case studies, the following results across the different cases are derived.

Every interviewee without exception has stressed the importance of community development in relation to OSSH. Many interviewees stressed the role of OSSH in lowering barriers to participation, and enabling experimentation and involvement in activities which participants might not usually consider. This had the knock-on effect in increasing participation. Consequently, all interviewees noted a greater adoption of OSSH over time.

In this context, opportunities for SMEs increase due to the extent to which open technologies lower barriers to entry. Many interviewees mentioned that the existence of OSSH allowed them to participate in a market they were otherwise not able to. This was not only because of the direct effects of the easy availability of the technology providing them a lower barrier to entry for their product itself, but also in terms of service development and delivery using Open Source tools.

A number of interviewees mentioned that the long-term availability of Open Source code, without the possibility of it being deprecated or having support withdrawn, provides a degree of certainty for end-users and those building on platforms which cannot be matched by private-sector offerings. In this context, several interviewees mentioned that OSSH played a role in developing de facto standards.

Open Source Software interviewees typically took for granted the existence of high quality, low cost (or free) tools, such as compilers (e.g. GCC). However, Open Source Hardware interviewees were more concerned about the cost and availability of tooling (such as toolchains for developing core designs in hardware description languages). They also stated that Open Source development methodologies were more applicable to hardware designs which were similar to software (such as core designs in HDL) than those which were more physical. One interviewee working on a project which combined a microprocessor core design with a traditional printed circuit board (PCB) design stated that different communities had arisen around the core design (which was more like software) and the PCB, with the core design community being more effective than the PCB community.

Almost all interviewees noted that the use of open technologies was beneficial to the environment, whether by directly decreasing energy and materials consumption (such as in datacentres), or indirectly through decreasing unnecessary re-creation of existing infrastructure.

In one case (Software Heritage), funding from the public sector and NGOs allowed the development of products which otherwise would likely not exist at all. Software Heritage, funded mainly by INRIA and UNESCO, aims to collate a universal catalogue and repository of software source code. Its existence has caused the development of peripheral businesses and activities, such as software deposit and academic research.

Foundations are a significant driver in OSSH ecosystems, providing a number of important services, such as standardisation, knowledge transfer, and the ability to handle aspects of project management (such as finances, and the logistics of arranging conferences) which the project itself did not have the desire or skillset to handle. Some mentioned that the existence of an EU "Foundation for Foundations" as an umbrella organisation may be beneficial in helping smaller projects.

All interviewees stressed that their project did not exist in a vacuum and there was a very high level of intercommunication and interdependence between projects. This is a function of both the strength of Open Source communities, and the common practice of developing and governing in the open. The result is that it is the default for communities to communicate with each other, and to share information, both positive and negative, about their projects with each other. This is in contrast to the culture of many corporates which have a reluctance to communicate with their competitors and other industry entities, partially through a fear of trade secret leakage, and partially for competition law reasons. Many open technology projects directly influence the direction and development of other projects. There would also seem to be a two way causative effect between this open intercommunication between projects, and the fact that many individuals participate simultaneously in more than one project.

There is a widely varying set of criteria which the projects or organisations set themselves for success. For some, the metrics are the number of downloads of the project. For many, it is the extent of community interest and participation. For others, it is the number of other projects and products which incorporate that particular technology. For others, it is seeing the variety of unexpected uses to which a particular project is put. For one, it was seeing that their project "made the world a better place".

Lessons Learned

To recap, the domains elaborated are: Maker to Manufacturer (how projects started outside the industrial domain: for example academia or research) can be leveraged by adoption through OSSH mechanisms and scaled, in ways that might otherwise have been impossible; Open Hardware Computing and Infrastructure, showing how open hardware methodologies can be applied to traditionally proprietary areas of endeavour, shifting innovation further up the value chain; End User Applications, showing how OSS projects can provide products which can effectively compete with proprietary solutions in delivery for end-users; Automotive and Embedded, covering the implementation of OSS into devices, including vehicles; and Public Sector which demonstrates how public sector bodies can make use of OSS to improve service quality and improve citizen engagement.

There are several common threads which represent lessons learned from the case studies.

OSS has the effect of moving differentiating innovation up the value chain

Companies will try to differentiate themselves based on the characteristics which are closest to their consumer: for example, a consumer buying a car is interested in the experience of using the infotainment system, but is not interested in the operating system on which the infotainment system runs. Therefore the buying choice (and hence the characteristic which differentiates that car from others) is influenced by the interface and functionality of the infotainment system, so the company will seek to differentiate its offering from its competitors at that level. The infotainment system is, of course, only one characteristic that the consumer will consider. Accordingly, there is an incentive for manufacturers to use an OSS subsystem for the non-differentiating aspects,

Where OSH is successful, there is a symbiotic relationship between business and the OSH project.

The free market operates best when businesses are competing to provide the best value-proposition for the customer, as opposed to creating monopolies and engaging in complex capital manipulation. OSH limits the opportunity for companies to engage in lock-in (a form of monopolistic practice) by ensuring that the core of their product offering remains open and that surrounding services, therefore, can continue to be provided by competitors.

Non-differentiating innovation (such as long-term stability, circular economy, environmental improvements) is stimulated. This is because companies see their investment better deployed to differentiate themselves at the point of service delivery, rather than invest in go-it-alone infrastructure development, where the perceived advantages of denying those developments to companies who may not be competitors at the point of service delivery are seen to be illusory. This means that the common aims of the shared research and development model facilitated by OSH become focussed more towards cost reduction. One common goal is to reduce energy consumption. Another is to reduce the cost of hardware replacement, and to increase the modularity of hardware so that only those components which need replacing need to be replaced. Software-defined-infrastructure moves this to the next level by enabling components to be repurposed dynamically.

OSSH provides opportunities that are unlikely to happen in the proprietary world.

The stability and flexibility of many open source projects provides opportunities for the code or designs to be used in ways which were never anticipated by the original developers. This is as true of OSH as OSS. For example White Rabbit, which was implemented by CERN as a way of timing events to within sub-nanosecond accuracy over a distance, has been repurposed for use in the finance sector as part of high-frequency trading.[6]

Community is key.

Every interviewee stressed the importance of community to their success. The most successful projects develop a virtuous circle where the more vibrant and active a community is seen to be, the more active contributors it attracts.

OSSH is international.

Irrespective of where a project was founded, or where its governance is stated to be located, the reality is that the project's community is likely to be drawn from all over the world, and, except for very specific use-cases, it is likely that the project is also consumed across many different locations worldwide.

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[6] https://ec.europa.eu/info/sites/info/files/research_and_innovation/open_science_monitor_case_study_white_rabbit.pdf

f. SWOT analysis of the European economy based on the industry domain case studies

In general, a SWOT analysis situatively explores the position of a decision maker by separately assessing their strengths, weaknesses, opportunities and threats for a specific context. The following SWOT analysis assesses the European OSSH ecosystem from the perspective of an EU policy maker. It offers a foundation for decision support for policy considerations.

Methodology

Input regarding the strengths, weaknesses, opportunities and threats of the European OSSH ecosystem has been collected from the five case studies presented. The strengths and weaknesses have been aggregated to create a picture for the European ICT sector. Finally, opportunities and threats relevant for European ICT policy have been derived following the PEST criteria, i.e. Political incl. legal, Economic factors, Sociological and Technological factors, where appropriate.

Strengths of the EU Open Source Software and Hardware ecosystem

The EU Single Market as the political and regulatory framework represents a highly competitive and jointly regulated economic space based on common values, enabling the sustainable growth of businesses and communities. The existence of EU success stories builds confidence in open and collaborative modes of development. The Single Market is well-supported by progressive regulation at EU level (e.g. the GDPR), indicating a close cultural match of OSSH and EU values. With regard to open standards and interoperability, the EU stands to mostly gain from OSSH, giving it a chance to compete with incumbent industries in other regions, e.g. Silicon Valley. The EU Single Market is an essential strength for EU Member States that intend to develop efficient government e-services. Joint development within the existing framework of EU collaboration facilitates sharing of R&D cost. Interoperable services benefit cross-border trade, while a federated architecture maintains the autonomy and sovereignty of the participating Member States. In addition, the EU is well integrated into international OSSH communities and acts as a bridge between East and West.

Related to the economic factors, the European OSSH community is characterised by a viable, diverse and innovative SME ecosystem that is well-integrated into the global upstream/downstream network. This not only encourages collaborative innovation, it also means that no major EU proprietary hardware or software companies are likely to try to derail efforts at standardisation, OSSH-focused procurement and collaborative development in order to eliminate competition.

Sociologically, it has to be noted that industry and community actors in the EU commonly overlap and expect a match between business self-interest and societal values. This includes awareness of the societal progress and wide-spread innovation induced by open collaboration, for example in knowledge sharing and preservation, diversity in access to information or in facilitating maker communities.This awareness is reinforced by a supportive culture where actors with different goals and aspirations effectively co-operate within the same ecosystem. The cultural match of societal values and business interests builds upon a tradition of cooperation and public-private partnership. It is expressed by the predominance of many centres of excellence and a tradition of sharing and openness, particularly in academia. This drives a healthy, tightly integrated European OSSH community that brought forward key innovations in the software and hardware space.

Finally, the most important technological dimension shows that open technologies enjoy a significant and growing profile across the European ICT sector. This is supported by the active promotion of an environment facilitating collaborative R&D both horizontally and vertically, i.e. both across domains, and at different positions on the value chain within the same domain.

Weaknesses of the EU Open Source Software and Hardware ecosystem

Generally, public institutions in the EU are slow to adjust to the modes of innovation introduced by the OSSH community. In particular in the public sector, incumbent proprietary solution providers often combine ownership of software with software services, inhibiting the development of OSSH solutions that are jointly maintained. For various reasons including familiarity with some solutions, public actors exhibit noticeable not-invented-here behaviour that prevents optimal reuse of functionality across countries. The effective separation of technology ownership from innovation is a key contribution of the wider OSSH community that has not been fully realised yet. Additionally, the lack of clarity in some areas of IP and regulation related to OSSH can be an inhibitor, as for example with the interaction of consumer protection and open licensing that generally excludes warranty Finally, well-established public-private collaboration methods, e.g. recognised standards-development organisations, did not adapt well to OSSH inspired changes in the ICT sector. As a result, they have little impact on market development, even though there is strong public interest in good regulation and fostering of the wider OSSH community.

Complementary, large enterprises still often prefer to innovate in other fields than software. Also here, incumbent proprietary solution providers often combine ownership of software with software services, inhibiting the development of vendor-independent OSSH solutions. This limits the potential investments into and thus the market impact of Open Source consumer applications. Long-established industries, like telecommunications, automotive, banking and insurance, still struggle with adopting OSSH and do not yet rise to their potential as contributors and collaborators. In addition, because of the general lack of access to risk capital in the EU for OSSH projects, EU/EFTA engineers still frequently seek funding overseas, for example in the Silicon Valley.

More generally the wider OSSH community is insufficiently recognised for the innovations it triggered. While many functions and initiatives of the community are welcomed warmly, public support and the recognition of the contribution of these solutions to the common good are still lacking in society. Examples of community initiatives that contribute significantly to the common good but struggle to find powerful public support as well as protection from manipulation or unfair competition are Wikipedia or Software Heritage. This is particularly astounding considering that besides significant spending on innovation and knowledge transfer by the European Commission (e.g., Horizon 2020), the wider OSSH community continues to out-innovate industry and academia in the ICT sector. There is too much emphasis on capital providers, large businesses and academia seeking to “protect” IP by failing to understand cases where the value can be unleashed by open licensing.

There is still a noticeable gap in converting ICT innovations into leading marketable products in the EU. Stakeholders lament a culture of aversion to failure. European businesses struggle in commercialisation and adoption of the technological potential of OSSH innovations in concrete marketable products. Progress has been made with the emergence of a healthy software startup scene and the success of leading open hardware companies. However, the gap has not been fully closed. European OSSH contributors still find it difficult to convert technological leadership in communities into market leading businesses.

Opportunities for Open Source Software and Hardware in the EU

As one of the three largest global players in international trade, together with the United States and China, EU regulation carries immense weight not just within the EU but also globally. Since the majority of EU Member States’ total trade is done with other Member States within the EU, a consistent regime for open technologies and IP throughout the common market presents an opportunity to foster economic growth and to strengthen innovation leadership. Through regulation, the EU will be able, in particular, to create an environment for hardware that respects open technologies. Similar opportunities include encouraging a stronger environment for capital funding of open technologies and leading the way for the adoption of OSSH technology in the public sector based on implementations jointly developed by the Member States, private parties and community contributors. The European public sector projects are a major share of software and hardware demand that can be used to encourage the maturing of the OSSH sector. The EU and the Member States as the key public sector consumers have a chance to both build up an efficient service provider portfolio on the base of European OSSH SMEs as well as coercing incumbent ICT solution providers to offer services on OSSH solutions, effectively severing the connection between service provider and product.

With regard to computing infrastructure, the strong ties between academia, the OSSH community and private enterprise present opportunities to promote flagship projects and centres of excellence. The ongoing move to software defined infrastructure makes it easier to promote open development methodologies, including, in particular, those relating to gateware, as well as software.

For end-user applications, there is an opportunity for the development of an application environment that is less constricted by dominant internet companies and serves users and consumers in a more sustainable way. Particularly accessible is the diverse SME ecosystem, where innovative OSSH vendors still regularly struggle with finding public support and servicing demand for public ICT support.

For embedded systems and the Internet of Things, hardware and software commoditisation, the availability of open hardware components combined with widely adopted Open Source operating system platforms as well as additive manufacturing shift value-added from manufacturing to the knowledge-intensive R&D as well as integration phases of the supply chain. This opens an opportunity to build a diverse network of industry subsectors innovating in a variety of technology areas by applying customised, energy efficient components into highly refined consumer products. Teaching computer science and system engineering basics based on OSSH puts the focus on working principles instead of tool knowledge.

Threats to Open Source Software and Hardware in the EU

The typically small to medium size actors are prone to takeovers and vulnerable to anti-competitive conduct, for example by acquiring and shutting down potential threats to incumbent platforms. Open Source licensing and high standards of open governance counteract this threat by restricting the control of businesses to their own organisations, but not the underlying technology. Optimal implementation of Open Source government and public sector e-services is threatened by administrative barriers, including protective regulation that favours local providers, as well as gratuitous differentiation that artificially establishes requirements for bespoke solutions instead of shared R&D. Regulation at EU level towards a network of federated governmental e-services shared by all Member States would remove such barriers to a single e-services market.

Another perceived threat is the dominance of US companies and technologies in many open technology sectors. The prevalent concentration may discourage the widespread experimentation with alternative implementations that is vital to OSSH innovativeness. Similarly, the increased role of emerging economies in providing the underlying manufacturing capability for much of the hardware and components used in the ICT sector pressures the market share of European manufacturers. To the extent that this pressure is based on the balance of comparative advantages between economies with a similar regulatory framework, it is an expression of healthy competition. A part of the competitive pressure on European manufacturers is, however, caused by competition based on a disregard for human rights and occupational health. This competitive distortion could be mitigated by the application of human-rights based principles in EU trade policy. In turn, this issue can be interpreted as an opportunity to benefit EU information security, digital sovereignty as well as ICT competitiveness through the application of a principled trade regime.

The highly developed EU economy particularly depends on knowledge and expertise. The continued failure to address open business models and processes in education and training including at tertiary level can be considered a threat to the long-term development of the OSSH ecosystem. Additionally, there is a noticeable brain drain of EU engineers that seek investment and employment in other innovative regions, like the USA or Japan. This presents a difficulty for EU companies engaging in R&D of the most cutting-edge silicon as well as software technologies. These concerns may be mitigated by policy that fosters the European investment and venture capital markets as well as modernisation and streamlining of ICT training and education.

Some communities perceive threats from the continued move of technologies into the cloud, where the traditional models requiring technologies to be opened (e.g. copyleft) do not work or work only poorly. This threat may be countered by encouraging a culture of collaboration based on social norms as opposed to the enforcement of IPR regimes. This is partially happening already in industry-driven Open Source projects that maintain a productive collaboration process while primarily applying permissive licensing schemes.

Table 4.1: Overview of the results of the SWOT analysis

Strengths	Weaknesses
P. Scale and growth potential of the EU Single Market regulatory framework E. Viable, diverse and innovative SME ecosystem S. Supportive culture of collaboration in a diverse ecosystem, centres of excellence T. Growing profile of open technologies across European ICT sector	P. Public institutions are slow in implementing and still legal uncertainty related to IP and standardisation E. Large companies prefer combination of ownership of software with software services by incumbent vendors S. Lack of recognition of economic role of OSSH communities T. Gap in converting ICT innovations into leading marketable products in Europe
Opportunities	**Threats**
P. Create an environment for hardware and software in the EU Single Market that respects open technologies E. Promotion of flagship projects and centres of excellence S. Development of an application environment that serves users and consumers in a more sustainable way T. Build a diverse network of industry subsectors innovating in a variety of technology areas with customised, energy efficient components	P. Danger to start-ups and SMEs by takeovers or suppression by Big Tech, administrative barriers in the public sector E. Dominance of US companies and technologies in many open technology sectors S. Brain drain of talent to USA and Asia, also following funding opportunities T. Disruption of common license models by a continued move of technologies into the cloud

g. Examples and quantitative analysis of business models

Introduction

In addition to the analysis of the business models in the context of the case studies, further examples of important and successful OSS based business models are presented. The well-known cases are complemented by an analysis of business models of OSS based start-ups, because CrunchBase provides a more detailed description than traditional company databases, like Amadeus. This analysis reveals the broad spectrum of business models applied in OSS. To complete the picture, start-ups, which base their business models on OSH, are investigated.

Important examples of OSS based business models

Based on the taxonomy presented by Okoli and Nguyen (2016), important examples for their 10 business models are presented.

Auxiliary services generate revenue for the developer by offering services that go beyond just the right to use the product. Such additional services can be product implementation, customisation, support, maintenance, consulting, training or localisation.

Examples of this model are:

- Red Hat, which offers a multitude of services, such as training, support and maintenance complementing its Linux kernel based Operating System. Red Hat has been acquired by IBM, which sells consulting services, hardware for OSS operating systems and numerous OSS complementing its hardware.
- NextCloud, a cloud storage and productivity suite, is being distributed under an OSS license for anybody to run. The company sells product support, consulting etc. and finances development with this.
- The Linux-based Android operating system is developed by Google and made available at the Android Open Source Project. Google complements it with marketplace, data and application services that enable its consumer data business.
- The TensorFlow machine learning library also developed by Google enables application developers to utilize machine learning, generating demand for cloud computing and data centre provision.

Corporate development and distribution is not a model that directly turns a profit, but is more about enabling the usage of software. Organisations pay developers to customise software to their needs and release these customisations to the OSS community, with the aim that the customised software is being maintained by the community.

Examples of this model are:

- Companies paying developers to contribute code to the Linux kernel. Companies use the kernel and mutually profit from their own development and the development efforts of others.
- Android smartphone manufacturers adapt Android to work with their hardware. The permissive license of Android allows these vendors to not publish these changes.
- Micro:bit, which develops low cost computers for the study of computer science in education, a cause also supported by companies.

Software as a Service (SaaS) with distribution of server software has gained significant popularity in recent years as cloud services have become more common. SaaS is not only a business model, but also based on a different technological thinking – that of an always-online world. In this model, OSS providers offer the software free of charge under an OSS license. You could run the software yourself, but this can be quite complicated and requires you to have the necessary hardware. So some companies today offer to take all the complexity away, run and host the software for you, to be accessed through the internet, for a, usually recurring, fee. These companies can be the original developer of the software, or they might be just a company that has specialised on these kind of offerings.

Example of this model are:

- WordPress, a very common OSS website software that you can either download and host by yourself free of charge, or can be hosted by WordPress.com itself or other hosting providers for a fee.
- Companies can host the OSS NextCloud suite and offer the software as a service to customers, getting paid (though there are also no-cost providers) for the effort and resources of hosting.

Open Core / Dual-licensing / Selling exceptions have some variance in this model, but the essential element is that a “core” version of the software is released under an OSS license, while a version with more features, is released under a proprietary license for a fee. This core version is often called “community/developer edition”.

Examples of this model are:

- Oracle MySQL, a database software, is available under a copyleft OSS license, but users can pay to receive a proprietary license version which does not have to conform to copyleft requirements.
- jooQ, a Java middleware, can be used freely under an OSS license, but commercial users are required to purchase software that is identical, but proprietary licensed.
- Revolution Analytics, now owned by Microsoft, which sells a paid enterprise version of its “R” statistics software, but offers it too as “R Open” under a FOSS licence.

In the **membership** model an individual or organisation can become a member or supporter of an OSS development organisation, by paying a fee. Common are different levels of membership fees. Some authors subsume the membership model under Open Source business models, it should however be considered a separate approach since the original developer cedes control of project governance to the new project established under the auspices of the foundation. Thus, this model represents collaborative development more than a business model of an individual company. This “umbrella organization model” is elaborated in the next subsection.

In **crowdfunding**, the project is financed through usually small donations of a greater number of either individuals or organisations, unlike memberships. Traditionally, those donations would be requested at the beginning of the development and would be one-time donations. A new variation of this model is an automatic monthly donation to finance a developer’s work, either on a specific project or as general support for their work.

Examples of this model are:

- Kickstarter, where a developer can offer a project for public support through one-time donations.
- Patreon, where the public can support a developer with a recurring, monthly stipend, similar to a normal income.
- Open Collective, where projects can be supported on a recurring basis, aiming to provide a yearly budget for projects.

In the **advertising** model, ads are displayed as part of the software, such as during the installation process, in the user interface of the software, or the manual. The developer receives money for displaying the ads to users of the software. The developer either implements the ads themselves or uses an advertising network. This

Examples of this model are:

- Mozilla, which sets a specific search engine provider as the default in their products and receives money for this.
- WordPress.com, which is a website system and displays ads on websites it hosts.
- AdBlock Plus, an ad-blocker plugin for web browsers, which receives money for not blocking specific ads.

The **update subscription** model usually relates to extensions to big OSS projects. For these, in order to receive updates, patches and bug fixes users need to become paying subscribers. This model is more usual in cases where the user base is small, but where it is critical for the users to receive frequent updates or bug fixes. The base software itself is usually still available free of charge.

Examples of this model are:

- Extensions for website software, such as WordPress or Joomla, where the user is paying for software in addition to the core product, which is available under a free of charge OSS license.

The OSS world has evolved to embrace online services such as Software as a Service. These services are increasingly complementing software that is running offline only or utilising a limited level of online interactions. With developments such as big data, machine learning and a seemingly ever-increasing number of software offerings, opportunities and risks are emerging for which business models embracing these are evolving. Using machine learning, for example, offers the possibility to analyse vast amounts of data and by extension also of user data, which can be monetised. The sheer number of software offerings make trust and security an increasing concern for users. OSS is not only a development model, but also an ethos based on freedoms, meaning that most developers of OSS are more cautious about the business models they choose for their products and that those business models should not have a negative impact on users.

The following models are still emerging in the OSS world and the workings are still evolving.

Selling user data is an emerging model which analyses users behaviour inside the product which is offered under an OSS license free of charge. Based on these analyses, user profiles are created which are sold either directly or to advertisers. In the OSS world, this model is currently very rare.

No widely known OSS examples exist for this model.

In **software certification**, the software is provided under a FOSS license and can be downloaded freely, but to use the branding of the developer, a certification fee is required. This can be used in areas requiring security or trust in the implementation of the software.

An example of this model is:

- Moodle, a digital learning platform, where the developer, “Moodle HQ” certifies that the implementing organisation of the software abides to Moodle HQ’s quality standard.

- LibreOffice, a productivity suite, where the developer, "The Document Foundation" refers to officially certified partners who offer support services.

This overview confirms the heterogeneity of OSS based business models, which has recently been even further expanded, e.g. due to technological opportunities and data availability.

Projects hosted at Open Source umbrella organisations

Foundations play an increasingly important role in the promotion of Open Source. There are two fundamentally different setups of foundations, those controlled by a single dominant entity and those open to all interested parties on equal terms.

The single-entity model often represents an attempt by a software vendor to establish a community around their software. Because of the inherent conflict between open collaboration and such a "managed community", such models are generally not very successful in attracting contributors. Companies that openly communicate their business interests without such a foundation and invite interested parties to collaborate, such as Red Hat, Nextcloud (see the case studies section) or the Qt Company, are more solidly established in the ecosystem.

The more common approach today are Open Source umbrella organisations that host a variety of projects under their auspices. These organisations are often referred to as Open Source foundations. Some of these organisations primarily attract industry collaborators, as is the case for OW2, the Eclipse Foundation, the Apache Foundation or the Linux Foundation. They usually invite outstanding individual contributors based on merit and sometimes provide funding for their work in the form of fellowships or employment. With these activities they play an important role in raising industry funding used to support the viability of key Open Source projects, as for example in the Core Infrastructure Initiative.[7] The KDE Community[8] or Software in the Public Interest (SPI)[9] are community-driven umbrella organisations that fulfill a similar role focused on facilitating a wide spectrum of projects.

Examples of this model are:

- The Linux Foundation, which provides funding for development of the Linux kernel and numerous other projects, has over 1000 corporate members, with most technology companies being members.
- The Apache Software Foundation, which defines the common Apache License and hosts numerous OSS projects and has a high number of individual members.
- The Eclipse Foundation, which for example hosts the Eclipse family of software development tools and recently relocated to Brussels.
- The Tor Project, which provides anonymization software, is financed by a smaller number of academic and organisational supporters.

Projects hosted at foundations often represent the collaboration in an industry consortium and develop software that drives commercial offerings. For example, OpenStack and Kubernetes are key building blocks to run data centres and commercial clouds. Other

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[7] https://www.coreinfrastructure.org/

[8] https://kde.org/

[9] https://www.spi-inc.org/

technologies like the Java Enterprise Edition, today hosted by the Eclipse Foundation under the name Jakarta Enterprise Edition, broadly enable the development of enterprise software.

The role and impact of Open Source umbrella organisations or foundations depends inherently on their governance model. A foundation can be considered pro-competitive and an open collaboration platform if all interested stakeholders have equal access to participation, decision making processes and conflict resolution. Membership fees should be transparent and nominal, for example based on organisational size and very low for individuals, so that barriers to entry are minimal. Such open governance combined with the application of Open Source licenses to all developed products enable an umbrella organization to act as a platform for industry collaboration, including finding consensus on technical developments, similar to standards development organisations.

Provided an umbrella organisation applies open governance as described, individual member organisations influence project decisions primarily on the merit of technical contributions. This reduces risks from projects being established at foundations by large enterprises. For example, the prominent Kubernetes project was established at the Linux Foundation in early 2016 after being initially developed by Google. In the fourth quarter of 2020, almost 500 different businesses contributed to the Kubernetes repositories.[10] Under open governance, any contributing company, including the original founder, needs to invest heavily into software development to retain a strongly influential position in the project. At the Linux Foundation, no single member or entity represents more than 2% of the overall budget. The potential of forks is an additional safeguard against domineering behaviour of individual members.

In summary, Open Source umbrella organisations or foundations today play an influential supportive role in the development and promotion of Open Source development and are key enablers of the Open Source ecosystem. Prominent organisations like the Eclipse Foundation, Apache Foundation or Linux Foundation, but also SPI or the KDE community have well-established open governance norms and are overall regarded positively by the wider Open Source community.

Quantitative analysis of OSS based business models

It is interesting to expand both the case studies and the prominent cases by analyses based on a larger scale of companies or organisations. Consequently, in the company database Amadeus, more than one thousand companies located in the EU Member States of the EU mentioning “Open Source” in their description have been identified.

Among these 1011 companies, 681 claim to provide “exceptional domain knowledge in the financial services and education sectors with software development and application management services built on expertise in niche proprietary, Open Source and legacy technologies.” Obviously, more than two thirds of the companies offer auxiliary services e.g. related to product implementation, customisation, support, maintenance, consulting, training or localisation. Many of the European affiliations of the large platforms, like Facebook, Amazon or Google, are among these companies basing their business partly on OSS.

Among the remaining third of companies, 135 provided sufficient detailed descriptions, which allowed a coding of their business model. The large majority of these companies

[10] Kubernetes development metrics are available on DevStats: https://k8s.devstats.cncf.io/d/11/companies-contributing-in-repository-groups?orgId=1&var-period=q&var-repogroup_name=Kubernetes accessed 14 March 2021.

provide either general IT services (51) based on OSS or just software developed based on OSS (40). Therefore, they belong also to the auxiliary services based business model. A significant number of companies is found, which mention Linux as base of their business model including the several affiliations of Red Hat in the EU Member States. In contrast, other OSS based systems, like Android or MySQL are mentioned only in very few descriptions. The business model of a few other companies is based on the development of in hardware embedded software based on OSS or in the provision of OSS tools.

In a second approach, start-ups listed in the database Crunchbase, which mention Open Source in their description and have their headquarters in the EU Member States, have been identified. The 757 companies are attributed in general multiple to different technologies, applications and industries. Therefore, a topic modelling, a kind of correlation analysis based on industries and technologies, to structure the multiple attribution to industries has been applied. Large clusters are around “Internet” and “Web”, but it is observed specific clusters e.g. around “cloud” and “blockchain”. Obviously, start-ups relying on OSS are entering new areas, which are not yet so visible among incumbents referring to OSS in their company descriptions.

Figure 4.2: Start-ups based on OSS differentiated by industries

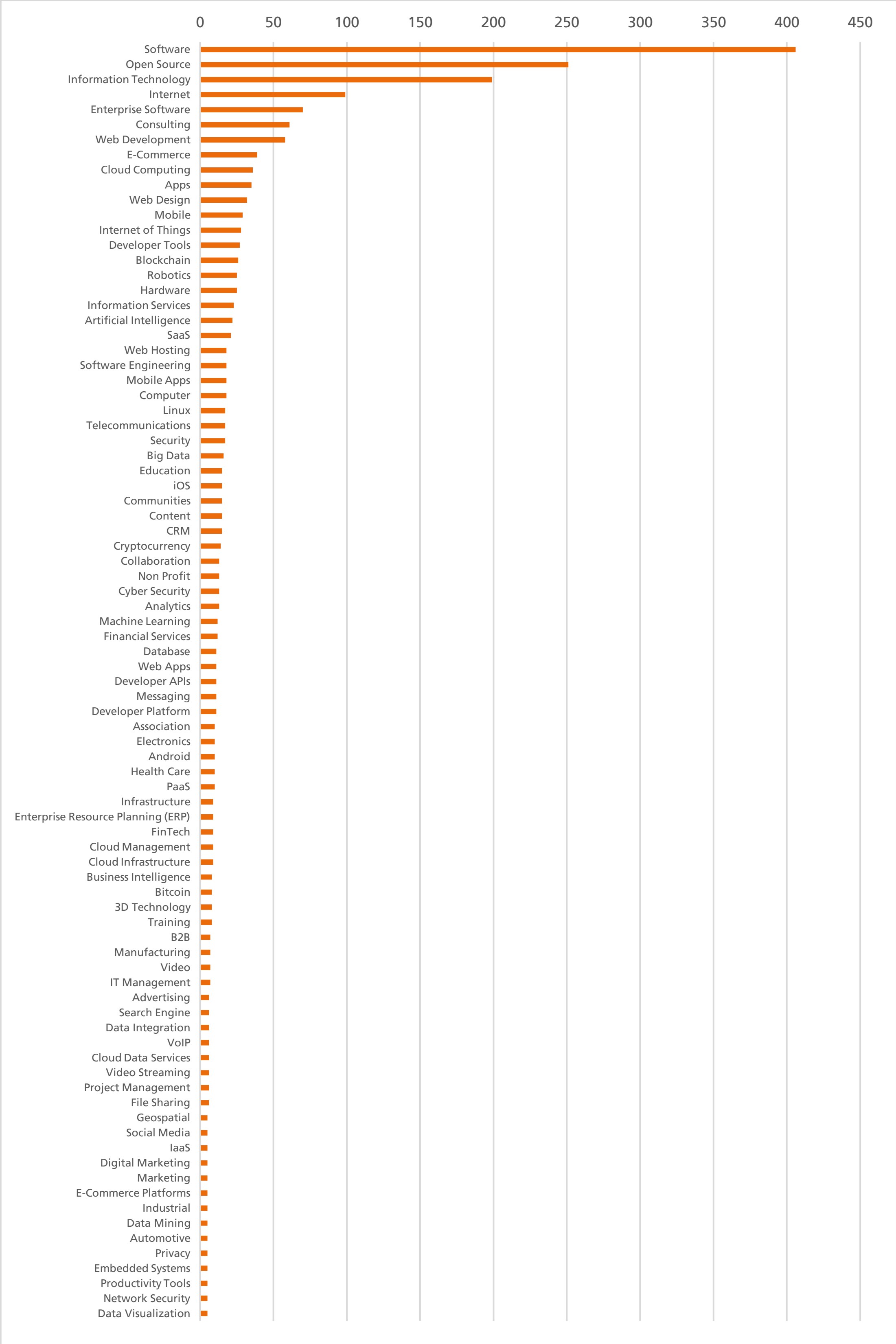


Figure 4.3: Results of topic modelling based on industries attributed to start-ups

Internet		Enterprise		Cloud	
Internet 99	Consulting 61	Advertising 6	Search Engine 6	Infrastructure 9	PaaS 10
Non Profit 13	Information Services 23	Enterprise Software 70	Education 15	3D Technology 8	Database 11
Cyber Security 13	Software Engineering 18	Enterprise Resource Planning (ERP) 9	Linux 17	Cloud Computing 36	Artificial Intelligence 22
Video Streaming 6	Data Integration 6	CRM 15	Computer 18	Machine Learning 12	SaaS 21
Health Care 10	Security 17	Association 10	Project Management 6	Cloud Management 9	Big Data 16
Content 15		Business Intelligence 8		Analytics 13	
Web		**Apps**		**Finance**	
Developer Tools 27	E-Commerce 39	Developer APIs 11	Mobile Apps 18	Communities 15	Cloud Data Services 6
Web Apps 11	Web Design 32	Mobile 29	Web Hosting 18	FinTech 9	Fin. Services 12
Web Development 58	IT Manag. 7	iOS 15	Android 10	Training 8	B2B 7
Developer Platform 11		Apps 35		Cloud Infrastructure 9	
Communication		**Blockchain**		**Hardware**	
Messaging 11	File Sharing 6	Cryptocurrency 14		Robotics 25	IoT 28
Telecom. 17	Collab. 13	Bitcoin 8		Hardware 25	Manufacturing 7
Video 7	VoIP 6	Blockchain 26		Electronics 10	

Overall, this first attempt of quantifying the shares of the different business models based on OSS reveals a strong focus on providing auxiliary services based on OSS with a strong focus on Linux. Only a few companies offer SaaS based on OSS. The other business models play in quantitative terms no significant role. However, OSS foundations are not listed in company databases, but the Apache, Eclipse and Linux foundations plus additional foundations are important representatives of the membership model.

Quantitative analysis of OSH based business models

The business models based on OSS are not immediately transferable to business models based on Open Source Hardware (OSH). Therefore, there are doubts about the adoption of OSH in businesses (Pearce, 2017). Due to the nature of hardware, namely that it must physically exist, i.e. production costs are incurred in order to have a product, many aspects of OSS are not transferable to OSH. However, some companies have proven that OSH based business models can be successful.

Open source hardware designs include the risk of losing market shares to imitators. Since in contrast to proprietary models, designs are not protected through patents or other rights Open Source lowers the technical barrier for imitators and imitation can be fatal to pioneering companies (Li & Seering, 2019). Additionally, Li and Seering (2019) discern that because of the nature of hardware, OSH is more vulnerable to competition than OSS. In OSH value can be created merely through manufacturing and selling an already existing open design, while in OSS such value creation does often make little sense since the software is always freely available.

Li and Seering (2019) conclude that there must be benefits from Open Source that compensate for associated Open Source risks to make it a viable business model. And indeed, there are several advantages for companies in open sourcing hardware designs:

1. Community members support through gathering market information, testing products and giving feedback. This decreases the chance of costly product failure.
2. Faster prototyping is possible due to a vast amount of OSH tools. Additionally, product go-to-market time can be shortened through the involvement of the community.
3. Community mentors (as defined by Li and Seering, 2019) provide resources in the form of customer channels and partnerships.
4. Costs of R&D are lowered due to product development from the community. "the community voluntarily engages with testing, refining designs, and solving technical challenges, which saved them a lot of time and money."
5. Marketing and sales costs are reduced since the product is introduced to the right customer pool during development already. Marketing might not be necessary at all.
6. Costs in recruitment can be lowered via recruiting from the community.
7. Usability for third-party programmers and partners is increased.
8. Legal fees can be reduced by avoiding IP-based licensing models (Pearce, 2017).

Furthermore, Li and Seering find out that open sourcing can increase the perceived value of a product by customers. The community helps with identifying market needs and provides instant feedback to product development. Since this leads to better products, customers perceive a higher functional value of open-sourced products. According to the authors, visibility of products in forums that discuss products' design and technology serves as a justification of the products' functionality and performance. This enhances trust among customers and their perceived functional value of the product. Lastly, Open Source products shift an approach of sole consumption of a product to an experience of learning and exploring with the product. This increases the perceived emotional value of customers. Li and Seering summarise that through an Open Source business model companies can boost customers' perceived value and cut down the cost of running the business.

It should be noted that these advantages of Open Source apply differently to different companies. Li and Seering (2019) detect strategies to mitigate the imitation risk in open sourcing and to create sustainable Open Source businesses. They identify the following as viable strategies to sustain a business that Open Sources its hardware designs: 1) the building of a brand. 2) fast innovation to outrun imitators 3) accumulation of experience with Open Source and then shifting to a proprietary model and 4) accumulation of enough market resources and then moving to other models that generate more revenue.

An empirically derived taxonomy of Open Source Hardware business models is presented based on company data originating from two sources (based on von Falkenhausen 2020). First, in Crunchbase has been searched for companies with a headquarter in the EU Member States mentioning "Open Source Hardware" and businesses and organisations in the list of certified projects from OSHWA. The search in Amadeus revealed only one hit. Businesses that do not exist anymore, that are not related to Open Source Hardware according to information provided on their website or are not listed in Crunchbase are not further considered for the analysis. The final result was a list of 44 organisations serving as database for the empirical analysis of Open Source Hardware business models.

For the development of the taxonomy the relevant components of Open Source business models were identified from literature. Shahrivar et al. (2018) perform a systematic literature review to determine features of Commercial Open Source Software (COSS) business models. They reveal eight components grouped into the categories value proposition, value creation and delivery and value capture. Value proposition encompasses COSS products and complementarities, COSS clients and users and eventually COSS competitive strategies. Value creation and delivery is bundled in the resources and capabilities of COSS businesses, organisational aspects of COSS and the positioning of COSS producers in the value network. They connect revenue capture with COSS revenue sources and COSS cost-benefits. Similarly, Pearce (2017) identifies value, revenue and logistics as the three components of business models in the Open Source.

Information about the business model components has been collected just via online research, but not by interviews with representatives of the businesses or organisations. Consequently, a further selection has to be made. The business model components value proposition, value network role, clients and users, revenue model and industry domain of products have been chosen for the analysis and the development of the taxonomy.

Table 4.2: Taxonomy of OSH business models (based on von Falkenhausen 2020)

Value proposition	Clients and users	Value network roles	Type
Provision of products, prevalently electronics, that can be used to make own products	Makers, educators, businesses	Suppliers, manufacturers, designers	Maker-oriented
Provision of products that offer specific solutions or focused around specific topics	Consumers, businesses	Manufacturers, designers	Solution- or product oriented
Customised hardware (and integrated software) solutions	Businesses	Manufacturers, designers	Customised solution providers
Non-for-profit approach based on donations	Diverse	Diverse	Non-for-profit organisation, NGO

Information about the categories was attained through research on the websites of the businesses, on GitHub and through information provided by Crunchbase. With qualitative knowledge about the businesses attained through web research, von Falkenhausen (2020) reviewed the final data base to detect patterns between categories. Value proposition was identified as the category showing the strongest discriminating pattern between businesses collected in the database. Hence, four business model types were derived based on their value proposition. The final taxonomy detects four types of business models, differentiating between value propositions. Table 4.2. gives an overview.

Based on the 44 organisations investigated, the types Solution-/ product-oriented Maker-oriented constitute in equal shares more than three-quarters of the represented businesses. Customised solutions providers are quite rare, whereas non-for-profit or NGOs represent around on fifth of the cases.

The revenue models are concentrated on sales of products. Most businesses have a shop on their website from which products can be bought. Only two companies provide services, like training, together with their products. The non-for-profit organisations or NGO generate revenues from donor funding, donations, foundations and sponsoring.

Type Maker-oriented

With its value proposition the business model type Maker-oriented targets the maker and EdTech scene. They offer products for fast hardware prototyping and do-it-yourself electronics building projects ranging from beginner to expert level. A subgroup of these businesses is focused on educational electronics. The websites of Maker-oriented businesses also include an online-shop. Their product portfolio includes in general boards, building kits, displays, cables, motors, cases, drones and sensors.

The revenue range of these business are between $1 Million to $10 Million. Only the revenue of Adafruit and SparkFun Electronics is estimated to range between $10 Million to $50 Million.

This business model targets private users, communities, schools and educators, entrepreneurs and businesses, who use Open Source electronics for prototyping, building projects, as components in products and education. In particular, Microduino is focusing its business on educational technology.

The majority of the companies are both designing and manufacturing hardware products. Whether the businesses manufacture themselves, or whether third parties manufacture the products, which the companies sell cannot always be revealed based on the public available information. Among the type Maker-oriented are also businesses just suppliers, e.g. serving as a “supermarket for electronics hardware” offer abroad portfolio of components. Fulfilling the role of a pure supplier, therefore, is a viable position in the value network.

The businesses attribute themselves in particular to electronics and hardware, but also software, DIY, drones, education, manufacturing, robotics, 3D-Printing and Internet of Things as industries, they are active in, according to their description provided in Crunchbase. Since these businesses share the same or similar markets, the industry domains, in which is type Maker-oriented are active, are rather homogenous.

These companies employ different product strategies with regard to their whole assortment and their usage of OSH. Some sell a mix of Open Source and proprietary hardware on either open and closed platforms. Many businesses sell their own designs in an assortment together with hardware from other companies, e.g. Raspberry Pi and Arduino. Some companies are specialised in drones by selling both electronics hardware components of drones for makers and built ready-to-use drones addressing the diversity of their customers’ demand.

The type Maker-oriented business has its main customer segment in the maker and Open Source community. The community is a strong driver of innovation and developer of products, as Li and Seering (2019) postulate. The self-marketing effect of OSH is driven through the spread of information about upcoming products via the community. In addition, the community provides quick and immediate feedback, reducing the risk of product failure.

Once the product is being sold, the community can be a source of product support and development with limited costs. Overall, the business model type Maker-oriented draws largely from Open Source advantages through the community. Therefore, it is crucial for businesses to grow a community around their product and maintain a close relationship with its contributors.

Type Solution- / product-oriented

The business model type Solution- / product-oriented offers products that fulfill the purpose to solve particular customer needs or close specific market gap. In contrast to type Maker-oriented, the solution- or product-oriented companies sell final products containing a specific value proposition. Since customers are in general not part of the product development process, there is a stronger need for customer-orientation, e.g. via stronger marketing efforts.

Products from these businesses included in the sample cover amongst others smart home ventilation systems, biological signal processing systems, body-sensing equipment, telescopic antennas, industrial automation devices, CNC machines, motion-control systems for photography and cinematography, environmental monitoring devices and cryptographic USB sticks. The estimated revenue range covers a spectrum to $10Million.

Both private consumers and commercial businesses buy products from the type of Solution- / product-oriented companies. However, these businesses have different target groups of customers depending on their products, e.g. industrial automation solutions for the industrial sector or smart climate control systems for private homes.

In general,all businesses within this category are both designing and manufacturing their products.

According to the information provided by Crunchbase, this type of business appears in quite diverse industry domains, like cloud data services, smart home, wearables, electronics, IT, Robotics, manufacturing, industrial automation, photography, 3D technology, environmental engineering and supply chain management. Since these companies use OSH as a tool to provide a solution that is not necessarily onöy linked to electronics or hardware, the industry domains, in which they are active, are quite diverse.

OSH is integrated to differing degrees in the companies' products. Some companies build its products' technology on already existing OSH designs, such as Raspberry Pi and Arduino, but also OSS. They, thereby, profit from these large communities and their expertise, as well as from the compatibility with other OSH components. Some employ Open Source designs to accelerate innovation for their pioneering products by attracting more developers to push their quality and eventually diffusion. Several businesses provide accessible documentation to all components of their products, but other companies do not disclose a full documentation of their hardware designs and sell also products, which are not Open Source.

Type Customised solution provider

Only two companies in the sample fall into type Customised solution providers. They provide hardware and integrated software solutions on demand. Their customer segments appear to be companies, which make use of their expertise. They operate on a small scale with less than ten employees. This type follows a very different value proposition strategy than the other types. Finally, its economic relevance is quite limited and not further investigated in detail.

Type Non-for-profit/NGO

Finally, almost 20% of the organisations in the database were identified as type NGO/ non-profit. These organisations are divided by von Falkenhausen (2020) into three subgroups:

Alliances and foundations to coordinate, support and partake in the development of technologies or products:

- RISC-V is an open standard instruction set architecture. RISC-V International was founded as a non-profit corporation in 2015 to create an open and collaborative community for software and hardware innovation based on the RISC-V ISA. It announced a collaboration with the Linux Foundation in 2018, which provides operational, technical and strategic support to RISC-V International. It members have to pay fees.
- The goal of the CHIPS Alliance is to provide a barrier-free collaborative environment that "lowers the cost of developing IP and tools for hardware development". It develops and hosts OSH code, interconnect IP and OSS development tools. Through the development of IP blocks, it enhances hardware development of, for example, RISC-V cores and neural network accelerator cores. The CHIPS Alliance and the CHIPS Alliance FUNd are hosted by the Linux Foundation. The CHIPS Alliance Fund accepts corporate members that provide funding for the infrastructure and activities.
- The BeagleBoard.org Foundation is a non-profit corporation that "provides education in and collaboration around the design of open-source software and hardware in embedded computing", mainly through a forum. Funding for board prototypes comes from manufacturing partners.

Communities that share knowledge, tools and methods in order to propel innovation in a specific area and to make that technology more affordable and accessible (Public Lab, Open Garages).

- Public Lab is a community and non-profit that has the mission to propel environmental justice through community science and open technology. It does so by raising awareness, enhancing scientific agency, building skills and mitigating certain exposures. It is funded by donations from foundations, public grants and programmes and individuals.
- Open Garages is a network of vehicle tuning shops. The website opengarages.org is the central source of information on vehicle technology for the Open Garages. It seems to be not very active anymore.

Organisations that develop solutions with OSH (Field Ready, Open Power Quality).

- Field Ready is a non-profit, non-governmental organisation that produces useful items through manufacturing for humanitarian and reconstruction aid. Field Ready, furthermore engages in training and capacity building. It receives funding through donations, and donor-funded projects.
- Open Power Quality makes hardware and software for low-cost distributed power quality data collection, analysis and visualisation. It is sponsored by departments of the University of Hawaii.

Conclusion

In this section a taxonomy has been presented for Open Source Hardware business models based on a sample of 44 organisations following von Falkenhausen (2020). It identifies four types of business models: "Maker-oriented", "Solution-/ product-oriented", "Customised hardware solution provider", and "Non-for-profit /NGOs", of which the first two are further analysed. The result shows that maker-oriented business models have different interdependencies with the community and benefit differently from Open Source than product-/ and solution-oriented business models.

The findings based on the 44 organisations face some limitations. The sampling is limited by the coverage of Crunchbase, which is addressing OSH much better than Amadeus. The further information, which is taken from Crunchbase together with information from companies' websites, induce a superficiality of results. A more qualitative approach preferred with interviews leads to deeper insights. However, the case studies complement this shortcoming, whereas the stakeholder survey might provide a broader coverage of organisations with OSH based business models and more detailed background information addressing the superficiality of the presented overview.

h. Summary of case studies, business models and taxonomies

The case studies have been conducted guided by a comprehensive analysis of different taxonomies. They also include specific success stories. In total, they build the basis of SWOT analysis of the European economy. Finally, the case-based analysis of business models is complemented by quantitative analysis of business models both related to OSS and OSH. All these insights are integrated in the comprehensive analysis of the results from the different methodological approaches and are eventually the basis for the derivation of the policy recommendations.

5. Economic Impact Analysis

a. Introduction

One main task of the project is focused on the analysis of the economic impact of OSS and OSH. Based on the previous chapter on the taxonomy, the various business models and the case studies at first the data is presented, our different analyses of the impact of OSS are based on. Secondly, both the models and the results of our macroeconomic analyses are displayed, which focus on economic growth, international competitiveness, but also innovation and employment. Thirdly, the econometric macroeconomic analysis is complemented by a twofold cost-based impact analysis, which allows us at least the quantification of the efforts, because market prices for OSS are not existent and data on companies' revenues generated based on OSS are not available. Data on motivations and time invested in OSS projects collected via a survey among individual contributors conducted by the Harvard Business School on behalf of the Linux Foundation (Nagle et al. 2020) qualitatively inform in particular our results on costs. In chapter 6, they are also validated by the results of the stakeholder survey. At first it is started from the macroeconomic level of the EU Member States, which allows us the quantification of the efforts by Member States. The overall efforts are linked back to the results of the macroeconomic analyses, i.e. the contribution of OSS to GDP in the EU, which allow us to generate cost-benefits ratios. Such ratios have been also asked at the stakeholder survey. Second, the most active contributors to OSS located in the EU Member States have been identified, which are responsible for a significant share of all contributions within the EU. For this sample, the efforts, they invest in OSS, have been calculated. Complementary to the insights from the macroeconomic analysis, this microeconomic company-based analysis reveals new insights about the investments of companies in OSS both by company size and by sector. Their investments are also linked with their performance, i.e. turnover and turnover per employee, to also address the benefit side. However, further insights are received from the stakeholder survey about the various types of benefits of OSS in general and the revenue companies generate based on OSS in particular.

Since such quantitative approaches are only possible for OSS, for OSH another more company-specific approach has been developed. Since almost no company is listed in databases of established companies, Crunchbase, a well established database on start-ups, have been analysed. In addition to the insights on OSH based start-ups, a new database on certifications of OSH projects provided additional insights. They complement the results from the case studies.

b. Database of OSS

In an ideal constellation, access both to data about the production and availability of OSS and eventually the distribution or use of OSS should be available, because the impact of OSS depends not only on the quantity of available code, but in particular on its diffusion, i.e. implementation. However, there are some limitations. Whereas information about the participation in the production of OSS is publicly available, the actual use of OSS by companies and other organisations is less transparent and can only be revealed in direct collaboration with companies, e.g. via interviews within the case studies, or surveys, e.g. the stakeholder survey. Therefore, it is concentrated in this report and this chapter on the involvement in OSS development in general and the most active OSS participants in particular.

Regarding the available OSS code, it relied on GitHub, the most prominent OSS repository, which has been used already in other studies (e.g. Nagle 2019a, Mombach et al. 2018). The OSS data obtained from the GitHub developer platform is provided by TU Delft in the context of the GHTorrent project (https://ghtorrent.org/). As the largest repository for OSS projects, GitHub provides unique systematised on the prevalence of OSS also across countries and organisations. Since Microsoft only acquired GitHub in 2019, possible implications have no influence on the data used, e.g. the time series, on which it relied on, because they cover only the time horizon 2000 to 2018. It has also been looked at GitLab and Software Heritage, but the GitHub database is more appropriate, because it is much bigger and provides longer time series. The relevance and soundness of GitHub as database can be supported by the number of publications listed in the Web of Science mentioning GitHub, which is more than 50 times of the papers mentioning GitLab.

GitHub is an internet-based system, which can also be accessed through a web interface, for hosting software and maintaining accurate version control. It was launched in early 2008. After its launch, GitHub quickly became the primary repository for OSS projects, with more than 1.3 billion OSS lines of code or commits. These commits are contributed by meanwhile more than 32 million users compared to 15 million in 2016 (GitHub 2016) originating from more than 680,000 organisations. GitHub was already back in 2016 by far the most popular code-hosting service for OSS development. Earlier empirical studies rely on SourceForge (Engelhardt & Freytag 2010, Engelhardt et al. 2013, Lakka et al. 2015). Meanwhile, platforms such as SourceForge, with 3.7 million users (SourceForge, 2016), and Launchpad, with 3.1 million users (Launchpad, 2016), have far fewer users than GitHub (Ojanperä et al. 2019) and are therefore of relatively minor importance. Finally, the archive data provided by SourceForge is not up to date any more, which does not allow an adequate assessment of the current impact of OSS.

Unfortunately, data about the diffusion of OSS code is in general not available. However, as outlined in the literature review OSS can be considered as user innovation or a form of co-creation between developers and users. Consequently, contributions to OSS code at GitHub also reflect their use. Therefore, it is proposed to rely on the contributions of code to GitHub following Nagle (2019a) and Wright et al. (2020) or Engelhardt & Freytag (2010), Engelhardt et al. (2013) and Lakka et al. (2015) relying on SourceForge, assuming that contributing leads also to implementing OSS. In a second step, it also promotes the learning of the contributors as they receive feedback from the crowd of more experienced users and are, therefore, able to better capture value from using the goods (Nagle 2018).

In addition to the commits, also the contributors are used, which represent eventually in general employees of companies and other organisations, e.g. foundations, research organisations or universities. They spend some or even all time of their work to the development of OSS code. This approach is similar to Lakka et al. (2015) and also Engelhardt & Freytag (2010) and Engelhardt et al. (2013) relying on SourceForge as a much smaller database. Similar to Borges et al. (2016), Mombach et al. (2018) analyse popular OSS projects hosted at GitHub, but the attribution of projects to countries is quite complex and difficult, because the majority of projects are driven by contributors located in several different countries.

However, the cost-based impact assessment relies on the organisations or in particular the companies and their involvement in GitHub based on the number of their linked contributors and their submitted commits plus the therefore necessary effort.

c. Macroeconomic impact analyses

Macroeconomic impact model framework

In order to conduct a comprehensive analysis of the impact of OSS, it is focused on GDP or economic growth, as well as on other impact dimensions. More specifically, it is concentrated on the impact assessment on dimensions including labour productivity (see also Ghosh 2006), trade, and global value chains. Since OSS code has also an influence on innovation, i.e. both on product and process innovation, this impact dimension is also included in our approach. The basic assumption is that the aggregate stock of OSS code is a source of information for innovating companies, which increases innovators' productivity. However, their direct impact on the creation of start-ups, another phenomenon of innovation, is included following Wright et al. (2020), but also the change of the number of companies addressing the impact of OSS on the improvement of competition by lowering entry barriers for the software and hardware market. Following Nagle (2019a), OSS contributions also lead to a direct increase of employment of ICT specialists, which is, therefore, also being considered.

In this section, the comparative econometric analysis of the economic effects of Open Source Software in the EU and EFTA Member States is presented, but also other relevant countries, for which the required data is available.

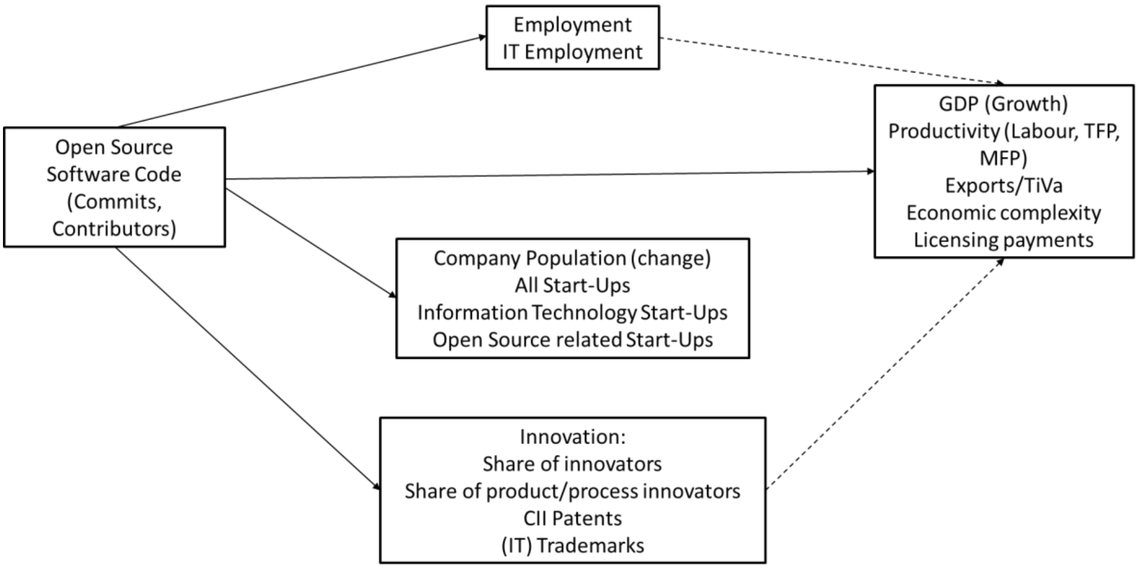
Frst, our data sources are presented, before our econometric modelling approach is elaborated. Then, the following dimensions are addressed in the assessment of the impact of OSS:[11]

1. Impact on economic growth
2. Impact on productivity
3. Impact on trade in value added, exports, economic complexity, and payment for intellectual property
4. Impact on innovation, patents, trademarks
5. Impact on start-ups and company population
6. Impact on (IT) employment

In Figure 5.1, the general structure of our impact model is displayed (not showing other explanatory variables for economic growth, such as the labour force, or for trade, such as distance) in order to give a simple overview of the most relevant impact dimensions which are going to be addressed. The possible impact of OSS on the 17 Sustainable Development Goals are known. However, their development over time is, in general, influenced by many other factors. Therefore, in our framework only innovation being the ninth Sustainable Development Goal is being explicitly considered.

[11] In contrast to more than one billion commits to the Open Source Software repository GitHub, only a small base of country-wide indicators is available for Open Source Hardware, e.g. 0.5 million commits related to the OSH platform Arduino. Therefore, the time series based on this data are not robust and it is not possible to generate reasonable and robust results by performing econometric analyses. However, Arduino has been analysed as a success case with the case study on OSH.

Figure 5.1: Impact Model Framework



Data collection for the macroeconomic analyses

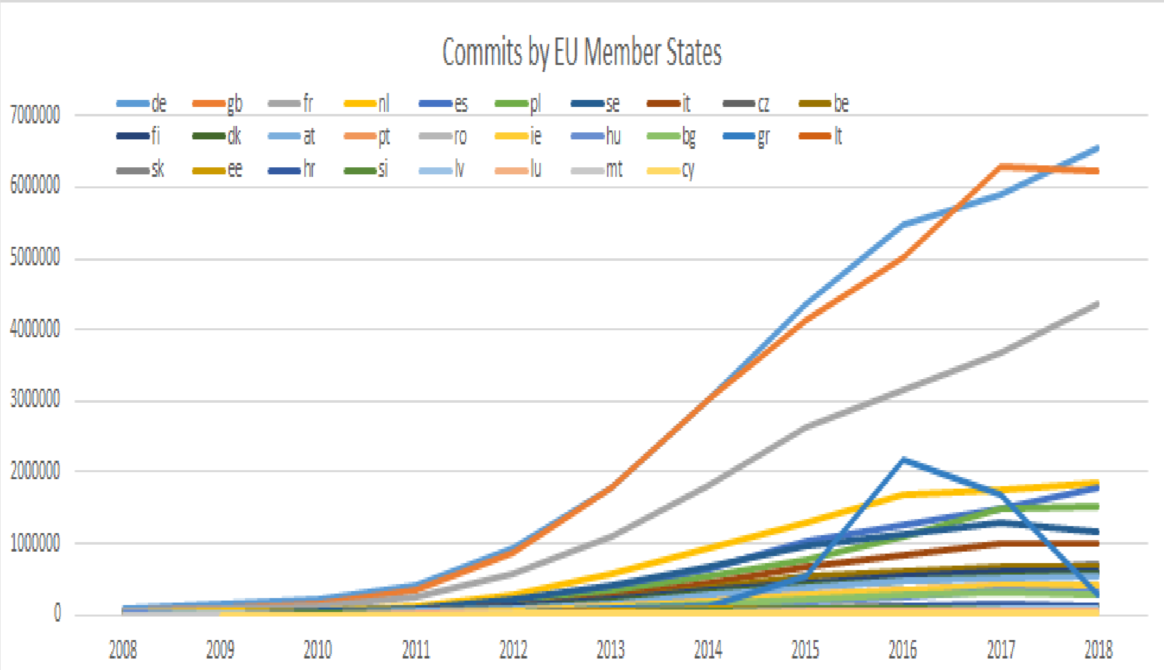
As mentioned above, the data collection first focuses on GitHub, the primary repository for OSS projects worldwide, to provide the background for the impact assessment and a discussion of how the variables of interest are measured.[12]

It then details the construction of the primary outcome variables of interest related to OSS contributions, i.e. commits, and contributors, i.e. GitHub users. Based on data derived from GitHub time series of commits and users - if possible - for all the 28 EU Member States from 2000 to 2018 are created.[13] For example, Nagle (2019a) only relies on 22 EU Member States and OECD countries due to the fact that for smaller EU Member States the number of contributions might be insufficiently low or some other data sources are not available or strongly biased, e.g. in Crunchbase there is a strong bias to US start-ups. Therefore, only in the optimal case, in combination with the variables listed in Table 5.1 a panel data set close to 500 observations as the basis for our econometric panel analyses is created.

[12] However, Software Heritage, a new platform that also includes content hosted at GitLab, has been considered, but it provides not the necessary time series data.

[13] The United Kingdom is included, because it belonged still to the EU in this period of time. Furthermore, only around half of the contributors and consequently of the commits can be attributed to a specific country, which is a significant underestimation of the investments, into OSS.

Figure 5.2: Number of GitHub commits per year and country



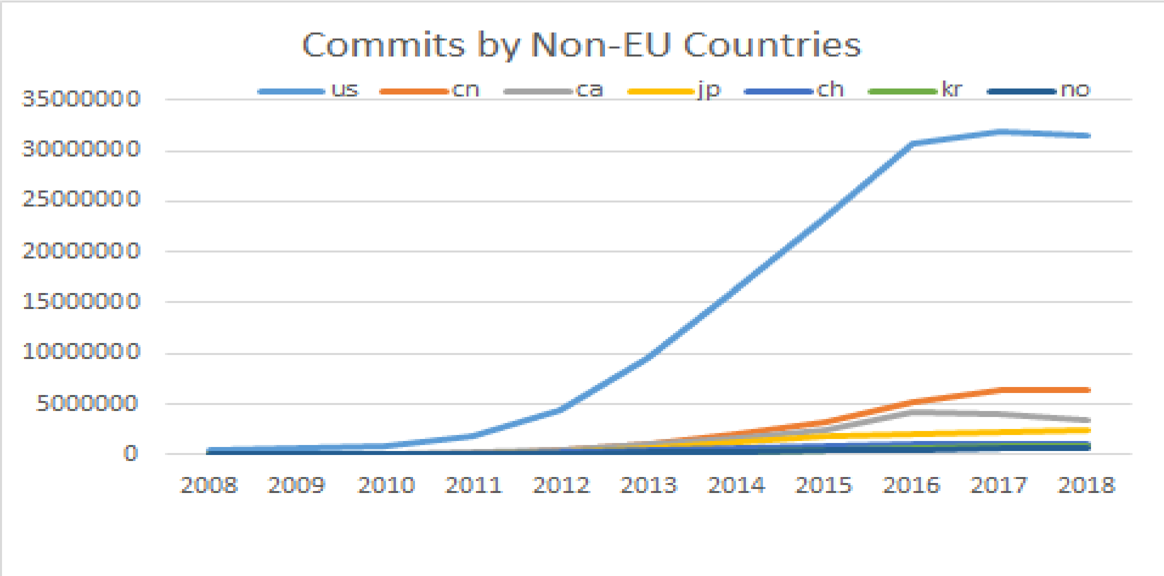
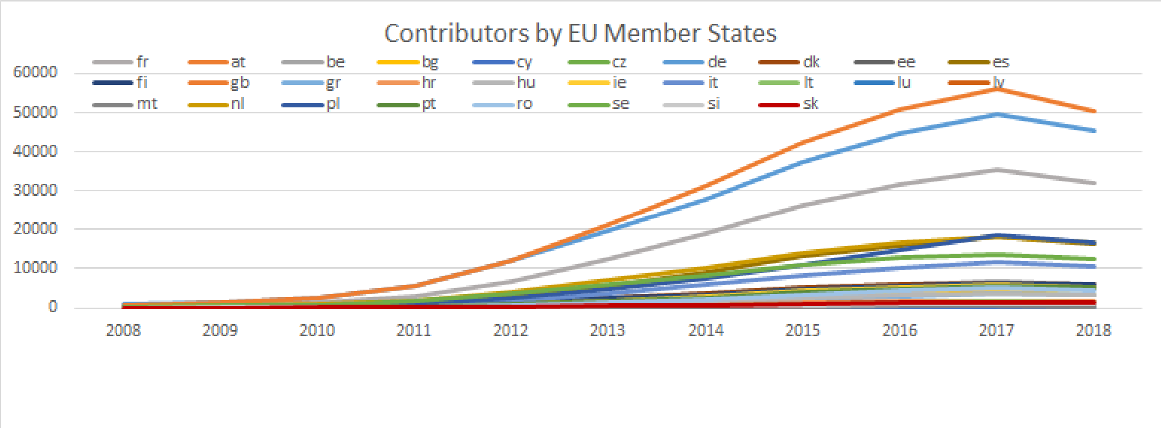


Figure 5.3: Number of GitHub contributors per year and country



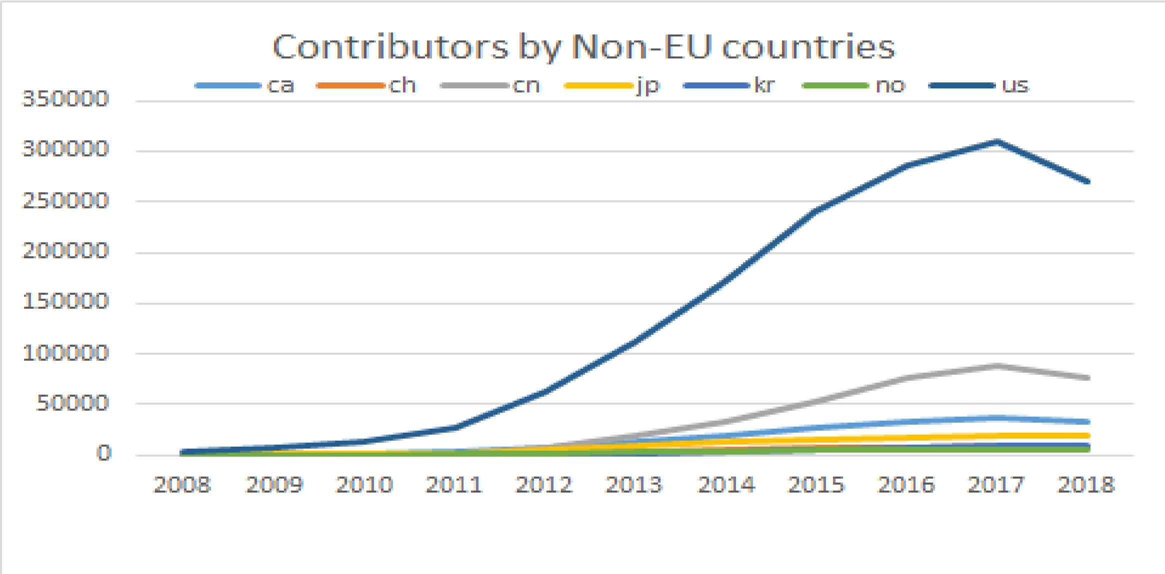


Table 5.1: Variables, description and sources

Variable	Description	Source
OSS Code	Number of GitHub Commits	GitHub/ GHTorrent project (https://ghtorrent.org/)
OSS Contributors	Number of GitHub Users	GitHub/ GHTorrent project (https://ghtorrent.org/)
Y	Value-added	OECD STAN Rev. 3
GDP	Nominal GDP	The World Bank WDI
TFP	Total Factor Productivity	TFP Penn World Tables 8.1 (http://www.rug.nl/ggdc/productivity/pwt/)
MFP	Change of Multifactor Productivity	OECD Multifactor Productivity
K	Aggregate capital stock	Berlemann and Wesselhöft (2017)
L	Total number of employees	OECD STAN Rev. 3
R&D	R&D expenditure	OECD Science, Technology and R&D Statistics

Pat	Stock of patents granted and patent applications at the European Patent Office	OECD Patent database
Lic	Payments for the use of intellectual property	World Bank World Development Indicators
ECI	Economic Complexity	ECI The Observatory of Economic Complexity (http://atlas.media.mit.edu/en/)
Start-ups	Number of start-ups	Crunchbase
Information Technology Start-ups	Number of start-ups in Information Technology	Crunchbase
Open Source Start-ups	Number of start-ups referring to OSS	Crunchbase
Company population	Change in company population in computer manufacturing and Information and Communication	EUROSTAT (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=bd_9ac_l_form_r2&lang=en)
IT-Employment	ICT employment	EUROSTAT (https://data.europa.eu/euodp/en/data/dataset/yS02f1YaXkfPyT0S8A6HmQ)
Employment	Total number of employees	ILO
TiVA	Domestic value added embodied in foreign final demand	OECD-WTO Trade in Value Added Database
EXGR	Gross exports	OECD-WTO TiVA Database
Dis	Distance	CEPII GeoDist database
Contig	Contiguity	CEPII GeoDist database
Comlang	Common language	CEPII GeoDist database
Pat	Patent applications	Patstat
CII	Computer-implemented inventions	PatStat
Trademark	Trademark registrations	EUIPO
Inno	Number of innovators	EUROSTAT CIS
Edu	Percentage of population with tertiary education	ILO Key Indicators of the Labour Market
Imp	Imports, percentage of GDP	World Bank WDI
Exp	Exports, percentage of GDP	World Bank WDI
Pop	Population growth rate	World Development Indicators
Unemployment	Unemployment rate as a percentage of labour force	World Development Indicators
Financial	Lending interest rate, domestic credit to private sector as a percentage of GDP	IMF International Financial Statistics
Institution	Corruption perception index (Transparency), administrative requirements index (Freedom House), bureaucracy costs (Freedom House, protection of IPR (Freedom House)	Transparency International (https://www.transparency.org/research/cpi/overview) Freedom House (https://freedomhouse.org/)

Impact on economic dimensions

Impact of OSS on GDP

Applying the approach used by Jungmittag et al. (1999) to calculate the impact of standardisation or by Nagle (2018) to analyse the influence of OSS on the micro level of US companies, the base-line model is based on a simple Cobb-Douglas production function as follows:

$$Y_{it} = A_{it-1} K_{it}^{\alpha} L_{it}^{\beta} \tag{1}$$

where Y denotes output, K denotes capital, and L denotes labour each in country i at time t, where the coefficients α, β refer measure their respective production elasticities. F(.) contains further log-linearised input factors or control variables. Most importantly, A_{it-1} denotes the knowledge stock, which is modelled based on a structural approach proposed by Bottazzi and Peri (2007). In this approach, the evolution of the knowledge stock is modelled as a function of R&D and the existing knowledge stock. If it is further allowed that there may be differential effects from foreign and domestic R&D expenditures, it is assumed the following log-linear function:

$$log(\dot{A_{it}}) = \varepsilon_1 logRD_{it-1} + \varepsilon_1 logRD_{it-1}^{ROW} + \varepsilon_1 logA_{it-1} \tag{2}$$

where $(\dot{A_{it}})$ refers to the change in the knowledge stock, RD_{it} are the R&D expenditures and the superscripts ROW refer to rest of the world. When taking logs of Eq. (1), approximating the change of the knowledge stock by the number of annual patents, our central equation of interest can be rewritten with logF(.) as generic logarithmed control function as follows:

$$\mathrm{logY_{it}} = \gamma_1 \mathrm{logRD_{it-1}} + \gamma_2 \mathrm{logRD_{it-1}^{ROW}} + \gamma_3 \mathrm{logPAT_{it}} + \alpha \mathrm{logK_{it}} + \beta \mathrm{logL_{it}} + \mathrm{logF(.)} \tag{3}$$

Now assuming that among the additional factors that constitute the other input factors and control variables also contain the use of OSS, our structural estimation model can be rewritten as follows:

$$\mathrm{logY_{it}} = \gamma_1 \mathrm{logRD_{it-1}} + \gamma_2 \mathrm{logRD_{it-1}^{ROW}} + \gamma_3 \mathrm{logPAT_{it}} + \alpha \mathrm{logK_{it}} + \beta \mathrm{logL_{it}} + \gamma_4 \mathrm{logOSS_{it-1}} + \gamma_5 \mathrm{logOSS_{it-1}^{ROW}} + \mathrm{logx_{it}} \mu \tag{4}$$

where $logx_{it}$ are logged version of generic control variables (see below) and OSS_{it-1} refer measures approximating the contribution to and use of OSS. Since Geiger (2017) and recently Nagle et al. (2020) confirm that the majority of contributors are paid for contributing to OSS, it can be assumed that both the contributors to OSS as well as the time they invest in submitting commits are a mainly a subgroup of the labour input L and to a smaller degree hobbyists making contributions in their free time.

How to estimate the Eq. (4) depends on the assumptions of the variables. Most importantly, because it is operated with relatively large T as compared to N, regular panel data methods may fail. An important issue relates to non-stationary time series. Typically, when time series are non-stationary, regular OLS-type regressions lead to inconsistency because usual asymptotic theorems (such as the law of large numbers of central limit theorems) no longer apply. Many time series, such as GDP, are known to be non-stationary. Likewise, the results in Bottazzi and Peri (2007) show that the relationship expressed in Eq. (2) contains not stationary variables. Moreover, given the vastly increasing volume of OSS, the time series are very unlikely to follow a stationary trend. However, if non-stationary time series are cointegrated, i.e. there exists a linear combination of them, such that the linear combination is stationary, special estimators can be developed to estimate the equations.

Cointegration techniques require that the relevant time series are non-stationary and that they control indeed for a long-term stationary relationship. The equations above are the long-term growth equations and in sum reflect the requirement to combine technological and economic indicators (Castellacci 2007). Likewise, Bottazzi and Peri (2007) devise a model in which it can expected that patent stocks, international patent stocks, and R&D are cointegrated. Applying panel cointegration estimators thus requires a step-wise procedure. First, the hypothesis that all time-series are non-stationary, using so-called panel-unit root tests has been tested. Second, it is tested whether the non-stationary time series are cointegrated using panel-cointegration tests. In particular, it is relied on the panel/group t-tests, which are known to outperform alternative tests in terms of power and size in finite samples. Finally, the cointegrating relationships is estimated based on the extensions of the Bottazzi and Peri (2007) model using alternative panel cointegration estimators, in particular DOLS (Dynamic OLS).

Panel data is used, which is available for the years 2000 to 2018 on a yearly basis and for the maximum of 28 EU Member States or a smaller number in case of data restrictions for specific time series or Member States. A number of other countries is also included, in specific, the USA, Japan, Korea, Canada, China, Norway, and Switzerland. As a measure for the output Y, the total value-added of a country is used. The capital stock K is the Berlemann and Wesselhöft (2017) aggregate capital stock. The authors provide the only available capital stock indicator that is consistent over all countries and uniformly covers the long-term panel dimension of almost 30 years. L is equated by the labour force in a country.

Besides Eq. (4), a number of different models is calculated with alternative outcome indicators and alternative control variables. To obtain consistent estimates, the following procedure has been followed. It is found that in particular R&D, the use of OSS, GDP, TiVa, and exports are non-stationary. In cases, where the dependent and at least one of the independent variables were non-stationary, cointegration was checked for. Our test results, always confirmed cointegration in these cases. So, these models are estimated with dynamic OLS. In the case, where the dependent variable and not at least one of the explaining variables where non-stationary, the non-stationary variables have been differenced until they became stationary and ran regular panel-fixed-effects models for the other variables. The estimation method is mentioned in the headers of the respective tables. It is noted that all models are in log-log form implying that the coefficients can be interpreted as elasticities.

Table 5.2: Impact of OSS Commits on GDP (DOLS)

	(1) All	(2) EU (Var1)	(3) EU (Var2)	(4) EU (Var3)	(5) Other
Log capital stock	0.71265***	0.66287***	0.67172***	0.56873***	0.52507***
	(14.69)	(13.03)	(13.68)	(10.33)	(13.31)
Log employment	0.23555*	0.09257	0.10556	0.08895	0.42886***
	(1.96)	(0.83)	(0.98)	(0.73)	(2.61)
Log payments for use of IP	0.04534***	0.05674***	0.05670***	0.05245***	0.04902***
	(3.85)	(5.16)	(5.35)	(4.41)	(3.45)
L.Log R&D expenditures	-0.06622**	-0.06985**	-0.07158**	-0.07118**	-0.06299
	(-1.98)	(-2.26)	(-2.40)	(-2.11)	(-1.34)
L.log R&D expenditures by ROW	-0.93139***	-0.72398***	-0.84036***	-0.93408***	-0.47722***
	(-4.81)	(-3.65)	(-4.45)	(-4.39)	(-3.12)
Log transnational patent applications	0.06357***	0.02375***	0.01974***	0.02513***	0.16022***
	(18.06)	(6.89)	(5.96)	(6.72)	(53.61)
Log GitHub commits	-0.03103***	-0.03124***	-0.03087***		-0.01671**
	(-6.24)	(-6.86)	(-7.00)		(-2.44)
Log GitHub commits by ROW	0.06849***	0.06716***			0.02832***
	(7.74)	(7.85)			(3.10)
Log GitHub commits EU (excl. focal)			0.06537***		
			(7.70)		
Log GitHub commits EU				0.04067***	
				(4.78)	
Country dummies	Yes	Yes	Yes	Yes	Yes
Observations	480	375	375	375	105
R^2	0.917	0.894	0.891	0.861	0.993
N_g	32	25	25	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results of the basic macroeconomic production function confirm the important role of the capital stock and employment for economic growth. Even the coefficients are in a reasonable range. The role of technological progress is represented by a set of variables. First, the import of foreign technologies measured by the payments for the use of intellectual property covering both licensing payments for patents, but mainly for copyrights including software is a significant driver for economic growth. In contrast, the domestic expenditures for R&D are reducing economic growth, which is at first glance a puzzling result, but it is a kind of investment with uncertain return. The R&D expenditures of the rest of the world are also negative for domestic growth, because they push the competitiveness of the other countries having a negative impact on the domestic balance of trade, i.e. both negative for exports and positive for imports. Eventually, GDP growth is reduced by slower increase of exports by domestic producers, whereas the higher imports reduce their shares at the home markets. Whereas domestic R&D expenditures as input indicator of innovation are negative for GDP growth, national patent applications are positive, because they secure domestic companies the exclusive use of the protected technologies and therefore international competitiveness.

The impact of national investments into OSS measured by the commits of the users, which can be attributed to a country, is significantly negative for national economic growth, which is similar to the effect of national spending on R&D. This can be explained by the fact that this investment produces costs mainly for the companies employing the software developers producing this code. And these development costs are not immediately compensated by an increase of productivity or international competitiveness, because every other country has a free access to this OSS code. However, the public good character of OSS code is confirmed by the significantly positive impact of the contributions to OSS, i.e. GitHub, by the rest of the world. The national growth is, therefore, significantly benefitting from the global investment into OSS. It has to be pointed out that this is different to global investment into R&D, which is hampering national growth, because here the results are not public and freely available due to secrecy measures or they are protected by intellectual property rights, like patents and other rights. Therefore, OSS measured by the code contributed to GitHub represents a pool of knowledge, which is accessible and usable by all companies and individuals worldwide, and is therefore a public good in its purest form. Consequently, it is an engine for economic growth like the knowledge pool introduced by Romer (1990) in his endogenous growth theory or the role of standardisation as driver for the diffusion of innovation by Acemoglu et al. (2012).

If theanalysis is just restricted to the EU Member States within this time period, the results are not changing. The positive role of OSS contributed by the rest of the world as well as the negative impact of the country-specific contributions for the growth of the EU Member States are almost identical to the results of the panel including all countries. If it is focused on the OSS produced by the EU Member States, the impact is only slightly smaller, i.e. the EU Member States benefit from the OSS contributions from the other EU members even not considering the massive contributions from the USA. Therefore, a final model is calculated for the EU Member states assuming that there is no significant difference between the impact of national contributions to OSS and contributions from other EU Member States. Consequently, a significant impact of the contributions of EU Member States on their national GDP was found. The elasticity of 0.04 means that a 10% increase of commits as from 2017 to 2018 contributed to GitHub is contributing 0.4% of GDP in the EU. This share is slightly higher than the increase by 0.1% reported by Ghosh (2006) based on a simulation model. They argued that back in 2006 this increase of output of 0.1% is equal to a bit more than €10 billion per year. In 2018, 0.4% of the total GDP of almost €16 trillion or exactly €15,900 billion in the EU according to Eurostat is a contribution of more than €63 billion per year. For comparison, the application of the Cobb-Douglas production function by Jungmittag et al. (1999) to assess the economic impact of standardisation revealed around €17 billion per year for the German economy, which has been validated by several follow-up studies in other EU Member States and countries outside Europe (European Commission 2016). Since the economic impact mechanisms of standardisation, i.e. the network effects (e.g. on the theoretical economic effect Weitzel 2004), are similar to those of OSS, but more focused on hardware and less on software, the quantitative economic impacts are comparable considering that Germany is responsible for around one third of GDP in the EU. Consequently, the findings of the application of the Cobb-Douglas function for assessing the economic impacts of standards in several EU Member States are interpreted as validation for the use of the same approach for estimating the economic impact of OSS for the EU.

Whereas the absolute number of commits are used in our basic regression, an alternative approach is also performed relying on the number of GitHub users or contributors per country and year. This indicator can be interpreted as the number of employees involved in the development of OSS, which are in their majority paid for by their companies (Geiger

2017; Nagle et al. 2020), irrespective of the share of their working time, they spend on contributing OSS code to GitHub (see also Lakka et al. 2015).

The results of this alternative approach to measure OSS development and use according to the concepts of user innovations or co-production are in general similar to the presented results based on GitHub commits. The elasticity of contributors to OSS is with 0.06 slightly higher than those of additional commits. However, this makes sense, since the number of commits can and has been increasing much stronger than the number of contributors. However, a 10% increase in the number of contributors would increase GDP growth by 0.6%, which would even represent a GDP increase of €95 billion per year.

Table 5.3: Impact of OSS Contributors on GDP (DOLS)

	(1) All	(2) EU (Var1)	(3) EU (Var2)	(4) EU (Var3)	(5) Other
Log capital stock	0.61387***	0.55873***	0.56022***	0.55052***	0.56485***
	(12.16)	(10.14)	(10.01)	(9.99)	(13.77)
Log employment	0.23417*	0.04696	0.04747	0.08222	0.21776
	(1.83)	(0.39)	(0.39)	(0.67)	(1.30)
Log payments for use of IP	0.04293***	0.05074***	0.05023***	0.05108***	0.06139***
	(3.47)	(4.33)	(4.26)	(4.29)	(4.19)
L.Log R&D expenditures	-0.08478**	-0.07736**	-0.08109**	-0.08630**	-0.06735
	(-2.35)	(-2.27)	(-2.38)	(-2.54)	(-1.45)
L.log R&D expenditures by ROW	-1.59074***	-1.32761***	-1.46516***	-1.53061***	-0.70856***
	(-5.26)	(-4.28)	(-4.80)	(-4.96)	(-3.11)
Log transnational patent applications	0.05540***	0.03544***	0.03651***	0.02662***	0.12108***
	(15.34)	(9.84)	(10.15)	(7.32)	(42.58)
Log GitHub contributors	0.02125	-0.02463	-0.02429		-0.00537
	(1.49)	(-1.53)	(-1.56)		(-0.52)
Log GitHub contributors by ROW	0.03897**	0.07809***			0.02637*
	(2.07)	(3.81)			(1.90)
Log GitHub contributors EU (excl. focal)			0.08542***		
			(4.20)		
Log GitHub contributors EU				0.06438***	
				(5.19)	
Country dummies	Yes	Yes	Yes	Yes	Yes
Observations	480	375	375	375	105
R^2	0.901	0.867	0.868	0.864	0.993
N_g	32	25	25	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In summary, national GDP and, therefore, also economic growth is significantly benefiting from the global pool of OSS code irrespective whether the number of commits or the number as users are used as indicators. If the contributions from the EU Member States are considered as one knowledge pool, elasticities of 0.04 for commits and 0.06 for contributors are found. If both of them can only be marginally increased in the future, the GDP of the EU including the UK will increase significantly even above €100 billion per year.

Impact of OSS on Productivity

The data and the findings of this basic regression allow us also to calculate the contribution of OSS to Labour Productivity (LP), e.g. as performed in Menon et al. (2018) for the Nordic countries on the impacts of standards. Consequently, the model is re-written in terms of labor productivity, i.e. Eq. (4) is divided by the labour force. The same model is used as before. However, since the productivity measures are stationary, the non-stationary variables have been differenced until the differenced versions become stationary, too, and then apply fixed-effects.

The results of the panel regression to explain the change of labor productivity in Table 5.4 reveal on the one hand the positive impact of the capital stock and on the other hand the negative influence of employment, which is the expected result. In addition, the established drivers of technological progress are positive drivers of labor productivity, i.e. payments for foreign IP and own R&D expenditures, but not the R&D expenditures by the rest of the world and the national patent applications. The number of national commits to GitHub is not a significant positive driver for labour productivity, but the commits by the rest of the world.

Table 5.4: Impact of OSS Commits on Labour Productivity (FE)

	(1) All	(2) EU	(3) Other
Log capital stock	0.84764***	0.87350***	0.74137***
	(19.32)	(15.79)	(9.58)
Log employment	-0.59355***	-0.68790***	0.00406
	(-4.05)	(-4.17)	(0.01)
Log payments for use of IP	0.14289***	0.14077***	0.14174***
	(8.49)	(7.51)	(3.03)
LD.Log R&D expenditures	0.15425**	0.18300**	-0.17651
	(2.00)	(2.24)	(-0.60)
LD.log R&D expenditures by ROW	0.22617	0.39193	-0.20053
	(0.56)	(0.84)	(-0.26)
D2.Log transnational patent applications	-0.00097	0.00384	-0.01646
	(-0.12)	(0.42)	(-0.89)
D.Log GitHub commits	0.01243	0.01320	-0.01706
	(1.37)	(1.38)	(-0.51)
D.Log #GitHub commits by ROW	0.13788***	0.09576**	0.31062***
	(3.96)	(2.40)	(3.97)
Constant	-20.26254***	-19.29215***	-28.16814***
	(-8.16)	(-6.66)	(-4.69)
Observations	576	457	119
R^2	0.755	0.732	0.847
N_g	34	27	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

As in the growth model, another approach with the number of active GitHub users or contributors is performed. Here, some differences are found for the other indicators representing technological progress. Both the R&D expenditures of the rest of the world and the national patent applications turn out to be significantly negative for the development of labour productivity. Turning to the number of GitHub users, it is found that the national users, like the national commits, have no significant influence. However, the number of contributors to OSS from the rest of the world is positive for the own labour productivity, which supports the public good characteristics of this free accessible knowledge pool.

Table 5.5: Impact of OSS Contributors on Labour Productivity (FE)

	(1) All	(2) EU	(3) Other
Log capital stock	0.85578***	0.86207***	0.76241***
	(21.43)	(17.36)	(10.02)
Log employment	-0.56605***	-0.69772***	0.19300
	(-4.22)	(-4.63)	(0.57)
Log payments for use of IP	0.12280***	0.12360***	0.12355***
	(7.95)	(7.19)	(2.78)
LD.Log R&D expenditures	0.12505*	0.14030*	-0.18413
	(1.77)	(1.88)	(-0.66)
LD.log R&D expenditures by ROW	-1.19720***	-1.25926***	-0.80798
	(-3.24)	(-2.95)	(-1.12)
D2.Log transnational patent applications	-0.03401***	-0.03202***	-0.03647**
	(-4.33)	(-3.66)	(-2.00)
D.Log GitHub contributors	0.00273	-0.01170	0.06877
	(0.10)	(-0.36)	(1.09)
D.Log GitHub contributors by ROW	0.33366***	0.34031***	0.28621***
	(7.90)	(7.19)	(2.89)
Constant	-20.55911***	-18.55091***	-31.67473***
	(-9.12)	(-7.08)	(-5.61)
Observations	576	457	119
R^2	0.795	0.777	0.868
N_g	34	27	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

National labour productivity is in general benefitting from the global pool of OSS code, which is confirming the studies performed on the microlevel of companies (Nagle 2019b). However, the national contributions to GitHub based on the number of commits as well as the number of national contributors are not significantly positive. Since the contributors are in general employees of companies, the positive productivity effect is at least partly compensated by the effect that with an increasing number of employees, labour productivity is reduced.[14]

Impact of OSS on export and trade in value-added

In addition to the impacts of OSS on growth, the even more relevant is its influence on international competitiveness and consequently trade. Assuming that standards are similar to OSS (Blind and Böhm 2019), Swann (2010) provided a comprehensive overview on existing studies on standards and trade, which have meanwhile grown in numbers and complexity (e.g. Blind et al. 2018).

Our baseline estimation model to identify the impact of OSS code is defined as follows. The dependent variable X takes on the values of gross exports (EXGR) and trade in value-added (TiVA) subtracting imports on the country level. A model of the natural logarithms of the trade flows from country i to the rest of the world at time t is estimated explained by the OSS contributions and controlling for several factors:

$$EXGR_{it} = a \quad + \lambda_1 logGDP_{it} \quad + \lambda_2 logavdis_i + \lambda_3 logavcontig_i + \lambda_4 logavconlang_i + \lambda_5 logRD_{it-1} + \lambda_6 logRD_{it-1}^{ROW} + \lambda_7 logPAT_{it} + \lambda_8 logOSS_{it-1} + \lambda_9 logOSS_{it-1}^{ROW} + u_{it} \qquad (5a)$$

$$TiVa_{it} = a \quad + \lambda_1 logGDP_{it} \quad + \lambda_2 logavdis_i + \lambda_3 logavcontig_i + \lambda_4 logavconlang_i + \lambda_5 logRD_{it-1} + \lambda_6 logRD_{it-1}^{ROW} + \lambda_7 logPAT_{it} + \lambda_8 logOSS_{it-1} + \lambda_9 logOSS_{it-1}^{ROW} + u_{it} \qquad (5b)$$

Our analysis covers again the period between 2000 to 2018. As in traditional trade models the trade flows are controled for the GDPs of the exporting country. Furthermore, a country-specific measure of the average distance between producers and consumers in a country (Head and Mayer, 2002), the number of contiguous countries and number of countries, that share a common (official) language, e.g. for Germany the number of countries with German as official language, are used.

The influence of the competitiveness related to variable R&D expenditures is as expected positive, but not significant, for the national level, whereas the expenditures by the rest of the world are significantly negative. The national patent applications as a second indicator for domestic competitiveness are significantly positive.

Even by controlling for R&D the national contributions of commits to GitHub are significantly positive, whereas the contributions by the rest of the world are negative. The productivity enhancing impact of contributing to OSS, as shown above is also strengthening the national competitiveness. The results are robust irrespective whether gross exports as depending variable or Trade in Value added (TiVa), which takes the imports into account, are used. In summary, national contributions to OSS are, like spending on R&D or filing patents, strengthening the competitiveness of the national economy in global markets. The commits by the rest of the world are also positive in the export, but not in the TiVa model.

[14] The impact of OSS on Total Factor Productivity and Multifactor Productivity has also been tested. However, ignificant and convincing results are not found, which is also caused by a smaller sample of countries used. The results are displayed in the Annex.

Table 5.6: Impact of OSS Commits on Exports (DOLS)

	(1) All	(2) EU	(3) Other
Log GDP	0.89258***	1.28299***	0.95771***
	(11.40)	(16.29)	(5.20)
Log distance	-0.43260	-1.45504	-0.08552
	(.)	(.)	(.)
Log contiguity	0.36917	0.59427	0.27270
	(.)	(.)	(.)
Log common languages	0.27181	0.25060	0.15986
	(.)	(.)	(.)
L.Log R&D expenditures	0.07078	0.04936	0.49450**
	(1.23)	(0.97)	(2.57)
L.log R&D expenditures by ROW	-1.82695***	-2.29031***	-0.88684*
	(-7.12)	(-9.39)	(-1.96)
Log transnational patent applications	0.05398***	0.09489***	-0.09972***
	(8.14)	(15.39)	(-7.88)
L.Log GitHub commits	0.04130***	0.04601***	-0.07191**
	(4.86)	(6.29)	(-2.35)
L.Log GitHub commits by ROW	0.05021***	0.04754***	0.10988***
	(3.75)	(3.91)	(3.10)
Country dummies	Yes	Yes	Yes
Observations	480	375	105
R^2	0.859	0.891	0.904
N_g	32	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.7: Impact of OSS Commits on TiVa (DOLS)

	(1) All	(2) EU	(3) Other
Log GDP	0.92513***	1.23027***	1.09098***
	(12.84)	(17.43)	(5.33)
Log distance	-0.29129	-1.08227	-0.15148
	(.)	(.)	(.)
Log contiguity	0.27694	0.33419	0.22362
	(.)	(.)	(.)
Log common languages	0.23291	0.14694	0.19498
	(.)	(.)	(.)
L.Log R&D expenditures	0.09639*	0.08186*	0.46195**
	(1.82)	(1.80)	(2.16)
L.log R&D expenditures by ROW	-1.03206***	-1.25704***	-0.63215
	(-4.37)	(-5.75)	(-1.26)
Log transnational patent applications	0.06896***	0.10811***	-0.10877***
	(11.31)	(19.57)	(-7.73)
L.Log GitHub commits	0.03602***	0.04050***	-0.05796*
	(4.60)	(6.17)	(-1.70)
L.Log GitHub commits by ROW	0.02035*	0.01148	0.08491**
	(1.65)	(1.05)	(2.15)
Country dummies	Yes	Yes	Yes
Observations	480	375	105
R^2	0.867	0.897	0.889
N_g	32	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Looking at the results based on the number of contributors to GitHub, the significant positive influence of national contributors disappears in the model based on all countries, but is confirmed for the subsample of EU Member States in the TiVa model. In addition, the number of contributors by the rest of the world also remains significantly positive.

Table 5.8: Impact of OSS Contributors on Exports (DOLS)

	(1) All	(2) EU	(3) Other
Log GDP	0.79159***	1.13724***	1.04060***
	(10.40)	(13.90)	(5.53)
Log distance	-0.31871	-1.30024	-0.15195
	(.)	(.)	(.)
Log contiguity	0.33386	0.23996	0.25048
	(.)	(.)	(.)
Log common languages	0.25799	0.04549	0.14711
	(.)	(.)	(.)
L.Log R&D expenditures	-0.00462	-0.04268	0.42477**
	(-0.08)	(-0.80)	(1.97)
L.log R&D expenditures by ROW	-4.55315***	-4.72808***	-2.88397***
	(-13.05)	(-13.92)	(-4.20)
Log transnational patent applications	0.12809***	0.13497***	-0.20064***
	(18.57)	(20.33)	(-13.93)
L.Log GitHub contributors	-0.03757	0.04441	0.03105
	(-1.55)	(1.64)	(0.78)
L.Log GitHub contributors by ROW	0.23055***	0.15493***	0.07741
	(7.90)	(4.89)	(1.52)
Country dummies	Yes	Yes	Yes
Observations	480	375	105
R^2	0.850	0.873	0.893
N_g	32	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The influence of OSS on international competitiveness reveals a consistent picture for the members of the EU, i.e. in general a competitiveness enhancing impact of national commits or contributions to OSS. In addition, the contributions by the rest of the world are also in general a positive driver for trade. Overall, OSS is obviously not only a positive driver for growth, but also for trade.

Table 5.9: Impact of OSS Contributors on TiVa (DOLS)

	(1) All	(2) EU	(3) Other
Log GDP	0.82653***	1.12332***	1.14700***
	(11.80)	(15.69)	(5.63)
Log distance	-0.19080	-0.99687	-0.20374
	(.)	(.)	(.)
Log contiguity	0.25024	0.09829	0.20751
	(.)	(.)	(.)
Log common languages	0.20505	0.00278	0.15582
	(.)	(.)	(.)
L.Log R&D expenditures	0.03709	0.00569	0.45764*
	(0.69)	(0.12)	(1.95)
L.log R&D expenditures by ROW	-2.90687***	-2.88172***	-1.74452**
	(-9.05)	(-9.70)	(-2.34)
Log transnational patent applications	0.11671***	0.12923***	-0.23936***
	(18.38)	(22.25)	(-15.33)
L.Log GitHub contributors	-0.00614	0.06604***	0.06792
	(-0.27)	(2.78)	(1.57)
L.Log GitHub contributors by ROW	0.13964***	0.06690**	0.00074
	(5.20)	(2.41)	(0.01)
Country dummies	Yes	Yes	Yes
Observations	480	375	105
R^2	0.857	0.884	0.885
N_g	32	25	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Impact of OSS on Economic Complexity and Technological Independence

For addressing the question whether OSS contributes to the technological independence of the EU and its Member States, two indicators are used, i.e. the Economic Complexity Index and the payments for intellectual property.

The Economic Complexity Index (ECI) ranks how diversified and complex a country's export basket is. Therefore, it can be used as an indicator of independence, because the higher this indicator is, the more diversified and less dependent on specific products is a country's export portfolio (e.g. Sweet and Eterovic 2019).

Again, the same model as in Eq. (4), which is estimated using fixed-effects, is applied.

At first, it has to be mentioned that the explanatory power of the panel regressions explaining economic complexity is lower than for the growth and productivity models, which is an indication that it is influenced also by other factors. Furthermore, the ECI of the considered countries is overall little influenced by domestic R&D activities, but also national commits. However, national patent applications have a significant influence on the development of countries' economic complexity. In addition, the import of technological know-how measured by the payment for the use of intellectual property is significantly improving the variety and complexity of countries' product portfolio. However, the increased contributions to GitHub by the rest of the world hamper countries' development of their economic complexity. The freely accessible pool of OSS code reduces countries' development of economic complexity. This negative impact of the pool of OSS code has to be interpreted. Despite the openness of the code hosted at GitHub, the indicator represents the competitiveness of foreign software developers, because the OSS code might be linked to proprietary code.

The model just based on the EU Member States confirms the results based on all countries. In contrast, the model with China, South Korea, Japan and the United States, the payment for intellectual property does not play a significant role, which can be explained by their large patent portfolios, but also strong software companies. Complementary, their domestic R&D expenditures push their economic complexity. However, they also experience a negative impact of the OSS code contributed to GitHub.

Table 5.10: Impact of OSS Commits on Economic Complexity Index (FE)

	(1) All	(2) EU	(3) Other
Log payments for use of IP	0.02892**	0.03046**	0.01421
	(2.15)	(2.20)	(0.42)
LD.Log R&D expenditures	0.05192	-0.03526	0.68485*
	(0.64)	(-0.45)	(1.86)
LD.log R&D expenditures by ROW	0.79070*	1.41390***	-1.39768
	(1.83)	(3.12)	(-1.43)
D2.Log transnational patent applications	0.02098**	0.02330***	0.00506
	(2.40)	(2.62)	(0.22)
D.Log GitHub commits	0.00781	0.01050	-0.05595
	(0.81)	(1.14)	(-1.12)
D.Log #GitHub commits by ROW	-0.21893***	-0.16432***	-0.36792***
	(-5.96)	(-4.34)	(-3.58)
Constant	0.61564**	0.54446*	1.09577
	(2.20)	(1.93)	(1.43)
Observations	526	424	102
R^2	0.075	0.050	0.437
N_g	31	25	6

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The models using the number of GitHub users instead of the commits reveals also a positive effect of the number of national contributors to GitHub, which would have been expected. Overall, the explanatory power of these models is limited.

Table 5.11: Impact of OSS Contributors on Economic Complexity Index (FE)

	(1) All	(2) EU	(3) Other
Log payments for use of IP	0.01006	0.00901	0.01215
	(0.76)	(0.66)	(0.41)
LD.Log R&D expenditures	0.03842	-0.05361	0.56029
	(0.47)	(-0.68)	(1.61)
LD.log R&D expenditures by ROW	0.31390	0.70488	-0.72891
	(0.71)	(1.52)	(-0.78)
D2.Log transnational patent applications	0.01578*	0.01238	0.02991
	(1.67)	(1.30)	(1.27)
D.Log GitHub contributors	0.06472*	0.10190***	-0.02192
	(1.87)	(2.86)	(-0.28)
D.Log GitHub contributors by ROW	-0.19755***	-0.14634***	-0.46476***
	(-3.85)	(-2.79)	(-3.84)
Constant	0.99424***	0.95866***	1.17035*
	(3.59)	(3.42)	(1.74)
Observations	526	424	102
R^2	0.040	0.027	0.494
N_g	31	25	6

t statistics in parentheses
** p < 0.10, ** p < 0.05, *** p < 0.01*

To analyse the impact of OSS on technological dependency further, the payments for the use of intellectual property, which are dominated by payments for software licences, are taken as a further dependent variable. In detail, it is tested whether the contributions to OSS by the Member States is going to reduce their payments for the use of foreign intellectual property rights, i.e. mainly payments for proprietary software.

$$logLic_{it} = a \quad + \lambda_1 logRD_{it-1} + \lambda_2 logRD_{it-1}^{ROW} + \lambda_3 logPAT_{it} + \lambda_4 logit + employment_{it} + \lambda_5 logOSS_{it-1} + \lambda_6 logOSS_{it-1}^{ROW} + u_{it} \qquad (6)$$

The explanatory power of the panel regressions to explain countries' payments for foreign intellectual property is much higher than for the regressions explaining economic complexity. In particular, it is found that the national patent applications reduce the foreign payments for intellectual property. For the latter, the employment in IT is a further factor, which is reducing their payments for intellectual property, i.e. increasing the domestic employment in the IT sector reduces the dependency on foreign intellectual property. For these countries, the R&D expenditures of the rest of the world are also reducing their payments for intellectual property. This is a counterintuitive result, because these expenditures should create intellectual property, for which they might have to pay for. However, the results of R&D might have not been adequately protected or these countries are investing in R&D in foreign countries reducing their payments for intellectual property.

Table 5.12: Impact of OSS Commits on payments for intellectual property (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.12984	-0.15104	0.77777
	(-0.44)	(-0.48)	(0.73)
LD.log R&D expenditures by ROW	-2.84631*	-2.40052	-5.52321**
	(-1.91)	(-1.40)	(-2.29)
D2.Log transnational patent applications	-0.20138***	-0.19293***	-0.26470***
	(-6.42)	(-5.49)	(-4.59)
Log IT-employment	0.64621***	0.69173***	-6.93500***
	(3.56)	(3.61)	(-3.62)
LD.Log GitHub commits	0.06321*	0.06338	0.04355
	(1.72)	(1.64)	(0.22)
LD.Log GitHub commits by ROW	0.82178***	0.81308***	0.81374***
	(6.46)	(5.66)	(3.06)
Constant	19.92397***	19.58012***	29.73158***
	(110.01)	(103.85)	(14.42)
Observations	558	473	85
R^2	0.161	0.157	0.353
N_g	33	28	5

t statistics in parentheses
** p < 0.10, ** p < 0.05, *** p < 0.01*

Whereas the national contributions of commits to GitHub have only a significant influence on the payments for intellectual property for the panel of all countries, the contributions by the rest of the world to OSS increase the payments. Since using the code provided to GitHub is in general not connected to licensing payments, the positive impact of the contributions by the rest of the world might be an indication of a. complementary relationship between OSS code and proprietary software or even hard. This means that those contributing to OSS code might have an business model, which connects OSS code with proprietary code, for which licensing fees are asked for. This result does consequently not support a substitutive relationship between OSS code and proprietary software code, but a complementary relation. The results of the models based on the number of OSS contributors are identical, which confirms the validity of our approach,

Regarding the economic complexity of countries, i.e. the diversity and complexity of their export portfolio, it is found results similar to the regressions for Trade in Value added and exports, i.e. national contributions to GitHub increase, whereas the contributions by the rest of world reduce economic complexity. This shows the consistency and validity of our approach. The payments for intellectual property are positively influenced by contributions to OSS by the rest of the world.

Table 5.13: Impact of OSS Contributors on payments for intellectual property (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.33520	-0.38368	1.16352
	(-1.29)	(-1.38)	(1.39)
LD.log R&D expenditures by ROW	-11.24660***	-11.04232***	-12.38116***
	(-7.73)	(-6.57)	(-5.80)
D2.Log transnational patent applications	-0.25445***	-0.24805***	-0.30697***
	(-9.46)	(-8.19)	(-6.92)
Log IT-employment	0.48315***	0.51782***	-6.23467***
	(3.05)	(3.09)	(-4.14)
LD.Log GitHub contributors	0.20095*	0.19468	0.25605
	(1.76)	(1.58)	(0.77)
LD.Log GitHub contributors by ROW	1.39937***	1.43290***	1.13434***
	(8.87)	(8.14)	(3.24)
Constant	19.91418***	19.56635***	28.86573***
	(126.57)	(119.05)	(17.84)
Observations	558	473	85
R^2	0.365	0.356	0.603
N_g	33	28	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Impact of OSS on innovation

Following Blind (2012), analysing the impact of regulation on innovation, and Blind and Münch (2019) focusing on the impact of standards on innovation as important drivers for growth and competitiveness, a similar approach to assess the impacts of OSS on innovation is applied. Regarding innovation, various measures are relied on. First, for the EU Member States the share of innovators is used, but also differentiated into product and process innovators based on data collected within the European Community Innovation Survey. Secondly, patents on computer-implemented inventions (CII) at the European Patent Office (Neuhäusler and Frietsch 2019) are taken, but also European trademark applications (trademark) in total and differentiated in the subcategory telecommunication services and scientific and technological services and research. A fixed-effect model is estimated covering the time period between 2000 and 2018 of the natural logarithms of the innovation variable in country i at time t explained by the OSS indicators controlling for several baseline variables:

$$inno_{it} = a + \lambda_1 logimp_{it} + \lambda_2 logexp_{it} + \lambda_3 logedu_{it} + \lambda_4 logGDP_{it} + \lambda_5 logRD_{it-1} + \lambda_6 logRD_{it-1}^{ROW} + \lambda_7 logPAT_{it} + \lambda_8 logOSS_{it-1} + \lambda_9 logOSS_{it-1}^{ROW} + fe + u_{it} \quad (7)$$

where the innovation variable by overall innovators, product and process innovators is differentiated. The regressions are run only for EU Member States, because the innovator variables stem from Community Innovation Survey and are not generally available for other countries.

In general, the explanatory power of the panel regressions on the number of innovators is not very high. However, the differentiation into the number of product and process innovators increases their explanatory power. In the first model explaining the number of innovators in general, only the R&D expenditures by the rest of the world is slightly positive, whereas the contributions to GitHub by the rest of the world has a significant negative influence, whereas the national contributions have the expected positive influence, which is not significant.

Looking at the number of product innovators, the export share of GDP is a positive driver as well as the transnational patent stock by the rest of the world, but also the share of the population with tertiary education. Whereas the impact of national commits to GitHub have no significant influence on the share of innovators, the commits by the rest of the world have a significant positive influence on the number of product innovators. In contrast, the commits to GitHub by the rest of the world have a negative influence on the share of process innovators in the EU Member States.

Table 5.14: Impact of OSS Commits on the share of innovators in EU Member States (FE)

	(1) Innovators	(2) Product innovators	(3) Process innovators
D.Log GDP	0.12452	-0.12476	0.26856
	(0.51)	(-0.24)	(0.72)
D.Log imports share GDP	-0.02755	-0.27417	-0.36410
	(-0.17)	(-0.82)	(-1.52)
D.Log export share GDP	0.14578	0.65716**	0.23833
	(0.93)	(1.97)	(1.00)
LD.Log R&D expenditures	0.08961	0.06624	0.16862
	(1.21)	(0.42)	(1.50)
LD.log R&D expenditures by ROW	0.86314*	-1.00083	-0.63379
	(1.92)	(-1.05)	(-0.93)
D2.Log transnational patent applications	0.01216	-0.00919	0.00437
	(1.40)	(-0.50)	(0.33)
Log share population with tertiary education	-0.04434	0.37402***	-0.07670
	(-1.26)	(5.02)	(-1.44)
LD.Log GitHub commits	0.00409	0.01279	0.00214
	(0.45)	(0.67)	(0.16)
LD.Log #GitHub commits by ROW	-0.08871**	0.13787*	-0.26339***
	(-2.45)	(1.79)	(-4.80)
Constant	-0.64291***	-3.91831***	-2.07311***
	(-6.09)	(-17.45)	(-12.96)
Observations	473	473	473
R^2	0.043	0.128	0.099
N_g	28	28	28

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The explanatory power of the models on the share of innovators using the number of contributors instead of the number of commits is also rather limited. In particular, the total number of innovators is not explained by any of the variables included in the regression model. However, the share of product innovators is driven by the export share of GDP, which is in line both with theory and other empirical investigations. Finally, the amount of national GitHub contributors is significantly driving the number of product innovators, whereas the contributors from the rest of the world have only an insignificant negative impact. In contrast, both the number of national contributors and global contributors have a significant negative impact on the share of process innovators. There seems to be a substitutive relationship between OSS contributors and the likelihood of companies being process innovators, i.e. the more countries invest in OSS, the less they are successful process innovators.

Table 5.15: Impact of OSS Contributors on the share of innovators in EU Member States (FE)

	(1) Innovators	(2) Product innovators	(3) Process innovators
D.Log GDP	0.13170	-0.07043	0.09268
	(0.52)	(-0.13)	(0.24)
D.Log imports share GDP	-0.04081	-0.24021	-0.40046*
	(-0.26)	(-0.72)	(-1.67)
D.Log export share GDP	0.15739	0.59807*	0.31272
	(0.99)	(1.79)	(1.30)
LD.Log R&D expenditures	0.09173	0.03883	0.20319*
	(1.23)	(0.25)	(1.80)
LD.log R&D expenditures by ROW	0.86359*	-1.28932	0.11998
	(1.70)	(-1.20)	(0.16)
D2.Log transnational patent applications	0.00743	-0.00641	0.00199
	(0.84)	(-0.34)	(0.15)
Log share population with tertiary education	-0.05435	0.35449***	-0.05536
	(-1.46)	(4.52)	(-0.98)
LD.Log GitHub contributors	-0.02416	0.16431**	-0.08354*
	(-0.73)	(2.35)	(-1.67)
LD.Log GitHub contributors by ROW	-0.01616	-0.04700	-0.15404**
	(-0.32)	(-0.44)	(-2.03)
Constant	-0.63212***	-3.83426***	-2.16067***
	(-5.69)	(-16.39)	(-12.85)
Observations	473	473	473
R^2	0.034	0.135	0.091
N_g	28	28	28

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Neuhäusler and Frietsch (2019) have developed a methodology to identify patents on computer-implemented inventions (CII), which represent a significant share of the patent applications in the EU Member States despite the exclusion of pure software patents from being patentable in Europe. In comparison to the low explanatory power of the regression models related to the number of innovators, the approaches to explain patents on CII reveal several significant explanatory factors. Whereas the R&D expenditures by the rest of the world has - as expected - a negative influence on the patents on CII, the national patent applications have a positive impact. In addition, the share of the population with tertiary education is a positive driver. Finally, the national contributions of commits to GitHub are although positive not significant, whereas the contributions by the rest of the world have a significant positive influence on the development of the patents on CII. These results are also robust for the subsample of EU Member States and even the small subsample of Non-EU Member States.

Table 5.16: Impact of OSS Commits on patents on computer-implemented inventions (FE)

	(1) All	(2) EU	(3) Non-EU
D.Log GDP	-1.30528*	-0.78896	-8.45950***
	(-1.67)	(-0.96)	(-2.82)
D.Log imports share GDP	0.12086	-0.02518	0.16674
	(0.26)	(-0.05)	(0.18)
D.Log export share GDP	-0.13606	-0.12933	0.65232
	(-0.30)	(-0.25)	(0.70)
LD.Log R&D expenditures	0.16386	0.26631	-2.23063*
	(0.66)	(1.07)	(-1.79)
LD.log R&D expenditures by ROW	-4.41515***	-4.58161***	-3.81957
	(-3.31)	(-3.03)	(-1.35)
D2.Log transnational patent applications	0.66074***	0.63728***	0.80108***
	(24.19)	(21.74)	(11.02)
Log share population with tertiary education	0.87040***	0.87915***	0.78463
	(7.45)	(7.45)	(1.37)
LD.Log GitHub commits	-0.00303	-0.00288	0.01099
	(-0.10)	(-0.09)	(0.09)
LD.Log #GitHub commits by ROW	0.56942***	0.55606***	0.52559*
	(5.11)	(4.57)	(1.91)
Constant	2.28967***	1.66208***	5.21177***
	(6.37)	(4.68)	(2.72)
Observations	592	473	119
R^2	0.635	0.640	0.670
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results with the number of active OSS contributors to GitHub are very similar to the approach based on the commits, which confirms the robustness of the approach. In the model based on all countries, even the number of national contributors to OSS has a positive influence on the development of patents on CII as an innovation indicator of the IT sector. The positive influence of the number of national contributors disappears in the model for the EU Member States, whereas it is even stronger for the other countries. Overall, a positive influence of OSS on innovations in the IT sector, if relied on patents on CII as an indicator, is observed.

Table 5.17: Impact of OSS Contributors on patents on computer-implemented inventions (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-0.14646	0.21166	-6.12006**
	(-0.19)	(0.26)	(-2.27)
D.Log imports share GDP	0.10274	0.02569	0.01840
	(0.23)	(0.05)	(0.02)
D.Log export share GDP	-0.37171	-0.38031	0.30540
	(-0.84)	(-0.74)	(0.37)
LD.Log R&D expenditures	0.03121	0.12755	-1.81514
	(0.13)	(0.52)	(-1.63)
LD.log R&D expenditures by ROW	-8.87903***	-8.46794***	-10.69638***
	(-6.09)	(-5.11)	(-3.54)
D2.Log transnational patent applications	0.62345***	0.60639***	0.74015***
	(23.45)	(20.96)	(11.34)
Log share population with tertiary education	0.63730***	0.69560***	0.26453
	(5.39)	(5.72)	(0.50)
LD.Log GitHub contributors	0.22091**	0.07135	0.78121***
	(2.26)	(0.66)	(3.58)
LD.Log GitHub contributors by ROW	0.68161***	0.77322***	0.19632
	(4.60)	(4.72)	(0.59)
Constant	2.92623***	2.14634***	6.80260***
	(8.11)	(5.92)	(3.83)
Observations	592	473	119
R^2	0.660	0.658	0.737
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Another option to measure innovation, in particular in the service sector (Schmoch and Gauch 2009), is to rely on the registrations of European trademarks at the EUIPO. Since there is no specific subcategory for software, both the total number of annual registrations and the subclass 38 Telecommunications services and the subclass 42 Scientific and technological services and research, which includes design and development of computer hardware and software, are taken. In order to be consistent, the same control variables are used as in the models explaining the patent applications on computer-implemented inventions.

Overall, no significant positive influence of commits to GitHub in the model based on all trademark registrations, but also in the model based on trademarks in telecommunications and on trademarks in scientific and technological services and research at least for the EU Member States, is found.

However, the models based on the number of contributors to GitHub instead on the number of commits, both for the overall registrations and for the two subclasses the following pattern is found. The number of national contributors and of contributors by the rest of the world have a significant positive influence on trademarks as innovation indicators. This result is confirmed for the total number of trademarks based on the subsample of EU Member States. For the subclasses, only the number of contributors from the rest of the world remains significantly positive.

Table 5.18: Impact of OSS Commits on trademarks (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-4.27692***	-3.79796***	-13.66455***
	(-4.14)	(-3.35)	(-4.10)
D.Log imports share GDP	0.55559	0.82566	-0.69713
	(0.92)	(1.13)	(-0.68)
D.Log export share GDP	-0.01159	-0.14353	1.09754
	(-0.02)	(-0.20)	(1.06)
LD.Log R&D expenditures	0.17382	0.32659	-2.40057*
	(0.53)	(0.96)	(-1.74)
LD.log R&D expenditures by ROW	-3.68493**	-2.62988	-5.36978*
	(-2.09)	(-1.27)	(-1.71)
D2.Log transnational patent applications	-0.09541***	-0.06605	-0.19174**
	(-2.64)	(-1.64)	(-2.37)
Log share population with tertiary education	2.39788***	2.44500***	2.28804***
	(15.54)	(15.11)	(3.59)
LD.Log GitHub commits	0.05031	0.06427	-0.16109
	(1.27)	(1.54)	(-1.17)
LD.Log #GitHub commits by ROW	0.17893	0.10233	0.56300*
	(1.22)	(0.61)	(1.84)
Constant	-1.14386**	-1.28211***	-0.51184
	(-2.41)	(-2.63)	(-0.24)
Observations	592	473	119
R^2	0.428	0.454	0.398
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.19: Impact of OSS Commits on trademarks in telecommunication services

	(1) All	(2) EU	(3) Other
D.Log GDP	-3.77140***	-2.98219***	-14.77799***
	(-3.62)	(-2.69)	(-3.81)
D.Log imports share GDP	0.55343	0.59757	-0.04342
	(0.91)	(0.84)	(-0.04)
D.Log export share GDP	0.01703	-0.03587	1.06289
	(0.03)	(-0.05)	(0.88)
LD.Log R&D expenditures	-0.14590	-0.02406	-2.16407
	(-0.44)	(-0.07)	(-1.35)
LD.log R&D expenditures by ROW	0.53000	1.33433	-0.70471
	(0.30)	(0.66)	(-0.19)
D2.Log transnational patent applications	-0.00805	0.01684	-0.09100
	(-0.22)	(0.43)	(-0.97)
Log share population with tertiary education	2.25700***	2.29534***	2.12545***
	(14.51)	(14.49)	(2.87)
LD.Log GitHub commits	0.01918	0.03804	-0.25262
	(0.48)	(0.93)	(-1.57)
LD.Log #GitHub commits by ROW	0.15831	0.12762	0.41164
	(1.07)	(0.78)	(1.16)
Constant	-3.26610***	-3.31097***	-2.81543
	(-6.82)	(-6.94)	(-1.14)
Observations	592	473	119
R^2	0.365	0.407	0.278
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.20: Impact of OSS Commits on trademarks in scientific and technological services and research

	(1) All	(2) EU	(3) Other
D.Log GDP	-4.05688***	-3.29540***	-13.96328***
	(-3.70)	(-2.72)	(-4.00)
D.Log imports share GDP	0.07998	0.02462	-0.14023
	(0.12)	(0.03)	(-0.13)
D.Log export share GDP	0.29802	0.38972	0.76007
	(0.47)	(0.50)	(0.70)
LD.Log R&D expenditures	-0.32545	-0.20387	-2.22456
	(-0.94)	(-0.56)	(-1.54)
LD.log R&D expenditures by ROW	-3.70338**	-2.46868	-6.83952**
	(-1.98)	(-1.11)	(-2.08)
D2.Log transnational patent applications	-0.11663***	-0.07856*	-0.27733***
	(-3.04)	(-1.83)	(-3.27)
Log share population with tertiary education	2.55537***	2.63431***	1.98441***
	(15.58)	(15.25)	(2.97)
LD.Log GitHub commits	-0.02265	-0.00763	-0.24679*
	(-0.54)	(-0.17)	(-1.71)
LD.Log #GitHub commits by ROW	0.27658*	0.15796	0.88258***
	(1.77)	(0.89)	(2.75)
Constant	-3.41828***	-3.55681***	-1.66426
	(-6.77)	(-6.84)	(-0.75)
Observations	592	473	119
R^2	0.429	0.450	0.414
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.21: Impact of OSS Contributors on trademarks (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-2.39705**	-1.67321	-11.75883***
	(-2.39)	(-1.53)	(-3.68)
D.Log imports share GDP	0.48192	0.83115	-0.64150
	(0.84)	(1.22)	(-0.66)
D.Log export share GDP	-0.37919	-0.62286	0.71238
	(-0.67)	(-0.91)	(0.73)
LD.Log R&D expenditures	-0.04571	0.03526	-2.37697*
	(-0.15)	(0.11)	(-1.81)
LD.log R&D expenditures by ROW	-10.70038***	-10.49952***	-9.16373**
	(-5.67)	(-4.80)	(-2.57)
D2.Log transnational patent applications	-0.19485***	-0.18525***	-0.20291***
	(-5.67)	(-4.85)	(-2.63)
Log share population with tertiary education	1.90863***	1.89564***	2.11117***
	(12.48)	(11.81)	(3.35)
LD.Log GitHub contributors	0.43817***	0.33350**	0.88418***
	(3.46)	(2.34)	(3.43)
LD.Log GitHub contributors by ROW	0.67368***	0.93136***	-0.40334
	(3.52)	(4.31)	(-1.02)
Constant	0.08968	0.02873	0.04075
	(0.19)	(0.06)	(0.02)
Observations	592	473	119
R^2	0.489	0.519	0.457
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.22: Impact of OSS Contributors on trademarks in telecommunication services (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-2.11118**	-1.29114	-11.35527***
	(-2.06)	(-1.18)	(-3.28)
D.Log imports share GDP	0.50202	0.60321	0.09951
	(0.86)	(0.88)	(0.09)
D.Log export share GDP	-0.32705	-0.41262	0.34287
	(-0.56)	(-0.60)	(0.32)
LD.Log R&D expenditures	-0.32883	-0.24870	-2.16257
	(-1.04)	(-0.77)	(-1.51)
LD.log R&D expenditures by ROW	-5.54314***	-4.90300**	-7.05120*
	(-2.88)	(-2.24)	(-1.82)
D2.Log transnational patent applications	-0.09508***	-0.07533**	-0.15080*
	(-2.71)	(-1.97)	(-1.80)
Log share population with tertiary education	1.82292***	1.87099***	1.66548**
	(11.69)	(11.65)	(2.44)
LD.Log GitHub contributors	0.46905***	0.22922	1.45713***
	(3.63)	(1.61)	(5.21)
LD.Log GitHub contributors by ROW	0.47876**	0.78832***	-0.87474**
	(2.45)	(3.64)	(-2.05)
Constant	-2.16915***	-2.30001***	-1.47379
	(-4.56)	(-4.80)	(-0.65)
Observations	592	473	119
R^2	0.420	0.454	0.434
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.23: Impact of OSS Contributors on trademarks in scientific and technological services and research (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-1.86311*	-0.84480	-11.38286***
	(-1.75)	(-0.73)	(-3.56)
D.Log imports share GDP	-0.00975	-0.00744	-0.04064
	(-0.02)	(-0.01)	(-0.04)
D.Log export share GDP	-0.08485	-0.07845	0.22174
	(-0.14)	(-0.11)	(0.23)
LD.Log R&D expenditures	-0.53509	-0.47633	-2.24064*
	(-1.62)	(-1.39)	(-1.70)
LD.log R&D expenditures by ROW	-11.50887***	-11.28082***	-11.71185***
	(-5.73)	(-4.84)	(-3.27)
D2.Log transnational patent applications	-0.22654***	-0.21080***	-0.27746***
	(-6.19)	(-5.18)	(-3.59)
Log share population with tertiary education	2.04006***	2.07025***	1.82553***
	(12.54)	(12.10)	(2.89)
LD.Log GitHub contributors	0.25582*	0.00808	1.29812***
	(1.90)	(0.05)	(5.02)
LD.Log GitHub contributors by ROW	0.98999***	1.38362***	-0.66366*
	(4.86)	(6.00)	(-1.68)
Constant	-2.15410***	-2.26914***	-1.14550
	(-4.34)	(-4.45)	(-0.54)
Observations	592	473	119
R^2	0.489	0.518	0.516
N_g	35	28	7

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The influence of OSS on innovation has been tested by using a number of different indicators. First, some influence on the share of innovators, in particular a positive regarding the share of product innovators and a negative measure on the share of process innovators, can be observed. In addition, the measures based on patents and trademarks are significantly positively influenced by OSS, in particular in the trademark-based models relying on the number of contributors. In particular, the contributions to OSS or GitHub by the rest of the world is pushing the number of patents on computer-implemented inventions, which confirms the complementarity between OSS and proprietary inventions and software being already highlighted in some sources included on the literature review and empirically validated by Lakka et al. (2015). Whereas, trademarks are not influenced by the number of commits contributed to GitHub, it is revealed that trademark registrations as such, but also for telecommunication services and scientific and technological services and research are positively influenced both by the number of national contributors to GitHub and the number of contributors from the rest of the world.

Impact of OSS on start-ups and company population

Following the argument by Nagle (2019a), Wright et al. (2020) and considering the influencing factors identified by the meta analysis by Arin et al. (2015), a similar approach to assess the impacts of OSS on the number of start-ups, which is also an indicator for the improvement of competition by lowering entry barriers, is applied. An increase in the availability of OSS and the number of people who understand OSS well enough to contribute to it may also have an impact on the number of start-ups that are founded in the IT space. Like Nagle (2019a) and Wright et al. (2020), the number of newly founded start-ups is used generated from the Crunchbase database of companies, which includes date of founding as well as industry, but also whether the start-ups refer in their description to OSS. Although Crunchbase covers not all start-ups and focuses on companies based in the USA, it has reasonable coverage throughout Europe and covers all European countries including the EU Member States relatively equally (Nagle 2019a). Therefore, although the number of start-ups in Crunchbase is likely an underestimate of the total number of start-ups in a given country, it is unlikely that this underestimate is greater in one European country than another.

A fixed-effect model is estimated covering the time period between 2000 and 2018 of the number of start-ups in general and OSS-start-ups in particular in country i at time t explained by the OSS indicators controlling for several baseline variables:

$$logstartups_{it} = a_i + \lambda_1 logRD_{it-1} + \lambda_2 logRD^{ROW}_{it-1} + \lambda_3 logitemployment_{it} + \lambda_4 logGDP_{it} + \lambda_5 logedu_{it} + \lambda_6 pop_{it} + \lambda_7 unemploy_{it} + \lambda_8 financial_{it} + \lambda_9 institution_{it} + \lambda_{10} logOSS_{it-1} + \lambda_{11} logOSS^{ROW}_{it-1} + fe + u_{it} \quad (8)$$

$$logOSS - startups_{it} = a_i + \lambda_1 logRD_{it-1} + \lambda_2 logRD^{ROW}_{it-1} + \lambda_3 logitemployment_{it} + \lambda_4 logGDP_{it} + \lambda_5 logedu_{it} + \lambda_6 pop_{it} + \lambda_7 unemploy_{it} + \lambda_8 financial_{it} + \lambda_9 institution_{it} + \lambda_{10} logOSS_{it-1} + \lambda_{11} logOSS^{ROW}_{it-1} + fe + u_{it} \quad (8a)$$

Finally, the robustness of our results is tested by explaining the change of the company population in two sectors, Computer Manufacturing and Information and communication, for the EU Member States, by the contributions to OSS.

In a first step, it is tested whether OSS has an influence on the foundation of start-ups in general, in a second step more precisely the impact on the foundation of start-ups in information technology and finally on Open Source related start-ups following the approach by Wright et al. (2020).

The following results are found. In addition to the expected negative influence of the R&D expenditures by the rest of the world, the share of the population with tertiary education and the pressure generated by unemployment on founding companies, the GitHub commits by the rest of the world are a driver for the growth of the numbers of start-ups. This result also confirmed for the subsample of EU Member States and even the small number of companies outside the EU. Finally, the models based on the number of contributors to GitHub are confirming the results based on the number of commits. Overall, the model on the influence of OSS on the growth of start-ups in general is very robust and support the positive impact of OSS, which has been revealed by Nagle (2019a) in particularly for France and by Wright et al. (2020) for a larger sample of companies all over the world.

Table 5.24: Impact of OSS Commits on start-ups (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	0.18157	0.23775	-0.06353
	(0.75)	(0.89)	(-0.12)
LD.log R&D expenditures by ROW	-1.95493**	-2.84011***	0.03832
	(-2.19)	(-2.66)	(0.03)
Log IT-employment	-0.15584	-0.24733	3.20224***
	(-0.86)	(-1.29)	(3.81)
D.Log GDP	0.15486	0.08120	1.19887
	(0.26)	(0.12)	(0.91)
Log share population with tertiary education	0.36024***	0.43947***	-0.68089**
	(3.22)	(3.62)	(-2.33)
lpop	-0.00800	0.00327	-0.09339*
	(-0.33)	(0.12)	(-1.81)
Unemployment rate	0.22258***	0.22481***	0.25442**
	(3.43)	(3.06)	(2.29)
Financial: private lending	0.04094	0.04008	-0.02416
	(1.45)	(1.36)	(-0.10)
Institution: government effectiveness	0.07713	0.09461	-0.42094
	(0.65)	(0.74)	(-1.17)
LD.Log GitHub commits	0.03829	0.03567	0.11393
	(1.48)	(1.31)	(1.28)
LD.Log #GitHub commits by ROW	0.80749***	0.89223***	0.52723***
	(10.71)	(10.03)	(4.25)
Constant	2.77759***	2.28929***	4.58874***
	(7.22)	(5.64)	(3.17)
Observations	355	279	76
R^2	0.443	0.487	0.533
N_g	25	20	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.25: Impact of OSS Contributors on start-ups (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	0.22276	0.27161	0.17302
	(0.87)	(0.95)	(0.33)
LD.log R&D expenditures by ROW	-4.14502***	-5.21410***	-2.16002
	(-3.98)	(-4.17)	(-1.59)
Log IT-employment	-0.15852	-0.28235	3.39226***
	(-0.82)	(-1.36)	(3.98)
D.Log GDP	0.31720	0.33422	1.61076
	(0.50)	(0.47)	(1.21)
Log share population with tertiary education	0.42397***	0.52913***	-0.79999***
	(3.56)	(4.07)	(-2.66)
lpop	-0.00044	-0.00076	-0.04648
	(-0.02)	(-0.03)	(-0.92)
Unemployment rate	0.21863***	0.20870**	0.23443**
	(3.06)	(2.50)	(2.08)
Financial: private lending	-0.00724	-0.00964	-0.09521
	(-0.24)	(-0.30)	(-0.41)
Institution: government effectiveness	0.26718**	0.35131**	-0.68545*
	(2.09)	(2.53)	(-1.90)
LD.Log GitHub contributors	0.04929	0.03642	0.08632
	(0.57)	(0.39)	(0.45)
LD.Log GitHub contributors by ROW	0.67359***	0.77069***	0.50715**
	(5.81)	(5.67)	(2.49)
Constant	2.82281***	2.29577***	5.41648***
	(6.85)	(5.23)	(3.67)
Observations	355	279	76
R^2	0.366	0.403	0.524
N_g	25	20	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

In a second approach, it is focused like Nagle (2019a) and Wright just on the start-ups in information technology, which are more explicitly benefit from OSS than all start-ups listed in Crunchbase. Indeed, it is observed a positive influence of employment in information technology on the development of start-ups in this domain. However, the positive impact of the number of commits or contributors by the rest of the world to GitHub on the number of start-ups is still significantly positive and in the same range as in the models based on all start-ups.

Table 5.26: Impact of OSS Commits on start-ups in information technology (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.85140*	-0.93982	0.54819
	(-1.71)	(-1.62)	(0.61)
LD.log R&D expenditures by ROW	-3.43238*	-3.34876	-3.19214
	(-1.87)	(-1.45)	(-1.52)
Log IT-employment	0.74809**	0.72964*	-0.21067
	(2.00)	(1.75)	(-0.14)
D.Log GDP	-1.11004	-1.02368	-0.99444
	(-0.91)	(-0.72)	(-0.43)
Log share population with tertiary education	0.29048	0.30112	0.57637
	(1.26)	(1.15)	(1.12)
Population	-0.09975**	-0.08859	-0.05070
	(-1.98)	(-1.52)	(-0.56)
Unemployment rate	0.61867***	0.73196***	-0.03976
	(4.63)	(4.60)	(-0.20)
Financial: private lending	0.00915	0.01098	-0.61569
	(0.16)	(0.17)	(-1.51)
Institution: government effectiveness	-0.66172***	-0.67633**	0.06502
	(-2.70)	(-2.46)	(0.10)
LD.Log GitHub commits	-0.06065	-0.05918	-0.10658
	(-1.14)	(-1.00)	(-0.68)
LD.Log #GitHub commits by ROW	0.57202***	0.52687***	0.65003***
	(3.68)	(2.74)	(2.97)
Constant	0.48558	-0.08085	5.57314**
	(0.61)	(-0.09)	(2.18)
Observations	355	279	76
R^2	0.256	0.272	0.245
N_g	25	20	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.27: Impact of OSS Contributors on start-ups in information technology (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.75975	-0.85965	0.96104
	(-1.53)	(-1.49)	(1.12)
LD.log R&D expenditures by ROW	-5.55708***	-5.19507**	-5.74797**
	(-2.77)	(-2.07)	(-2.57)
Log IT-employment	0.77855**	0.73244*	0.06822
	(2.08)	(1.76)	(0.05)
D.Log GDP	-0.76008	-0.64308	-0.63062
	(-0.62)	(-0.45)	(-0.29)
Log share population with tertiary education	0.31075	0.33923	0.41770
	(1.35)	(1.30)	(0.84)
Population	-0.10456**	-0.10142*	0.02027
	(-2.08)	(-1.73)	(0.24)
Unemployment rate	0.56618***	0.67484***	-0.05943
	(4.11)	(4.02)	(-0.32)
Financial: private lending	-0.01621	-0.00952	-0.80091**
	(-0.28)	(-0.15)	(-2.07)
Institution: government effectiveness	-0.50143**	-0.50375*	0.03329
	(-2.03)	(-1.81)	(0.06)
LD.Log GitHub contributors	-0.10870	-0.09421	-0.53708*
	(-0.65)	(-0.50)	(-1.70)
LD.Log GitHub contributors by ROW	0.70353***	0.64264**	1.14805***
	(3.15)	(2.35)	(3.43)
Constant	0.52622	-0.08612	6.84096***
	(0.66)	(-0.10)	(2.82)
Observations	355	279	76
R^2	0.259	0.271	0.327
N_g	25	20	5

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

However, the explanatory power of the models to explain the annual foundation of OSS related start-ups is not very high. Both the number of national commits to GitHub and the commits by the rest of the world are insignificant. These insignificant results are confirmed in the models based on the number of contributors, but also reflect the less robust results by Wright et al. (2020) by focusing just on OSS based start-ups.

Table 5.28: Impact of OSS Commits on OSS start-ups (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.46979	-0.33293	-0.77039
	(-1.41)	(-1.09)	(-0.50)
LD.log R&D expenditures by ROW	1.74200	0.51972	5.94903
	(1.41)	(0.43)	(1.67)
Log IT-employment	-0.39091	-0.33039	-3.87585
	(-1.56)	(-1.51)	(-1.54)
D.Log GDP	-0.00194	0.18525	-2.06145
	(-0.00)	(0.25)	(-0.52)
Log share population with tertiary education	0.22185	0.09327	2.40726***
	(1.43)	(0.67)	(2.75)
lpop	0.01726	0.01427	0.10383
	(0.51)	(0.46)	(0.67)
Unemployment rate	0.04652	0.05592	-0.10900
	(0.52)	(0.67)	(-0.33)
Financial: private lending	0.01602	0.02433	-1.00114
	(0.41)	(0.72)	(-1.45)
Institution: government effectiveness	0.02415	0.00382	0.33240
	(0.15)	(0.03)	(0.31)
LD.Log GitHub commits	-0.00473	-0.01512	0.30914
	(-0.13)	(-0.49)	(1.16)
LD.Log #GitHub commits by ROW	0.06738	0.12158	-0.57800
	(0.65)	(1.20)	(-1.55)
Constant	0.73384	0.88712*	2.49300
	(1.38)	(1.92)	(0.57)
Observations	355	279	76
R^2	0.033	0.033	0.199
N_g	25	20	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.29: Impact of OSS Contributors on OSS start-ups (FE)

	(1) All	(2) EU	(3) Other
LD.Log R&D expenditures	-0.46370	-0.31903	-0.80052
	(-1.41)	(-1.06)	(-0.51)
LD.log R&D expenditures by ROW	0.49417	-0.49144	5.29654
	(0.37)	(-0.38)	(1.29)
Log IT-employment	-0.36651	-0.32079	-3.78135
	(-1.47)	(-1.48)	(-1.46)
D.Log GDP	0.19388	0.37391	-2.56661
	(0.24)	(0.50)	(-0.64)
Log share population with tertiary education	0.17451	0.07337	2.06134**
	(1.14)	(0.54)	(2.26)
lpop	0.00852	0.00473	0.04395
	(0.25)	(0.15)	(0.29)
Unemployment rate	-0.02572	-0.00380	-0.18809
	(-0.28)	(-0.04)	(-0.55)
Financial: private lending	0.00845	0.01839	-0.83010
	(0.22)	(0.55)	(-1.17)
Institution: government effectiveness	0.07194	0.06070	0.38263
	(0.44)	(0.42)	(0.35)
LD.Log GitHub contributors	0.06922	0.06358	-0.01438
	(0.63)	(0.64)	(-0.02)
LD.Log GitHub contributors by ROW	0.18084	0.17679	0.04903
	(1.21)	(1.24)	(0.08)
Constant	0.94799*	1.01334**	2.74607
	(1.79)	(2.20)	(0.61)
Observations	355	279	76
R^2	0.049	0.047	0.166
N_g	25	20	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Based on the findings by Wright et al. (2020), who rely on a much larger sample of countries and focus on IT start-ups, it is even possible to determine the number of start-ups founded based on a realistic 10% increase of commits to GitHub by each EU country in 2016. In total, this would lead to more than 650 new IT start-ups in the EU.

Table 5.30: Predicted Increase in the Number of Start-Ups in Information Technology with 10% Increase in 2016 GitHub Commits based on Wright et al. (2020)

EU country	**Predicted Increase**
Germany	171.426
France	111.500
Netherlands	58.755
Spain	57.792
Italy	33.078
Sweden	28.226
Finland	26.140
Belgium	24.524
Poland	23.346
Ireland	21.385
Denmark	17.854
Austria	15.351
Portugal	12.810
Estonia	9.289
Czech Republic	9.048
Hungary	6.886
Romania	6.706
Greece	6.566
Bulgaria	3.932
Lithuania	2.367
Luxembourg	1.880
Slovenia	1.701
Cyprus	1.454
Slovak Republic	1.312
Latvia	1.247
Croatia	0.510
Malta	0.368
Total EU	**654.525**

As another option to analyse the influence of OSS on the entry and exit of companies in markets is to investigate its impact on the change of company population. Since this data is provided for some EU Member States, the same model is performed as for the start-ups for the change of company population in Computer Manufacturing, i.e. Manufacture of computer, electronic and optical products, manufacture of electrical equipment, and Information and Communication, which includes computer programming. The results for the smaller sample of EU Member States due to restricted data availability reveal indeed a significant negative influence of the number of commits by the rest of the world on the change of the company population in the Information and Communication industry, i.e. the OSS activities by the rest of the world reduce the number of European companies in this market. This negative effect cannot be observed for the hardware market, i.e. for the manufacturing of computers. However, the mentioned significant negative effect related to the company population in the Information and Communication market eventually disappears in the model based on the number of contributors to GitHub.

Table 5.31: Impact of OSS Commits on change of company population in Computer Manufacturing and Information and Communication (FE)

	(1) Computer M. EU	(2) I&C EU
LD.Log R&D expenditures	-6.71223*	-10.64985***
	(-1.77)	(-2.63)
LD.log R&D expenditures by ROW	-25.23838*	0.86845
	(-1.66)	(0.05)
Log IT-employment	-3.21543	-2.69451
	(-1.18)	(-0.93)
D.Log GDP	-7.47938	11.75851
	(-0.81)	(1.19)
Log share population with tertiary education	-1.64632	-7.20510***
	(-0.95)	(-3.92)
lpop	-0.58765	1.36025***
	(-1.53)	(3.33)
Unemployment rate	-1.68203	1.92879*
	(-1.61)	(1.73)
Financial: private lending	0.92220**	-0.81631*
	(2.20)	(-1.83)
Institution: government effectiveness	-0.57817	-1.38221
	(-0.32)	(-0.72)
LD.Log GitHub commits	0.00623	0.00700
	(0.02)	(0.02)
LD.Log #GitHub commits by ROW	0.14986	-3.07968**
	(0.12)	(-2.29)
Constant	7.34386	33.61147***
	(1.27)	(5.48)
Observations	279	279
R^2	0.059	0.192
N_g	20	20

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.32: Impact of OSS contributors on change of company population in Computer Manufacturing and Information and Communication (FE)

	(1) Computer M. EU	(2) I&C EU
LD.Log R&D expenditures	-6.59914*	-10.92644***
	(-1.75)	(-2.70)
LD.log R&D expenditures by ROW	-19.71376	6.96982
	(-1.20)	(0.40)
Log IT-employment	-3.36467	-2.53109
	(-1.23)	(-0.87)
D.Log GDP	-8.75512	11.20948
	(-0.94)	(1.12)
Log share population with tertiary education	-1.39599	-7.58957***
	(-0.82)	(-4.14)
lpop	-0.53490	1.36846***
	(-1.39)	(3.32)
Unemployment rate	-1.22648	1.84634
	(-1.12)	(1.57)
Financial: private lending	0.97059**	-0.69563
	(2.32)	(-1.55)
Institution: government effectiveness	-0.80308	-2.15323
	(-0.44)	(-1.10)
LD.Log GitHub contributors	0.19962	-0.27480
	(0.16)	(-0.21)
LD.Log GitHub contributors by ROW	-1.24806	-2.05858
	(-0.70)	(-1.07)
Constant	6.15992	34.13889***
	(1.07)	(5.51)
Observations	279	279
R^2	0.062	0.183
N_g	20	20

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Impact of OSS on IT employment

Following Nagle (2019a), a similar approach to assess the impacts of OSS on IT-employment is applied. Prior literature incl. Ghosh (2006) has argued that contributing to OSS allows individuals to learn how to program as part of a team building a large piece of software, rather than just coding on their own. Further, an increase in the usage of OSS at firms and a rise in the number of start-ups (both discussed above) can also increase the demand for labour employed in IT related jobs as the outcome variable, which is also an indicator of economic growth. However, IDC (2019) and BITKOM (2020) point to the employment-saving impact of OSS based on their company surveys. Overall, it cannot be expected from a theoretical perspective that the contribution to OSS is going to increase in IT employment

A fixed-effect model is estimated covering the time period between 2000 and 2018 of the share of IT-employment on total employment in country i at time t explained by the OSS indicators controlling for several baseline variables:

$$it-employment_{it} = a \quad + \lambda_1 logedu_{it} + \lambda_2 logGDP_{it} + \lambda_3 logRD_{it-1} + \lambda_4 logRD_{it-1}^{ROW} + $$
$$+\lambda_5 logOSS_{it-1} + \lambda_6 logOSS_{it-1}^{ROW} \quad + fe + u_{it} \qquad (9)$$

Since it is also argued, that OSS has not only employment impacts in the IT sector, but on employment in general (e.g. Ghafele & Gilbert 2014), the same regression are performed taking the total employment as variable to explain.

$$employment_{it} = a \quad + \lambda_1 logedu_{it} + \lambda_2 logGDP_{it} + \lambda_3 logRD_{it-1} + \lambda_4 logRD_{it-1}^{ROW} + $$
$$+\lambda_5 logOSS_{it-1} + \lambda_6 logOSS_{it-1}^{ROW} \quad + fe + u_{it} \qquad (10)$$

The results of the regression model explaining the development of the share of IT-employment using the GitHub commits reveals that the R&D expenditures by the rest of the world have a negative influence. This result can be explained by the increased competitiveness by the rest of the world, which has negative implications for the domestic companies and consequently their employment. However, the national R&D expenditures cannot compensate for this competitive pressure. Surprisingly, the national patent applications have also a negative impact. Finally, neither the national nor the global contributions of commits to GitHub have a significant influence.

If looking at the results of the model based on the number of contributors to GitHub, it turns out that the number of national contributors is still not significant. However, with an increasing number of contributors to GitHub from the rest of the world the domestic growth of the share in IT employment is reduced, in particular for the Member States of the EU. Obviously, there is a negative influence of contributions to OSS on the labour market in IT.

The models explaining the development of employment in general do not reveal a significant influence of OSS either measured by the number of commits or the number of contributors. The only exception is the positive influence of the number of contributors to GitHub by the rest of the world for the other countries. Their IT-employment can obviously benefit from the global pool of OSS.

Table 5.33: Impact of OSS Commits on share of IT employment (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	-0.27582	-0.33683	-0.08615
	(-1.38)	(-1.51)	(-0.54)
LD.Log R&D expenditures	0.01209	0.02229	0.07287
	(0.17)	(0.29)	(1.10)
LD.log R&D expenditures by ROW	-1.62229***	-2.00241***	-0.14609
	(-4.26)	(-4.41)	(-0.90)
D2.Log transnational patent applications	-0.02503***	-0.02963***	-0.00219
	(-3.23)	(-3.32)	(-0.54)
Log share population with tertiary education	0.16103***	0.15776***	0.00389
	(4.80)	(4.30)	(0.09)
LD.Log GitHub commits	-0.00248	-0.00268	-0.00355
	(-0.29)	(-0.28)	(-0.29)
LD.Log #GitHub commits by ROW	0.03649	0.04689	-0.00499
	(1.14)	(1.25)	(-0.29)
Constant	0.46641***	0.47219***	1.06173***
	(4.50)	(4.28)	(7.22)
Observations	558	473	85
R^2	0.134	0.147	0.055
N_g	33	28	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.34: Impact of OSS Commits on employment (FE)

	(1) All	(2) EU	(3) Other
D.Log GDP	0.00721	0.05874	-0.39244***
	(0.11)	(0.84)	(-2.80)
LD.Log R&D expenditures	-0.03327	-0.03622	-0.09548
	(-1.46)	(-1.50)	(-1.52)
LD.log R&D expenditures by ROW	-0.02196	0.12037	-0.17067
	(-0.18)	(0.85)	(-1.21)
D2.Log transnational patent applications	-0.00362	-0.00059	-0.00923**
	(-1.47)	(-0.21)	(-2.58)
Log share population with tertiary education	0.11430***	0.10721***	0.36408***
	(10.62)	(9.36)	(12.66)
LD.Log GitHub commits	0.00032	0.00010	-0.00391
	(0.12)	(0.03)	(-0.63)
LD.Log #GitHub commits by ROW	0.01068	0.00204	0.02860**
	(1.05)	(0.17)	(2.08)
Constant	15.23173***	14.82739***	16.09483***
	(460.19)	(430.13)	(167.37)
Observations	592	473	119
R^2	0.231	0.207	0.730
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.35: Impact of OSS Contributors on share of IT employment

	(1) All	(2) EU	(3) Other
D.Log GDP	-0.28595	-0.34652	-0.08762
	(-1.40)	(-1.51)	(-0.55)
LD.Log R&D expenditures	0.01255	0.02207	0.06618
	(0.18)	(0.28)	(0.99)
LD.log R&D expenditures by ROW	-1.57066***	-1.94905***	-0.07869
	(-3.71)	(-3.89)	(-0.41)
D2.Log transnational patent applications	-0.02224***	-0.02642***	-0.00155
	(-2.87)	(-2.95)	(-0.38)
Log share population with tertiary education	0.16665***	0.16427***	0.01273
	(4.74)	(4.25)	(0.30)
LD.Log GitHub contributors	0.03517	0.03288	-0.00434
	(1.13)	(0.95)	(-0.17)
LD.Log GitHub contributors by ROW	-0.02805	-0.02022	-0.00862
	(-0.63)	(-0.39)	(-0.30)
Constant	0.46051***	0.46590***	1.03078***
	(4.27)	(4.04)	(6.74)
Observations	558	473	85
R^2	0.134	0.145	0.061
N_g	33	28	5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Whereas the number of commits to GitHub have neither an influence on the share in IT employment nor on the absolute number of employment, a significant positive influence on employment, in particular in Europe, by the number of contributors to GitHub in the rest of the world can be observed. This means the more developers in the rest of the world contribute to GitHub or OSS, the more is the employment in Europe growing. However, an 1% increase of contributors in the rest of the world pushes employment only by 0.03% in Europe.

Table 5.36: Impact of OSS Contributors on employment

	(1) All	(2) EU	(3) Other
D.Log GDP	0.06697	0.11866*	-0.34926**
	(1.04)	(1.68)	(-2.59)
LD.Log R&D expenditures	-0.04058*	-0.04399*	-0.08274
	(-1.80)	(-1.83)	(-1.37)
LD.log R&D expenditures by ROW	-0.27239**	-0.10578	-0.41011**
	(-2.08)	(-0.68)	(-2.57)
D2.Log transnational patent applications	-0.00702***	-0.00423	-0.01096***
	(-2.90)	(-1.53)	(-3.20)
Log share population with tertiary education	0.09664***	0.08991***	0.34220***
	(8.73)	(7.55)	(11.85)
LD.Log GitHub contributors	0.00547	0.00569	0.01515
	(0.60)	(0.54)	(1.28)
LD.Log GitHub contributors by ROW	0.03918***	0.03290**	0.02492
	(2.84)	(2.06)	(1.38)
Constant	15.27515***	14.86720***	16.16386***
	(451.93)	(418.62)	(167.67)
Observations	592	473	119
R^2	0.255	0.226	0.749
N_g	35	28	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Summary of the macroeconomic impact

Based on the results of our econometric analyses based on time series of EU Member States data to assess the economic impact of OSS, the following conclusions can be derived.

First, national GDP of the EU Member States is significantly benefiting from the global pool of OSS code, even if controlled for other indicators for the global knowledge pools, like R&D expenditures and the stock of patents. However, the national contributions to the global pool of OSS code are not necessarily a significant driver for domestic GDP. Obviously, OSS code has the characteristics of a public good with non-rivalry in consumption and non-excludability of users. Therefore, free-riding is an efficient strategy, at least derived from the results of the macroeconomic production model. However, it is possible to identify and to quantify a significant economic impact of the commits or contributors to GitHub from the EU Member States on the GDP in the EU. The impact ranges from €60 billion to €95 billion to the GDP in the EU in 2018. Since only around half of the commits or contributors to GitHub can attributed to countries, like the EU Member States, the above mentioned figures are at the lower bound, in particular if further admittedly much smaller OSS repositories, like GitLab, are considered.

The insights from the production model are confirmed by the estimations of labour productivity, which is also benefiting from the global pool of OSS code. Even the national contributions to GitHub based on the number of commits is pushing labour productivity.

These insights from the macroeconomic level are consistent to the insights on firm productivity on the micro level (Nagle 2018, Nagle 2019b).

The influence on OSS on international competitiveness reveals that national contributions strengthen the domestic competitiveness measured by exports or Trade in Value added. However, the global pool of OSS is challenging the export performance. This is consistent with the finding that the economic complexity of countries, i.e. the diversity and complexity of their export portfolio, is benefitting from national contributions to GitHub increase, whereas the contributions by the rest of the world reduce economic complexity. However, the payments for intellectual property are not significantly influenced by contributions to OSS or GitHub, which can probably be made by the coarseness of the data.

The influence of OSS on innovation has been tested by using a number of different indicators, but reveals no strong link. Since innovation is characterised by differentiation from existing state of science and technology or competitors, contributing to or relying on OSS code allows mainly marginal and not necessarily radical changes. However, the contributions to OSS or GitHub by the rest of the world is increasing the number of patents on computer-implemented inventions, which confirms the complementarity between OSS and proprietary inventions and software being already highlighted in studies based on single cases or company data (e.g. Aksoy-Yurdagul 2015).

Following Nagle (2019a) or Wright et al. (2020), a significantly positive impact of OSS on start-ups in information technology is revealed. Relying on the model by Wright et al. (2020), it can be predicted that a 10% increase of commits to GitHub by the EU Member States will generate more than 650 additional start-ups in information technology in the EU.

Finally, no robust positive influence of contributions to OSS can be revealed, i.e. neither on the share of IT employment nor on the absolute number of employment. Since from company surveys (e.g. BITKOM 2020) and other studies (IDC 2019) it is known that they use OSS to save labour cost and to tackle the shortage of skilled software developers, an immediate positive impact of OSS on employment cannot be expected.

Overall, based on our results from the different macroeconomic regression analyses, it is observed that OSS is pushing growth, mainly driven by positive productivity and competitiveness impacts. However, the relationship of OSS to innovation is rather ambivalent, whereas Wright et al. (2020) find significant and large impacts on start-ups, Finally, OSS is not necessarily a direct driver for employment, but only indirectly via positive productivity and competitiveness effects.

However, these findings are complemented and validated by the insights of the case studies and the stakeholder survey.

Limitations of the macroeconometric analysis

Our macroeconomic analyses face several limitations. Starting at the variables explaining the various economic impact dimensions, it has to be admitted that the GitHub repository is not reflecting the complete stock of OSS. Even the variables used, i.e. the commits and the contributors, are not completely covering all the contributions of the various countries to GitHub, because only around half of the accounts have a link to a specific country. Overall, this limitation might underestimate the involvement and investment into OSS. However, relying on this database allows us to run analyses both on the macroeconomic level, but as seen in the following chapter on the cost-based approach impact analyses, also on the micro level. Taking both perspectives together generates a rather comprehensive picture of the economic impact of OSS.

In addition, not all relevant variables for explaining the various economic dimensions might have been considered, i.e. the omitted variable bias might lead to the attribution of effects to the included variables. Consequently, some effects of omitted variables might have been attributed to the variables representing OSS, i.e. an overestimation is possible. However, the inclusion of R&D expenditure, which is a much wider concept than OSS, but also of patents should reduce the size of the omitted variable bias to a rather insignificant level.

So far only the contribution to OSS are used, but it is not known whether these investments have been successful, i.e. whether the OSS code is eventually used in practice. However, this information can only be collected via the case studies and the stakeholder survey. Overall, both the problem of over- and underestimation are relevant, but with the latter being more relevant.

The dependent variables are in general not OSS-specific, but rather general indicators of economic activity, competitiveness or innovation. However, the objective is to assess the general economic impact of OSS. Therefore, first general indicators, like GDP or exports, are used. However, where possible regression models are run to explain OSS specific indicators, like in the case of OSS-based start-ups, software patents or IT employment. In other areas, like GDP or export, OSS-specific indicators are not available.

The claim of revealing causal relationships and not only simple correlation can be justified by relying on time series of dependent and independent variables. However, all concerns related to endogeneity, i.e. the OSS variable itself might positively be influenced, e.g. by innovation, cannot be addressed. In case of such complex relationships, significant relationships might be not found or the significant relations are caused by endogeneity. However, these mutual relationships can only be disentangled via real experiments, which is in the context of this study not a feasible option.

Finally, the mentioned limitations are addressed by additional insights both from the case studies and the stakeholder survey. The case studies reveal further more detailed impacts of OSS, whereas the stakeholder survey attempts to collect more OSS specific benefits, but in particular also data about its use. The area of OSH is explicitly addressed in the case studies to start to fill the data gap in this only emerging field compared to OSS.

Alternative approaches of macroeconomic impact analyses

To put the findings of our macroeconometric analysis into the context of other studies trying to assess the economic impact of OSS, results of other recent papers or reports are presented.

An alternative approach - called “substitution principle” - tries to measure how much a collection of hard-to-measure assets is valued by counting the sum of the money necessary to substitute them, e.g. analysing the value of Apache server software by assessing the value of similar proprietary software equivalents. For example, Greenstein & Nagle (2014) analyse a data set consisting of a 1% sample of all outward-facing web servers used in the United States. With their estimate of the number of Apache Web Servers publicly reachable in the United States, they compute a pecuniary cost of replacing all of these Apache Web Servers with proprietary web server software. Based on the valuations of licence fees, the cost of replacing all publicly reachable Apache WebServers in the United States would be between $514 million and $12.8 billion, with a middle estimate of $2 billion. These estimates are equal to between 1.3% and 8.7% of the stock of prepackaged software in the United States.

A further alternative approach to measuring the economic impact of OSS in general and not only focused on an important but still specific OSS is based on the calculation of the savings OSS could provide (see BITKOM 2020, which shows the high relevance of cost savings as drivers to contribute and implement OSS). Therefore, the approach developed and applied by Daffara (2012) and ran update of the previous insights following Daffara (2020) are presented.

Daffara (2012) criticises that most of the current evaluation methods are based on assessing “sales”, i.e. the direct monetisation of OSS. However, this approach is missing the large, mostly under-reported and underestimated aspect of OSS use that is not “sold”, but, for example, is directly implemented through an internal work force or embedded in services or infrastructure.

Estimating these savings, that the EU economy as a whole receives from OSS, not only the turnover of companies that identify themselves as providing OSS through one of several business models, but also companies where such a monetisation is ancillary to a complementary market, for example hardware or software services, is the objective of the approach by Daffara (2012). In addition, the work that is performed without monetary compensation and the OSS that is distributed widely embedded in phones or cars are taken into account. Therefore, Daffara (2012) questions approaches, like the one applied by Greenstein and Nagle (2014) to Apache server software, due to the assumption that OSS is perfectly exchangeable with a proprietary alternative, in particular if the degree of non-substitutability is significant. In addition, users may be unwilling to pay a positive price for such an alternative.

Therefore, Daffara (2012) proposes a different approach based on the savings from data that is related to the degree of reuse of OSS. He started from an inclusive market view of the total IT spending on software development and support leading to a volume of $468 billion in 2020 for Europe, which is according to Gartner (various years) 4% of investment directly or indirectly imputable to IT. Based on references to several studies, Daffara (2012) claims that 35% of this software is OSS, in 2019 even 60% (Daffara 2020 referring to Synopsis Survey) leading to cost reductions of $280 billion.

To provide an indication of the savings of OSS introduced by this code reuse process, Daffara (2012; 2020), like Greenstein and Nagle (2014) or Nagle (2019a), applied the model of code cost estimation (Constructive Cost Model) called COCOMOII adapted for the specifics of OSS reuse. The model is based on a set of different cost estimates for separate parts of software projects. However, reusing external resources introduces both savings due to the reduced development effort but also some costs as well related to the increased risk due to the lack of control of an external resource, like the OSS project itself, and tailoring and “glue code” development necessary to adapt and integrate the software component with the rest of the code.

By adding to the costs related to reuse the effort necessary to identify and select the OSS components to be reused (the so called “integration cost” of 15%) Daffara (2012) estimates that the total savings attributable to a 35% reuse are equivalent to 31% of total coding effort. The shared code in a reused OSS project generates an additional reduction in maintenance and development cost of 14% following Jones and Bonsignour (2012). Since he assumes in 2020 60% of OSS instead of 35%, the share of 14% is also almost doubled to 27%. Consequently, he reports another source of savings of almost $75 billion, i.e. 27% of the $280 billion. In total, OSS generates direct savings of $354 billion per year in 2020.

In addition to the direct savings, Daffara (2012) assumes that the reinvestment of these savings into IT itself derived from the observation that the percentage of IT investment does not decrease, even when the percentage of OSS increases. The assumption is based on the observation that IT investment remains roughly unchanged over several years across spending groups. However, this is still a quite rigorous assumption, which needs certainly further validation.

Finally, Daffara (2012) cites Brynjolfsson and Hitt (2003), who find that the measured long-run contributions of computerisation are significantly above computer capital costs with a factor of 5 or more. Then, he assumes that the savings related to the use of OSS will generate the same productivity effect. Based on the data in 2012, Daffara (2012) estimates a long term result in productivity and efficiency improvement that was equivalent to $342 billion per year in 2012 and even $1.7 trillion per year based on the savings of $354 billion in 2019.

Recently, IDC (2019) published a white paper on the economic impact of Red Hat Enterprise Linux (RHEL), which comes to similar results applying a different approach. Starting from a global business revenue of $188 trillion in 2019, IDC (2019) assumes an “IT footprint” of $81 trillion, e.g. email for employees, production management systems, inventory control software, engineering design software, customer relationship management (CRM), website management. Almost half of these systems are assumed to be based on Linux, i.e. $35 trillion. Finally, the software and applications running on RHEL are assumed to be $10 trillion of business revenue. Almost one third is attributed to Europe, which is double, but still in the same range of the value calculated by Daffara (2020).

In summary, Daffara (2012, 2020) presents a transparent analysis of the contribution of OSS, which not only includes the savings possible by OSS, which have been analysed by Greenstein and Nagle (2014) just for the Apache OSS server software. In addition to the savings due to code reuse, he assumes cost savings in maintenance and development cost. Crucial in this approach is the assumption of 60% of all software being OSS. This assumption is not supported by empirical evidence. The five times higher economic impact due to productivity and efficiency improvements goes back to the factor published by Brynjolfsson and Hitt (2003). The results released by IDC in 2019 on behalf of the Linux foundation uses also a top down approach, but the economic impact of Red Hat Enterprise Linux (RHEL) for Europe alone is double as high as the value Daffarra (2020) calculated for OSS in general. It is mainly based on a survey among industry experts. Unfortunately, neither the sampling nor the response rate is made transparent. In the following section another approach is applied starting from the cost needed to produce OSS to generate a lower bound of the possible impact by assuming that the benefits should at least compensate the invested costs.

d. Cost-based impact assessment

Introduction

The macroeconomic analyses are based on the contributions to GitHub at the level of the EU Member States and other countries with significant activities. Most of the presented alternative approaches to assess the economic impact of OSS are derived from the global or national budgets of information technology or software. Due to missing market prices for OSS and lacking data on companies’ revenues based on OSS, these approaches are based on quite vague assumptions about the share of OSS within these budgets or software code. Consequently, the approaches generate rather high numbers of economic impact of OSS with up to trillions. To generate a baseline for the economic impact of OSS, cost-based impact assessments have been conducted, which are based on two pillars. They allow us at least to quantify in monetary terms the efforts both the EU Member States and the most active companies located in the EU Member States invest into OSS. The basic assumption beyond this approach is that the benefits derived from these investments at least outweigh the invested costs. Consequently, the findings of the cost-based approach present only a lower bound.

Again, it is started at first from the macroeconomic level of the Member States of the EU, which allows us the quantification of the efforts by Member State. The overall efforts are linked back to the results of the macroeconomic analyses, i.e. the contribution of OSS to GDP in the EU, which generate cost-benefit ratios. Second, the most active contributors to OSS located in the EU Member States, which are responsible for a significant share of all contributions within the EU, have been identified. For this sample, the efforts, they invest in OSS, have been calculated. Complementary to the insights from the macroeconomic analysis, this microeconomic company-based analysis reveals new insights about the investments of companies in OSS both by company size and by sector. It is also tried to link their investments with their performance, i.e. turnover and turnover per employee, to also address the benefit side. Further insights about the benefits of OSS in general and the revenue companies generate based on OSS in particular are provided from the stakeholder survey. In addition, further data has been collected via a survey conducted by the Linux Foundation's Core Infrastructure Initiative (CII) and the Laboratory for Innovation Science at Harvard (LISH) within a survey for contributors to FOSS. Eventually, all these insights complement the current findings on costs.

The cost of investing in Open Source Software in the EU

Based on our analyses of contributions to GitHub as the most relevant Open Source platform the financial costs, which are connected to these investments, are calculated. Following Nagle (2019a), the social value creation can be estimated that results from these contributions in a manner similar to that used in Ghosh (2006) by calculating the replacement cost that it would take a private firm to create this code. Although this methodology is not perfect, it is a standard process for valuing goods with no price (Nordhaus, 2006), like Open Source Software.

Firstly, the number of GitHub accounts attributed to EU Member States are taken and multiplied with the average personnel costs in the computer programming sector provided by Eurostat (http://appsso.eurostat.ec.europa.eu Annual detailed enterprise statistics for services). In general, the last available values are from 2017. These average costs are also at the lower bound, because software developers might earn more than the average employee (e.g. Nagel 2019a for France), but it can be differentiated between the personnel costs in the different EU Member States.

Secondly, the Constructive Cost Model II (COCOMO II) is used to estimate the number of person-months it would take to create the commits contributed by developers located in the EU Member States. If assumed that all commits contributed in 2018 are only one line of code, then this can be used as input into the COCOMO II process. Although this estimate of one line of code per commit is necessarily an underestimate, the modal number of lines of code per commit is generally 1 according to Nagle (2019a). However, this effort can be considered a lower bound. Eventually, the COCOMO II calculation with default parameters estimates is used to calculate the required person-months of effort to write the lines of code. In a next step, again the average personnel costs and the apparent labour productivity in the computer programming sector are used in order to assess the overall personnel cost and value added at factor costs required for the development of OSS in the EU.

Table 5.37: OSS Contributors and related costs and value added per EU Member State in 2018

EU Member State	Employees in computer programming (in full-time equivalents)	Contribu-tors to GitHub in 2018	Contribu-tors / employees	Contributors * Average personnel cost (in 1000 Euros)	(Contributors * Average personnel cost) /employees	Contributors * Apparent labour productivity	(Contributors * Apparent labour productivity) /employees	Turnover per person employed - thousand Euros
Germany	620,791	45,527	0.07	3,086,730.6	4.97	3,683,134.3	5.93	174.1
United Kingdom	658,351	50,562	0.08	2,351,133	3.57	4,611,254.4	7.00	158.6
France	371,303	32,047	0.09	2,297,769.9	6.19	2,730,404.4	7.35	169.2
Netherlands	153,194	16,643	0.11	1,076,802.1	7.03	1,388,026.2	9.06	193.9
Spain	242,901	16,283	0.07	727,850.1	3.00	858,114.1	3.53	115.2
Poland	123,654	16,879	0.14	438,854	3.55	433,790.3	3.51	60.4
Sweden	117,811	12,333	0.10	1,011,306	8.58	818,911.2	6.95	216.7
Italy	205,361	10,521	0.05	559,717.2	2.73	724,896.9	3.53	140.6
Czech Republic	64,021	4,960	0.08	171,616	2.68	195,424	3.05	88.6
Belgium	51;617	5,972	0.12	459,246.8	8.90	513,592	9.95	199.4
Finland	50;084	5,838	0.12	377,134.8	7.53	510,825	10.20	173.6
Denmark	46;102	5,897	0.13	482,374.6	10.46	580,854.5	12.60	200.3
Austria	38,778	4,777	0.12	323,402.9	8.34	352,542.6	9.09	156.6
Portugal	50,963	5,067	0.10	157,077	3.08	182,412	3.58	68.9
Romania	89,267	4,569	0.05	103,716.3	1.16	131,587.2	1.47	46.7
Ireland	50,152	5,098	0.10	359,918.8	7.18	771,327.4	15.38	837
Hungary	55,825	3,437	0.06	86,612.4	1.55	102,078.9	1.83	67.8
Bulgaria	47,876	3,367	0.07	76,430.9	1.60	90,572.3	1.89	45.6
Greece	17,112	3,224	0.19	108,648.8	6.35	111,228	6.50	79.3
Lithuania	14,257	1,528	0.11	34,991.2	2.45	40,644.8	2.85	49.5
Slovakia	27,485	1,375	0.05	42,762.5	1.56	47,300	1.72	86.3
Estonia	9,012	1,240	0.14	38,564	4.28	46,004	5.10	70.5
Croatia	16,432	1,667	0.10	35,340.4	2.15	51,010.2	3.10	63.7
Slovenia	10,578	979	0.09	34,558.7	3.27	41,313.8	3.91	90.3
Latvia	13,442	945	0.07	20,317.5	1.51	24,759	1.84	45.2
Luxembourg	9,809	420	0.04	31,584	3.22	40,572	4.14	249.2
Malta	4.432	390	0.09	13,338	3.01	41,457	9.35	271.4
Cyprus	3.820	293	0.08	9024.4	2.36	32,142.1	8.41	406.1
Sum/average	3.164.430	261,838	0.08	14,516,822.9	4.59	19,156,178.6	6.05	158.0

Table 5.38: OSS commits, necessary effort and related costs and value added per EU Member State in 2018

EU Member State	Employees in computer programming (in full-time equivalent units)	Commits to GitHub in 2018 in Mio	Efforts in years	Efforts in years / employees	Efforts in years /contributors	Efforts in years * Average personnel cost - Mio Euros	(Efforts in years * Average personnel cost)/ employees	Efforts in years * Apparent labour productivity Mio Euros	(Efforts in years * Apparent labour productivity)/ employees	Turnover per person employed - thousand Euros
Germany	620,791	6.563	3862.2	0.006	0.085	261.86	0.42	312.46	0.50	174.1
United Kingdom	658,351	6.211	3635.5	0.006	0.072	169.05	0.26	331.56	0.50	158.6
France	371,303	0.437	2473.4	0.007	0.077	177.34	0.48	210.73	0.57	169.2
Netherlands	153,194	0.184	953.4	0.006	0.057	61.69	0.40	79.51	0.52	193.9
Spain	242,901	0.178	921.7	0.004	0.057	41.20	0.17	48.57	0.20	115.2
Poland	123,654	0.152	773.0	0.006	0.046	20.10	0.16	19.87	0.16	60.4
Sweden	117,811	0.117	578.0	0.005	0.047	47.39	0.40	38.38	0.33	216.7
Italy	205,361	0.101	493.5	0.002	0.047	26.25	0.13	34.00	0.17	140.6
Czech Republic	64,021	0.703	331.5	0.005	0.067	11.47	0.18	13.06	0.20	88.6
Belgium	51,617	0.662	310.2	0.006	0.052	23.85	0.46	26.68	0.52	199.4
Finland	50,084	0.620	288.4	0.006	0.049	18.63	0.37	25.26	0.50	173.6
Denmark	46,102	0.562	258.6	0.006	0.044	21.15	0.46	25.47	0.55	200.3
Austria	38,778	0.531	243.0	0.006	0.051	16.45	0.42	17.94	0.46	156.6
Portugal	50,963	0.424	190.1	0.004	0.038	5.89	0.12	6.84	0.13	68.9
Romania	89,267	0.348	152.8	0.002	0.033	3.47	0.04	4.40	0.05	46.7
Ireland	50,152	0.398	177.1	0.004	0.035	12.50	0.25	26.79	0.53	837
Hungary	55,825	0.315	137.00	0.002	0.040	3.45	0.06	4.09	0.07	67.8
Bulgaria	47,876	0.286	123.1	0.003	0.037	2.79	0.06	3.31	0.07	45.6
Greece	17,112	0.264	112.8	0.007	0.035	3.80	0.22	3.89	0.23	79.3
Lithuania	14,257	0.123	48.5	0.003	0.032	1.11	0.08	1.29	0.09	49.5
Slovakia	27,485	0.118	46.5	0.002	0.034	1.45	0.05	1.60	0.06	86.3
Estonia	9,012	0.113	44.3	0.005	0.036	1.38	0.15	1.64	0.18	70.5
Croatia	16,432	0.120	47.2	0.003	0.028	1.00	0.06	1.45	0.09	63.7
Slovenia	10,578	0.093	35.7	0.003	0.036	1.26	0.12	1.50	0.14	90.3
Latvia	13,442	0.080	30.2	0.002	0.032	0.65	0.05	0.79	0.06	45.2
Luxembourg	9,809	0.048	17.1	0.002	0.041	1.29	0.13	1.66	0.17	249.2
Malta	4,432	0.030	10.3	0.002	0.026	0.35	0.08	1.09	0.25	271.4
Cyprus	3,820	0.026	7.5	0.002	0.026	0.23	0.06	0.87	0.22	406.1
Sum/ average	3,164,430	30.330	16,302.7	0.005	0.062	937.08	0.30	1.24	0.39	158.0

In 2018, the Member States of the EU had more than 260,000 software developers contributing to GitHub assuming that one GitHub account represents one developer. This number is slightly above the 233,800 of full-time equivalents in the whole Europe of OSS related employment reported by teknowlogy (2019). However, it can be considered as lower bound, because only around half of the contributors reveal their country of origin. However, these contributors represent over 8% of the almost 3.1 million employees in the computer programming sector being aware of the fact that not only employees in this sector contribute to GitHub.[15] The range of this share is between 4% in Luxembourg to 19% in Greece. The share of 8% is very close to the 7.4% of the volume of OSS and IT services market of the total software and IT services market reported by teknowlogy (2019) and in line of the employment figures reported in SMART(2015/0015).

If the total number of more than 30 million commits in 2018 from the EU Member States and apply the COCOMO II model are taken, more than 16,000 years of full-time equivalents are needed, which is similar to the effort Ghosh (2006) reported for a global sample of the most active contributors. This is less than 10% of the OSS related full-time equivalents reported by teknowlogy (2019), but which includes also the employees providing OSS related IT services being responsible for more than 90% of the turnover in the whole OSS related markets. If this effort is related to the 260,000 software developers contributing to GitHub, then they would spend less than 10% of their time to contribute commits to GitHub, which is much lower than the 20%, i.e. the one day per week announced by Google some time ago (Colombo et al. 2013). However, the ratio is in the range of the 6 hours a week revealed in a recent survey, which validates our result and consequently our approach to measure the effort in developing OSS. In Germany, the share is almost 9%, whereas it is around 2.5% in Cyprus and Malta. Taking all employees in the computer programming sector in the EU, slightly more than 0.5% of their time is spent contributing to write Open Source code measured by commits to GitHub.

If now the number of contributors from each EU Member State is taken and multiplied with the average personnel cost per EU Member State, the costs are almost €15 billion in 2018 in all EU Member States.[16] If instead of the average personnel cost the apparent labour productivity is taken, which is defined as value added at factor costs, almost €20 billion is reached in 2018. These figures are in the same dimension as those published by teknowlogy (2019) on the OSS and IT services market in Europe, which is 7.4% of the total software and IT services market, but not transparently defined. Within the French OSS and IT services market, more than 90% belong to OSS related IT services according to teknowlogy (2019). More than half of the small part of OSS is related to infrastructure software and platforms, one third to application software products and less than 10% to SaaS. Among the Open Source related IT Services, almost two thirds belong to system integration, more than 20% to outsourcing and slightly more than 10% to outsourcing.

Based on data generated by JC MARKET RESEARCH (2020) combining a company-based bottom-up and country-based top-down approach the size of the Open Source services market in Europe was just below €5 billion in 2019, of which almost half are consulting services followed by one third for the implementation of OSS, 15% for support maintenance and management services and less than 10% for training services. Open Source services are mainly implemented in IT and telecommunication with almost one third, followed by one fifth in manufacturing, 17% in banking, financial services and insurance, 12% in life sciences and healthcare, one tenth in retail and distribution and the remaining other sectors.

Applying the same approach to the effort in years to generate the more than 30 million commits in 2018 by the Member States of the EU, the costs amount to almost €1 billion based on country-specific average personnel cost or €1.2 billion using the apparent labour productivity.[17] For comparison, Ghosh (2006) estimated that firms on a global level have invested €1.2 billion in developing OSS in 2005.

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15 Korkmaz (2020) also finds a significant contribution by academia to GitHub.

16 If the different price levels in the Member States are considered, the effort is around 10% less.

17 If the different price levels in the Member States are considered, the effort is around 10% less.

Reconsidering the results from the regression model for calculating the contribution of Open Source to the GDP of the EU, €63 billion based on commits to GitHub or €95 billion based on contributors in 2018 are estimated. Comparing both approaches based on the commits,a cost-benefit relation of 1:63 is revealed, whereas if based on the number of contributors it is 15:95. In the latter case, it is assumed that the 260.000 software developers in the EU contributing to GitHub work full time on Open Source. However, current studies report at maximum 10%, which means that the effort has to be divided by 10 leading to a similar cost-benefit ratio of 1:60.

However, the contribution of OSS to the GDP in 2018 is not only based on the OSS code developed in 2018, but also on the code in previous years. Bernhardsson (2016) reveals for different OSS projects a half-time of 3.33 years, i.e. only 50% of the code is used after 3.33 years. However, Linux has even a half-time above six years, i.e. after six years still more than 50% of the code is used. However, Bernhardsson (2016) shows also that the half-time of OSS more recently released is significantly lower. Consequently, he speculates that OSS code seems to change at a much faster rate in modern projects. Eventually, a linear depreciation rate of 10% per year is assumed due to missing information and the same effort per year, then the effort in 2018 has to be multiplied by 5.5, which leads us to a cost-benefit ratio of slightly above 1:10.

So far, only personnel cost are considered. However, also the cost for the hardware the OSS developers are using have to be included. According to Eurostat (http://appsso.eurostat.ec.europa.eu Annual detailed enterprise statistics for services), the annual investment per personnel is slightly above in €5,000 in the computer programming sector in the EU Member States in 2018. If this amount is mulitplied with the 260,000 contributors to GitHub, an investment of €1.3 billion is reached. Assuming that the investment is only for computer hardware and a depreciation rate of 100% for computer hardware, this cost for hardware can be added to the personnel cost leading to total cost of €2.3 billion in 2018. However, this is a maximum assumption. Consequently, the cost-benefit ratio would then be slightly above 1:4.

This ratio is in the line of the argument by Brynjolfsson and Hitt (2003), who find that the measured long-run contributions of computerisation are significantly above computer capital costs with a factor of 5 or more. Recently, Jones and Summers (2020) present a calculation of the social returns to innovation, which are under very conservative assumption at least 4. Since contributions to OSS can also be perceived as a specific form of innovation, our conservative calculation of a cost-benefit ratio of 1:4 for the EU is in line with the two referenced studies.

In a further step, the efforts related to the development of Open Source at GitHub are linked to the productivity performance in the computer programming sector per EU Member States measured as turnover per employee provided by Eurostat. This measure reflects the approach by IDC (2019) asking executives whether using Red Hat Enterprise Linux (RHEL) provided any advantage related to an increase in revenue from using RHEL, a decrease in expenses, or an increase in employee productivity. Their respondents divided their advantages pretty evenly, i.e. one-third to increased revenue, one-third to decreased expenses, and one-third to increased productivity. However, the displayed quantitative assessment is just equally divided into the revenue increasing and expense reducing impacts.

The Figures 5.4 and 5.5 reveal that the efforts to Open Source per employee both based on the average personnel costs and the apparent labour productivity are positively correlated to the turnover per employee. In detail, the correlation coefficient is 0.25 for the average personnel cost and even 0.50 for the apparent labour productivity. These positive correlations based on cross-country data are no evidence for a causal relationship. However, the results of the econometric time series analysis reveal a positive influence of

OSS on GDP and even productivity. Therefore, an increase of expenditures from €40 per employee e.g. in Romania, to almost €500 per employee in France or Germany might contribute to a theoretically maximum increase of the turnover per employee in the computer programing sector up to from €45 thousand to more than €150 thousand, which would mean a theoretically maximal cost-benefit ratio of up to 200.

Figure 5.4: Effort per employee multiplied with average personnel cost vs turnover per employee in computer programming per EU Member State

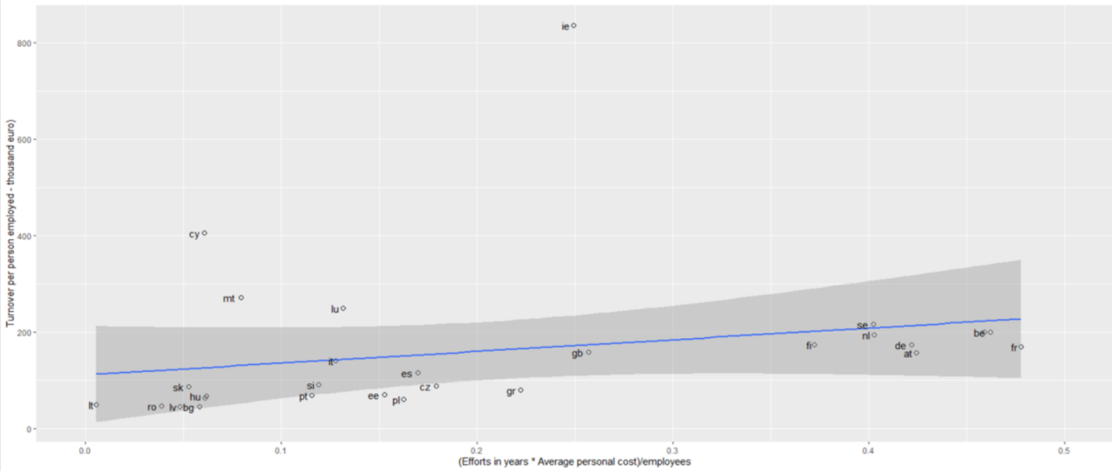
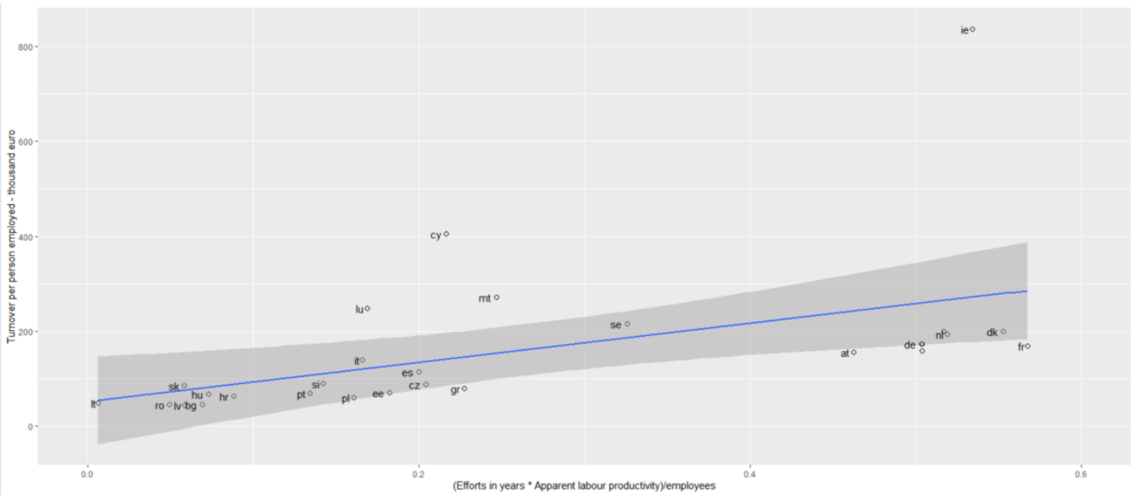


Figure 5.5: Effort per employee multiplied with apparent labour productivity vs turnover per employee in computer programming per EU Member State



Characteristics of companies located in the EU contributing to Open Source Software

Complementary to the construction of country-specific time series of GitHub commits and contributors, the contributions of individual companies and other organisations, e.g. foundations, to GitHub have been investigated being aware that individual contributors do not always disclose their affiliation, i.e. they do not always name the organisation for which they are working.

However, the identification of companies via their contributors allow us to identify at least the investment in OSS in the EU per economic sector and in combination with the size of the companies a differentiation of companies' investment in OSS by company size. This mainly cost-based approach to assess the economic impact of OSS in the EU is certainly generating figures at the lower bound. As argued above, market-based approaches using market prices for OSS are due to missing sales prices for OSS only possible based on additional information provided by the companies. Therefore, also the revenues of companies investing in OSS or relying their business model on OSS have to be considered. This investigation is performed in particular in the context of the stakeholder survey.

It has been started with the analysis of contributions to GitHub by matching the 10,000 organisations, which also includes OSS projects, with at least 10 contributors to a database of European companies or companies with affiliations in Europe. It has to be noted that the most active contributing companies are Microsoft, Google, IBM, ORACLE and Facebook, which are all US based. This first matching revealed more than 3,000 matched companies. OSS projects as well as foundations and other types of organisations, like universities, are consequently not included in the matching to the company database. In order to improve the quality of the matching, the 3,000 results have been matched back to the list of organisations listed in GitHub, which revealed almost 2,000 companies located in the Member States of the EU. Finally, some manual cleaning in particular of the large contributors has been performed. For example, the European affiliations of Microsoft had to be removed, because both the number of GitHub accounts and the commits linked to Microsoft cannot be easily differentiated by country.

At first, the following figures reveal the general characteristics of the companies. First, the major active companies in GitHub are quite broadly distributed between the EU Member States and are not only concentrated in the larger EU Member States. The vast majority of companies are rather small both based on their turnover and their employees. Finally, almost half of the companies located in the EU Member States and active in GitHub are attributed to the IT sector, which is supported by the survey of contributors to Linux by Nagle et al. (2020). Whereas several companies come from the various service sectors, the number and share of manufacturing companies is below 10% again endorsed by the sector affiliations of the contributors surveyed by Nagle et al. (2020).

For comparison, companies in the European company database Amadeus have been identified, which mention “Open Source” in their description. Regarding the distribution by country also a broad diversity of EU Member States with companies mentioning “Open Source” has been found, but compared to the contributors to GitHub, the number of companies from the United Kingdom is relatively lower in Amadeus, whereas the share of German companies is higher. This can be explained also by the size distribution, i.e. the share of small companies active in GitHub is much higher than those listed in Amadeus mentioning “Open Source”. This is true based both on turnover or employee classes. The reason is the bias of companies listed in Amadeus towards larger companies. However, the distribution of companies per sector is rather similar between the major contributors to GitHub and the companies listed in Amadeus mentioning “Open Source”. The share of IT companies is almost 45% lower among GitHub contributors than among the companies in Amadeus, which can again be explained by the size bias towards larger companies listed in Amadeus. Overall, the companies identified via GitHub represent slightly better a realistic picture of those contributing to Open Source and justify their use for the further analytical steps.

Figure 5.6: Number of companies contributing to GitHub per EU Member State (n= 1763)

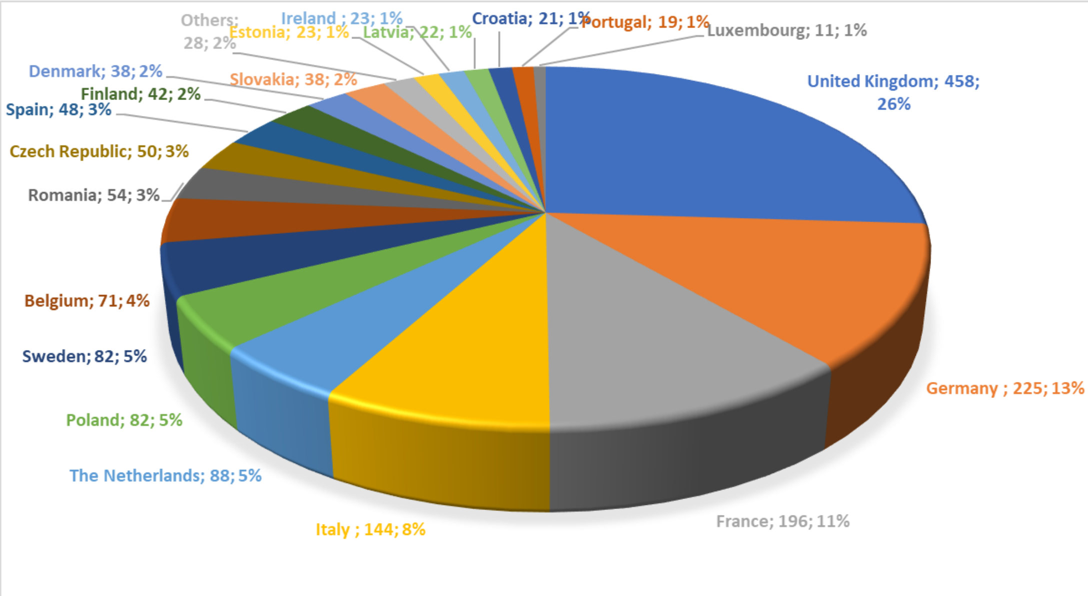


Figure 5.7: Number of companies listed in Amadeus mentioning Open Source per EU Member State (n= 895) (source: Amadeus)

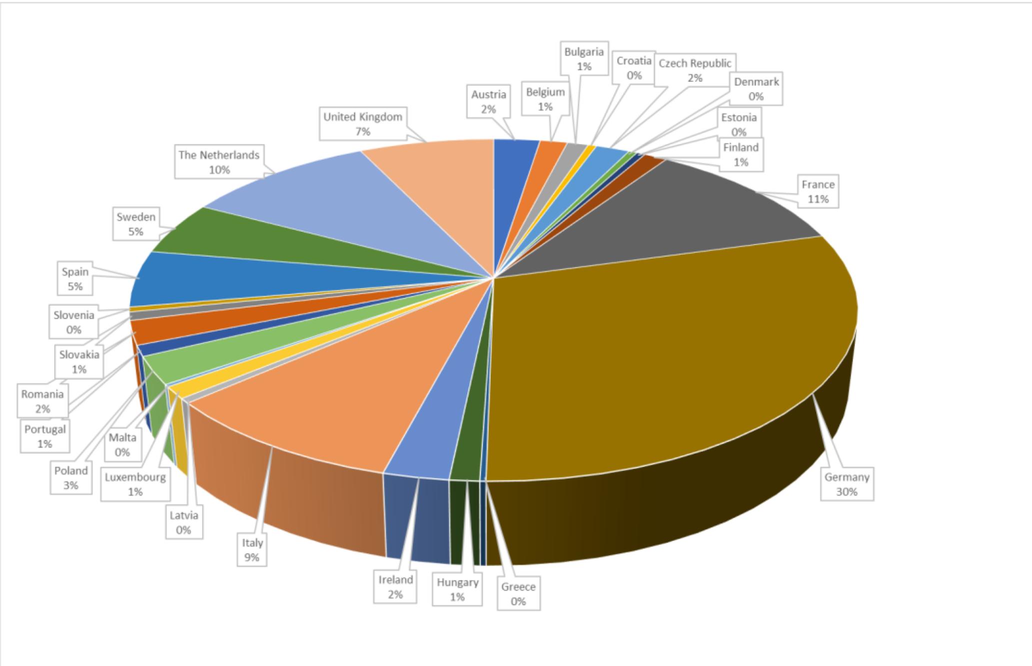


Figure 5.8: Share of companies contributing to GitHub in EU Member States per turn over class (n = 1763)

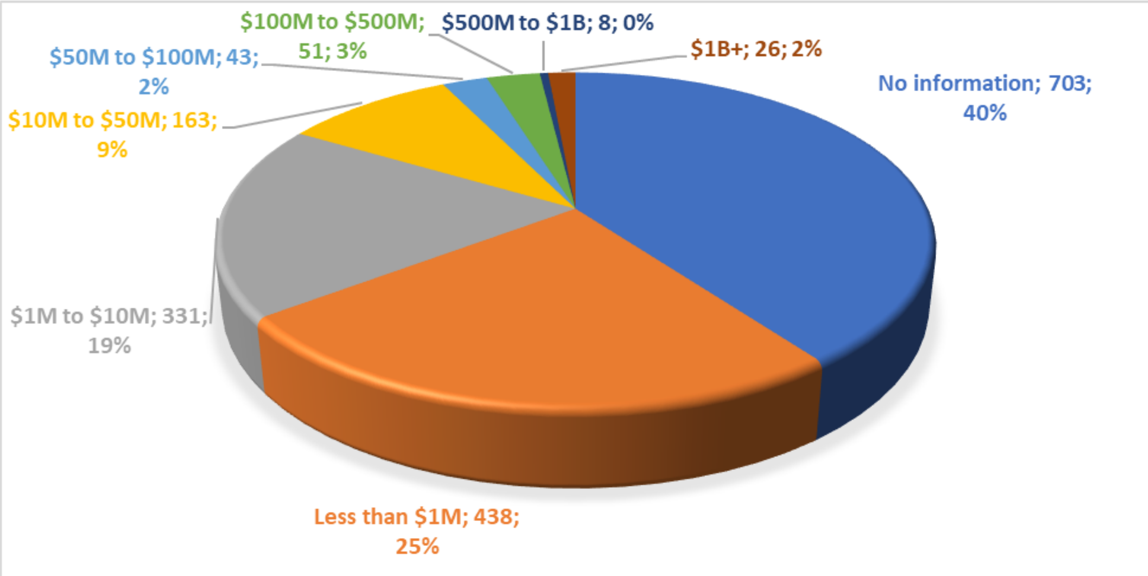


Figure 5.9: Share of companies listed in Amadeus mentioning Open Source per turn over class (n= 703) (source: Amadeus)

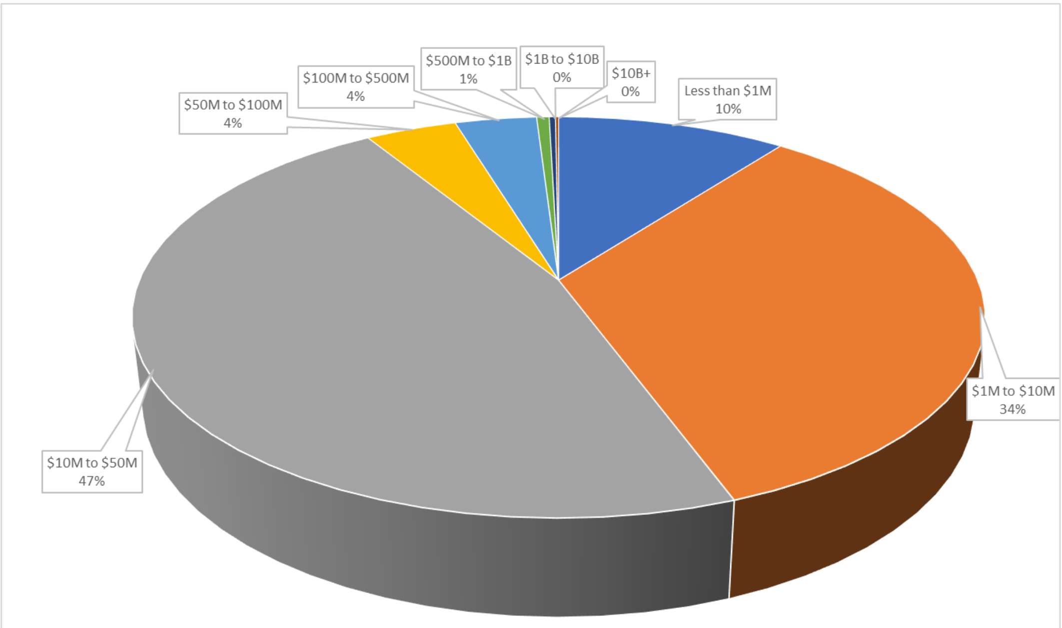


Figure 5.10: Share of companies contributing to GitHub in EU Member States per employee class (n = 1763)

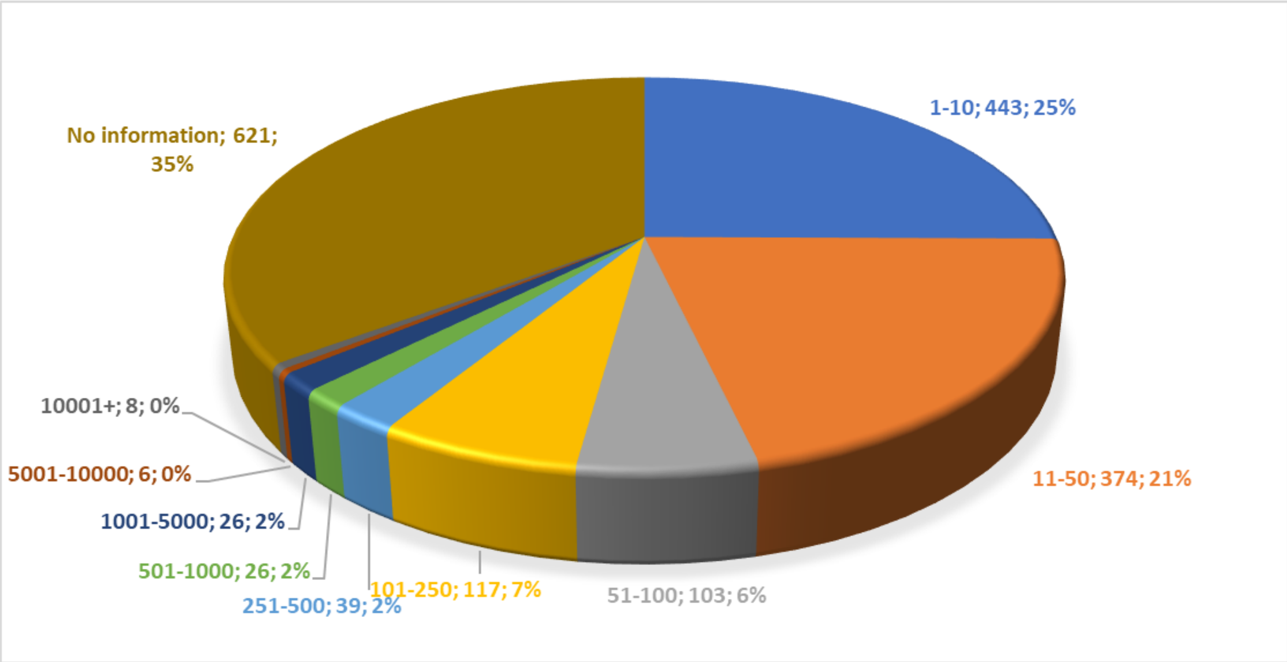


Figure 5.11: Share of companies listed in Amadeus mentioning Open Source per employee class (n = 972) (source: Amadeus)

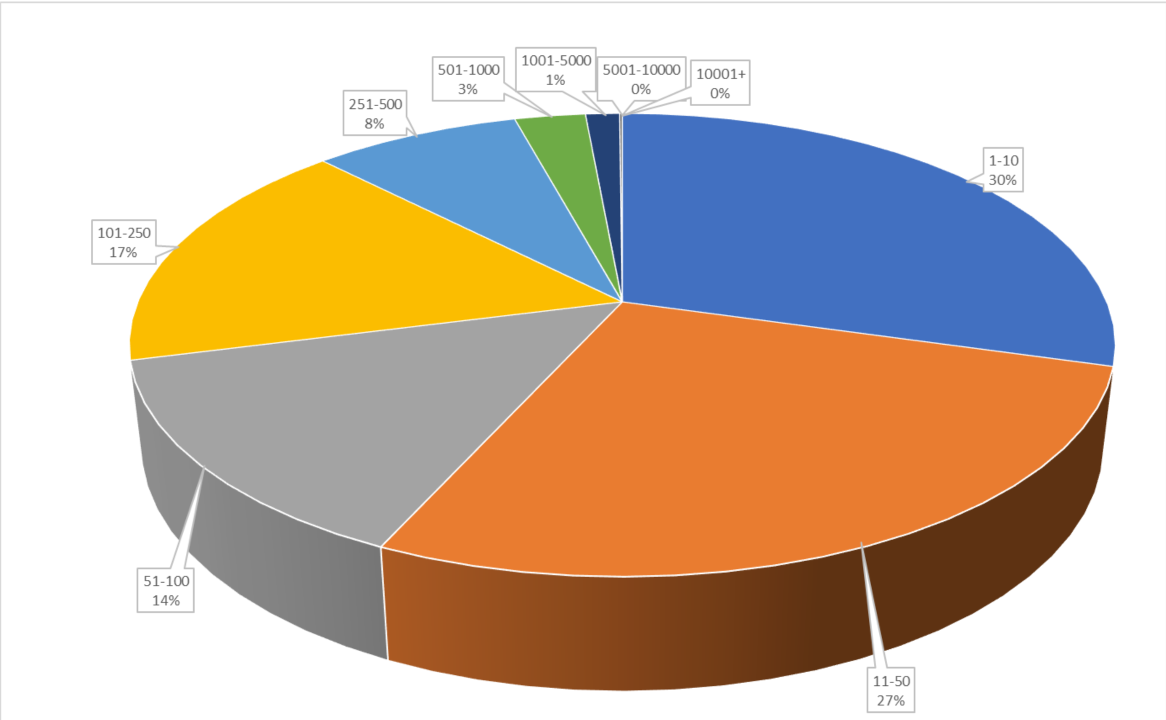


Figure 5.12: Share of companies contributing to GitHub in EU Member States per sector (n = 1763)

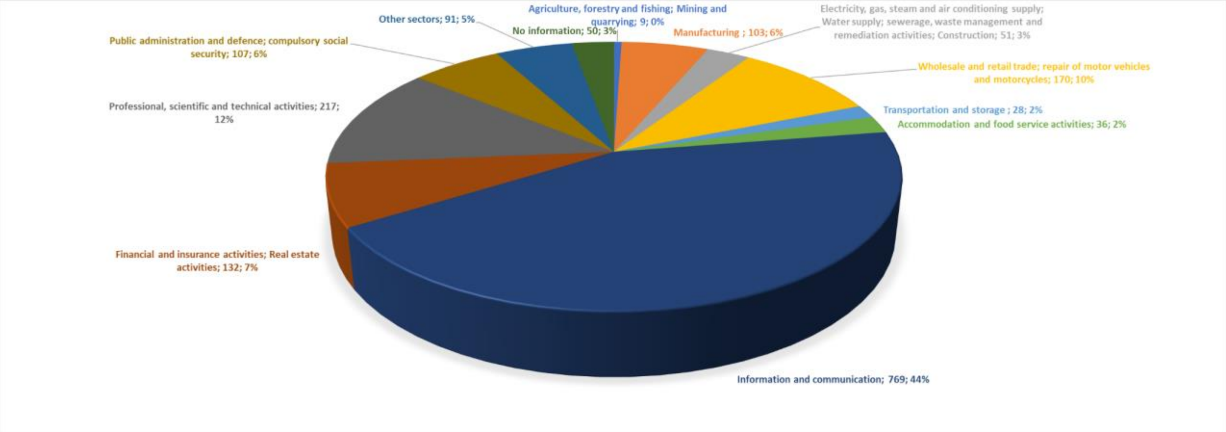
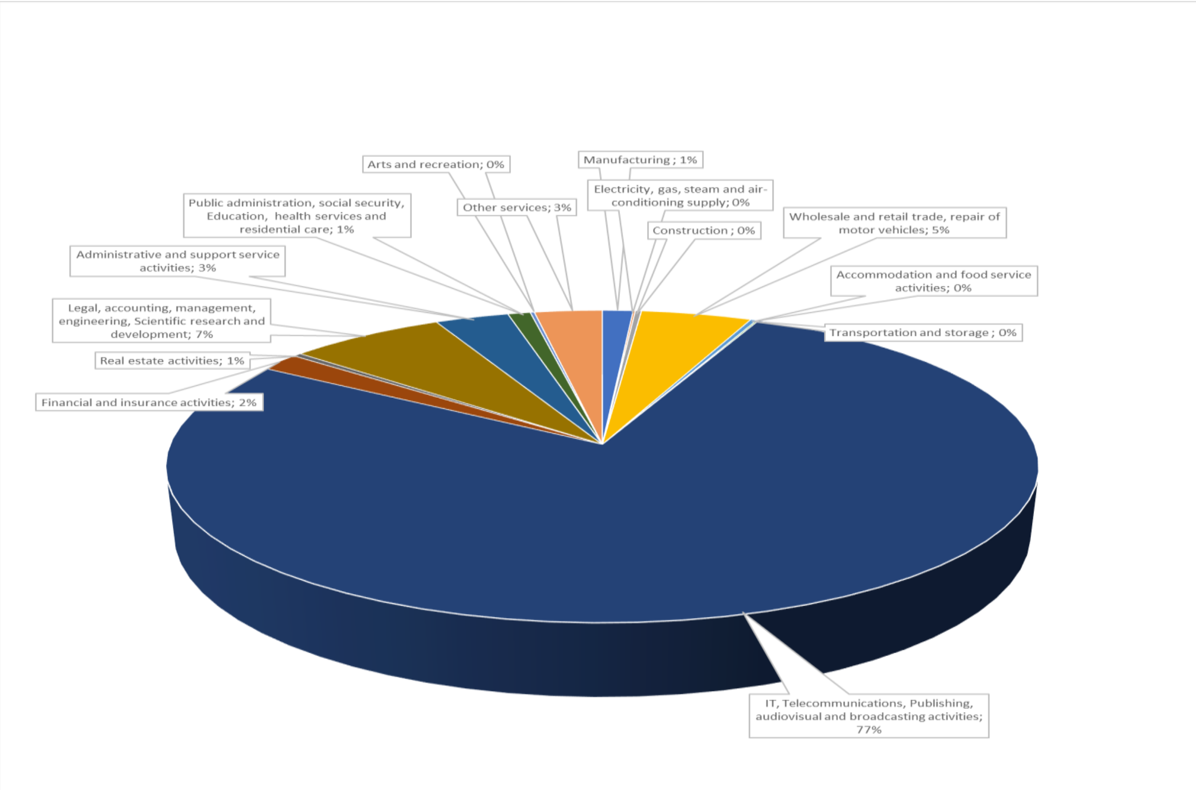


Figure 5.13: Share of companies listed in Amadeus mentioning Open Source per sector (n = 1151) (source: Amadeus)



Contributions of companies located in the EU to Open Source Software

Complementary to the determination of the efforts to OSS based on the number of contributors and commits to GitHub at the level of the EU Member States, also the investments of the major contributing companies located in one of the EU Member States have been analysed on the micro level. This is complementary to the analysis of contributions at the EU Member State level in the previous chapter.

This sample of the most active companies in GitHub in 2018 based on the number of contributors is responsible for more than 12% of the contributors, i.e. more than 30,000 out of 260,000, and even for more almost one third of the commits, i.e. one million out of three million. This relationship makes sense, because of the focus on top 10,000 organisations with the highest numbers of accounts, which due to their size and due to economies of scale are more likely to submit more commits per account to GitHub. Finally, the companies employ slightly more than one million employees, which is around one third of all employees in the computer programming sector in the EU. For comparison, a global sample of companies making the most contributions to OSS in 2005 employed slightly more than half a million employees generating a revenue of €263 billion (Ghosh 2006). Therefore, it can be claimed that the sample is representative for the companies in the EU Member States contributing to OSS, in particular to GitHub. However, the high share of almost one third of the commits from the EU by these companies indicate a bias to companies being very active in contributing code to OSS. This analysis based on companies allows us to differentiate the efforts and related costs invested in OSS further by the size of the companies and the sectors they are active in.

Overall, a high share of small companies among the most active companies participating in OSS has been observed. If the companies are differentiated by size based on the number of employees, a rather robust pattern can be found. The smaller the companies active in OSS, the more contributors are listed in GitHub, the more commits they provide and the more efforts they invest. The companies with less than 10 employees have more contributors than employees. This can be explained by the fact that these micro companies have several accounts per employee. However, the employment data in Amadeus might be also not always up to date. Overall, the companies with up to 50 employees are responsible for almost half of the contributors or accounts at GitHub within the sample.

The contributors or accounts per company is only slightly increasing with company size only starting with companies with more than one thousand employees. Overall, the whole sample of top contributing companies have on average slightly below 20 contributors or accounts per company. Looking at the ratio of contributors per employee, a clearly declining trend can be observed with increasing company size, which makes completely sense. In total, 2.7% of the employees in the sample of companies are contributing to OSS in GitHub. This value is lower than the 8% related to the employees in the computer programming sector at the EU Member State level, which is not considering the employees in other sectors contributing to GitHub.

In a second step, also the commits to GitHub provided by the companies in the sample are investigated, because they reflect real effort in contrast to the number of contributors. However, almost half of the commits have been provided by companies with up to 50 employees. The commits per company are around five thousand for most size classes with the exception of the very large companies. Again, the commits per employees are sharply declining with the number of employees. On average the employee in the sample contributes 8 commits in 2018, which is slightly less than the 10 commits based on the number of the EU level considering again only the computer programming sector.

Table 5.39: Contributors to GitHub in the sample of companies differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Contributors in 2018	Contributors/company	Contributors/ employee
1-10	474	1,611	7,891	17.813	4.898
11-50	381	9,885	6,319	16.896	0.639
51-100	104	7,656	2,196	21.320	0.287
101-250	119	18,044	2,442	20.872	0.135
251-500	39	13,750	1,030	26.410	0.075
501-1,000	27	17,757	554	21.308	0.031
1,001-5,000	26	54,246	1,052	40.462	0.019
5,001-10,000	6	44,252	90	15.000	0.002
10,001+	8	978,315	554	69.250	0.001
No information	623		9,130	14.702	
Sum	1,763	1,145,516	31,258	17.730	0.027

Table 5.40: Commits to GitHub in the sample of companies differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Commits in 2018	Commits/ company	Commits/ employee
1-10	474	1,611	2,366,997	5,343.108	1,469.272
11-50	381	9,885	2,243,612	5,998.963	226.971
51-100	104	7,656	799,523	7,762.359	104.431
101-250	119	18,044	496,543	4,243.957	27.518
251-500	39	13,750	212,334	5,444.462	15.442
501-1,000	27	17,757	91,351	3,513.500	5.145
1,001-5,000	26	54,246	255,810	9,838.846	4.716
5,001-10,000	6	44,252	27,787	4,631.167	0.628
10,001+	8	978,315	74,876	9,359.500	0.077
No information	623		2,997,579	4,827.019	
Sum	1,763	1,145,516	9,566,412	5,426.212	8.351

Finally, the effort necessary for each company in the sample to write the code is calculated based on the assumption that commits are only one line of code following Nagle (2019a) that the modal number of lines of code per commit is generally 1. Since the calculated effort is highly correlated with the number of commits, the same pattern is found. Since the effort is measured in person-months, in the micro companies can be observed, that a high share of time is devoted to contributions to OSS. If the companies between eleven and one hundred employees are taken, 5% of the full-time equivalents spend their time on Open

Source. In the whole sample, it is below 0.3% and again below the 0.5% generated in the analysis of the EU level, where only the employees in computer programming are taken as reference. In addition, our sample is characterised by quite large companies, e.g. including Telefonica or SAP, compared to the overall industry distribution of company size characterised by more than 90% micro companies.

Table 5.41: Efforts in years spent for commits to GitHub in the sample of companies differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Effort in 2018	Effort/ company	Effort/ employee
1-10	474	1611	807.871	1.82364	0.50147
11-50	381	9885	758.727	2.02868	0.07676
51-100	104	7656	288.289	2.79893	0.03766
101-250	119	18044	153.908	1.31545	0.00853
251-500	39	13750	69.074	1.77112	0.00502
501-1,000	27	17757	27.229	1.04726	0.00153
1,001-5,000	26	54246	85.601	3.29233	0.00158
5,001-10,000	6	44252	8.580	1.42992	0.00019
10,001+	8	978315	24.672	3.08402	0.00003
No information	623		989.273	1.59303	
Sum	1,763	1,145,516	3213.224	1.82259	0.00281

After the analysis of the sample of companies contributing to GitHub by company size, they are differentiated by sector following NACE 2. The companies are grouped in some sectors together in order to have a sufficient number of companies in a group. First, almost half of the companies in Information and Communication are also responsible for more than half of the contributors followed by companies conducting professional, scientific and technical activities. The wholesale and retail trade and the financial sector are also quite active followed by the manufacturing sector, which has a share of less than 10% among all contributors. Overall, the number of contributors per company is quite similar between the sectors varying around the overall average of 17 contributors per company.

Table 5.42: Contributors to GitHub in the sample of companies differentiated by sector in 2018

Sectors (NACE 2)	Number of companies	Contributors in 2018	Contributors/ company
Agriculture, forestry and fishing; Mining and quarrying	9	188	20.89
Manufacturing	103	1,950	18.93
Electricity, gas, steam and air conditioning supply; Water supply; sewerage, waste management and remediation activities; Construction	51	1,609	31.55
Wholesale and retail trade; repair of motor vehicles and motorcycles	170	2,761	16.24
Transportation and storage	28	422	15.07
Accommodation and food service activities	36	651	18.08
Information and communication	769	13,758	17.89
Financial and insurance activities; Real estate activities	132	2,837	21.49
Professional, scientific and technical activities	217	3,656	16.85
Public administration and defence; compulsory social security	107	1,711	15.99
Other sectors	91	1,216	13.36
No information	50	754	15.08
Sum	1,763	31,513	17.87

The distribution of commits among the sectors is quite similar to the pattern based on contributors. The average number of commits of around five thousand per company is also quite similar between the sectors, but with almost ten thousand by manufacturing companies.

Finally, the analysis of the effort by the company reveals the same pattern based on the commits. One average the companies in the sample invest almost two full-time equivalents in 2018 to make contributions to GitHub.

Table 5.43: Commits to GitHub in the sample of companies differentiated by sector in 2018

Sectors (NACE 2)	Number of companies	Commits in 2018	Commits/ company
Agriculture, forestry and fishing; Mining and quarrying	9	61,964	6,884.89
Manufacturing	103	975,009	9,466.11
Electricity, gas, steam and air conditioning supply; Water supply; sewerage, waste management and remediation activities; Construction	51	279,428	5,478.98
Wholesale and retail trade; repair of motor vehicles and motorcycles	170	856,182	5,036.36
Transportation and storage	28	157,886	5,638.79
Accommodation and food service activities	36	162,710	4,519.72
Information and communication	769	3,846,231	5,001.60
Financial and insurance activities; Real estate activities	132	1,147,348	8,692.03
Professional, scientific and technical activities	217	1,280,853	5,902.55
Public administration and defence; compulsory social security	107	494,598	4,622.41
Other	91	194,893	2,141.68
No information	50	270,140	5,402.80
Sum	1763	9,727,242	5,517.44

Table 5.44: Effort in years to GitHub in the sample of companies differentiated by sector in 2018

Sectors (NACE 2)	Number of companies	Effort in 2018	Effort/ company
Agriculture, forestry and fishing; Mining and quarrying	9	19.6	2.18
Manufacturing	103	347.0	3.37
Electricity, gas, steam and air conditioning supply; Water supply; sewerage, waste management and remediation activities; Construction	51	93.1	1.83
Wholesale and retail trade; repair of motor vehicles and motorcycles	170	270.5	1.59
Transportation and storage	28	49.1	1.75
Accommodation and food service activities	36	50.3	1.40
Information and communication	769	1269.1	1.65
Financial and insurance activities; Real estate activities	132	415.6	3.15
Professional, scientific and technical activities	217	442.5	2.04
Public administration and defence; compulsory social security	107	154.5	1.44
Other	91	55.3	0.61
No information	50	95.7	1.91
Sum	1763	3262.3	1.85

In a final step, it focused on the companies in Information and Communication and analyse them by company size. Overall, the same pattern is found as for all companies. In detail, the micro and small companies are responsible for a significant share of contributors and commits. This bias towards small companies can be detected both in the overall sample and the subsample of companies active in Information and Communication.

However, the focus on the sector Information and Communication allows a comparison with the analysis based on the EU Member States level, where it is referred to the computer programming sector as a reference. At the EU level, 8% of the employees contribute to OSS taking the number of employees in the computer programming sector as reference. In the subsample of the most active companies in Information and Communication, the value is just above 6%. However, the number of commits per employee at the macro level is slightly below 10, whereas in the sample of the most active companies it is 16, which underlines their strong engagement in contributing code to GitHub.[18] The effort per employee is also quite similar, which underlines the validity of the approach, because both the top down and the bottom up approach come to quite similar results.

[18] The difference between the ratio based on the commits and the efforts based on using COCOMO II can be explained by the non-linear effort function, i.e. the higher the number of lines of code or commits the higher the required effort due to the above average increasing complexity of coding.

Overall, this cost-based analysis has revealed the pattern of investments in OSS by the EU Member States, but also by the sectors and the company size based on the sample of the most active contributors to GitHub.

Table 5.45: Contributors to GitHub in the subsample of companies in Information and Communication differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Contributors in 2018	Contributors/company	Contributors/ employee
1-10	157	644	1,081	6.89	1.679
11-50	217	5,931	3,474	16.01	0.586
51-100	66	4,807	1,548	23.45	0.322
101-250	72	11,361	1,426	19.81	0.126
251-500	18	6,500	432	24.00	0.066
501-1,000	12	7,980	283	23.58	0.035
1,001-5,000	13	27,300	802	61.69	0.029
5,001-10,000	2	12,281	21	10.50	0.002
10,001+	3	120,287	92	30.67	0.001
No information	209		2,881	13.78	
Sum	769	197,091	12,040	15.66	0.061

Table 5.46: Commits to GitHub in the subsample of companies in Information and Communication differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Commits in 2018	Commits/ company	Commits/ employee
1-10	157	644	331,125	2,109.08	514.17
11-50	217	5,931	977,426	4,504.27	164.80
51-100	66	4,807	621,889	9,422.56	129.37
101-250	72	11,361	306,496	4,256.89	26.98
251-500	18	6,500	124,817	6,934.28	19.20
501-1,000	12	7,980	42,389	3,532.42	5.31
1,001-5,000	13	27,300	160,985	12,383.46	5.90
5,001-10,000	2	12,281	2,048	1,024.00	0.17
10,001+	3	120,287	18,260	6,086.67	0.15
No information	209		775,073	3,708.48	
Sum	769	197,091	3,360,508	4,369.97	17.05

Table 5.47: Efforts in years spent for commits to GitHub in the subsample of companies in Information and Communication differentiated by company size in 2018

Size classes	Number of companies	Employees (sum)	Effort in 2018	Effort/ company	Effort/ employee
1-10	157	644	122.16	0.78	0.18968
11-50	217	5,931	315.95	1.46	0.05327
51-100	66	4,807	233.20	3.53	0.04851
101-250	72	11,361	94.09	1.31	0.00828
251-500	18	6,500	42.27	2.35	0.00650
501-1,000	12	7,980	12.66	1.06	0.00159
1,001-5,000	13	27,300	56.05	4.31	0.00205
5,001-10,000	2	12,281	0.54	0.27	0.00004
10,001+	3	120,287	5.74	1.91	0.00005
No information	209		237.57	1.14	
Sum	769	197,091	882.66	1.46	0.00448

Correlations between companies' investment in Open Source Software and turnover

In the analysis of the cost related to the investment into OSS at the EU Member States level, a positive correlation with the turnover per employee in the computer programming sector could be revealed. In order to validate this positive link at the level of EU Member States, which is not necessarily a causal relationship, the costs of individual companies related to their investment in OSS are linked to their total turnover and their turnover per employee. In particular, the latter is a measure of the benefits of OSS, which covers both the cost-saving and the revenue enhancing effect as presented by IDC (2019) and Nagle (2018) for Linux.

At first, no significant positive correlation can be found between the number of contributors or commits per company on the one side and the turnover or the turnover per employee on the other side. Therefore, in a second step, it is controlled in a simple multivariate model with all variables in logarithms for company size based on the number of employees (Empl), the sector and the country.

This approach reveals with companies' operating revenue as dependent variable the following result. For all three cost variables, a positive relationship can be observed. However, only the coefficient related to the number of contributors to GitHub is significant, but not the number of commits or the related efforts. It is acknowledged that other explanatory variables, like capital, are missing and that causality cannot be claimed, because of missing time series and a clear identification strategy. However, the positive link between the investment in OSS and output, measured as GDP, already revealed at the level of the EU Member States can be confirmed. Therefore, it can be assumed that this positive link, found at the macro level, is also present at the micro level as already shown by Nagle (2018).

Since logarithmic values are used, the coefficient of 0.158 can be interpreted as elasticity.Under very simplistic assumptions, an increase of 1% in the number of contributors increases companies' turnover by 0.158%. The elasticity in the macroeconomic model based on the contributors revealed the value of 0.064, i.e. if the number of contributors to OSS in the European Member States would be increased by 1%, GDP would increase by 0.064%. Overall, similar ranges of impacts both on companies' turnover at the micro level and on EU Member States' GDP can be observed.

Table 5.48: Results of regression analyses

VARIABLES	(1)	(2)	(3)
lnContributors	0.158***		
	(0.0492)		
lnCommits		0.0207	
		(0.0282)	
lnEffort			0.0190
			(0.0263)
lEmployment	0.997***	1.015***	1.015***
	(0.0258)	(0.0260)	(0.0260)
Sector dummies	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes
Observations	744	731	731
R-squared	0.849	0.849	0.849
N	744	731	731
R2	0.849	0.849	0.849
Log likelihood	-1097	-1082	-1082

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The regression analysis are replicated also with the turnover per employee as dependent variable, because this would include both the turnover enhancing and the cost saving impact of contributing and using OSS. However, the approach did not reveal any significant results.

Summary of the cost based impact analysis

In summary, the analysis of the sample of European companies being the most active organisations in GitHub in 2018 complements the analysis based on the Member State level and reveals several additional insights. First, the engagement of companies in OSS can be quantified based on the number of contributors, commits and efforts. The differentiation of companies in the sample by size reveals that the smaller the companies are, the higher is their relative investment into Open Source. This is an important insight, which is relevant for the derivation of policy implications. Second, the differentiation of the companies into sectors confirms on the one hand the dominant role of the Information and Communication sector, but also reveals the relevance of the other sectors, e.g. companies conducting professional, scientific and technical activities. The actual involvement of the companies in contributing to Open Source in the manufacturing sector leaves obviously still some room for expansion. However, the level of involvement differs not very much between the sectors. The company size bias is the striking pattern across all sectors and also just looking at the companies active in the Information and Communication.

Finally, there is a positive correlation between the investment into OSS and companies' turnover per employee at the macro level of the EU Member States. This ratio encompasses both the labour cost saving and the revenue enhancing effect of contributing to or using OSS. At the level of our sample of companies, it is revealed only a significant positive link between the number of contributors to GitHub and companies' turnover, but not when relied on the number of commits and the related effort. The turnover per employee is not positively correlated with any indicator, i.e. the number of contributors, commits or the effort, at the micro level of our sample.

Although this approach has revealed new and robust insights from the cost perspective, the benefits of contributing and using OSS are not well covered by the available data. Therefore, in the stakeholder survey, also questions are included related to the nature and market size of OSS and OSH and the related business models, which contribute to a completion and validation of the data-based approach generated findings. In particular, additional information about the revenue based on OSS, but more importantly also other not immediately revenue creating benefits allow us to interpret the quantification of the benefits and eventually confirm the so far revealed cost-benefit ratios.

e. Summary of the economic impact analysis

The analyses of the economic impact of OSS faces at first the challenge of limited data both about the production and stock of OSS code and in particular its use, impacts and benefits. Consequently, they are focused on the available data on the production of OSS code, because here it can be differentiated both between contributions per country and per organisation. Based on previous studies it can be assumed that the producers of OSS code are also using it actively. Furthermore, the benefits, e.g. related to productivity, for companies actively contributing to OSS is significantly higher than for those just using the OSS code produced by others (e.g. Hecht 2020). Therefore, it is expected that the cost for investing into OSS development is not only covered by the benefits, e.g. increase in revenues or productivity, but significantly outweighed.

In the first step, macroeconomic time series models have been set up based on EU Member States and some other relevant OSS active countries to identify the influence of the contributions and investments into OSS on various impact dimensions. It is started with its impact on the GDP of the EU and find a significant influence of the contributions by the Member States. Eventually, it is possible to quantify the impact on GDP ranging between €60 and 95 billion in 2018. Complementary, the labour productivity within the EU Member States is not only benefitting from the global pool of OSS code, but also the national contributions to GitHub.

International competitiveness measured by exports or Trade in Value added, but also the economic complexity of countries, i.e. the diversity and complexity of their export portfolio, is strengthened by national contributions to OSS, but challenged by the global pool of OSS is challenging the export performance.

The link between OSS and innovation measured by various indicators is rather weak. The frequent marginal contributions to OSS code as a form of incremental innovation are difficult to link to radical innovation, e.g. required for patents to be granted. However, OSS is a driving force for start-ups in information technology. Based on the results of the model by Wright et al. (2020) covering more than 180 countries, a 10% increase of commits to GitHub by the EU Member States will generate almost one thousand additional start-ups in information technology in the EU. Finally, no robust positive influence of contributions to OSS on employment in general and in IT in particular can be observed, which can be explained by the ambivalent effect of OSS of not only generating additional revenue requiring additional employees, but also saving own software developers.

Overall, based on our results, it can be observed that OSS is pushing growth, mainly driven by positive productivity and competitiveness impacts. However, the relationship of OSS to innovation is rather ambivalent with the exception of its positive impact on start-up creation revealed by Wright et al. (2020). Finally, OSS is not necessarily a direct driver for increasing employment, but only indirectly via positive productivity and eventually competitiveness effects.

In a second step, the econometric macroeconomic analysis is complemented by a twofold cost-based impact analysis, which allows us at least the quantification of the efforts, because market prices for OSS are not existent and data on companies' revenues generated based on OSS are not available.

At first, it is started from the macroeconomic level of the Member States of the EU and quantify their efforts related to OSS. The overall efforts are eventually linked back to the results of the macroeconomic analyses, i.e. the contribution of OSS to GDP in the EU. Consequently, a range of the ratio of costs to benefits, i.e. additional GDP, for the EU can be determined.

Second, for the most active contributors to OSS located in the Member States of the EU the efforts, they invest in OSS, have been calculated. Complementary to the cost calculation for the Member States, this microeconomic company-based analysis reveals insights about the investments of companies in OSS both by company size and by sector. It has to be highlighted that in particular very active micro companies are responsible for a significant share of contributions to GitHub. Furthermore, about half of the investments come from companies in the Information and Communication sector. The other half is broadly distributed by service companies, but also some manufacturers. Linking the investments of these very active companies with their performance, i.e. turnover and turnover per employee, to address also the benefit side, does not reveal significant relations. Finally, the comparison of the costs between the macroeconomic and the microeconomic company-based approaches reveals rather consistent results, which confirms our overall approach.

However, both the macroeconometric and the cost-focused analyses still show some gaps or missing links. Therefore, further insights from the stakeholder survey are generated about the benefits of OSS in general and the revenue companies generate based on OSS in particular. Further findings from the survey conducted by the Linux Foundation's Core Infrastructure Initiative (CII) and the Laboratory for Innovation Science at Harvard (LISH) can be used. The results of these two, but also other surveys help to validate our findings on impacts in general and in particular the cost-benefit ratios found so far.

f. Open Source Hardware companies

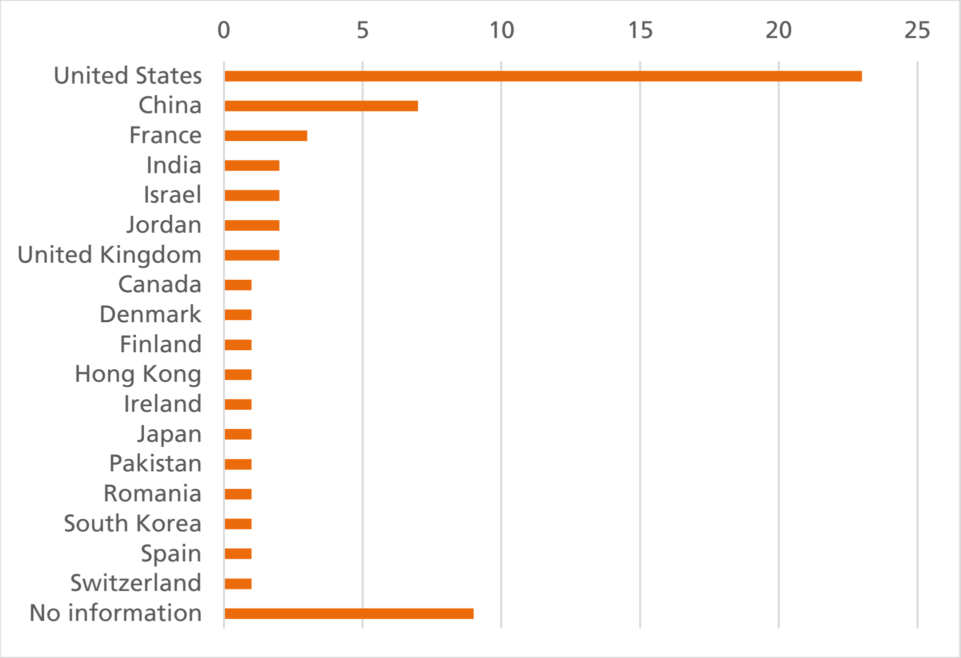
Introduction

In contrast to the broad and detailed data incl. time series about companies active in OSS, there is little information about companies being engaged in OSH. For example, whereas in the database of European companies almost one thousand companies referencing "Open Source" in their description can be found, there is with the exception of the RISC-V Foundation, which relocated as RISC-V International as Swiss nonprofit business association to Switzerland in 2020. Therefore, in the first step it is focused on the start-ups in this area, before a certification platform for OSH products is investigated.

Start-ups

A search for "Open Source Hardware" in Crunchbase reveals globally only 61 companies. Only eight of them have their headquarters in the EU.

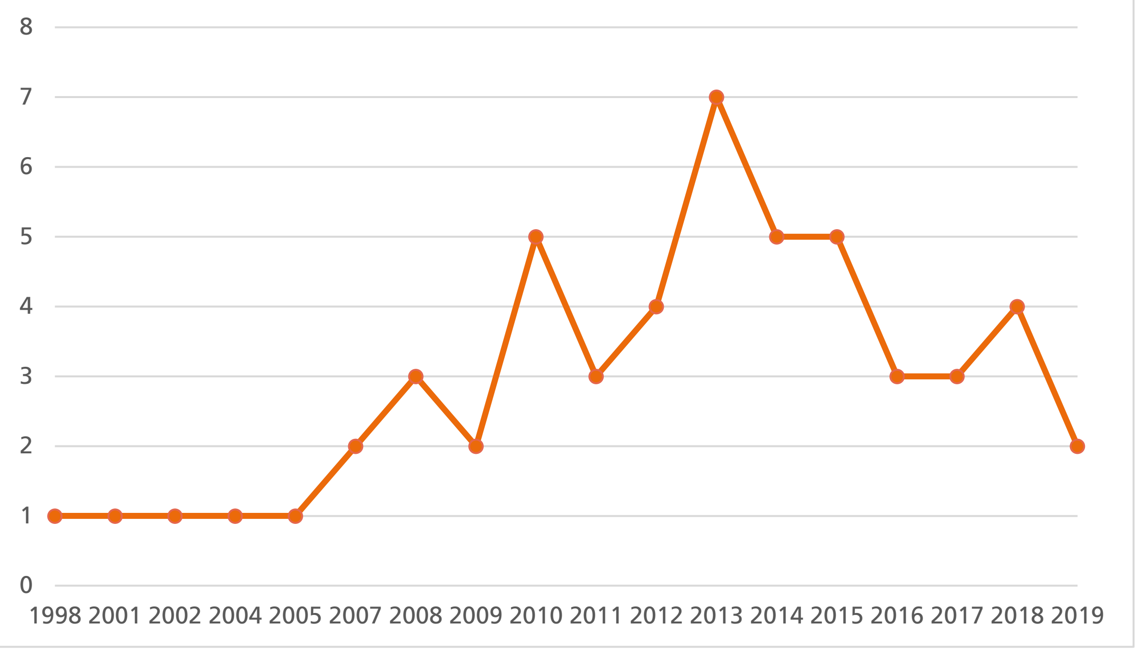
Figure 5.14: Number of companies listed in Amadeus mentioning Open Source Hardware per country (n = 61) (source: Crunchbase)



Looking at the year of foundation, some dynamic development up to 2013 can be observed. Since then, however, a declining number of companies founded based on OSH can be seen. Despite the shortcomings of the data quality of Crunchbase, e.g. by not including yet all recently funded companies, these figures cannot confirm a dynamic positive development.

The limited growth among companies based on OSH can also be confirmed by the share of more than 75% of companies having less than 50 employees. More than half of the 61 companies do not provide information about their revenue. Among the other half, one third has revenues below $1 million and the other two third between $1 and $10 million, which is also an indication for their limited growth potential.

Figure 5.15: Number of companies listed in Crunchbase mentioning Open Source Hardware per year of foundation (n = 61)



Finally, a look is taken at the industries, the start-ups are attributed to. In addition to the combination between hardware and software, a significant list of companies in the consumer electronics area can be observed. Manufacturing is mentioned by one sixth of the start-ups. Overall, the list of industries and their combination suggest a broad diversity of sectors and also the convergence between hard- and software in various fields of applications.

Figure 5.16: Number of companies listed in Crunchbase mentioning Open Source Hardware differentiated by number of employees (n = 61)

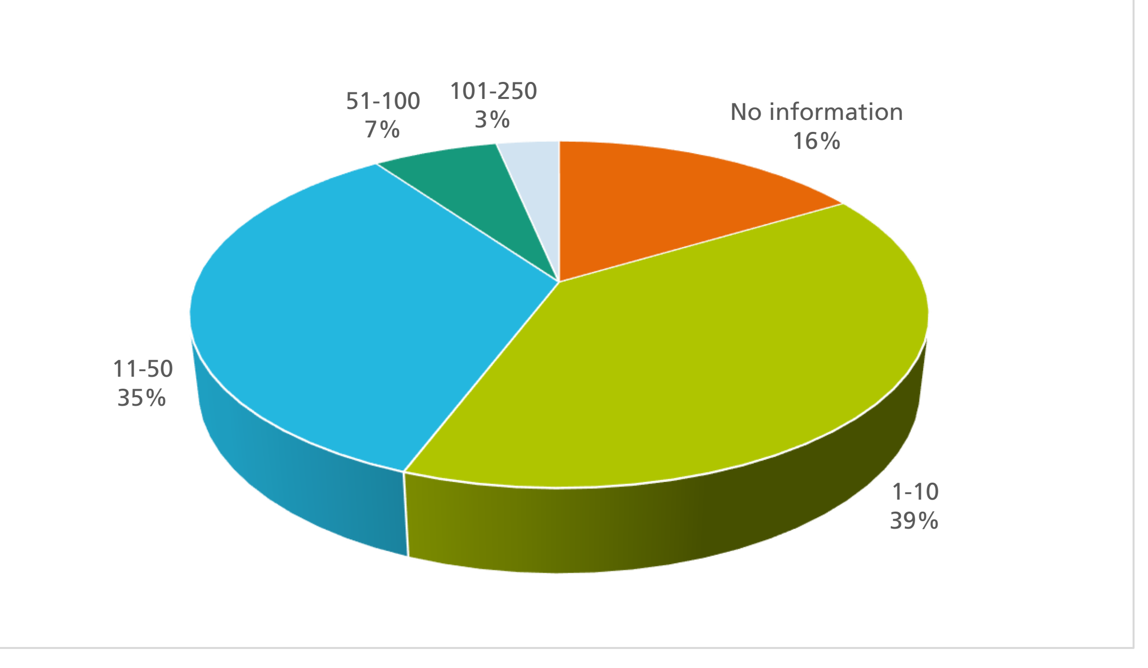


Table 5.49: Industry groups of start-ups in Crunchbase mentioning Open Source Hardware (n = 61)

Industry Groups	n
Hardware, Internet Services, Software	6
Hardware, Software	6
Hardware, Information Technology, Software	3
Education, Hardware, Software	2
Hardware	2
Hardware, Information Technology, Internet Services, Software	2
Software	2
Agriculture and Farming, Artificial Intelligence, Community and Lifestyle, Data and Analytics, Food and Beverage, Hardware, Health Care, Internet Services, Science and Engineering, Software	1
Agriculture and Farming, Food and Beverage, Software	1
Commerce and Shopping, Consumer Electronics, Consumer Goods, Hardware, Internet Services, Manufacturing	1
Commerce and Shopping, Consumer Electronics, Hardware	1
Commerce and Shopping, Consumer Goods, Content and Publishing, Design, Manufacturing, Media and Entertainment, Mobile, Software	1
Commerce and Shopping, Consumer Goods, Software	1
Commerce and Shopping, Hardware, Manufacturing, Science and Engineering	1
Community and Lifestyle, Consumer Electronics, Consumer Goods, Hardware, Internet Services, Science and Engineering, Software	1
Community and Lifestyle, Hardware, Software	1
Community and Lifestyle, Internet Services	1
Community and Lifestyle, Manufacturing	1
Consumer Electronics, Consumer Goods, Education, Hardware, Internet Services, Software	1
Consumer Electronics, Consumer Goods, Hardware, Manufacturing	1
Consumer Electronics, Consumer Goods, Hardware, Science and Engineering	1
Consumer Electronics, Design, Hardware, Manufacturing, Software	1
Consumer Electronics, Education, Hardware, Manufacturing, Science and Engineering	1
Consumer Electronics, Hardware	1
Consumer Electronics, Hardware, Information Technology, Software, Transportation	1
Consumer Electronics, Hardware, Manufacturing	1
Consumer Electronics, Hardware, Science and Engineering, Software	1
Content and Publishing, Education, Media and Entertainment	1
Content and Publishing, Hardware, Media and Entertainment	1
Energy, Software	1
Financial Services	1
Financial Services, Information Technology, Payments, Software	1
Hardware, Health Care, Information Technology, Internet Services, Professional Services, Software	1
Hardware, Information Technology, Internet Services, Privacy and Security, Software	1
Hardware, Internet Services, Manufacturing, Science and Engineering, Software	1
Hardware, Manufacturing	1
Hardware, Professional Services, Software	1
Hardware, Science and Engineering, Software, Sustainability	1
Hardware, Software, Transportation	1
Health Care	1
Information Technology	1
Information Technology, Software	1
Manufacturing	1
Transportation	1
No information	1

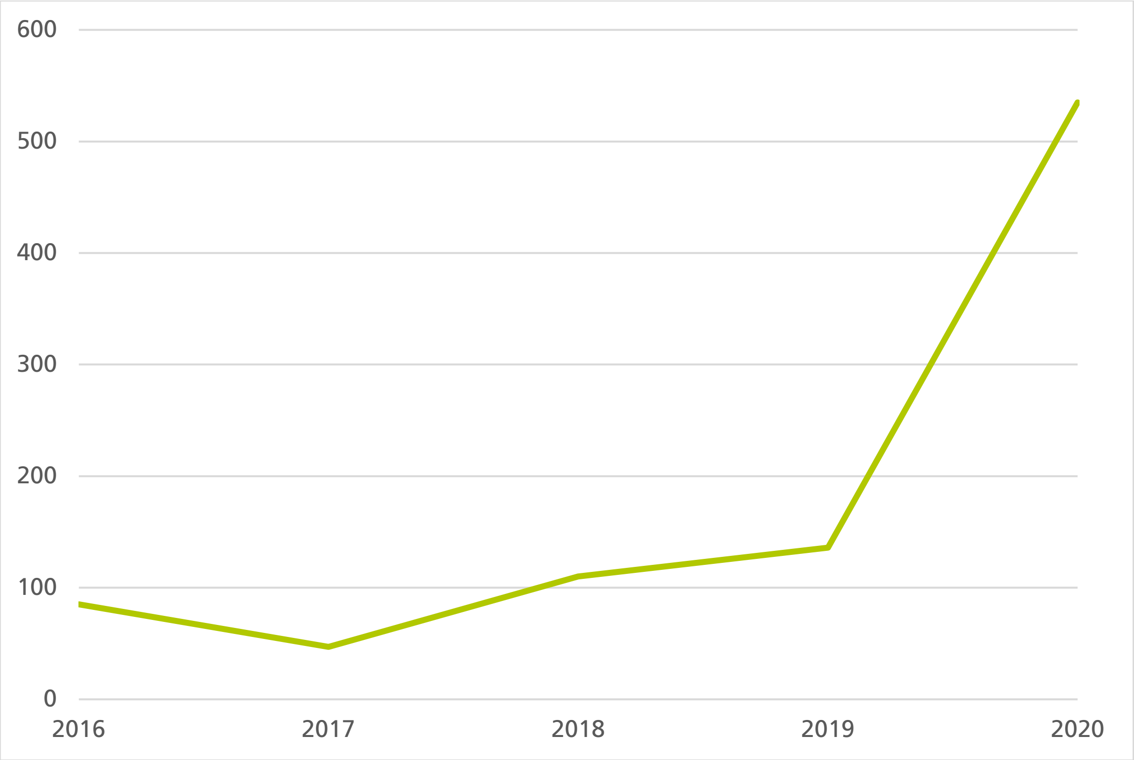
Certifications

Finally, a quite new and not yet well established data source to characterise the companies active in the area of OSH is introduced.

OSHdata (https://oshdata.com/) is an independent project that launched in 2020, starting by taking a look back and generating a static report about the state of OSH ahead of the 10th Annual Open Hardware Summit in March 2020. According to OSHdata the OSH community is dynamic, growing, and still in its early days as a formal movement. OSHdata provides certifications for OSH projects. The following figures are based on OSHdata (2020) according to their licensing database (https://certification.oshwa.org/list.htm.l).

As of May 2020, there are over 900 certified projects from 37 countries. The number of certifications is increasing. Getting from 200 to 300 certified projects took nearly a year, but getting from 400 to 900 in 2020 took around six months. Nearly 60% of the certified products are available for sale at an average sale price of $211.47, though there is a big range here. The leading project category with almost 70% is electronics, which is confirming the distribution of industries of the companies listed in Crunchbase. However, there are only 10% projects about 3D printing, which is also not explicitly mentioned as an industry in the Crunchbase list.

Figure 5.17: Number of certifications of Open Source Hardware projects by year (Source: https://certification.oshwa.org/list.html)



The companies located in the Member States of the EU are second only to the United States in terms of the number of certified projects. European companies and creators have certified 205 different projects, versus 633 in the United States. Combined, they represent 90% of all certified projects worldwide.

The distribution of certifications across the EU is as expected led by the technology and manufacturing leaders of Germany. However, the Open Source Hardware capital of Europe is obviously Plovdiv in Bulgaria thanks to the outsized contributions from companies, like Olimex and ANAVI Technology, which put Bulgaria in second position close after Germany. Companies from all other listed EU Member States, like France or Spain, have ten or less certificates.

Figure 5.18: Number of certifications of Open Source Hardware projects by category (Source: https://certification.oshwa.org/list.html)

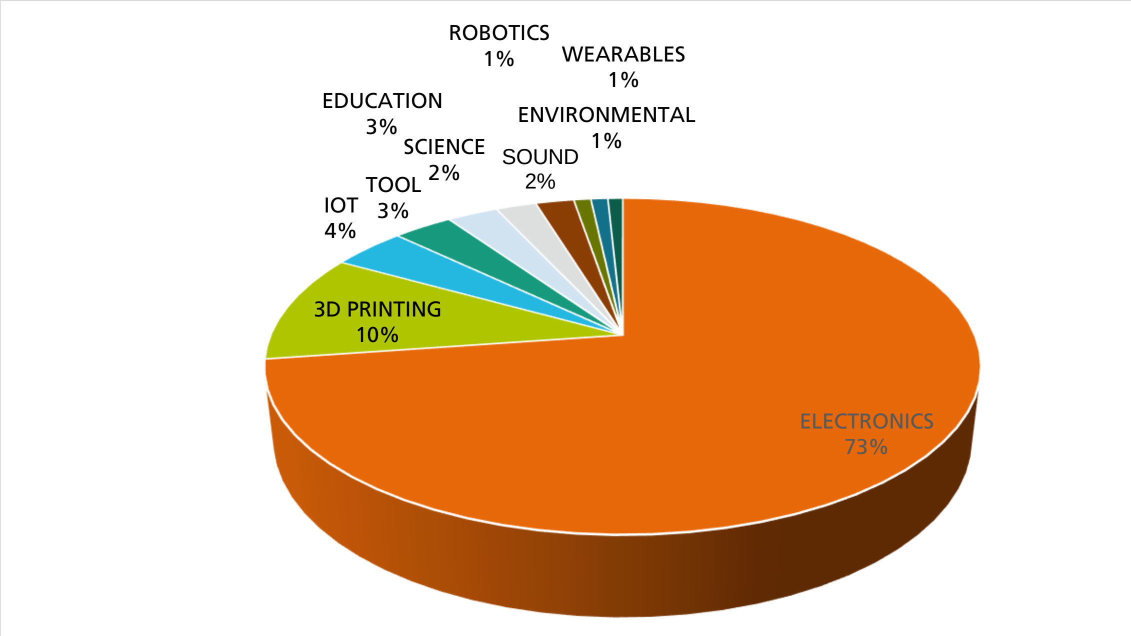


Table 5.50: Number of certifications of Open Source Hardware projects by EU Member States (Source: https://certification.oshwa.org/list.html in May 2020)

EU Member State	Total
Germany	72
Bulgaria	69
France	10
Spain	8
Switzerland	7
Poland	6
Italy	5
Sweden	5
Croatia	3
Greece	3
Belgium	2
Slovakia	2
The Netherlands	2
Austria	1

In the report by OSHdata (OSHdata 2020), it is highlighted that these statistics about certificates report do not cover companies which make products that meet the Open Source Hardware definition, but have not (yet) certified their products. Finally, they also admit that the certifications do not fully capture the OSS development that occurs in conjunction with OSH development.

Open Source Software foundations

Since OSS foundations play an important role for the development of OSS and have also economic impact, a recent overview of foundations generated by Cánovas (2020) is provided. He built a dataset composed of a number of foundations using different sources. First, he initially relied on the list of foundations available in flossfoundations.org, an online community created in 2005 by representatives from the Python, Apache Software, Perl and Free Software Foundation. The original aim was to share experiences and expertise in the field of free software and foundations. However, this list is outdated. Therefore, he complemented this list by incorporating additional foundations identified via other sources, like http://opensource.com and http://oss-watch.ac.uk.

For each foundation, they extracted its URL, the legal organisation type, the number of projects they cover (if any and publicly available) and a brief description. At the end of the search process, they eventually constructed a dataset composed of 89 foundations. Table 5.51 (see first two columns) shows the list of foundations collected reporting only aspects (a) and (c) due to space limitations.

Table 5.51: Open Software foundations (Source: Cánovas 2020)

NAME	URL	Size	SIZE RQ1	RQ2			RQ3
				GEO. DIST.	COVERAGE	MISSION	RQ4
Apache Software Foundation	http://www.apache.org/foundation/	312					
Associacao SoftwareLivre.org	http://associacao.softwarelivre.org/		X	n/a	n/a	n/a	n/a
Benetech	http://www.benetech.org/		X	n/a	n/a	n/a	n/a
BioBricks Foundation	http://bbf.openwetware.org/		X	n/a	n/a	n/a	n/a
Blender Foundation	http://www.blender.org/blenderorg/blender-foundation/			X		X	n/a
BSD Fund	http://bsdfund.org/				X		n/a
Creative Commons	http://creativecommons.org/		X	n/a	n/a	n/a	n/a
Django Software Foundation	http://www.djangoproject.com/foundation/	1					
Document Foundation	tp://www.documentfoundation.org/	1					
Dojo Foundation	http://dojofoundation.org/...				X	X	n/a
Eclipse Foundation	http://www.eclipse.org/org/foundation/	216					
El Centro de Software Libre Electronic Frontier Foundation	http://www.csol.org.			X		X	n/a
Free Knowledge Institute	http://www.eff.org/		X	n/a	n/a	n/a	n/a
Free Software and Open Source	http://freeknowledge.eu/		X	n/a	n/a	n/a	n/a
Foundation for Africa	http://www.fossfa.net/		X	n/a	n/a	n/a	n/a
Free Software Foundation	http://www.fsf.org/		X	n/a	n/a	n/a	n/a
Free Software Foundation Europe	https://fsfe.org			X	X		n/a
Free Software Foundation India	http://www.fsf.org.in/			X	X		n/a

Free Software Foundation Latin America	http://www.fsfla.org			X	X		n/a
FreeBSD Foundation	http://freebsdfoundation.org/		X	n/a	n/a	n/a	n/a
Fundación Via Libre	http://www.vialibre.org.ar/		X	n/a	n/a	n/a	n/a
Gentoo Foundation	https://www.gentoo.org/inside-gentoo/foundation/	1			.	. .	. .
GNOME Foundation	http://foundation.gnome.org/	1					
Identity Commons	http://idcommons.net/					X	n/a
Internet Systems Consortium	http://www.isc.org/	9				X	n/a
ITPUG (Italian PostgreSQL Users' Group)	http://www.itpug.org/index.en.html			X		X	n/a
JS Foundation	https://js.foundation				X		n/a
JPUG (Japanese PostgreSQL Users' Group)	http://postgresql.jp			X			
KDE e.V.	http://ev.kde.org/			X			
Linux Expo of Southern California	http://www.socallinuxexpo.org/			X		X	n/a
Linux Foundation	http://linux foundation.org/	67			X		n/a
Linux Fund	http://linuxfoundation.org/				X		
Linux International	http://www.li.org/					X	n/a
Linux Profesional Institute	https://www.lpi.org/		X	n/a	n/a	n/a	n/a
LogiLogi Foundation	http://foundation.logilogi.org/	1				X	n/a
Mambo Foundation Inc.	http://mambo-foundation.org/					X	n/a
Mozilla Foundation	http://www.mozilla.org/foundation/	9					
NetBSD Foundation	http://www.netbsd.org/donations/	1					
NLnet Foundation	http://www.nlnet.nl/			X			n/a
NLnet Labs Foundation	http://www.nlnetlabs.nl			X	X		n/a
NumFocus Inc.	https://www.numfocus.org/	43			X		n/a
One Laptop Per Child Association Inc.	http://www.laptop.org/		X	n/a	n/a	n/a	n/a
Open Hardware Foundation	http://www.openhardwarefoundation.org/		X	n/a	n/a	n/a	n/a
Open Health Tools	http://www.openhealthtools.org/					X	n/a
Open Media Now! Foundation	http://www.openmedianow.org/					X	n/a
Open Source Applications Foundation	http://www.osafoundation.org					X	n/a
Open Source Digital Voting Foundation	http://www.osdv.org/	1				X	n/a
Open Source For America	ittp://opensourceforamerica.org/about-osfa/our-mission/		X	n/a	n/a	n/a	n/a
Open Source Geospatial Foundation	attp://www.osgeo.org/content/foundation/abouthtml	32					
Open Source Initiative	http://opensource.org		X	n/a	n/a	n/a	n/a
Open Source Software Institute	http://www.ossinstitute.org/					X	n/a
OpenBSD Foundation	http://openbsdfoundation.org/.	7					

Open Education Consortium	http://www.oeconsortium.org/about-oec/		X	n/a	n/a	n/a	n/a
OpenDoc Society	http://www.opendocsociety.org/		X	n/a	n/a	n/a	n/a
OpenID Foundation	http://openid.net/foundation/		X	n/a	n/a	n/a	n/a
OpenSourceMatters	http://www.opensourcematters.org/	1					
Oregon State University Open Source Lab Alliance	http://osuoslorg/					X	n/a
Parrot Foundation	http://www.parrot.org/foundation	1					
Participatory Culture Foundation	http://pculfure.org/		X	n/a	n/a	n/a	n/a
Peer-Directed Projects Center (freenode)	http://freenode.net/pdpe.shtm		X	n/a	n/a	n/a	n/a
Plone Foundation	http://plone.org/foundation	1					
PostgreSQL Brasil	http://postgresql.org.br			X		X	n/a
PostgreSQLEurope	http://postgresql.et			X			n/a
PostgreSQLUS	http://postgresqlus	1		X			n/a
PostgreSQLFr.org	http://asso.postgresql.fr			X			n/a
Public Software Fund	http://www.pubsoft.org/	43				X	n/a
Python Software Foundation	http://www.python.org/psf/	1					
Shuttleworth Foundation	http://www.shuttleworthfoundation.org/		X	n/a	n/a	n/a	n/a
Software Freedom Conservancy	http://sfconservancy.org	46			X	X	n/a
Software Freedom Law Center	http://www.softwarefreedom.org/		X	n/a	n/a	n/a	n/a
Software in the Public Interest	http://www.spi-inc.org/	45			X		n/a
Software Libre Argentina	http://www.solatorg.at/			X			n/a
Software Libre Chile	http://www.softwarelibre.cl/			X			n/a
Software Livre Brasil	http://www.softwarelivre.org/			X		X	n/a
Subversion Corporation	http://subversionorg/				X		n/a
Symphony Software Foundation	https://symphony.foundation/	1					
TeX Users Group	http://tug.org/		X	n/a	n/a	n/a	n/a
The Open Planning Project	http://theopenplanningproject.org/					X	n/a
The Perl Foundation	http://perlfoundation.org/	1					
The Software Conservancy	http://www.tsc.org/		.			X	n/a
Twisted Software Foundation	http://twistedmatris com/trac/wild/TwistedSoftwareFoundation				X	X	n/a
TYPO3 Association	http://association.typo3.org/		.			X	n/a
Wikimedia Foundation	ittp://www.wikimediafoundationorg	1					
Wikiotics Foundation	https://wikiotices.org/en/Wikiotices_Foundation	1				X	n/a
Wordpress Foundation	http://wordpressfoundation.org	1				X	n/a
X.Org Foundation LLC	http://www.x.org/wiki/XorgFoundation	1					
Xiph.org	http://xiph.org/	23				X	n/a

XMPP Standards Foundation	https://xmpp.org/about/xmpp-standards-foundation.htm		X	n/a	n/a	n/a	n/a
Zope Foundation	http://foundation.zope.org/	1				X	n/a

In a first step, Cánovas (2020) concentrated on foundations with the goal to support the development of a specific set of software projects. Other foundations focusing on training, certification or evangelisation of OSS in general have been excluded. In Table 5.51, foundations showing a black square fall in the former category (and a cross for the rest). Eventually, 24 foundations were discarded at this stage by Cánovas (2020).

The other remaining 65 foundations are currently involved in more than 800 software projects. This is a low number in comparison to the number of projects being developed in OSS repositories, like GitHub, with more than 67 million of repositories (number taken from Octoverse https://octoverse.github.com/#community-overview though the number of real projects under active development is probably, at least, an order of magnitude smaller than that). However, some of the projects covered by these foundations are among the ones with most impact in OSS, like the projects of the Apache Software Foundation (e.g., the Apache Web Server), the Linux Foundation (e.g., Linux Kernel, one of the top 10 most GitHub forked projects) or the Symphony Foundation (e.g., Symphony project, also one of the top 10 projects in GitHub with most code participation of the community). Almost three quarters of the analysed foundations are specifically aimed at supporting OSS development efforts. Foundations not focused on software are mainly devoted to support and promote the OSS movement.

Important for our EU focused analysis is the geographical location of the foundations. Only 18 software foundations were mainly focused on the development of local OSS communities. For instance, the Free Software Foundation Europe, KDE e.V. and PostgreSQL Europe are three foundations whose activities focus on projects developed in Europe. Overall, the majority of foundations have an international scope and cannot be attributed to a specific region and country. This is an important characteristic, in particular to be considered when deriving the policy recommendations.

However, the role of contributions from the EU Member States to the three largest foundations are specified. Looking in detail at the contributions to the Linux foundation, it can be seen that the EU Member States contributed almost 20% of the kernel edition Linux-5.11 (2021-02-14) (http://www.remword.com/kps_result/index.php). However, in almost half of the contributions an attribution to a specific country is not possible. Therefore, the almost 30% of the respondents from the EU Member States to the survey by Nagle et al. (2020) reflects better their actual share of contributions to the Linux kernel.

However, in the ranking of the more than one hundred organisations contributing their works to this kernel release, no company among the top ten has a headquarter in an EU Member State. Here, the well-known US-based large companies, like Intel, Google, IBM and Oracle, are listed as well as the Chinese mobile communication company Huawei.

Consequently, the survey by Nagle et al. (2020) reveals concerns related to corporate influence in OSS foundations. It is suggested to assure greater transparency of corporate involvement to reduce accusations of hidden agendas. An additional requirement is for the governance of OSS projects to ensure paid contributors do not crowd out volunteer contributors and prevent a single company from dominating contributions to essential projects. Consequently, the majority of respondents to the survey requests to run OSS projects in foundations with neutral governance so that no single organization controls it.

The meanwhile European based Eclipse Foundation has in contrast to the Linux Foundation more than half of their corporate members located in Europe and even a higher share of European committers. In contrast to the more flexible governance of the Linux foundation, the governance is the same throughout the projects or communities of practice at the Eclipse Foundation.

Finally, the contributions to the Apache Foundation cannot be quantified. They provide only a map with their contributors at their homepage, which reveals a significant contribution from Europe.

Overall, the contributions from the EU to the largest foundations are in line with the findings from our analysis of GitHub commits and contributors. However, the Eclipse Foundations is in particular driven by companies and contributors located in the EU.

6. Results of the Stakeholder Survey

a. Objectives

The aim of the stakeholder survey was to gather and analyse the views of a broad set of stakeholders on the impact of OSS, but also OSH, hereby creating a robust empirical representation of the opinions and issues at stake. In addition, it is aimed to complement the results of the literature, data base and case study driven approaches to assess the impact of OSS and OSH with input from the respondents of the stakeholder survey. Altogether, this body of evidence is used to derive policy recommendations.

b. Methodology

The approach of designing the survey follows the state-of-the-art. It reflects our experiences with similar surveys about IPRs in ICT (Blind et al. 2011; Blind et al. 2017) or OSS and standardisation (Blind and Böhm 2019). The structure of surveys and questionnaires in the study area performed by other institutions, e.g. the University of Bern (2018), teknowlogy (2019), but in particular BITKOM (2020) are taken into account.

Based on the insights from the literature review, the case studies, which already followed a rather detailed interview guideline, the above-mentioned surveys and the insights from the economic analyses, the questionnaire was started to be designed in the summer 2020. The survey format is a mix of closed and open-ended questions, with an emphasis on the former. A first draft was distributed asking for feedback among the experts of the OFE, but also the European Commission. There have been several rounds of feedback until the questionnaire was finalised and put online using the lime survey tool at the beginning of September. The first deadline for responding to the questionnaire was the date of workshop of November 5th 2020. Eventually, the final deadline of the survey was November 20th 2020.

The final structure of the survey includes the following topics:

- Section A: Position of the person answering the questionnaire
- Section B: Basic economic information about the organisation (incl. position on software-hardware scale and business model, innovation activities, protection strategies)
- Section C: Involvement in Open Source communities (incl. type of participation, incentives, role of copyright licenses, differentiation by areas)
- Section D: Benefits and costs of OSSH
- Section E: Final comments

By the beginning of September, specific experts, but also the several mailing lists have been informed about the survey. Also Twitter was used to distribute the link to the survey also e.g. by the Twitter account of the Eclipse foundation.

These mailing lists and contacts assured in addition to the notes published at the project website of DG CONNECT that the consultation achieved a broad coverage of different types of stakeholders including a sufficient number of eventually filled-out questionnaires. It was decided to go for an open stakeholder consultation in contrast to a closed survey approach, which would have allowed controlling for the responses, because the interest was to open the survey for all interested stakeholders.

c. Results

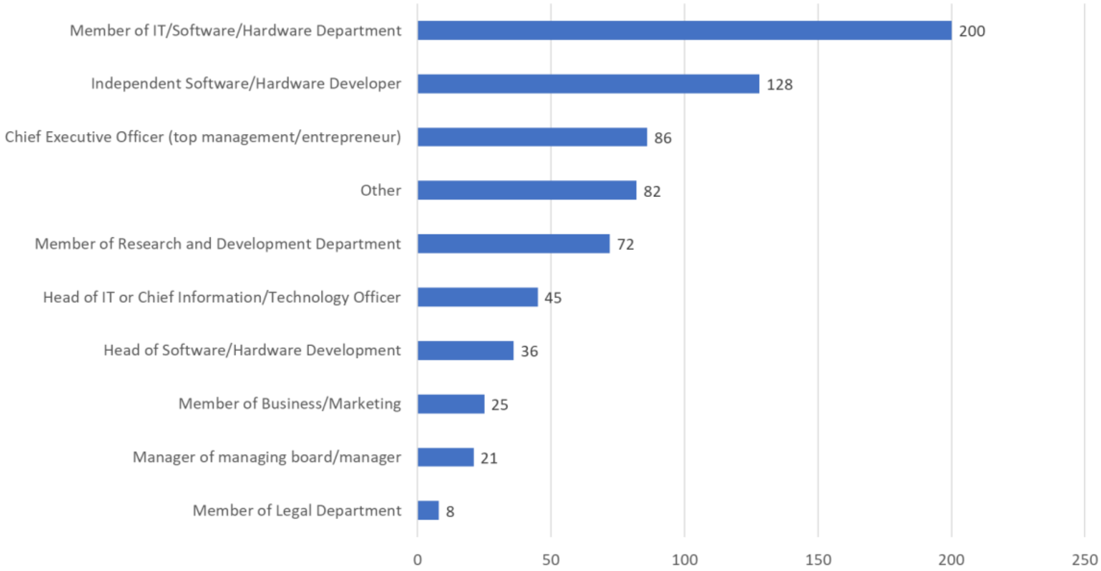
In the following sections, the results of the stakeholder survey are presented. Overall, almost one thousand respondents started to complete the survey. However, only 115 of the respondents did continue to answer the then following questions to the very end, whereas 826 provided partial answers.

In the following chapter, the results are presented starting with the profiles of the respondents and their organisations covering companies and different types of private and public institutions, their involvement in Open Source communities and finally their perception of costs and benefits of OSSH.

Respondents

More than 600 participants revealed their position in their organisation. The majority of the answers come from members of the IT departments similar to the survey conducted by BITKOM (2020) followed by independent software developers. However, more than 10% of the respondents are the Chief Executive Officers or in the top management. In general, responses from small organisations having below 250 employees or younger organisations are provided by their CEOs, whereas in the larger organisations members of the IT departments have answered. These differences have to be taken into account interpreting the differences in the answers between small and large organisations.

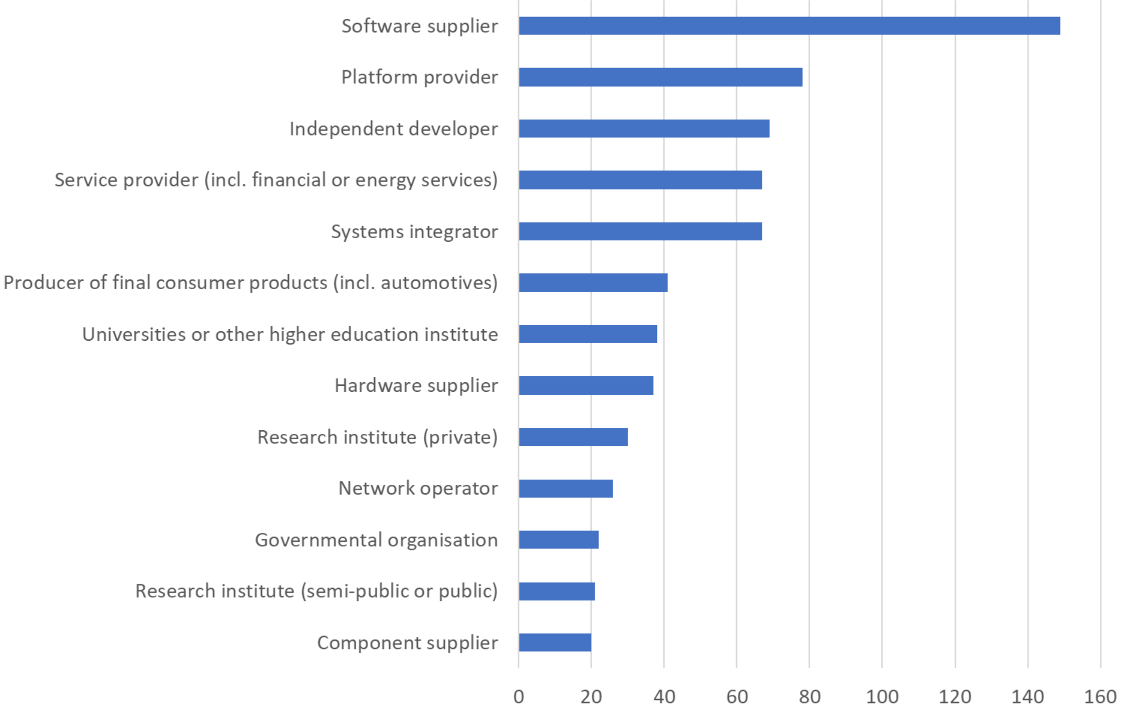
Figure 6.1: Position of respondents (absolute number of answers)



Basic economic information about the organisation

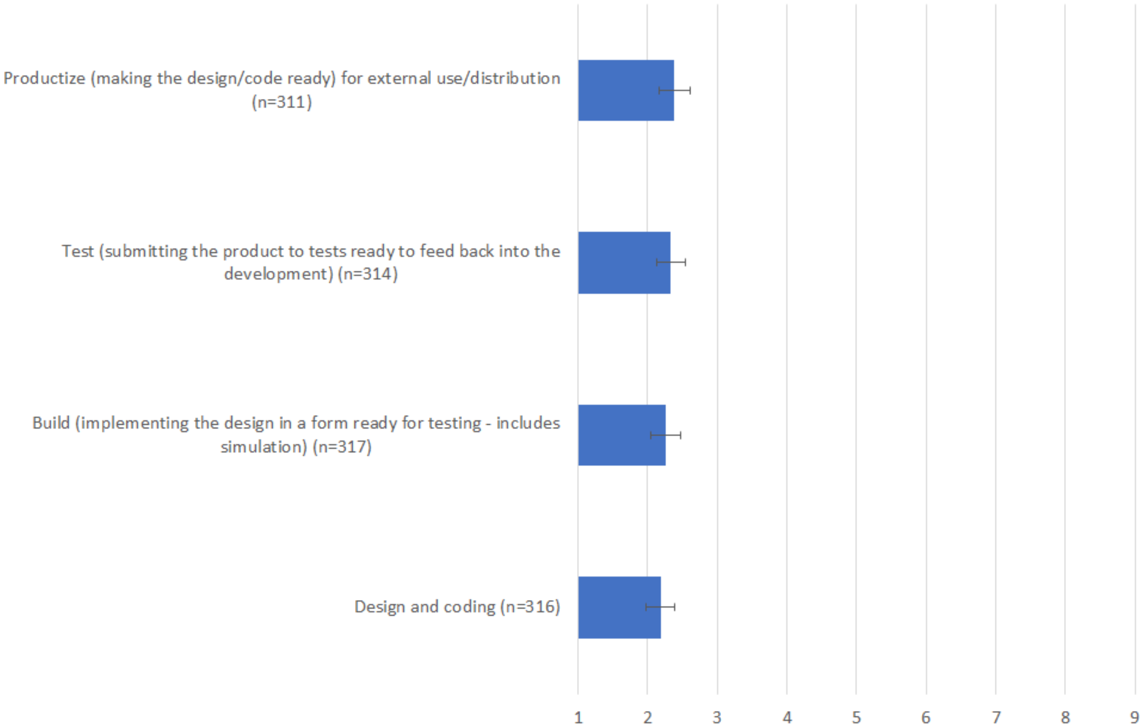
In general, the business models of the respondents' organisations are rather diverse as displayed in Figure 6.2. In general, organisations have between one and two business models, sometimes even three and more (see also Blind and Böhm 2019 or Blind et al. 2017). Almost one quarter of the responding organisations are providing software, another 10% are independent software developers, i.e. more than 30% of the respondents have a strong software background. More than 40% of the respondents are representing organisations producing components, final goods or services, being platform providers, systems integrators or network operators. In addition, more than 10% are employed by private or public research institutes or universities. Some respondents are also from governmental institutions. Overall, the distribution of the respondents resembles the pattern of a similar stakeholder consultation performed by Blind and Böhm (2019) addressing the interface between standardisation and Open Source.

Figure 6.2: Organisation's or organisational unit's core business model (absolute number of answers; multiple answers possible)



Complementary to the information about the respondents' business model, the assessment of their activities in designing, building, testing and production on a spectrum from software hardware was asked for. In general, the majority of the respondents positions themselves at the very end of softwareness. However, the average answers move slightly more to hardwareness, when the consecutive phases from design to production are considered.

Figure 6.3: Hardwareness vs softwareness (from software = 1 to hardware = 9)



The strong focus on hardware is supported by the fact that only two responding organisations are only using or contributing to OSH, whereas the more than two thirds are only using or contributing to OSS, but more than 20% both to OSS and OSH. Consequently, it can be assumed that the answers to the following questions refer mainly to Open Source Software and not to Open Source Hardware.

The majority of the responding organisations, of which more than 80% of those disclosing the location of their headquarters are located in Europe, have been founded after the year 2000. Consequently, only 20% of the slightly more than 100 organisations revealing their total number of employees are large organisations with more than 250 employees. In contrast more than 40% are micro companies with up to 10 employees founded mainly in the last ten years and the remaining share of slightly less than 40% employ between 11 up to 249 employees. Overall, this distribution is in line with the pattern already found by identifying the companies located in the EU contributing to GitHub.

Among all employees of the around hundred organisations disclosing the relevant information, slightly below 10% full-time equivalents are devoted to the development of software in general, whereas 1.5% full-time equivalents are involved in the development of OSS or OSH. This percentage seems to be rather low. However, if the 0.5% of the full-time equivalents of the companies in the Information and Communication sector identified as contributing to GitHub are considered, which is even below 0.3% for all companies being major contributors to GitHub, then this share makes sense. Since these shares are based on full-time equivalents, it can be assumed also based on the analysis of the companies contributing to GitHub and other surveys, that the share of contributors to OSS among all employees is even ten times the number of full-time equivalents.

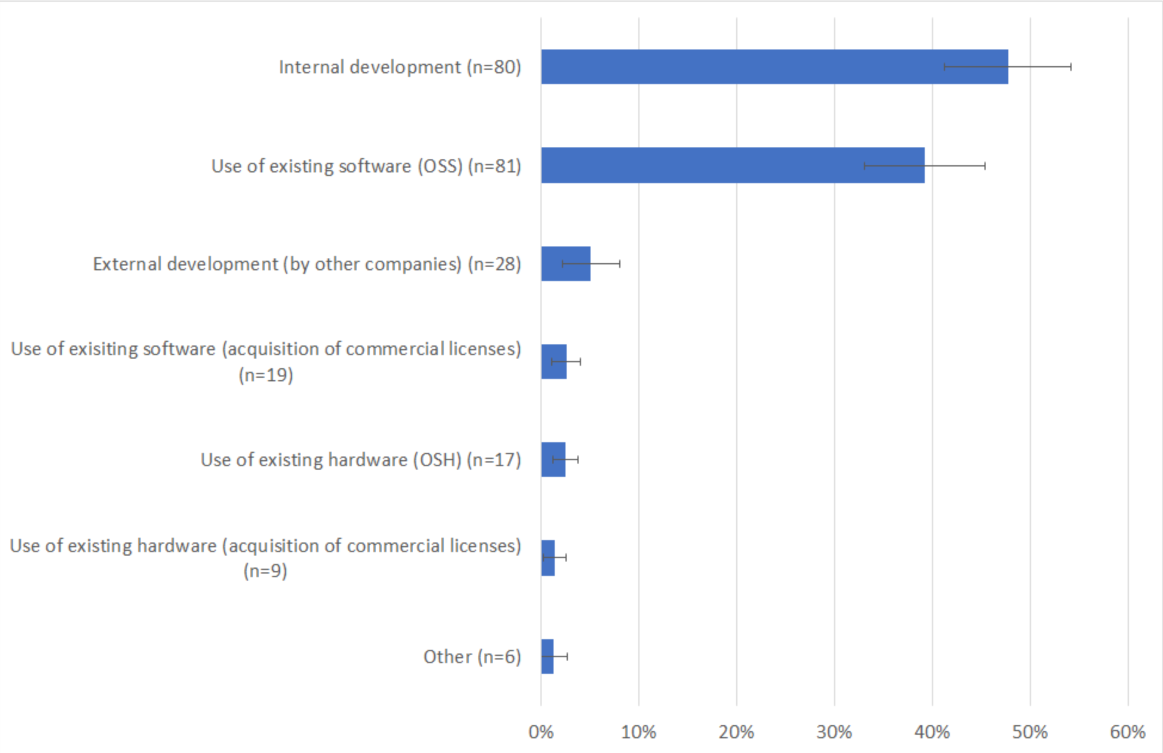
However, the shares of full-time equivalents involved in the development of software in general and the development of OSS or OSH for the smaller and micro organisations are much higher. In the micro organisations, three quarter of the employees are involved in the development of software in general and two thirds in the development of OSS. In the small and medium-sized organisations, less than half of the employees are involved in the development of software and around one quarter in the generation of OSS. This structural pattern, i.e. the proportionally stronger involvement of micro and small organisations as contributors to OSS is in line with the findings based on the data derived from the major contributors to GitHub.

Whereas a sufficient number of the respondents to the stakeholder survey is able to provide information about total employment and those employed for developing software in general or Open Source Software in particular, there is obviously a challenge to attribute shares of turnover to both proprietary and Open Source based software, but also related services. Those few in particular micro and small organisations providing reasonable and consistent numbers about the different types of turnover attributed in general much more than half of their turnover to Open Source based software, but in particular to OSS related services. This strong focus on OSS related services compared to software is in line with the findings of the study of teknowlogy (2019) for France.

Overall, the responding organisations are very innovative. First, their expenditures for innovation amount to more than 20% of their total turnover mainly due to the high shares reported by the micro and small organisations. More than 80% claim to have developed, published or contributed to new software/hardware products, which are for more than half of them assumed to be market novelties. In the Community Innovation Survey, the average share among all companies in the EU with market novelties is in general below 10%. In addition, one third of the organisations' turnover is generated with products being novel to the own organisation for the small sample of respondents providing the relevant information, again a value much higher than for the average company within the EU. Although, the sample of the responding organisations is certainly biased, it can be stated that both the input into innovation activities, but also the results based on them are much higher than those of average companies in the EU.

Furthermore, almost all respondents declare that the new software/hardware contains OSSH. Looking more into the details of sources in the development of the software/hardware, almost 50% of the contributions are attributed to the internal development. However, the use of existing OSS is the second most important source for the development of software with almost 40% and in particular important for micro organisations, which is in line of the 35% claimed by Daffara (2012),. This pattern reveals the strong complementarity between internal development and relying on OSS, whereas purchasing external development services or the acquisition of commercial licenses do play only minor roles.

Figure 6.4: Contributions of different sources for the development of software/hardware in percentage

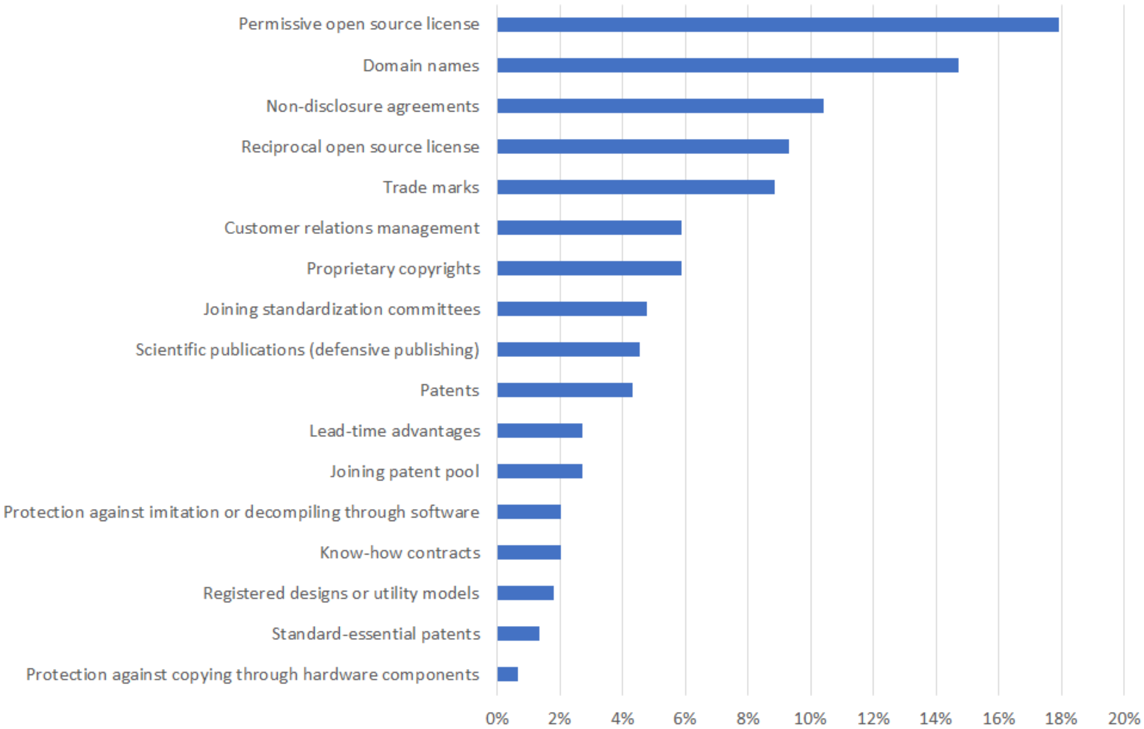


Finally, the respondents have been asked for their strategies for the protection of their organisation's know-how. Whereas traditional intellectual property rights, like patents and registered designs and utility models, do only play a minor role for the responding organisations, permissive Open Source licenses are the most implemented approach. Domain names are also very often used, which is in line with the findings by Blind and Böhm (2019). Interestingly, non-disclosure agreements are ranked at the third place. And they are often used in combination with permissive Open Source licenses, but not with reciprocal Open Source licenses. Obviously, there is a complementary relationship between a rather permissive licensing strategy and trying to secure secrecy. Furthermore, trademarks and customer relationship management are used by several respondents. Finally, some of the responding organisations participate in standardisation committees.

In summary, the responding organisations are very innovative. The development of new software is based mainly on internal efforts, but also relies on the use of Open Source, whereas purchasing external development services and proprietary software licenses are not widely used. The protection of their know-how is based on permissive or reciprocal

Open Source licenses. However, complementary domain names and trademarks are often protected and customer relations management implemented, but also secrecy is important, because non-disclosure agreements are frequently signed.

Figure 6.5: Use of strategies for the protection of organisation's or organisational unit's know-how (shares of all answers based on 441 responses)



In a second question, it is also asked for the types of copyleft licenses, which are implemented in the OSS activities of the respondents, because licenses are most important for the use of and the contribution to OSS according to the survey among GitHub contributors summarised by Geiger (2017). Permissive OSS licenses, e.g. MIT, BSD, Apache, are again most popular followed by the well established strong copyleft OSS licenses, e.g. GPL, GNU AGPL. This confirms the consistency of the answers, because in the ranking of the protection strategies permissive licenses are more popular than reciprocal licenses. However, both weak copyleft licenses and ultra-permissive licenses are less frequently used in the OSS projects, where the respondents participate.

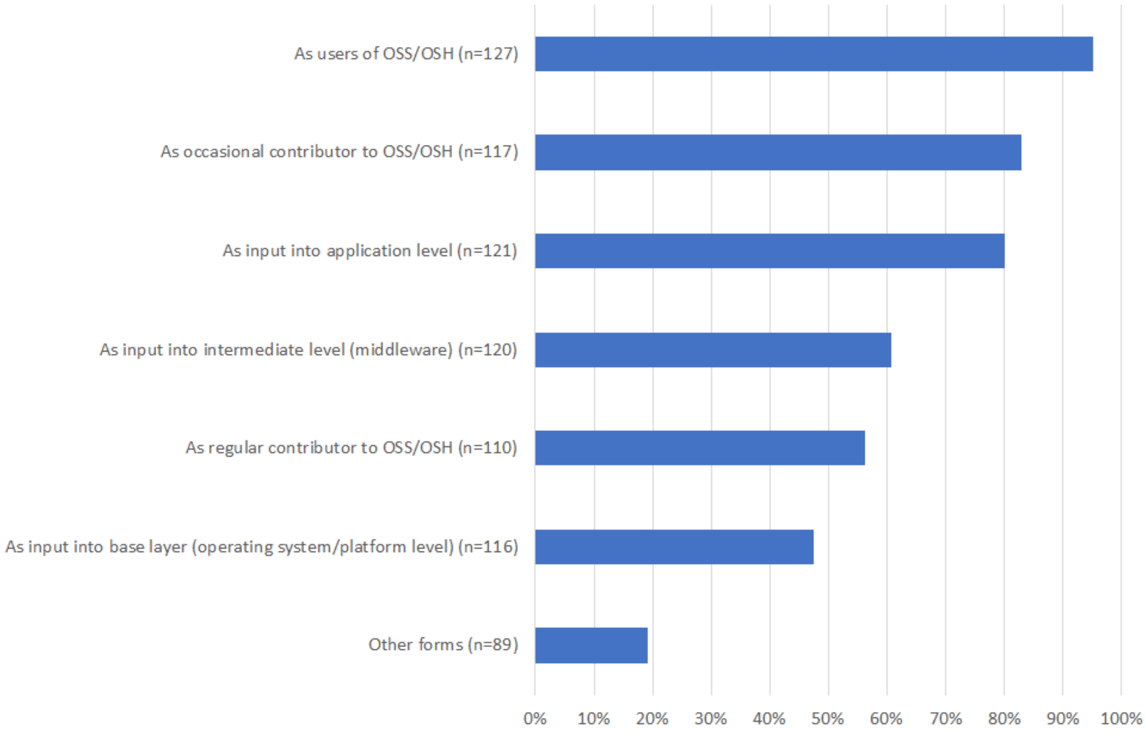
Figure 6.6: Participation in OSS activities depending on copyleft licenses (absolute number of answers)

Involvement in Open Source

Almost 90% of the responding organisations are currently involved in OSS development activities. The involvement in OSH is only confirmed by two respondents. Therefore, the following answers are interpreted just in the context of OSS.

In general, all responding organisations are using OSS, i.e. more than 95%. The involvement takes different forms. In general, the organisations of more than three quarters of respondents are occasionally contributing to OSS. The summary of the GitHub survey by Geiger (2017) revealed similar shares. Furthermore, in particular, OSS is used by 80% of the respondents as input into the application level, slightly more than 60% as input into the intermediate level, i.e. middleware, and slight below 50% as input into base layer, i.e. into the operating system or the platform level. This ranking confirms the pattern already found by the survey performed by Blind and Böhm (2019) as well as the on average ten projects organisations are involved in.

Figure 6.7: Usage/Contribution to OSSH



In addition to the question about the usage and contributions to OSS, it was also asked about how organisations participate in the development of OSS. The majority of the responding organisations allow in general individual employees or teams to contribute or participate to projects of the OSS community, which is in line with the 2020 survey performed by the TODO Group (Hecht 2020). Consequently, most of these organisations provide changed OSS code from their developments back to the community. Complementary, more than half of the respondents have internal policies that foster the use of OSS, e.g. purchasing policies. However, less than one third of the responding organisations are initiating and supporting projects for the OSS community from within their organisations, i.e. proactive contributing organisations are not in the majority. Furthermore, less than a quarter of the responding organisations are offering courses on OSS. Furthermore, very few are financial sponsors of public events that foster OSS, e.g., conferences, or are paying members or sponsors of OSS foundations. Buying support services and subscriptions for enterprise editions of OSS is a rare exception among the answering organisations.

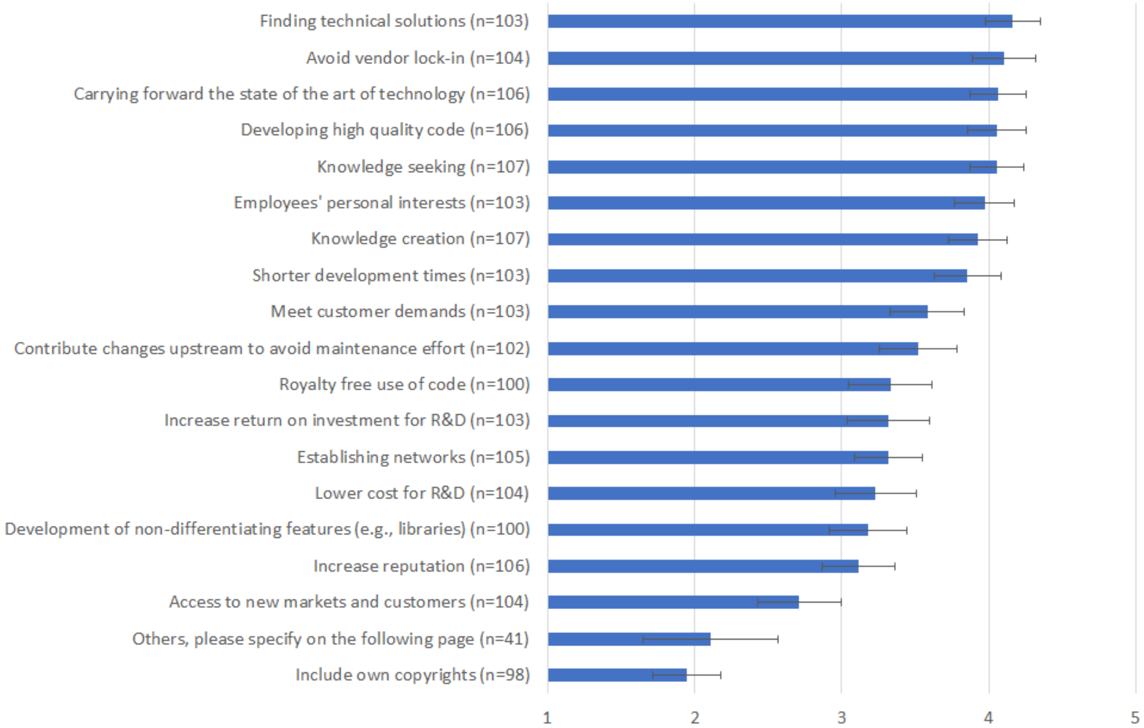
Figure 6.8: Type of participation in the development of OSSH (absolute number of answers)

In order to identify the motivations of organisations to join OSS development, the respondents were asked to assess the relevance of a set of incentives (Figure 6.9). Finding technical solutions is the top priority of the responding organisations, which is also complementary to carrying forward the state of the art of technology ranked at number three and developing high quality code at four. These incentives have been also named being most relevant in the stakeholder consultation performed by Blind and Böhm (2019). Avoiding vendor lock-in is voted as being the second relevant incentive, like in the French survey conducted by teknowlogy (2019). On the fifth position of relevance is knowledge seeking, slightly ahead of knowledge creation. Employees' personal interest are also of high relevance for the responding organisations to join the development of OSS, which is in line with the high relevance of self-interest revealed by the recent survey among Linux developers performed by Nagle et al. (2020). Speeding up the development process via OSS is ranked above average. Meeting customer demand is still assessed above average, whereas contributions to OSS for accessing new markets and customers are of lower relevance.

The cost saving aspects by contributing to OSS have for the responding organisations an above average relevance in the sense of avoiding internal maintenance effort by contributing changes upstream and of a royalty free use of code. Related to R&D, the incentives for an organisation's decision to join OSSH development is by increasing their returns on investment for R&D or by lowering their cost for R&D are also rated above average.

In addition, the establishment of networks and relatedly the increase of the own reputation are assessed to be above medium relevance as well as the development of non-differentiating features, e.g., commonly used libraries. Finally, the inclusion of own copyrights into OSS is not important for the responding organisations, which is also the lowest ranked incentive in the study by Blind and Böhm (2019). Overall, their ranking of motives to join OSS activities is very similar to ours. In the survey by BITKOM (2020), the answers to the questions about reasons to participate in OSS development reveal that more than 80% of the responding companies are interested in reducing financial expenditures. This motive is in particular of higher priority for companies outside the IT sector. The high importance of this generic financial motive is linked to our incentive to avoid vendor lock-ins, which is ranked second, and other reasons, like avoiding maintenance effort, royalty free use of code or lowering R&D costs. For almost two third of the respondents to the BITKOM survey contributing to OSS is part of their understanding of OSS and self-image. In addition, more than half of them contribute to OSS in order to screen existing trends in OSS, which is close to the incentive of knowledge seeking in our survey. Finally, contributing to OSS is not relevant for companies' brand strategy in the BITKOM survey, which is confirmed by the limited relevance of the reputation as incentive within our survey.

Figure 6.9: Incentives to join OSSH development (Scale: 1 = very low to 5 = very high relevance)



Furthermore, the respondents have also been asked in which areas they use, integrate, develop or participate in OSS. OSS is most often used in container technology, IT and cyber security, cloud computing and big data & analytics. The use related to artificial intelligence or machine learning Internet of Things (IoT) is mentioned by less respondents and least related to high performance computing and blockchain. This ranking is similar to the results of the study by BITKOM (2020), where the use of OSS is highest in related to container technology, followed by big data and analytics, cloud computing and Internet of Things. For artificial intelligence and machine learning, the use of OSS is only relevant for 10% of the respondents and for blockchain not at all, which is similar to our results. The ranking of the areas based on the answers to the question on integrating OSS is similar to the order related to use in our survey and again quite close to the results of the BITKOM survey. The answers to the question about the further development of OSS, but also about participating in OSSH are almost equally distributed with only high performance computing and blockchain receiving less answers. Complementary, only a few respondents indicate that OSSH is not relevant in the different areas with the exception of blockchain. Almost all companies answering to the BITKOM survey are not involved in the further development of OSS. Finally, it has also to be mentioned that a significant number of respondents do not know the answers to the above mentioned questions, in particular related to blockchain, but also high performance computing, which is an indication in combination with the results of the BITKOM survey that the relevance of OSSH in these two areas is only at the very beginning.

Table 6.1: Use, integration, development or participation in OSSH per area (absolute number of answers)

	Container technology	Big Data & Analytics	Cloud Computing	Internet of Things (IoT)	Artificial Intelligence / Machine Learning	Block-chain	IT security / Cyber security	High Performance Computing
Use of OSSH	69	51	56	33	35	20	58	24
Integration of OSSH	37	26	31	19	22	6	27	14
(Further) development of OSSH	19	15	17	21	20	8	20	12
Participating in OSSH	15	14	17	18	17	6	21	11
OSSH is not relevant	1	7	3	9	5	17	3	11
Do not know	10	17	15	20	20	30	13	26

Benefits and costs of OSSH

In order to complement and detail the cost-benefit analysis at the macro level the respondents to the stakeholder survey have asked for the relevance of the benefits, but also the cost of using or contributing to OSSH for their organisations.

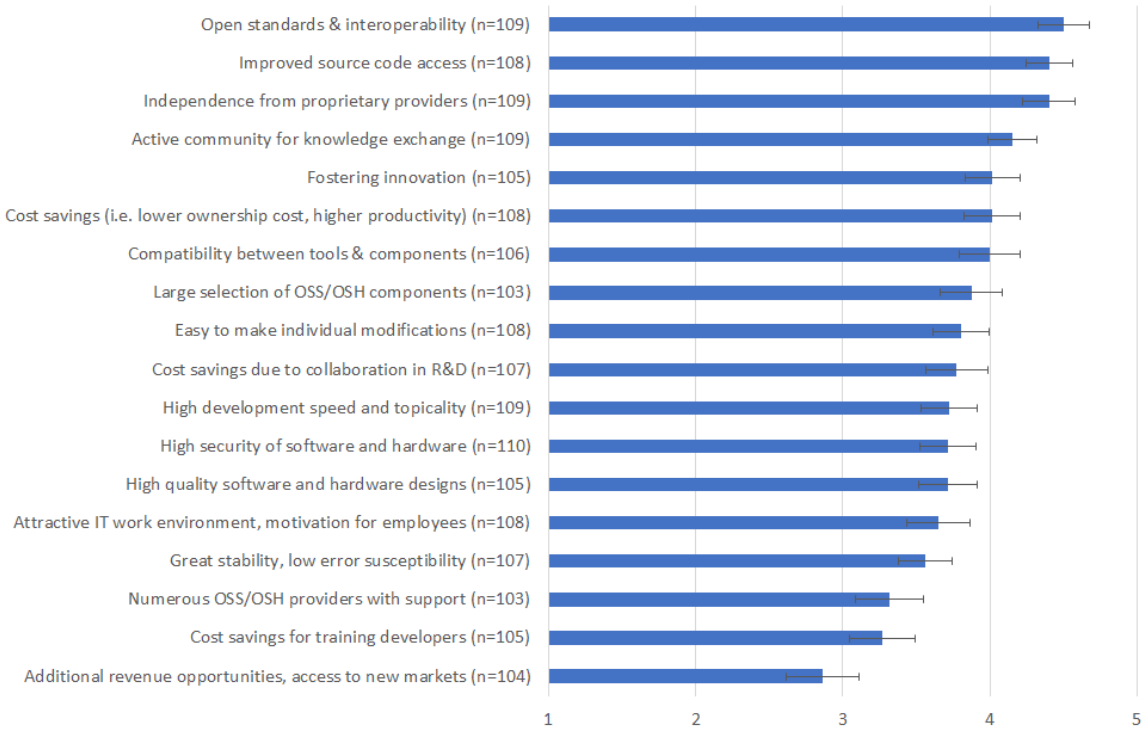
Obviously, the use and contribution to OSS generates the highest benefits in the form of supporting open standards and interoperability, which is similar to the benefits of standards generated in traditional standardisation processes (European Commission 2016) and in line with theory (e.g. Weitzel 2004). However, these benefits generate at least no direct impact on companies' revenues and not necessarily on their costs and therefore also not on their profits. In the BITKOM survey (2020) this advantage is not ranked amongst the three most frequently named advantages of OSS, but in the survey by the University of Bern (2018). The improved access to source code ranked on the second position reduces their expenditures, because less cost for internal development or for sourcing proprietary code are needed. The third benefit of independence from proprietary providers of software code, which is named as the second most significant advantage in the German BITKOM survey and third most important motivation in the French survey by teknowlogy (2019), is complementary to the easier access to software code and has also a cost reducing impact for the responding organisations. The high relevance of cost savings by using OSS is also the most often mentioned advantage by the responding companies in the BITKOM study and mentioned as the third most relevant motivation to use OSS by French companies (teknowlogy 2019). These three benefits are evidently assessed between high and very high relevant significantly above the following benefits.

On the fourth position, the access to an active community for knowledge exchange is assessed just above being highly relevant. Fostering innovation, cost savings in the sense of total cost of ownership and compatibility between tools and components are all benefits of using or contributing to OSS assessed to be of high relevance. Again both the interoperability and the cost saving dimensions are related to these benefit dimensions plus the role of OSS for fostering innovation.

In the spectrum between high and medium relevance are the large selection of OSSH components provided by numerous providers, the ease to make individual modifications, saving cost due to collaboration in R&D, high development speed and topicality, high security, great stability and low error susceptibility, but also quality of software and hardware, attractive IT work environment motivating employees, and eventually cost savings for training developers as benefits. Significantly below medium benefits areas lowest rated benefit additional revenue opportunities or access to new markets by using or contributing to OSSH.

Summarising the assessment of the numerous benefit dimensions, open standards securing interoperability and compatibility are followed by several benefits contributing to directly or indirectly to cost savings on the top list of benefits. Security and quality related issues are still rated above medium, but not as high, whereas the respondents to the GitHub survey summarised by Geiger (2017) highlight the more secure OSS compared to proprietary software. Finally, the use and contribution to OSSH to generate additional revenue opportunities or market access is less than a medium benefit for the responding organisation. This general pattern has to be considered in the context of the overall assessment of the impact of OSS. It has also to be noted that there are with the exception of the cost saving advantage some differences between the ranking of the benefits in our stakeholder survey and the ranking of advantages in the BITKOM survey, which can also be explained by its heterogeneous sector-specific assessments.

Figure 6.10: Benefits of using or contributing to OSSH (Scale: 1 = no benefits to 5 = very high benefits)

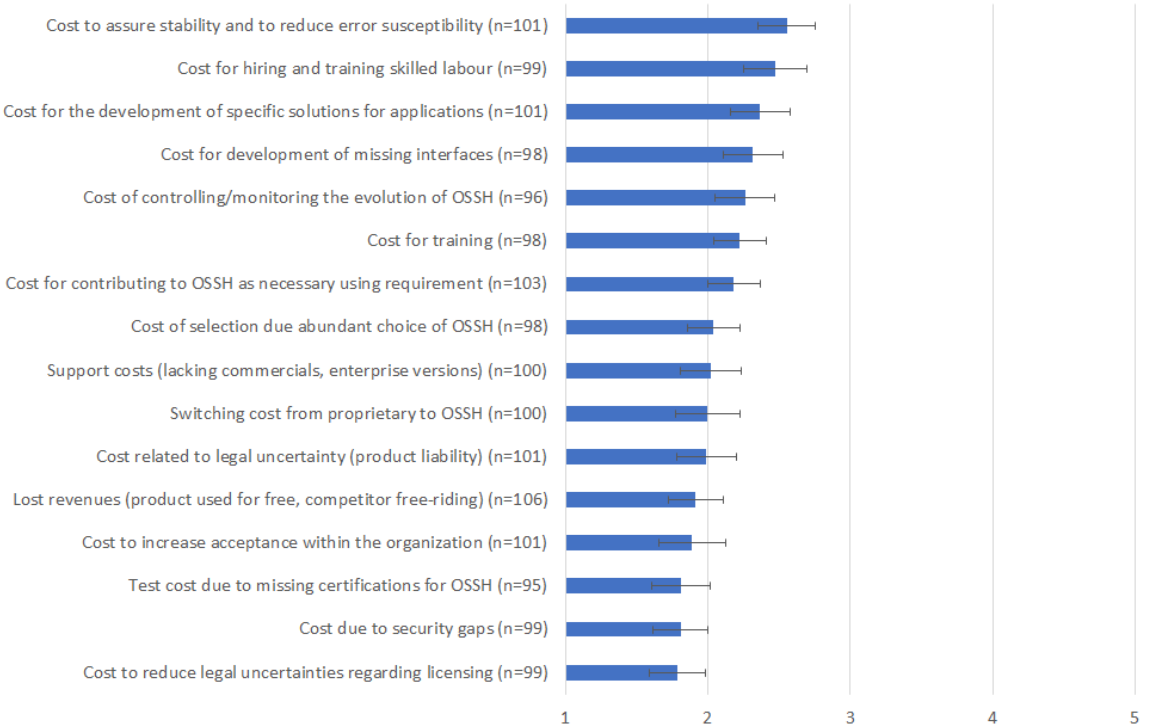


In order to complement the detailed list of benefits related to the use of or contribution to OSSH, the stakeholders have been asked also for the different cost aspects related to the use of and contributions to OSS. First, all cost dimensions are ranked below medium, whereas all benefit dimensions are assessed above medium with the important exception of additional revenue opportunities or access to new markets by using or contributing to OSS. Furthermore, micro and small and medium-sized organisations rank the benefits higher than large organisations. In particular, small and medium-sized organisations rate the revenue opportunities and the access to new markets above medium and therefore higher both than micro and large organisation. The large organisations assess in contrast the costs higher than the smaller organisations.

The highest assessed cost dimension is related to assuring stability and reducing error susceptibility, whereas the benefits of great stability and low error susceptibility via using and contributing to OSS are among the less beneficial benefit dimensions. Consequently, these two assessments complement each other. The cost for hiring and training skilled labour are ranked as the second important cost dimension, which is confirming the lack of skilled labour as the most significant disadvantage preventing the use of OSS among the companies interviewed in the context of the study by BITKOM (2020). Cost for the development of specific solutions for applications, of missing interfaces and of controlling/monitoring the evolution of OSSH are following assessed above low as well as training cost and the cost for contributing to OSSH as necessary requirements for using OSSH. Due to abundant choice of OSSH, the responding organisations also face at least low cost related to the necessary selection. If the selection is made, support costs due to lack of commercial support and missing enterprise versions might arise, but also switching cost from proprietary to OSSH. Costs related to legal uncertainty, such as developer and supply chain product liability, are slightly rated below low. Lost revenues, e.g. customers using products for free or competitors' freeriding, are among the less relevant cost dimensions, which is complementary to the limited additional revenue opportunities or access to new markets by using or contributing to OSSH. The explanation is that if using or contributing to OSS does not generate immediate revenues, the cost of revenue loss are consequently also low. It has also to be pointed out that the respondents of large organisations perceive high costs to increase the acceptance of OSS and OSH with their own organisation, which is less a problem in micro and small organisations. Finally, the test cost due to missing certifications for OSSH are assessed to be low, as well as the cost due to security gaps and to reduce legal uncertainties regarding licensing. The latter two are also rarely named as disadvantages of using OSS in the BITKOM survey. However, security gaps are named as the most relevant barrier by the respondents to the survey by the University of Bern (2018).

In summary, the respondents perceive on average only a low cost level of using and contributing to OSSH related to the various dimensions. However, cost for assuring stability, the development of specific applications and interfaces are above average as well the costs for hiring and training the personnel.

Figure 6.11: Costs of using or contributing to OSSH (Scale: 1 = no costs to 5 = very high costs)



In order to aggregate the various benefit and cost dimensions and to conclude and validate the cost-benefit assessment, the respondents were asked to provide their overall cost-benefit ratio. As expected based on the assessments of the benefits and costs, one third perceive very high benefits and low costs, more than another third either very high benefits and medium costs or at least high benefits and low costs.

Figure 6.12: Overall cost-benefit-ratio of using or contributing to OSSH (n = 101)

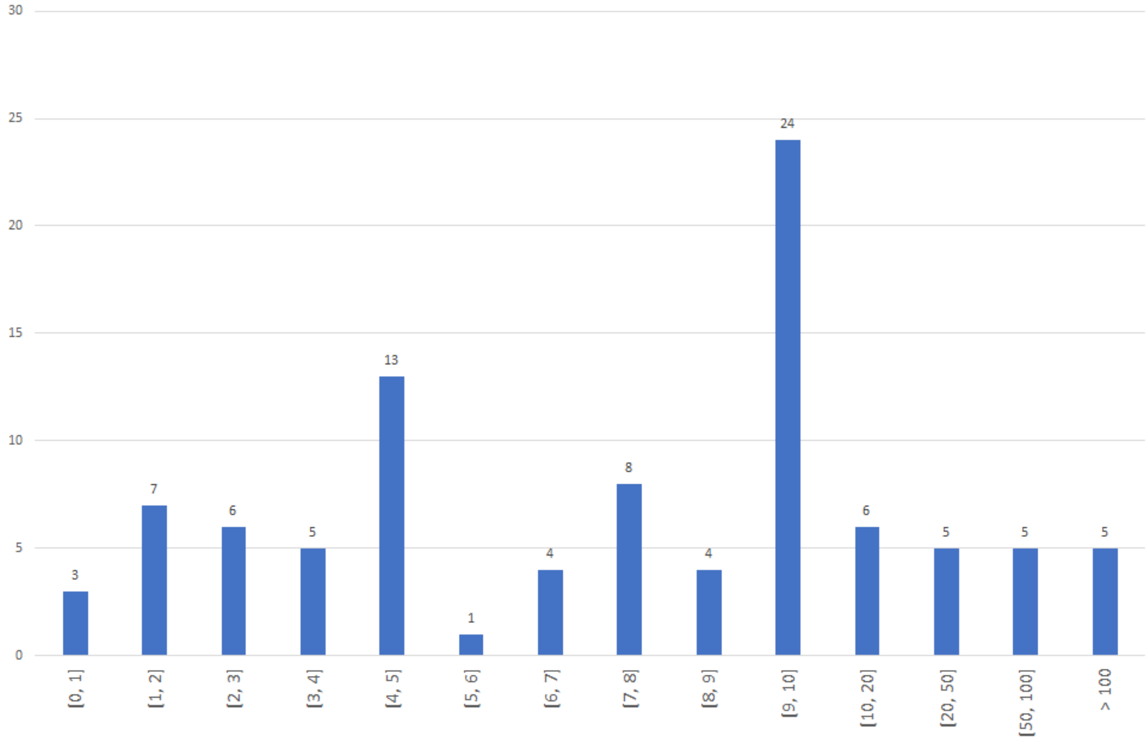
	No costs	Low costs	Medium costs	High costs	Very high costs
No benefits	1%	1%	1%	0%	0%
Low benefits	1%	0%	0%	0%	0%
Medium benefits	2%	2%	5%	1%	0%
High benefits	3%	18%	10%	0%	0%
Very high benefits	2%	33%	19%	1%	1%

Complementary to this qualitative assessment, in a last step the respondents have been asked to provide a quantitative assessment of a benefit-cost ratio of using or contributing to OSSH. For example, the ratio is 1 if the benefits equal costs, the ratio is 10, if the benefits are 10 times higher than the costs.

Whereas the average value of the ratio is 1:17 due to some outliers, the most named value is 1:10 followed by 1:5. This range of rates on investments (RoIs) are similar to those RoIs calculated by Pearce (2016) for Open Source scientific hardware development. It also has to be mentioned, that the cost-benefit ratio decreases with the size of the organisations, which is in line with the separate assessments of the numerous benefit and cost dimensions.

In the 2020 survey by the TODO Group, Hecht (2020) also shows that on a qualitative scale, that more than two thirds of the respondents report very high or high return on investment of their membership within an Open Source foundation.

Figure 6.13: Assessment of quantitative benefit-cost ratio of using or contributing to OSSH (absolute number of answers)



Conclusion of stakeholder survey results

Despite the limited response to the stakeholder survey, the analysis of the responses reveals sound and internally consistent results. In addition, the results are also in line with the insights from methodologically similar analyses. The differentiation of the sample into large and small or medium-sized organisations reveals interesting insights, which also guide the derivation of policy recommendations.

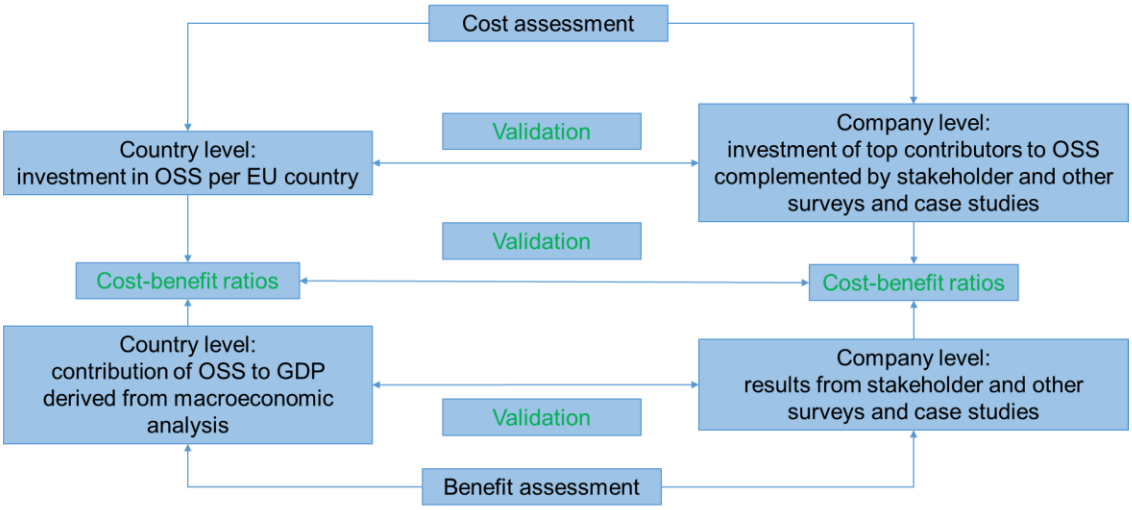
7. Summary of different analyses

The literature review, the case studies, the statistical analysis and the results of the stakeholder survey together deliver a comprehensive picture of the landscape and the impact of Open Source. The results from the various sources are synthesised to identify the stakeholders, to sketch the subject matters of OSS and OSH and eventually to analyse the various dimensions of impacts. Eventually, these insights are used to derive policy recommendations presented in the final chapter.

a. Overall Approach

In order to give an overview of the different approaches to analyse in particular the OSS landscape, the subject matters and eventually the various impact dimensions, Figure 7.1 presents the different components and their interrelationships.

Figure 7.1: Overall Approach



In the remaining chapter, it is started with the main insights from the econometric analyses, which focus on the assessment of the benefits at the level of the Member States, before it is moved to the cost assessment first also at the level of the Member States and then secondly on a sample of the most active companies with a headquarter located in the EU. Then, the insights from the stakeholder survey and other surveys provide additional information to the cost dimension, but also to the benefit dimensions mostly on a semi-qualitative level before it is concluded with the mostly qualitative findings from the case studies. Finally, cost-benefit ratios are determined not only at the macro level, but also at the micro level, which both are eventually matched in a last step to validate the findings from different levels and methodological approaches.

b. Main results of the different analyses

Main insights from the econometric analyses

Based on the results of our econometric time series analyses based on EU Member States data it is revealed that the GDP of the EU Member States is significantly benefiting from the global pool of OSS code. It is possible to identify and to quantify a significant economic impact of the commits or contributors to GitHub from the EU Member States on the GDP in the EU ranging from €60 billion to €95 billion to the GDP in the EU in 2018. These contributions are consistent with the range of the impacts of standards on the GDP measured by studies conducted in several Member States of the EU. Since only around half of the commits or contributors to GitHub can be attributed to countries, like the EU

Member States, and data from other OSS repositories cannot be used, the above mentioned figures are at the lower bound.

Not only GDP, but also the labour productivity in the EU is benefitting from the pool of OSS code. National contributions strengthen the domestic competitiveness measured by exports or Trade in Value added, but in parallel the global pool of OSS is challenging the export performance. Since innovation is characterised by differentiation from existing state of science and technology or competitors, contributing to or relying on OSS code allows mainly marginal and not necessarily radical changes, which represents a measurement problem. Therefore, strong innovation-pushing impact of OSS cannot be observed. However, the creation of start-ups in information technology benefits from OSS on, i.e. it can be predicted that a 10% increase of commits to GitHub by the EU Member States will generate more than 650 additional start-ups in information technology in the EU. Finally, OSS is not a direct driver for employment, but only indirectly via positive productivity and competitiveness effects.

Main complementary insights of the cost-based impact analyses

In the quantification of the investment of the EU to OSS, at least more than 260,000 contributing software developers in 2018 representing over 8% of the almost 3.1 million employees in the EU in the computer programming sector can be identified. This number is close to the 233,800 full-time equivalents of OSS related employment reported by teknowlogy (2019) for the whole Europe. However, the number of contributors can be considered as lower bound, because only around half of the contributors reveal their country of origin. However, the share of 8% is very close to the 7.4% of the volume of the OSS and IT services market compared to the total software and IT services market reported by teknowlogy (2019). In addition to the involvement of companies, academic institutions are contributing to OSS. For the USA, Korkmaz (2020) finds that academia is responsible for almost one third of the contribution to OSS.

If taking the total number commits from contributors located in the EU Member States in 2018, more than 16,000 full-time equivalents are needed, which is a similar value Ghosh (2006) reports as the contributions of a global sample of the most active contributing companies in 2005. If this effort is related to the 260,000 software developers contributing to GitHub, then they would spend less than 10% of their time to contribute commits to GitHub, which is in the range reported in a recently published survey. Taking all employees in the computer programming sector in the EU, slightly more than 0.5% of their time is spent to contribute to OSS.

If the number of contributors from each EU country are taken and multiplied them with the average personnel cost per EU country, the costs are almost €15 billion in 2018 in all EU Member States. These figures are in the same dimension as those published by teknowlogy (2019) on the OSS and IT services market in Europe being slightly below 10% of the total software and IT services market. Applying the same approach to the effort in years to generate the more than 30 million commits in 2018 by the Member States of the EU, the personnel costs amount to almost €1 billion, which is close to the global value reported for 2005 by Ghosh (2006).

Finally, at the company level a high share of small companies is observed among the most active companies participating in OSS. The smaller the companies' active in OSS, the more contributors they have, the more commits they provide and consequently the more efforts they invest. Overall, the companies with up to 50 employees are responsible for almost half of the contributors or commits to OSS within the sample, which has been investigated.

Still, almost half of the companies in Information and Communication are responsible for more than half of the contributors followed by companies conducting professional, scientific and technical activities. The wholesale and retail trade and the financial sector are also quite active followed by the manufacturing sector, which has a share of less than 10% among all contributors. Overall, the number of contributors per company is quite similar between the sectors varying around the overall average of 17 contributors per company. Finally, the focus on the sector Information and Communication allows a comparison with the analysis based on the EU Member States level, where it is referred to the computer programming sector as a reference. At the EU level, 8% of the employees contribute to OSS if it is referred to the number of employees in the computer programming sector. In the subsample of the most active companies in Information and Communication, the value is just above 6%. However, the number of commits per employee at the level of the Member States is slightly below 10, whereas in the sample of the most active companies it is 16, which underlines their strong engagement in contributing code to GitHub. The effort per employee is also quite similar, which underlines the validity of the approach, because both the top down and the bottom up approach come to similar results.

Overall, this cost-based analysis has revealed the pattern of investments in OSS by the EU Member States, but also by the sectors and the company size based on the sample of the most active contributors to GitHub.

In summary, the analysis of the sample of European companies being the most active organisations in OSS in 2018 complements the analysis based on the Member State level and reveals several additional insights. First, it has been possible to determine the engagement of companies in OSS based on the number of contributors, commits and efforts. The differentiation of companies in the sample by size reveals that the smaller the companies are, the higher is their relative investment into Open Source. This is an important insight, which is relevant for the derivation of policy implications. Second, the differentiation of the companies into sectors confirms on the one hand the dominant role of the Information and Communication sector, but also reveals the relevance of the other sectors, e.g. companies conducting professional, scientific and technical activities. The actual involvement of the companies in contributing to Open Source in the manufacturing sector leaves obviously still some room for expansion. However, the level of involvement differs not very much between the sectors. The company size bias is the striking pattern across all sectors and also just looking at the companies being active in the Information and Communication.

Reconsidering the contribution of OSS to the GDP of the EU in 2018 and combining it with the efforts by the EU to contribute to OSS not only in 2018, but also the years before, because the contribution of OSS to the GDP in 2018 is not only based on the OSS code developed in 2018, but also on the code in previous years. Eventually, a cost-benefit ratio of slightly above 1:10 is calculated. Considering also hardware cost for the 260,000 contributors to OSS, the cost-benefit ratio would then be slightly above 1:4. This ratio is in the line the computer capital costs related to the long-run contributions of computerisation (Brynjolfsson and Hitt 2003) or the social returns to innovation (Jones and Summers 2020).

Main complementary insights from the stakeholder survey

Although the cost-based approach has revealed new and robust insights from the cost perspective, the benefits of contributing and using OSS are not well covered by the available data. Therefore, the stakeholder survey includes questions related to the nature and market size of OSS and OSH and the related business models, which contribute to the completion and validation of the data-based approach generated findings. In particular, additional information about the revenue based on OSS, but also other benefits allow us to put the quantification of the benefits and the so far revealed cost-benefit ratios into a broader context.

The stakeholder survey attracted significant attention with more than 900 experts starting the survey. However, in particular the questions related to the quantification of investments and in particular revenue related to OSS and OSH despite being tested in a pilot with several experts reduced the responses eventually leading to slightly more than 100 respondents going completely through all questions.

Almost one quarter of the responding organisations are providing software, another 10% are independent software developers, i.e. more than 30% of the respondents have a strong software background. This pattern is consistent with company-based analysis of the most active contributors to OSS. However, it also observed that other business models by more than 40% of the respondents are representing organisations producing components, final goods or services, being platform providers, systems integrators or network operators. Finally, several respondents claim to have two or even three different business models confirming the results of previous studies.

Since there is an interest in the complementarity between OSS and OSH, the respondents has been asked for the assessment of their activities in designing, building, testing and production on a spectrum from software hardware. In general, the majority of the respondents positions themselves at the very end of softwareness. However, the average answers move slightly more to hardwareness, when the consecutive phases from design to production are considered. Overall, the rather small OSH communities are not well represented in the survey.

The large majority of the responding organisations has been founded after the year 2000 and even almost 50% after 2010, which is an indication of a high share of start-ups among the respondents. Consequently, only 20% of the slightly more than 100 organisations revealing their total number of employees are large organisations with more than 250 employees. In contrast more than 40% are micro companies including a high share of start-ups with up to 10 employees and the remaining share of slightly less than 40% employ between 11 up to 249 employees. Overall, this distribution of size is in line with the pattern found by identifying the companies located in the EU contributing to GitHub.

Among all employees of the around hundred organisations disclosing the relevant information, slightly below 10% full-time equivalents are devoted to the development of software in general, whereas 1.5% full-time equivalents are involved in the development of OSS or OSH. However, the shares of full-time equivalents involved in the development of software in general and the development of OSS or OSH for the smaller and micro organisations are much higher. In the micro organisations, three quarter of the employees are involved in the development of software in general and two thirds in the development of OSS. In the small and medium-sized organisations, less than half of the employees are involved in the development of software and around one quarter in the generation of OSS. This structural pattern, i.e. the proportionally stronger involvement of micro and small organisations as contributors to OSS is in line with the findings based on the data derived from the major contributors to GitHub.

The respondents face problems in attributing shares of turnover to both proprietary and Open Source based software, but also related services. Those few, in particular micro and small, organisations providing reliable information attributed in general much more than half of their turnover to Open Source based software, but in particular to OSS related services, which is in line with other studies.

The responding organisations claim to be very innovative, i.e. both their expenditures for innovation and their shares of turnover with market novelties are very high, compared to average companies in the EU. Almost all respondents declare that their new software or hardware contains OSSH. Looking more into the details of sources in the development of the software/hardware, almost 50% of the contributions are attributed to the internal development. However, the use of existing OSS is the second most important source for the development of software with almost 40%, being mentioned in previous studies, and being in particular important for micro organisations including start-ups, which supports the start-up promoting impact of OSS revealed by Wright et al. (2020). However, those responding make use of permissive or reciprocal Open Source licenses, but only few use patents and other formal intellectual property rights to protect their know-how, i.e. their innovativeness cannot be measured by these traditional innovation indicators. However, complementary domain names and trademarks are often protected and customer relations management implemented. Secrecy is also important, because non-disclosure agreements are frequently signed.

As found in the literature and other recent studies, almost all responding organisations are using OSS and more than three quarters of the respondents are at least occasionally contributing to OSS. Consequently, the basic assumption of the macroeconometric approach that the contributors are also making use of OSS is confirmed. In detail, despite the bias of the survey towards OSS users and contributors, it can be assumed that at least an additional one third, i.e. one quarter divided by three quarters, of the contributors are making use of OSS. In our study based on the whole EU, more than 260,000 contributors have been identified. Consequently, at least one third can be added, i.e. almost another 90,000 employees, who might be at least actively using OSS.

In line with other recent studies, the majority of the responding organisations in general allow their employees to contribute or participate in projects of the OSS community. Consequently, most of these organisations provide changed OSS code from their developments back to the community. However, less than one third of the responding organisations are initiating and supporting projects for the OSS community from within their organisations, i.e. proactive contributing organisations are in the minority.

Furthermore, the respondents have also been asked in which areas they use, integrate, develop or participate in OSS. OSS is most prominent in container technology, IT and cyber security, cloud computing and big data & analytics. The use related to artificial intelligence or machine learning Internet of Things (IoT) is mentioned by fewer respondents and least related to high performance computing and blockchain, where several respondents do not know the answers to the above mentioned questions. Obviously, the relevance of OSS in these two areas is only at the very beginning. In general, our results are similar to those of other studies.

The most important motivations of organisations to join OSS development are finding technical solutions being complementary to carrying forward the state of the art of technology. Avoiding vendor lock-in is voted as being the second relevant incentive supported by results of several other studies. On the fourth position of relevance is knowledge seeking, slightly ahead of knowledge creation. Employees’ personal interests are also of high relevance for the responding organisations to join the development of OSS. It has to be highlighted, that accessing new markets and customers via contributions to OSS are of low relevance, i.e. revenue generation via OSS use or contribution is of minor importance. In contrast, the cost saving aspects by contributing to OSS have for the responding organisations, in particular for companies outside the IT sector, an above average relevance in the sense of avoiding internal maintenance efforts, the royalty free use of code, but also increasing their returns on investment for R&D or by lowering their cost for R&D. Finally, the establishment of networks and relatedly the increase of their own reputation are assessed to be above medium relevance as well as the development of non-differentiating features, e.g., commonly used libraries.

In order to complement, specify and validate the cost-benefit analysis performed at the macro level the respondents to the stakeholder survey have been asked for the relevance of the benefits, but also the cost of using or contributing to OSSH for their organisations. The use and contribution to OSS generates the highest benefits in the form of supporting open standards and interoperability, which is similar to the benefits of standards (European

Commission 2016). In parallel, the results of the macroeconomic studies about the economic benefits of standards in various Member States of the EU reveal impacts on GDP being consistent with the results for the role of OSS for the GDP of the whole EU. However, this benefit generates at least no direct positive impact on companies' revenues, but indirect benefits via network externalities. The improved access to source code ranked on the second position - being also assessed to be very important in other surveys - reduces organisations' expenditures, because less effort mostly for the internal development of software is needed. Since one important incentive to use and to contribute to OSS is avoiding vendor lock-in, the independence from proprietary providers of software code is an important benefit for the respondents to the stakeholder consultation, but also other surveys. Furthermore, the access to an active community for knowledge exchange, but also the innovation fostering effect are all benefits of using or contributing to OSS assessed to be of high relevance. Summarising the assessment of the numerous benefit dimensions, open standards securing interoperability and compatibility followed by several benefits contributing to directly or indirectly to cost savings are on the top list of benefits. Security and quality related issues are still rated above medium. Finally, the use and contribution to OSSH to generate additional revenue opportunities or market access is less than a medium benefit for the responding organisations with the exception of the small and medium-sized organisations. Related to the overall assessment of the impact of OSS, the results of the stakeholder survey reveal that the immediate revenue or turnover generating impact of OSS is of minor importance, whereas interoperability contributing to network effect and cost savings also due to independence from vendors of proprietary software represent the major benefits. This assessment of the benefits of OSS are in line with the results of the econometric analyses revealing the positive impact of the pool of OSS for the economy of the whole EU, which is not only due to the costless access to this knowledge source, but also due to the network effects. Furthermore, micro and small and medium-sized organisations rank the benefits related to OSS higher than large organisations, which explain their significant contributions to OSS revealed in the analysis of the largest contributors to GitHub. Consequently, it can be concluded that micro and small companies benefit more from their use and contributions of OSS compared to large companies.

In our macroeconomic, but also company-based analyses the costs related to the generation of OSS have been investigated assuming that they are at least outweighed by the benefits. So far, mainly on the personnel costs have been focused needed for contributing to OSS complemented by the cost for hardware. In order to widen the scope of the cost related to the use and contribution to OSS, the stakeholders have been asked for different cost aspects. In general, all cost dimensions are ranked below medium, but larger organisations assess them higher than the smaller organisations. The cost for hiring and training skilled labour are ranked as the second important cost dimension confirmed by other studies. Therefore, the focus on personnel cost in the cost-benefit analysis of OSS is justified.

However, the highest assessed cost dimension is related to assuring stability and reducing error susceptibility of OSS, which may be also caused by the low investment in security issues complemented by the need for bug/security fixes, free security audits, and simplified ways to add security-related revealed by Nagle et al. (2020). This cost or risk dimension is not covered by our statistical analysis and might therefore depreciate some of both the investments and the contributions to GDP and therefore of the positive impact related to OSS. Finally, problems related to the interoperability of OSS generate further costs, e.g. for development of specific solutions for applications or due to missing interfaces. In summary, the respondents perceive on average only low costs of using and contributing to OSSH related to the various dimensions. Therefore, the focus on personnel cost to assess the impact of OSS is an appropriate approach, because the other cost dimensions are with the risk of error susceptibility.

Finally, in order to aggregate the various benefit and cost dimensions and to validate the results of the quantitative cost-benefit assessment, the respondents were asked to provide their overall cost-benefit ratio. As expected based on the assessments of the benefits and costs separately, one third perceive very high benefits and low costs, more than another third either very high benefits and medium costs or at least high benefits and low costs, which is in line with other survey results. Complementary to this qualitative assessment, in a last step the respondents have been asked to provide a quantitative assessment of a cost-benefit ratio of using or contributing to OSS. The most named value is 1:10 followed by 1:5. A cost-benefit ratio of 1:4 has been calculated by bringing the expenditure for personnel and the investment into ICT hardware necessary at the level of the EU Member States in relation to the contribution of the pool of OSS to the GDP in the whole EU. Therefore, it can be concluded that according to a cost-benefit ratio of 1:4 the costs needed for the investment in OSS will generate benefit, which are four times higher, according to our macroeconomic approach, but also based on the assessment of the stakeholders. Therefore, an internal consistency of this cost-benefit ratio can be claimed, which is also validated by external sources, e.g. related to innovation expenditures in general or ICT hardware in particular.

Main complementary insights from the case studies

The search for quantitative data related to OSH to be used for statistical and econometric analyses has generated no satisfying results reflecting also the very few scientific publications in this only emerging area. Furthermore, the stakeholder survey has gained in general sufficient attention, but the number of answers related to OSH have been insufficient and the exclusive focus on OSH activities among the Open Source communities is obviously a rare exception. Therefore, the selection of the case studies has acknowledged this gap and addresses two cases in the OSH domain. On the one hand, the case “Maker to manufacturer - process innovations” addresses in particular Arduino, White Rabbit, MyriadRF and RepRap. On the other hand, the case “Open Hardware computing and infrastructure” considers RiscV/SiFive, Open Compute Project, but also White Rabbit. In the OSS domain, in the context of “End-user applications” Nextcloud, LibreOffice, CentOS and OW2 are investigated, whereas the case “Automotive and embedded” includes Yocto, CentOS and the case “Public sector” analyses XRoad, Software Heritage and OW2.

According to the assessment of the experts interviewed in the context of the case studies, the European OSS and OSH ecosystems are well elaborated, because many key OSS and OSH projects are founded or based in Europe. However, they are often not commonly recognised as European innovations. The European public sector plays an important role in OSS and OSH, e.g. many results are based on public funding and are in general in the public domain. One important insight is that OSS and OSH contributions solve immediate needs and exhibit a long tail of value generation. However, often only immediate impact might be measurable, because long term impact is influenced by too many additional factors. Finally, OSS and OSH innovations lower barriers to entry for participants and create bridges between hobbyist or volunteer communities and enterprises. These bridges foster innovation, but also increase the efficiency of labour markets.

Many OSS and OSH projects represent collaborative research and development reducing duplicate effort and risk of up-front investments. They impact a broad spectrum of economic domains and consequently there is no typical domain or sector specifically influenced by it. The collaborative research and development aspect is reflected in different funding sources because the majority of projects built on shared funding. Consequently, these projects do not aim to be profitable, which is also supported by principles, like “opening design” and “open when ready”, which aim not to exclusively appropriate revenues. However, there are exceptions of consumer-focused applications aiming to generate revenue in highly competitive markets.

Related to input factors, tooling and component availability complemented by a supportive regulatory framework are commonly mentioned as important for development of the whole ecosystem. Although the combination of OSS and OSH licensing on the one hand with other IPR, in particular patents, is often considered toxic for collaboration and not wide-spread (see also Blind and Böhm 2019), many participants consider licensing an add-on to open collaboration

It is important to highlight that no specific focus topics, like cybersecurity, AI, HPC etc., stand out as specifically impacted by OSS or OSH as general-purpose technologies. In contrast, OSS and OSH "look for their application" in the market. The stakeholder and other surveys reveal that OSS is, for example, of higher relevance for cybersecurity than for HPC. This inconsistency can be explained by the individual views of experts expressed in the context of interviews being conducted as basis for the case studies, whereas the stakeholder survey and other surveys, e.g. by BITKOM (2020) or teknowlogy (2019) collect the perceptions of a larger more diversified crowd of several hundreds of experts. Finally, OSS and OSH bridge the Open Source communities, industry and the public sector although with an emphasis on industry, which is increasingly represented in OSS projects by corporate contributors as recently revealed by Nagle et al. (2020), but also Geiger (2017) and Hecht (2020). Despite the increasing interest and investment by corporations in OSS, the interviewees highlight the importance of personal skills, knowledge and experience by the individual OSS developers. Although an increasing demand can be observed for experts with skills related to OSS by industry, e.g. BITKOM (2020), the interviewed experts complain about a lack of teaching with and of OSS, but also OSH. Therefore, attracting and retaining contributors is a challenge for many OSS and OSH communities, e.g. multiple projects mention a high attrition rate or contributor fluctuation as also revealed by Nagle et al. (2020).

In the focus of the case studies was also the investigation of the overlaps between OSS and OSH, which has been revealed by the answers to the stakeholder survey to a limited extent. The cases reveal that both OSS and OSH ecosystems are highly and efficiently integrated with some overlaps, e.g. software support for OSH. The strong bias towards software in the stakeholder survey is, therefore, complemented by the insights of some case studies, which explicitly focus on the interfaces between OSS and OSH.

In addition to industry and academia, umbrella organisations, like foundations, play an important role in the whole OSS, but less in the OSH ecosystem by providing credibility, reputation-based impact and neutral, pro-competitive governance (see also Blind and Böhm 2019).

From the case studies, it can be concluded that the EU has a lot of potential to develop the OSSH ecosystem based on the statements of several experts, but some remain sceptical of bureaucratic challenges or lack of collaboration and OSSH adoption. Overall the case studies reveal that the real success of OSSH collaboration is not represented in existing statistics, which represent only the baseline measurable benefits. For example, there is no statistical data on "the availability of designs and tools to students so that they can work on the real thing".

c. Comprehensive analysis

The literature review, the case studies, the stakeholder survey and eventually the statistical and econometric analyses deliver a comprehensive picture of the stakeholders involved in OSS, but also OSH, the subject matters and eventually the different impact dimensions. Therefore, the following sections are structured accordingly.

Stakeholders

Overall, at least more than 260,000 software developers can be identified contributing to OSS located in the EU Member States, which is close to the full-time equivalents of OSS related employment reported by teknowlogy (2019) for the whole Europe. In addition to the involvement of companies, academic institutions are contributing to OSS. For the USA, Korkmaz (2020) finds that academia is responsible for almost one third of the contribution to OSS. Therefore, a significant share of the contributors to OSS is linked to universities and other research organisations also in Europe, which is supported by around 15% of the respondents to the stakeholder survey linked to universities or to research institutes.

At the company level, a high share of small or even micro companies is observed among the most active companies participating in OSS, of which more than half can be attributed to the information and communication sector followed by companies conducting professional, scientific and technical activities. The wholesale and retail trade and the financial sector are also quite active followed by the manufacturing sector, which has a share of less than 10% among all contributors. Overall, more than one million employees are employed by the most active companies contributing to OSS with headquarters in the Member States of EU, which is more than double of the number Ghosh (2006) reported in 2005 for all companies at the global level.

From the stakeholder survey, it is known that one quarter of the responding organisations are providing software, while another 10% are independent software developers, i.e. more than a third of the respondents have a strong software background. However, also other business models are observed by more than 40% of the respondents representing organisations producing components, final goods or services, being platform providers, systems integrators or network operators. Finally, several respondents claim to have two or even three different business models confirming the results of previous studies (e.g. Blind and Böhm 2019). Since a large majority of the organisations responding to the survey has been founded after the year 2000 and even almost 50% after 2010, this is an indication of a high share of start-ups, which is in line of more than 40% being micro companies with up to ten employees.

In addition to the numerous organisations from industry, but also the public sector, like universities, being active in contributing in OSS, it has to be mentioned that the important role of Open Source foundations by providing credibility, reputation-based impact and neutral, pro-competitive governance (see also Blind and Böhm 2019). Although, the majority is active on an international level with headquarters in the USA, some foundations have a dedicated focus on Europe. Finally, it has to be explicitly mentioned that recently the Eclipse Foundation, one of the world's largest Open Source foundations, moved its headquarters to Brussels.

Related to OSH, only detailed information from the case studies are available, where in particular the success case of Arduino located in Switzerland has to be mentioned. The analysis of the very few start-ups based on OSH reveals only a small number being located in Europe compared to the USA, but also Asian countries. However, European companies hold almost one quarter of the certificates released by a US based certification platform. Overall, the very limited number of OSH based companies justified a case study based approach to analyse them, which has been reflected by the two case studies focusing on OSH.

Subject matter

As already indicated above, at this juncture OSS is certainly much more relevant than OSH, which is only in a very emerging phase. Consequently, the overlap between OSS and OSH is still limited but existent as reported by the respondents to the stakeholder survey, whereas the case studies revealed several cases where OSS is supporting OSH, like in the case of Arduino, but also others.

From the stakeholder survey supported by other studies, it is revealed that OSS is most often used in container technology, IT and cyber security, cloud computing and big data &

analytics. The use related to artificial intelligence or machine learning Internet of Things (IoT) is mentioned by fewer respondents and least related to high performance computing and blockchain. Obviously, the relevance of OSS in these two areas is only at the very beginning.

According to the case studies, no specific focus topics, like cybersecurity, AI, HPC etc., stand out as specifically impacted by OSS or OSH as general-purpose technologies. In contrast, OSS and OSH “look for their application” in the market.

The stakeholder and other surveys reveal that OSS is for example of higher relevance for cybersecurity than for HPC. This inconsistency can be explained by the individual views of experts expressed in the context of interviews being conducted as basis for the case studies, whereas the stakeholder survey and other surveys, e.g. by BITKOM (2020) or teknowlogy (2019) collect the perceptions of a larger more diversified crowd of several hundreds of experts.

In detail, the case study “End-user applications” investigates Nextcloud, LibreOffice, CentOS and OW2, whereas the case “Automotive and embedded” includes Yocto, CentOS. Finally, in order to address the increasing role of OSS in the public sector, a specific case study analyses the projects XRoad, Software Heritage and OW2.

As indicated above, the selection of the case studies has acknowledged the gap of statistical data related to OSH and addresses two cases in the OSH domain. The case “Maker to manufacturer - process innovations” includes in particular Arduino, White Rabbit, MyriadRF and RepRap, whereas the case “Open Hardware computing and infrastructure” considers RiscV/SiFive, Open Compute Project, but also White Rabbit.

Impact dimensions

The case studies, the stakeholder survey and the macroeconometric analyses have identified several impact dimensions of Open Source Software. The impacts of Open Source Hardware have only been analysed in-depth in the case studies complemented by some statistical information about the few companies, incl. start-ups, being active in this area. In the following section, the results from the different methodological approaches are condensed to the most relevant impact dimensions.

Starting at the generic level of the impact on GDP in the EU including the UK, a significant and large impact of up to €100 billion per year by OSS contributions has been calculated, which are also an indicator for its use known from the stakeholder and other surveys. According to the responses from the stakeholder survey the pool of OSS can be seen both as an easily accessible knowledge pool, which is contributing to growth according to the endogenous growth theory. However, it can be also perceived in addition as a public infrastructure generating massive positive network externalities supported by the high rating by the stakeholders of the benefits of open standards and interoperability provided by the use of and the contributions to OSS. Therefore, OSS has also a further growth enhancing impact in the dimension of the previously quantified impact of the stock of technical standards. Furthermore, OSS contributions are increasing the labour productivity in the EU, which can be explained by their labour cost saving effect reported as major benefits in different surveys among companies, but also being rated as very relevant in the stakeholder survey.

The missing significant impact of OSS on the labour market in general and IT employment in particular in the macroeconomic models can again be explained by the results of the stakeholder and different other surveys. As stated above, saving labour cost by relying on OSS is reported as a major benefit by many companies supported by the high share of OSS as input for the development of own new software. This is not only reducing costs, but also risks revealed as additional factors in the case studies. Consequently, this direct saving effect is reducing the companies' demand for skilled labour, because it will be higher than the employees they are going to hire to contribute to or use OSS actively. Furthermore, generating additional revenue or getting access to new markets are only less relevant incentives or benefits for companies contributing to and using OSS according to responses from the stakeholder survey, but also the statement of experts interviewed in the context of the case studies. It is well possible that OSS contributions partially reduce labour demand by eliminating duplicate effort between enterprises. This also represents an efficiency gain. However, there are exceptions in consumer-focused applications aiming to generate revenue in highly competitive markets. Overall, missing rises in revenues are not increasing companies' demand for software developers. Finally, both different surveys and the case studies reveal a shortage of skilled developers to be able to contribute to and use OSS. Therefore, even with an increasing demand the limited supply side of skills is prohibiting a significant expansion of employment.

Since innovation is characterised by differentiation from existing state of science and technology or from competitors' products and services, contributing to or relying on OSS code allows mainly marginal and not necessarily radical changes, which generates a measurement problem, in particular when relying on traditional innovation indicators, like patents, but also trademarks. Furthermore, software development as such can be perceived as research and development or innovation activity, but also as output of innovation, which consists of another measurement challenge. Although OSS is often the base for innovation as revealed in the case studies, the assessments from the stakeholder and other surveys reveal no consistent picture of high relevance of OSS for innovation. Therefore, overall no strong innovation-pushing impact of OSS is observed in the results of the macroeconometric analysis.

However, the creation of start-ups in information technology benefits from OSS on, i.e. it can be predicted that a 10% increase of commits to GitHub by the EU Member States will generate more than 650 additional start-ups in information technology in the EU per year. The very positive impact of OSS on start-ups is confirmed by the results of the stakeholder survey, which reveal that micro organisations being mainly created in the last ten years report compared to medium-sized or large organisations very high values related to many benefit dimensions of OSS, whereas most connected cost dimensions are less relevant for them. In particular, they also reveal that OSS is almost as relevant as internal development as input for new software supporting its innovation fostering impact for this specific type of company. In summary, start-ups benefit both from the easy accessible pool of code, but also from the compatibility and interoperability impacts.

One immediate impact dimension of OSS is the market size of OSS and related service markets. teknowlogy (2019) reports 233,800 of full-time equivalents in the whole Europe of OSS related employment, which is close to the more than 260,000 software developers contributing to GitHub located in the Member States of the EU in 2018being identified. However, this number can be considered as a lower bound, because only around half of the contributors reveal their country of origin. These contributors represent over 8% of the almost 3.1 million employees in the computer programming sector being aware of the fact that not only employees in this sector contribute to GitHub. The share of 8% is very close to the 7.4% of the volume of OSS and IT services market of the total software and IT services market reported by teknowlogy (2019). In absolute terms teknowlogy (2019) reports a market volume of almost €25 billion in 2019 for OSS and related services, which is in the same dimension of the €15 billion total personnel cost necessary for the 260,000 contributors from each EU country. For comparison, Ghosh (2006) estimates that the European market for IT services related to or involving OSS was €26 billion in 2006.

Looking in detail at the companies being responsible for this market volume, a very large share of micro and small companies has been revealed via the analysis of the major contributors to GitHub located in the Member States of the EU. This finding is in line with the argument elaborated above related to start-ups, i.e. the smaller the organisation the higher the benefits and the lower the costs related to OSS as they report in the stakeholder survey. Finally, the sample of these companies employ slightly more than one million employees, which is around one third of all employees in the computer programming sector in the EU. For comparison, a global sample of companies making the most contributions to OSS in 2005 employed slightly more than half a million employees and had a revenue of €263 billion (Ghosh 2006).

In addition, OSS is still mainly dominated by companies from the information and communication sector with a strong focus on software. This finding has been confirmed both by the analysis of the major contributing companies to GitHub, the stakeholder survey and the case studies complemented by a quantitative analysis of OSS based start-ups. Looking at the demand side, according to JC MARKET RESEARCH (2020) Open Source services are mainly implemented in IT and telecommunication with almost one third, followed by one fifth in manufacturing, 17% in banking, financial services and insurance, 12% in life sciences and healthcare, one tenth in retail and distribution and other sectors. From the case studies, it is revealed that OSS is even more generic and impacts a broader spectrum of economic domains and consequently there is no typical sector specifically influenced by it.

Complementing the immediate quantitative economic impacts of OSS, it is revealed as most important motivations of organisations to join OSS development the finding of technical solutions and carrying forward the state of the art of technology. Avoiding vendor lock-in is voted as being also a very relevant incentive, which is supported by several other studies. This impact dimension is particularly crucial for achieving digital autonomy or technical sovereignty. In addition, employees' personal interest being linked to network and reputation building are also of high relevance for the responding organisations to join the development of OSS supported by the recent survey results based on the assessment of Linux contributors by Nagle et al. (2020).

Since one important incentive to use and to contribute to OSS is avoiding vendor lock-in, the independence from proprietary providers of software code is an important benefit for the respondents to the stakeholder consultation, but also other surveys.

In our macroeconomic, but also company-based analyses the costs related to the generation of OSS assuming that they are at least outweighed by the benefits are investigated. In order to widen the scope of the cost related to the use and contribution to OSS beyond personnel costs needed for contributing to OSS complemented by the cost for hardware, the stakeholders are asked for many different cost aspects. However, all cost dimensions are ranked below medium, but larger organisations assess them higher than the smaller organisations. The cost for hiring and training skilled labour are ranked as the second important cost dimension confirmed by other studies. Therefore, the focus on personnel cost in the cost assessment of OSS is justified.

However, the highest assessed cost dimension is related to assuring stability and reducing error susceptibility of OSS, which may be also caused by the low investment in security issues complemented by the need for bug/security fixes, free security audits, and simplified ways to add security-related revealed by Nagle et al. (2020). This cost or risk dimension is not covered by our statistical analysis and might, therefore, depreciate some of both the investments and the contributions to GDP and, therefore, of the positive impact related to OSS. Finally, problems related to the interoperability of OSS generate further costs, e.g. for development of specific solutions for applications or due to missing interfaces. In summary, the respondents perceive on average only low costs of using and contributing to OSSH related to the various dimensions.

Summarising the assessment of the numerous benefit and therefore impact dimensions, open standards securing interoperability and compatibility followed by several benefits contributing directly or indirectly to cost savings are on the top list of benefits. Improvements of security and quality of code via OSS use and contributions are relevant benefits, but OSS generates also additional costs and risks related to security. Finally, the use and contribution to OSSH to generate additional revenue opportunities or market access is less than a medium benefit for the responding organisations with the exception of the small and medium-sized organisations. Related to the overall assessment of the impact of OSS, the results of the stakeholder survey reveal that the immediate revenue or turnover generating impact of OSS is of minor importance, whereas interoperability contributing to network effects and cost savings also due to independence from vendors of proprietary software represent the major benefits. This assessment of the benefits of OSS are in line with the results of the econometric analyses revealing the positive impact of the pool of OSS for the economy of the whole EU, which is not only due to the costless access to this knowledge source, but also due to the network effects. Furthermore, micro and small and medium-sized organisations rank the benefits related to OSS higher than large organisations, which explain their significant contributions to OSS revealed in the analysis of the largest contributors to GitHub. Consequently, it can be concluded that micro and small companies benefit more from their use and contributions of OSS compared to large companies.

From the case studies, some further and more complex impact dimensions can be derived. First, around OSS, but also OSH complex ecosystems supported by an innovation-friendly regulatory framework have developed, which are themselves often the origin of innovation, but also the fruitful environment for start-ups.

Secondly, so far it has mainly been focused on the private sector. However, the European public sector plays an important role in OSS and OSH, e.g. many results are based on public funding and are in general in the public domain. In turn, the public sector is also an important user and implementer in particular of OSS, i.e. OSS can have a strong impact in the public sector as elaborated in the respective case study.

Finally, cost-benefit ratios both at the macro and micro level of organisations are determined. First, the contribution of OSS to the GDP of the EU in 2018 are assumed to be the benefits. Secondly, the costs are considered as the efforts by the EU to contribute to OSS not only in 2018, but also the years before, because the contribution of OSS to the GDP in 2018 is not only based on the OSS code developed in 2018, but also on the code in previous years. Eventually, a cost-benefit ratio of slightly above 1:10 is calculated. Considering also hardware cost for the 260,000 contributors to OSS, the cost-benefit ratio would then be slightly above 1:4. This ratio is in the line of the computer capital costs related to the long-run contributions of computerisation or the recently calculated social returns to innovation.

In order to complement, specify and validate the cost-benefit analysis performed at the macro level, the respondents to the stakeholder survey have been asked for the relevance of the benefits, but also the cost of using or contributing to OSSH for their organisations. In order to aggregate the various benefit and cost dimensions and to validate the results of the quantitative cost-benefit assessment, the respondents were asked to provide their assessment of overall cost-benefit ratio. As expected based on the assessments of the benefits and costs separately, one third perceive very high benefits and low costs, more than another third either very high benefits and medium costs or at least high benefits and low costs, which is in line with other survey results. Complementary to this qualitative assessment, in a last step the respondents have been asked to provide a quantitative assessment of a cost-benefit ratio of using or contributing to OSS. The most named value is 1:10 followed by 1:5. As mentioned above, a cost-benefit ratio of 1:4 has been calculated by bringing the expenditure for personnel and the investment into ICT hardware necessary at the level of the EU Member States in relation to the contribution of the pool of OSS to the

GDP in the whole EU. Therefore, it has been concluded that according to a cost-benefit ratio of 1:4 the costs needed for the investment in OSS will generate benefits which are four times higher according to our macroeconomic approach, but also based on the assessment of the stakeholders. Therefore, an internal consistency of this cost-benefit ratio can be claimed, which is also validated by external sources, e.g. related to innovation expenditures in general or ICT hardware in particular.

d. Is there a “dark side” to Open Source Software?

A number of arguments have been presented that emphasize downsides or risks of OSSH development. While there is no substantial academic research on a potential dark side of Open Source, debates continue within the ecosystem and on social media. Most positions represent partial interests, so conclusions should be drawn carefully. The discussions center on the inherent conflict between the roles of small and large enterprises in the ICT sector as well as situations where the sharing of IPR may be counterproductive.

A common argument is that large cloud businesses “intercept and monetize” OSS by creating proprietary derivatives of the original software that they integrate into their cloud offerings. While this does in fact happen, as for example in the way AWS offers a derivative of ElasticSearch, the actors involved perform their expected roles as software developers versus vertical integrators in a self-balancing ecosystem, encouraged by the prevalent use of permissive Open Source licenses that explicitly enable such uses of the software. A related argument that “big tech is siphoning off the Open Source ecosystem” or “strip-mining” ignores the fact that large ICT enterprises are at the same time the largest Open Source contributors, with Microsoft, Google and Red Hat (IBM) among the top.

Another argument is that Open Source licensing is becoming more complex, especially by way of the introduction of proprietary source-available licenses like the server side public license (SSPL). This claim is misleading since, while Open Source licenses are in fact well-understood, mostly standardised and approved against the requirements of the Open Source Definition, this new set of licenses attempts to add conditions to the use of the software that reintroduce proprietary licensing and vendor lock-in. They are not considered Open Source licences by the Open Source Initiative and users exhibit a strong preference against them. Related but not the same is the ethical-source movement that aims at tying the use of software to respecting human rights. While such ethical requirements currently contradict the Open Source Definition, exploring ethical issues is a worthwhile endeavour to evolve the understanding of Open Source. Arguments against ethical licensing should not be understood as reservations against human rights, but as arguments that software licensing (which is the focus of the Open Source Definition) is not an appropriate mechanism to achieve this. At this juncture, the approach of the wider Open Source community is to avoid ethical judgements in licensing by requiring that OSS can be used by anybody for any purpose, ethical or otherwise.

Exacerbating the issue between software developers and cloud providers is the claim that “commercial Open Source software” (COSS) companies, a misleading term referencing venture capital funded Open Source producing businesses, represent a majority of OSS contributions. However, the contributions of this well-funded, vocal group are dwarfed by the joint contributions of the wider Open Source community and especially by those of industry consortia collaborating at major Open Source foundations. Many of these businesses struggle to balance the non-differentiating nature of OSS with the inherent need of businesses to differentiate in the eye of the consumer. As established in this report, cost savings from shared R&D expenditure attract a much larger share of participants compared to the sole provision of a technical solution. Some COSS businesses enjoy high valuations based on the Open Source licensed software they produce. Such valuations are questionable if they are based on more than the complementary revenue stream facilitated by the Open Source product. Since use of the Open Source product is out of the control of the business, the asset value of the product should be considered close to zero or at best based on a goodwill evaluation. This argument is in line with community representatives pointing out that such companies own trademarks and services they offer, but that the product is a public good. While from a legal perspective the business may be able to maintain ownership of the product, for example through the use of contributor license agreements, the Open Source licenses and community norms enforce that it can be used by anybody for any purpose, including making derivatives or forks.

A separate and more politically oriented debate centers on the potential downsides of sharing IPR from a competition or geopolitical perspective. Collaboration on OSSH development reduces the options to, for example, impose sanctions or control technology proliferation. It also instantly makes the collaboration results available to everybody, defining a new state of the art. Open Source licensing and collaboration provide instruments also for policy makers to influence on what technologies businesses should compete. This influence is welcome and often intended. In international competition with authoritarian capitalist regimes, the balance of manufacturing is determined by comparative advantages in the respective countries. This makes it a political decision whether or not such competition based on workers living standards and respect for human rights is acceptable. This is not primarily a discussion about IPR policy, however sharing technologies based on Open Source licenses provides the blueprints for this competition.

Regarding the competition of software vendors and cloud operators, it is obvious that there is a need in the market for both software development as well as complementary services and vertical integration. A conflict of interest is inherent in that software developers wish to continue innovating, while integrators are interested in a stable, slow-changing product. There is no intrinsic value for the integrator in a relationship with the software developer. Such value can, however, be demonstrated for example based on the expertise gained from developing the software. There may also be reasons for integrators to avoid engaging for example because the developer does not reach the scale to be considered a reliable supplier or based on unattractive contributor licensing agreement terms. This makes the situation a two-sided issue to be balanced by negotiations between the two parties.

Regarding the arguments about IPR policy, there is a clear possibility for situations to evolve where sharing IPR is counter-productive or where secrecy is of value, for example during the development of a new weapons system. Even there, however, OSS would likely be used as foundational technology. The dynamic nature of this “differentiate or collaborate” scenario means that today’s innovations will become tomorrow’s commodities. Situations where secrecy provides technological advantage are reduced by the shift of innovation higher up the stack that OSSH introduces. Decisions should be made based on how the value induced by IPR may be effectively realized. Secrecy or exclusivity is one approach. Developing key innovations openly is another methodology that reduces the possibility of others suppressing the use of the technology, both because it is a direct challenge to secrecy but also, more subtly via creating prior art, because it makes it more difficult for others to enclose aspects of the technology through applying for patents.

In conclusion, observations of negative effects of OSSH production represent the creative destruction aspect of open competition. The cycle of wider adoption of a technology by big tech companies devalues investments made by developers in an earlier phase. The analysis in this report shows that while there naturally are winners and losers, the benefits outweigh the cost by far. It should be kept in mind that there are proven ways to differentiate based on the development of an OSSH product, as illustrated by Google’s use of trademarks to implement the Android certification programme. Political considerations are best kept separate from business arguments. If there is a well-understood interest not to share a technology with an adversary, the reasons for such a decision should be weighed against the economic impact.

8. Public Policy Analysis

a. Approach

The material scope of the public policy analysis covers both adopted internal and external OSS and OSH policies. The policies are analysed according to two dimensions, internal and external, as well as against a number of different criteria that provide a comprehensive overview of policies in the jurisdiction included in the territorial scope of the study.

Table 8.1: Dimension and criteria of policies

Dimension	Criteria
Internal Public sector aimed policies referring to how the public authority in question implements OSS & OSH in its own organisation.	• The level of prescriptiveness of a policy, throughout the jurisdiction. • The degree to which public procurement policies take OSSH into account. • How effectively the policy is being executed. • The degree of competence with regard to OSS and OSH within the public authority.
External Private sector aimed policies referring to how the public authority in question engages with other actors, specifically in the private sector.	• To what degree the jurisdiction supports private actors in adopting and developing OSS and OSH. • To what degree the jurisdiction makes guidance available for private actors. • Whether the jurisdiction's administration takes on a role (and if so, what role) with regard to OSS and OSH communities. • To what degree OSS and OSH are being taken into account in neighbouring policy fields.

b. Analytical framework

Data gathering and policy impact analysis is carried out through desk research, structured interviews with technical and policy experts, as well as through a questionnaire distributed to key stakeholders. Interviews are recorded and if of value transcribed.

After sufficient policy data has been gathered and outlined, the respective OSSH policies' relevance, role and merit for cybersecurity and Artificial Intelligence is analysed. The data is also used to compare worldwide policy actions and EU policy actions. Moreover, the potential transferability of the OSS policies to the realm of OSH is outlined and analysed. This also feeds into the policy recommendations.

The analytical framework, which is described in detail below, is also used to compare the EU's policy actions to a set of individual countries' approaches. These countries are Brazil, China, India, Japan, South Korea and the USA. From these analyses, promising and high-impact policy actions are extrapolated and described in detail, feeding into the policy recommendations.

This framework is informed by the previous policy analysis conducted by OpenForum Europe (OFE) and Fraunhofer ISI, as well as by the frameworks developed by the Center for Strategic and International Studies (Lewis, 2010), the Red Hat and Georgia Tech OSPI Project (Noonan et al., 2008) and the Spanish National Open Source Software Observatory (CENATIC et al., 2010). Up to 2010, these studies covered important ground in identifying global policies, and while today there may be no actively maintained research on Open Source policies, the aforementioned frameworks - together with the gathered historical data - are important data points to inform a successful framework today.

Although enabling compatibility requires common criteria, there is risk in relying only on common criteria, as important details and context can be missed. This framework therefore employs both qualitative and quantitative methods.

Collecting data determining the status of all indicators forms the basis for an overview and comparison of OSS and OSH policies in the EU Member States and other countries. With this information, it is possible to arrive at a structured survey of which countries have policies in which areas. This is complemented with qualitative information, providing more depth and context to the quantitative information.

In addition to this, grading the prevalence of policies by assigning marks (points) is used to create an index of the prevalence of OSS and OSH policies across the world. This makes it possible to assess the maturity of countries regarding Open Source policy on a number of different dimensions. This index is used to provide an immediate overview and identify key gaps, as well as areas to be further investigated in detail.

When marking, a number of factors are taken into account, in order to achieve an objective and reproducible result. Based on existing policy evaluation frameworks and literature (such as by the Overseas Development Institute (ODI), BetterEvaluation (BE) and the Australian Department of Foreign Affairs and Trade (DFAT) common Methods Lab and the United States CDC), a guiding set of questions were developed (Gasper, 2005; Pasanen & Shaxson, 2016; Centers for Disease Control and Prevention, 2013):

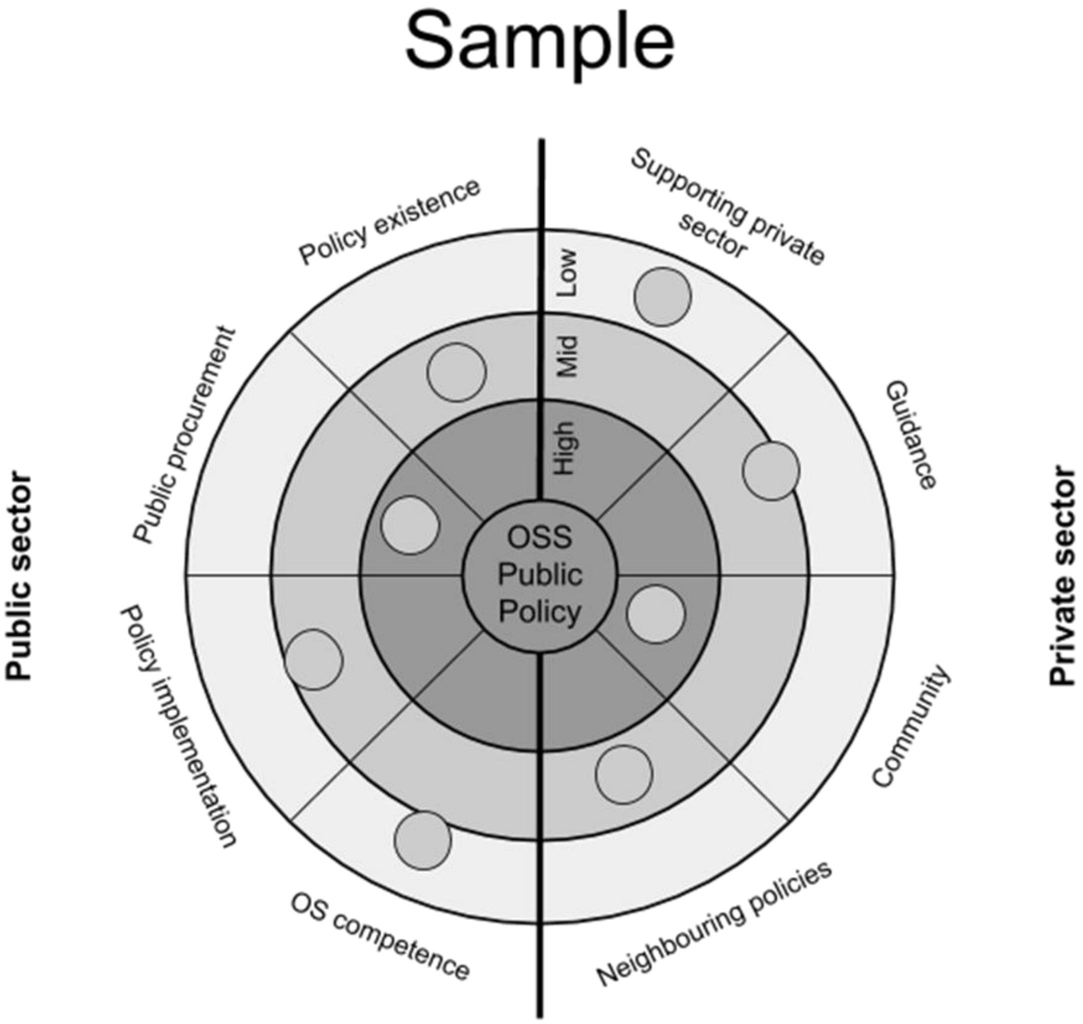
- Is the policy formalised, documented and communicated?
- Is the policy well designed to achieve the intended goal?
- Is it using resources efficiently in the pursuit of its goal?
- Have relevant stakeholders, such as other government officials, businesses and communities been consulted?
- Does the policy produce value-add for the jurisdiction?
- Are there positive or negative outcomes from the policy?
- Have there been any unintended consequences from the policy?
- Is the policy action well aligned to its legal, economic and societal environment?
- Have experiences from previous policy actions or other jurisdiction been taken into account?
- Does the policy take secondary goals into account?

This index could be used for a number of further purposes, and could be continually updated on a regular basis to achieve a trusted source for OSS and OSH policies. The data could also be visualised in many ways; for example, the sample figure below clearly maps countries along the two axes of internal policies and external policies.

Table 8.2: Criteria and Indicators

Criterion	Indicator	Max Mark
	Dimension: Public sector	**65**
Policy existence	Is there a policy on OSSH? If so, what is the most prescriptive level of the policy in force?	
Policy existence	Norm	5
Policy existence	Decree	10
Policy existence	Law	15
Policy existence	**Criterion total mark**	**15**
Public procurement	Is a public procurement policy in place which favours OSSH? If so, under which of the below categories does the policy fall?	
Public procurement	Advisory, where the use of OSSH is permitted	5
Public procurement	Preference, where the use of OSSH is given preference, but not mandated)	10
Public procurement	Mandatory, where the use of OSSH is required	15
Public procurement	**Criterion total mark**	**15**
Policy implementation	If there is an OSSH policy, how effectively is the policy being implemented?	10
Policy implementation	Is any enforcement of the OSSH policy foreseen?	5
Policy implementation	**Criterion total mark**	**15**
OS competence	Does the public administration have an internal strategy on OSSH?	5
OS competence	Does the public administration have an Open Source office?	5
OS competence	Does the public administration share its OSS and OSH policies and solutions with other public administrations?	5
OS competence	Does the public administration use OSSH in its own developments, including development which it outsources?	5
OS competence	**Criterion total mark**	**20**
	Dimension: Private sector	**45**
Supporting private sector	Are there any laws or rules that aim to support the private sector in exploiting existing OSSH?	5
Supporting private sector	Are there any laws or rules that aim to encourage the private sector to develop new OSSH?	5
Supporting private sector	Does a strategy exist to use OSSH for industrial development?	10
Supporting private sector	**Criterion total mark**	**20**
Guidance	Are there services that provide OSS/OHH-related guidance to the private sector (e.g., through explaining: OS licensing schemes, intellectual property rights, equal opportunities, procurement rules and how to participate in OSSH communities)?	5
Guidance	**Criterion total mark**	**5**
Community	Is the public authority nurturing Open Source communities?	5
Community	Is the public authority a good open community citizen?	5
Community	**Criterion total mark**	**10**
OS present in neighbouring policies	To what degree do policy actions in neighbouring fields (such as research & innovation, cybersecurity, telecommunications, AI, HPC etc.) take OSSH into account?	10
OS present in neighbouring policies	**Criterion total mark**	**10**
	Total of achievable mark	**110**

Figure 8.1: Sample visualisation of OSS policy prevalence



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This index could be used for a number of further purposes, and could be continually updated on a regular basis to achieve a trusted source for OSS and OSH policies. The data could also be visualised in many ways; for example, the sample Figure 8.1 above maps countries along the two axes of internal policies and external policies.

c. Public policy analysis

From an initial review of the research it becomes clear that in the early 2000s a first wave of interest in OSS policy started, probably prompted by more and more OSS projects gaining mainstream status and the intention to reduce procurement costs. Thus most policies concentrated on public procurement; while this is mostly still true, Open Source policy is now spilling over into a wider array of policy areas. As from the beginning of the

2010s this first wave ended and a new wave started in ca. 2015, with different aims. In this section an overview of research with a global scope is provided. When investigating countries, more insight into research covering the specific territory is provided.

Until the end of the 2000s, the OSS company Red Hat together with the Georgia Institute of Technology performed research into developing a structured model to identify OSS policies on a national level, around the world under the “Red Hat/Georgia Tech Open Source Index Project”. This project included a mapping of the maturity of policies related to OSS and a ranking of 75 countries (RedHat, 2011; Noonan et al., 2008).

The Center for Strategic and International Studies maintained a comprehensive overview of Open Source policy initiatives around the world. The latest version was published in March 2010 and lists 364 Open Source policy initiatives (Lewis, 2010).

In 2010 the Spanish National Open Source Software Observatory (today within the General Secretariat of Digital Administration) published a report on the state of affairs of OSS, in terms of public and private sector support and adoption by regions and countries. Information on the methodology and the questionnaires used is also enclosed within this report, and it is aimed to leverage these elements in this study (CENATIC et al., 2010).

Table 8.3: Regional distribution of approved OSS initiatives globally up to 2010 (Lewis, 2010)

Regional Distribution of Approved Initiatives*				
	R&D	Advisory	Preference	Mandatory
Europe	45	37	36	8
Asia	19	16	22	2
Latin America	8	6	12	31
North America	5	8	2	1
Africa	3	1	4	8
Middle East	1	2	2	0

Motivations

There are a variety of reasons why governments decide to adopt or not to adopt public policies that favour or take into account OSS and OSH. Scholars have contributed to structuring the understanding around this issue (Comino & Manenti, 2005; Hahn, 2009; Lee, 2006; Oram, 2011), yet most studies into governmental involvement in Open Source have been conducted within the first wave of OSS. The technological, political, economic and legal landscape has evolved since the early 2010s and thus also have the main motivations for governments to support Open Source.

There is no dominant classification of motivations, yet Lee (2006) suggests four overarching motivations: economic, technological, political and legal concerns. Broadly speaking, based on the surveyed countries, the dominant motivations for governments have evolved over time, yet remain delineated between global regions, representing a maturing of understanding the strengths and weaknesses of Open Source.

Within the first wave of OSS, economic concerns around the cost of procurement seem to have been the major engine for countries adopting OSS. According to our analysis, this is to a large degree true for all jurisdictions, though early on Asian and South American countries’ governments also were more active in taking political as well as ideological considerations into account - partly caused by their geopolitically weaker alignment to the United States. Open Source at this point was in general not chosen based on its technological merits, and legal concerns played more the role of inhibiting the adoption of Open Source.

After new adoptions of Open Source public policy actions reduced as from the beginning of the 2010s, OSS gained its ubiquitous position within the software private sector. While some jurisdictions continued support for Open Source relatively unaffected by this, a new paradigm developed broadly on how Open Source was conceived in the public sector. Open Source was not any more primarily framed as a way to reduce public procurement costs (though this still plays an important role in Western countries); instead, aspects such as software sector support, technological independence and digitalisation became dominant.

Economic concerns

Until around 2010, economic concerns were the main motivator in the first wave of governmental Open Source policies. Open Source was often considered mainly for being cheaper to procure than proprietary software, and its wider benefits for software development on an industrial scale were not then valued to the same extent. Governments were motivated by the usual (mostly zero) procurement cost, while sometimes underestimating the switching costs (e.g., training, compatibility, data availability) involved in migrating to a new software solution.

Another consideration to be addressed is the issue of underproduction of a public good, where a government will financially support a project that it considers in the public interest. Concerns were sometimes raised around how preferring OSS could impede and distort competition, yet within the second wave of Open Source it is considered that Open Source can be a tool for improving the competitiveness of lagging companies, thus stepping forward in creating more open competition in the ICT market.

Table 8.4: Economic concerns

Economic concerns	Cost savings	Production costs
		Marginal pricing
		Costs of maintenance
	Switching costs and network effects	Switching between OSS and proprietary software
		Lock-in costs
		(Lack of) Compatibility
	Underproduction of public goods	Underproduction of public goods
		Public subsidies for gift-giving
	Market competition and technology neutrality	Government support of OSS promoting / impeding competition
		Local industry support

Technical concerns

When governments establish policies around Open Source, until recently the main consideration was often the improved availability of data saved in Open Source (usually using open standards), which is important for governments for archiving purposes. Issues of compatibility between OSS and proprietary software were also considered a factor. Recently, the potential technical benefits of Open Source are increasingly highlighted as an issue. The open nature of Open Source has potential associated inherent benefits in terms of the security, availability and customisability of software.

Table 8.5: Technical concerns

Technical concerns	Compatibility	Incompatibility of proprietary software and OSS
		Regulatory approaches to promoting software compatibility
	Security	
	Usability	
	Availability	
	Customisability	
	Local language	
	Reproducibility for archiving	

Political concerns

In recent years, political concerns have played a bigger role in the decision-making processes regarding OSS. Whilst in Asia and Brazil these concerns already formed part of the earlier policy discussions, in the EU this has now become a more politicised issue and thus one of the main motivators for considering Open Source under the umbrella of "Digital Sovereignty", and the desire to become less dependent on a few suppliers when it comes to digital infrastructure. In the first wave, this had often been presented as a concern relating to the need to avoid dependence on Microsoft products; now, this has developed into a wider push to have more choice, in some parts with a broader concern around dependence upon United States-based companies. Apart from this, developing countries specifically considered OSS as a way of preserving foreign exchange assets, as use of OSS resulted in fewer imports of commercial software products.

This aside, governments also consider Open Source an opportunity for improving the transparency of governmental processes and thus improving access to information and governmental services, thus strengthening democracy as a whole. Open Source is thus also considered as a way to improve the digitalisation both of governments and of industry within a given jurisdiction.

Table 8.6: Political concerns

Political concerns	Governance	Strengthening democracy
		Improving access for the public
		Increasing transparency
	Independence	Vendor independence
		Technology independence
		Conserving foreign exchange assets
		Anti-United States complex
	Digitalisation	Increase digital skills
		Digitalisation of government
		Software industrial policy

Legal concerns

Legal issues have long played a minor role in the public discussion around Open Source, although at the expert level legal concerns can play a major role. During the first wave of Open Source, questions around compliance with the international trade regime were raised, yet with the rise of Open Source in the public sector such concerns appear to have faded somewhat. Mostly in developing countries, Open Source was also considered as a way to combat issues with the piracy of proprietary software.

Today, a new legal issue has arisen, in the form of trade conflicts centered around access to technology. Open Source here offers the chance to mitigate such risks by removing software from the scope of trade disputes; as the software is available to everyone, it is difficult (indeed in theory impossible) to restrict access to specific software programmes or components published under an Open Source licence to any specific party.

Table 8.7: Legal concerns

Legal concerns	An approach to software piracy
	Risks of indemnification
	Difficulty to restrict access
	Compliance with international trade regime

d. Comparative actions

A number of other factors, such as perceived policy space, policy culture, opportunity structure and others, shape the specific motivations which are turned from general objectives into actual policy. Generally, similar to the motivations observed by countries, within the surveyed countries geographical and chronological differences can be observed..

Before going into the comparison of the different countries' policy actions, an understanding of the types of actions is provided which different countries can take and have taken, so as to showcase options available to governments. Commonly, public policy actions can be delineated by being targeted at the private or public sector.

Policies aimed at the public sector typically fall under two main categories. The first category targets either improving competence regarding Open Source within the public sector in order to support the digitalisation of the public administration itself and reap the rewards from that for the public sector, or using the size of the public administration as a lever to achieve a wider set of advantages. The second category usually relates to public procurement policies favouring OSS over proprietary software. Such policies have different scopes, implementation mechanisms and levels of prescriptiveness, ranging from binding laws adopted by the legislative body of the jurisdiction to simple norms adopted by an executive body within the public sector. Policies aimed at improving the competence of the public sector typically revolve around internal strategies, such as an Open Source strategy, prescribing or guiding the use of Open Source within the organisation itself or guidelines on the re-use of OSS within the public sector of the jurisdiction. Another policy action is the creation of an Open Source Programme Office (OSPO) (also sometimes known as a competence centre), which centralises the expertise of the public sector around Open Source.

Policy actions aimed at the private sector are more varied and tend to be aimed at a number of different stakeholders. Among the possible actions here is guidance and support for companies regarding Open Source and its collaborative development paradigm. This can be coordinated through an OSPO, publishing guidance, offering training and consulting services. In addition, some governments are directly involved in setting or influencing industrial policy through steering their industry toward innovating through Open Source. Government can also be involved in improving ICT education through Open Source, e.g. through working with universities to create programmes around open technologies and the development of Open Source. Another possible action is to support the creation of communities in the jurisdiction, through community engagement, directly or indirectly, attempting to widen the Open Source community and thus improve adoption of OSS and OSH. Government can also directly fund or certify Open Source projects that it sees strategic importance for either the public or private sector, or projects that are seen as a public good.

For this study, the following countries' policies regarding Open Source were analysed:

- European Union institutions policy
- EU Member States:
  - Bulgaria
  - France
  - Germany
  - Italy
  - Poland
  - Spain
- Other countries:
  - Brazil
  - China
  - India
  - Japan
  - South Korea

- United Kingdom
- United States

A detailed per-country analysis is available in the following chapters; here, an overview and comparison of policies are presented.

In previous discussions the geographical differences between the world's regions were highlighted, and these differences become clear when delineating results between geographical regions. Generally speaking, governments in the EU and the Americas focus on the public sector with policy actions, while governments in Asia (with the exception of India) tend to focus their efforts more toward developing the country's private sector.

Looking into the collected data more in detail, a majority of EU Member States (except Germany and Poland) have a formalised policy on OSS; in most cases this means a decree-level public procurement policy favouring OSS over proprietary software. In opposition to this, in Asia only India has a formalised public procurement preference for OSS on the national level. The Chinese government, through its research institutes, has an informal preference toward OSS, yet this policy is not legally applicable to the public sector.

The implementation of policies remains an issue in essentially all jurisdictions. The effectiveness of implementation of public procurement policies seems not in correlation with the level of prescriptiveness of the policy or even a formal enforcement mechanism. Here, Bulgaria has shown that enforcement does not lead to implementation. In reality, the level of institutionalisation, the politicisation of Open Source and to what degree a cultural and educational shift toward Open Source appears a stronger predictor for a successful implementation. Yet, the only truly convincing implementation has occurred at the regional level (e.g., in the regions of Catalonia in Spain or Kerala in India), where Open Source has become a core component of a digital shift and thus ingrained in the digital culture of the administration. Achieving this on a national level seems to be a challenge not yet met by any of the surveyed countries.

Another issue identified is connected to the development of Open Source by public administrations. While many jurisdictions have legislation demanding the development and reuse of Open Source solutions within the public sector, after such laws or decrees are adopted the follow-up often is lacking. There is a close connection to the issues of institutionalisation and education, as previously mentioned. Adopting a law instructing a public administration to develop and reuse OSS does not necessarily lead to these public authorities doing just that. Here, the absence of concrete implementation guidance should be highlighted. Many jurisdictions have a law, but no Open Source strategy to make the legislation implementable, as many factors have to be considered.

As previously discussed, there are different reasons why governments adopt Open Source for the public sector. Besides making the government more digitally adept and reducing costs, some governments also see Open Source as a tool from a normative perspective, aiming at achieving a greater level of transparency. The analysis concludes that this aspect plays a greater role in the EU than it does in other parts of the world, where economic and political concerns play a larger role.

Table 8.8: Overview and comparison of Open Source policies

Criterion	Max Mark	Bulgaria	France	Germany	Italy	Poland	Spain	United Kingdom	United States	Brazil	China	India	Japan	South Korea
Dimension: Public sector		52%	65%	0%	63%	2%	57%	51%	54%	14%	40%	40%	0%	31%
Policy existence	15	15	5	0	10	0	15	10	10	0	5	10	0	10
Public procurement	15	15	10	0	15	0	5	5	10	0	10	10	0	0
Policy implementation	15	3	8	0	4	0	5	6	6	0	5	5	0	0
OS competence	20	1	19	0	12	1	12	12	9	9	6	1	0	10
Dimension: Private sector		2%	29%	16%	13%	2%	20%	11%	0%	4%	56%	27%	7%	76%
Supporting private sector	20	0	0	2	0	1	0	0	0	0	14	5	1	17
Guidance	5	0	0	2	0	0	2	0	0	0	2	2	2	5
Community	10	1	10	1	4	0	6	3	0	1	4	4	0	6
OS present in neighbouring policies	10	0	3	2	2	0	1	2	0	1	5	1	0	6
Total of achievable mark		27%	47%	8%	38%	2%	38%	31%	27%	9%	48%	33%	3%	53%
Criterion	Max Mark	Bulgaria	France	Germany	Italy	Poland	Spain	United Kingdom	United States	Brazil	China	India	Japan	South Korea

Shifting the focus of analysis away from public policies aimed at the public sector toward the private sector, it is clear that the geographical area of analysis shifts from the EU and the UK, the United States and Brazil to Asia. In the case of Japan, noteworthy here is that even though on the face of it Japan does not now have a large number of policy actions, and in the past (similar to other East Asian countries) had extensive industry support and public sector involvement with Open Source, as of late governmental focus in Japan has shifted toward other areas, as the Japanese government concluded that industry would not require further governmental support in this field.

Yet, in Asia, more so than in the EU and the Americas, Open Source is defined by early governmental leadership or influence. The various ministries of economy were writing industrial policy in reaction to the ubiquity of Open Source within western IT companies, often picking up on a trend that was visible at the spearhead of the local industry. The leader here is South Korea, which comes out on top regarding the most expansive Open Source policy in terms of private sector support.

Within South Korea, Open Source has a prominent position when it comes to digital industrial policy, making heavy use of institutionalising the support, through a number of agencies that produce guidance, training and support for industry, while at the same time moderately working toward building an Open Source community and incorporating elements of openness within wider digital policy. China again uses more informal policy instruments to steer local industry, but (through ownership of important technology companies) still exerts strong influence on local industry, and supports innovation and technological sovereignty through Open Source.

India is an outlier to some degree, and as a government acts more like an EU country toward Open Source, focusing on the public sector, without any significant emphasis on technological sovereignty from the 2000s on.

EU Member States have long placed little emphasis on the potential of Open Source policy for stimulating the private sector. There is an overlap with the United States' policy on this, also focusing actions on the public sector. Yet, from the perspective of the structure of the private sector, in the early 2000s EU Member States were closer to Asia, having only a weaker ICT sector, especially when it comes to software, while the United States has a private sector with software capabilities that are dominant around the world. It is clear that Asian governments have focused a lot on political and financial capital towards developing the local ICT sector, with Open Source being one of the instruments employed. In the countries that today have increased software capabilities on the private sector side (i.e., South Korea and China) Open Source has played an important role in industrial policy. The causal relationship is difficult to ascertain, yet it is also clear that EU Member States governments have taken a more laissez-faire approach to this and today, the EU is on the back foot when it comes to capabilities in this area.

e. European Union institutions

Background and context

An overarching Communication on the digitisation of public administrations in the EU is the eGovernment Action Plan, which aims at making these administrations more open, efficient and inclusive by enabling mobility of citizens by cross-border interoperability and facilitating digital interaction between the public sector and citizens and businesses (European Commission, 2016). Its latest versions for the years 2016-2020 started out with 20 actions that were extended with actions proposed by the public. It does not specifically refer to Open Source, yet it states the importance of openness and transparency in public administrations. Several internal and external actions have been implemented on the European level to support the uptake and development of Open Source for leveraging its benefits throughout the Union.

Internal policies of EU Institutions

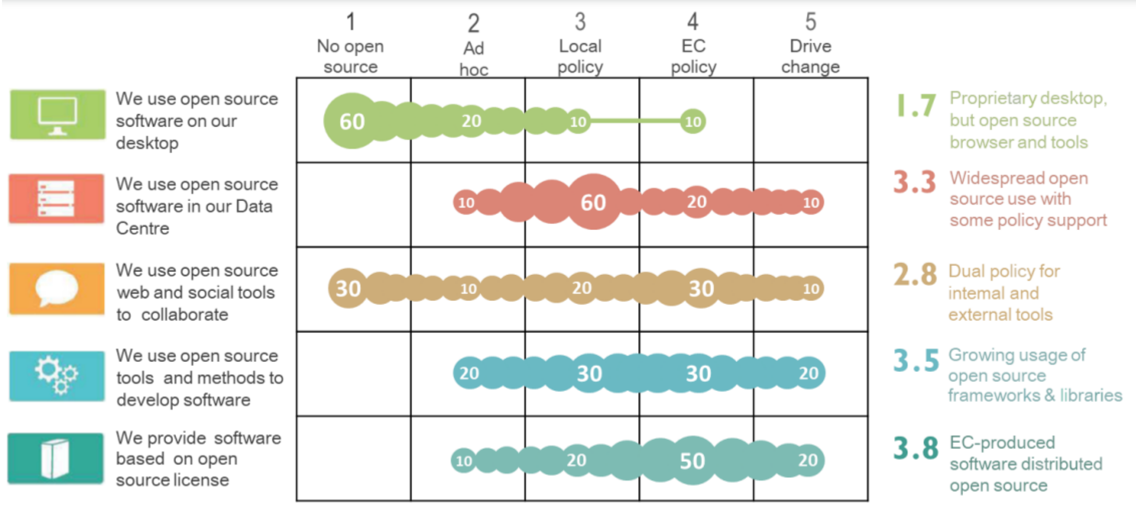
Over the years, the EU's institutions have built a robust policy foundation for the support of Open Source. A strategy concerning the internal use of OSS was first adopted by the European Commission in 2000, and recommended the use of the Apache Web Server for UNIX systems (European Commission, n.d.). Some of the changes over the years have included encouraging the use of Linux as a server OS, the use of Apache to power the europa.eu server and the development and formal approval of the European Union Public Licence (EUPL), which is now used by several private and public organisations.

Since then, the strategy has been regularly revised, with the previous strategy covering 2014-2017, and a renewed strategy for 2020-2023 (European Commission, 2020). The latest strategy, published on October 21, 2020 commits the European Commission to continue and expand efforts in order to increase the adoption of Open Source, fair treatment of OSS in public procurement and a preference for OSS in future internal developments, including software developed by third parties. It also sets up an Open Source Programme Office (OSPO) at the European Commission in order to facilitate implementing the Strategy and giving a more formal structure to Commission's actions in the subject, including organising relevant training, supporting distribution, contribution and usage of code.

The European Commission has achieved significant milestones in its open source adoption, including the introduction of the EUPL in order to provide an open source license compatible with EU and Member State law; publishing open source software developed for the European Commission on the dedicated platform Joinup, an eGovernment platform under the ISA programme, where users can share and reuse Open Source solutions within the public sector. The changes were also introduced internally, using OSS in data and web servers, corporate solutions and others, while at the same time ensuring equal opportunities for Open Source in procurement. Initiatives such as the Europe Coding Week, Bug Bounties Programme and European Interoperability Reference Architecture are also a part of activities fulfilling the goals of the strategy.

In 2020 the "Study on Open Source Software governance at the European Commission" has been conducted in order to analyse the state of OSS in the institution (European Commission & KPMG, 2020). It provided an updated EC Open Source Software Adoption Maturity Index, and as shown on the figure below, the best-scored category is production of new software and releasing it as OSS, which is being mostly done within the ISA2 programme and in some units of DIGIT, the Directorate General for Informatics of the European Commission. The user-facing dimension of desktop applications is rated with a lowest score.

Figure 8.2: EC Open Source Software Adoption Maturity Index



While the previous version of the strategy seems to be fairly successful, the latest strategy has a potential to give a ‘more pronounced voice of OSS’ and a new angle of digital sovereignty.

External policies

Apart from the official internal policies of the European Institutions, throughout the years there have been several related EU-funded actions aimed at coordinating interoperability activities and developing solutions for public administrations.

For instance, the ISA programme introduced in 2010, followed in 2016 by ISA², represented a significant step towards fostering interoperability within public administrations by supporting several Open Source activities and solutions. Its predecessor, the IDABC programme, had been introduced as long ago as 2004 (European Commission, n.d.).

The first ISA programme, which ran from 2010 to 2015, created a framework that allowed EU Member States to cooperate on creating efficient digital cross-border public services (European Commission, 2016). With a budget of some 160 million euros, it comprised over 40 actions in different clusters: trusted information exchange, interoperability architecture, assessment of the ICT implications of new EU legislation, and accompanying measures.

The ISA² Programme (2015-2020) had the similar aim of supporting the development of digital solutions for public administrations, businesses and citizens in Europe, using interoperable cross-border and cross-sector public services developed under the programme. A budget of €131 million was distributed over five years. It encompassed 54 actions, in areas such as monitoring the application of EU law, telecommunications, big data for public administrations, public participation, e-procurement, financial data reporting, and many others (European Commission, n.d.). The continuation of the ISA² programme is planned under the Digital Europe Programme with an adjusted scope. (Joinup, 2020).

In 2020, the programme launched a “Digital Response to COVID-19”, offering to list and to structure a number of digital approaches to mitigate the crisis (Sowińska, 2020). Among the offered approaches, over a third of the almost 500 solutions are open source, thus available to help medical staff, public administrations, businesses, and citizens in their daily activities can be found.

The Open Source Observatory (OSOR) project is also a part of the ISA² programme (Open Source Observatory, 2021), first developed and managed as both an observatory and a repository in order to support the Member States in their actions. Its focus has changed since then to be fully a repository of news on Open Source projects and implementations relevant to the public sector and serving as a platform for exchanging information and sharing resources, while the repository function is provided by the Joinup platform. At the time of writing, more than 2,000 news articles and over 600 events have been published on the site. Outside of the informational and dissemination aspects of the project, it promotes OSS through community engagement and it maintains its own community of over 500 members. OSOR also provides ad-hoc legal support relating to the licensing of OSS.

EU-FOSSA 2 (Free and Open Source Software Auditing) is another relevant EU-level initiative. The initial pilot project was initiated in 2015, when the European Parliament secured an initial budget of €1 million for a European Commission pilot project to audit the security of the EU's most critical OSS. After a public consultation, Apache HTTP Server and KeyPass were selected for a detailed security audit. This initiative was followed by EU FOSSA 2, with a €2.6 million budget (European Commission, 2019).

EU-FOSSA 2 has led to the Commission ordering best-practice studies on topics such as "Open Source in public administrations worldwide; issues relating to licensing and IT support and the roadblocks for greater use; and interacting with leaders from the Open Source community, to identify and implement solutions" (Ramos, 2019). The project, introduced on the wave of the infamous "Heartbleed" security bug, was completed in June 2020, and seems to have been a success (European Commission, n.d.). From a broader perspective, this is an initiative that closes the distance between the EU institutions and the OSS communities through a bottom-up, technology-led push. As such, the EC has progressed from being a user of Open Source to actively contributing to its stability, reliability, and security through the EU-FOSSA and EU-FOSSA 2 projects.

In terms of OSS licensing, in 2017 the European Commission created the aforementioned European Public Licence (EUPL), a Free and Open Source licence. Its use has been encouraged among European Institutions and EU Member States, and its latest version (published in 2017) is available in 23 languages (EUPL, 2021). It is legally consistent with the copyright law of all Member States and compatible with many other popular open source licences, which makes it a unique tool that increases the take-up of OSS in public administrations. As a result, the EUPL has been formally included in some Members States' policy documents, has been used in numerous open source projects by the European public sector and is one of open source licences formally recognised by the Open Source Initiative. Another noteworthy initiative from the European Commission regarding licensing is the Joinup Licensing Assistant tool, which provides guidelines about various licences that could be used for software (and their respective terms and conditions) in an easy, user-friendly way (Joinup, n.d.).

Most of the policies on the EU level have "advisory" status for EU Member States, and consist of guidelines and good practices aiming to implement them. Nevertheless, some have gathered significant attention and influenced the use of Open Source or local Open Source policies. The documents usually refer to the overarching terms of "openness" of digital infrastructures, data sharing (either between governments or the private sector), and interoperability. Open Source, in some countries, is framed within the notion of "digital sovereignty" and entered the discourse on the European level with the Berlin Declaration, signed in December 2020. The Declaration listed several goals aimed at contributing to a value-based digital transformation by addressing and strengthening digital participation and streghthening Europe's digital sovereignty. Its signatories pledged to implement by 2024 "common standards, modular architectures and – when suitable – open source technologies in the development and deployment of cross-border digital solutions" in their Member States and called upon the European Institutions to "promote the development, sharing and reuse of open source standards, solutions and specifications across borders".

Yet another instrument, initially developed under the IDABC and ISA programme and, is the European Interoperability Framework (EIF). In its 2017 version, it proposed 47 recommendations for public administrations on how to improve the governance of interoperability activities (European Commission, n.d.). Its first version was adopted in 2010, and the content was revised following a public consultation in 2016 which indicated the need for an update in order to retain alignment with fast-forwarding changes in the ICT landscape. The EIF also reflected EU policies that appeared throughout this time, such as the revised Directive on the reuse of Public Sector Information, the eIDAS Regulation and initiatives such as the European Cloud Initiative.

The EIF calls for the use of OSS, as it enables reusability and helps to save development costs; it also recommends that Member States ensure a level-playing field for OSS and give preference to such software based on the specific needs of the administration in question. Implementing these recommendations happens through National Interoperability Frameworks, which build on the EIF to align national initiatives in local contexts of Member States.

Within the realm of digital government and interoperability, an important step was the Tallinn Declaration on eGovernment (European Commission, 2017). On 6 October 2017, ministers from 32 European countries agreed on this forward-looking declaration. The Declaration has a series of key commitments made by the participating Member States on the importance of Open Standards to support interoperability, and the opportunity for Open Source to underpin critical infrastructures and empower the Public Sector to innovate and develop cutting edge e-Government solutions.

The Next Generation Internet (NGI), a European Commission initiative with the goal of shaping Europe's digital development in an inclusive way based on European values, has received an investment of more than €250 million between 2018 and 2020 (Next Generation Internet, n.d.). It gathers and funds several research innovation and research projects on diverse digital topics ranging from network infrastructures to digital platforms and social innovation. In its position paper on the scope of NGI, it pinpoints the importance of openness that should come together with innovation and cooperation (Next Generation Internet, 2019). The programme, published in August 2019, states that NGI will invest in OSS and OSH in order to open up key technology components for increased transparency, security and resilience. As of December 2020, 450 awarded projects from third parties are OSSH and covering all the components of the IT stack. Third parties funded in the NGI programme are mostly individuals (54%) and micro-entreprise or SMEs (28%).

There are a number of recent digital files which connect to Open Source but rarely refer to it explicitly. The Commission's Communication "Shaping Europe's digital future" from February 2020 set out the broader vision of where (and in some instances how) the EC aims to produce policy in order to shape Europe's position on digital matters (European Commission, 2020). In order to protect and enhance Europe's position digitally and subsequently geopolitically, as well as protect EU values, it underscores the importance of "European technological sovereignty"; however, it does not mention Open Source as its possible enabler. On the other hand, it is a high-level document which points into general directions of policymaking, and on the European level, Open Source seems to be seen in rather technical terms. In some Member States, namely France and developing in Germany, the strong existence of Open Source as a political term, used in a broader definition of digital openness can be observed.

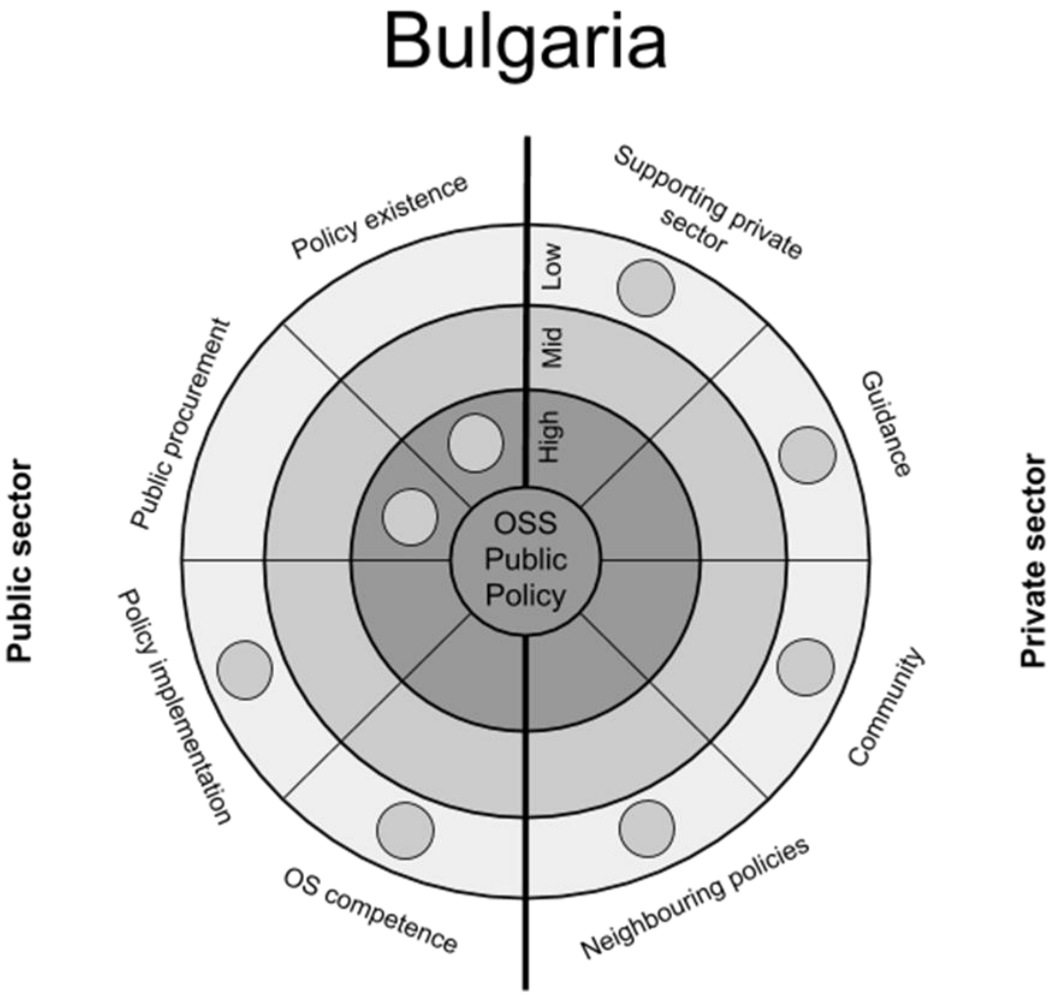
The Communication proposes that the EU should make more investments, not only through Member States, but also through the new EU Multiannual Financial Framework (MFF). Areas listed as priorities for the EU are innovation, connectivity, smart energy and transport structures, enhanced cybersecurity, and digital skills. Strong emphasis is put on data infrastructures, but this is extensively addressed in a different document that came out around the same time, which is the European Strategy for Data (European Commission, 2020).

The European Data Strategy aims at leveraging data for the benefit of citizens and to strengthen local companies in the sector. It states that during the next MFF, active from 2021-2027, the Commission will invest in a High Impact Project on European data spaces and federated cloud infrastructures. Such data spaces would be developed in nine different areas (such as health or mobility), where many Open Source projects might find their place. They would have to meet specific requirements both in terms of functionality (data sharing tools, data governance frameworks, and the improvement of availability, quality and interoperability of data), but also requirements of environmental performance, security, data protection, interoperability and scalability. It is closely linked to the European Open Science Cloud (EOSC) that together with other partnerships could help steer investments in this area. Depending on the distribution scheme and requirements, an impact for the Open Source ecosystem might be seen.

Open Source has not reached an equal level of political awareness throughout the Member States and in all European institutions. While there is a number of policies that show the direction on how to increase the uptake and development of Open Source, few policy documents from neighbouring policies touch upon the subject. Unintended consequences of such lack of knowledge among policymakers around Open Source could result in the omission of Open Source in the drafting of legislative documents, which sometimes might result in a negative impact on the sector. It could have happened in the Copyright Directive case, but it did not thanks to a strong community reaction (OpenForum Europe & FSFE, 2017).

f. Public policy actions in EU Member States

Bulgaria



Policy context

Historically, Bulgaria used to be called the "Silicon Valley of Eastern Europe" due to its well-developed hardware sector back in the 1970s and early 1980's as the big ICT provider for the needs of the Soviet Bloc. Its centrally planned ICT acumen has struggled with the economic transformation to a free market economy in the 90's and the country has yet to achieve its digital potential, especially as the positive outcomes expected from the accession of Bulgaria to the EU in 2007 were hampered by the global financial crisis (Petrov, 2018).

Bulgaria has been putting the ICT sector and digitisation high on the policy agenda in recent years in order to catch up with older Member States as the digitisation of industries lags behind the EU average. It is characterised by a low use of technologies such as big data analysis and cloud computing among SMEs and the industry, with underlying factors such as relatively high investment costs, understaffing, and lack of digital skills (McKinsey&Company, 2018).

Bulgaria's economic situation is less favourable than in other Member States, with the lowest GDP per capita in the EU and low wages which motivate many citizens to leave the country, which results in a significant emigration of its population to other EU Member States observed every year (Hristova & Petrova, 2017; National Statistical Institute Bulgaria, 2020; European Commission, 2020).

The country ranks last in the Digital Economy and Society Index, performing well in areas such as connectivity and digitising government, while falling short in terms of digital skills which are on the lowest level in the EU, and underperforming in integrating digital technology in its industries (European Commission, 2019). When it comes to ICT specialists and graduates, Bulgaria ranks as 23rd and 22nd respectively, which is only made worse by its high emigration levels.

On the other hand, the labour market conditions are improving, and GDP has been growing in recent years, accompanied by several initiatives taken by the government that places high importance on digitising the country. A number of Bulgaria's DESI indicators have been improving over the last couple of years; further, the software sector's revenues are increasing every year and monthly compensation in the software sector surpasses the country's average more than three-fold, which might attract new talent and strengthen the pathway to a more digitised and prosperous country (The Bulgarian Association of Software Companies, 2018).

Bulgaria was one of the first Member States in the EU to implement a national strategy for the Information Society in 1999, followed by the eGovernment strategy in 2002, prepared by the specialised Coordination Centre for Information, Communication and Management Technologies (Tzitzellkov and Decheva, 2016). In 2006, Bulgaria adopted a National Interoperability Framework in compliance with the European framework which is one of the instances of the country's smooth transposition processes (Council of Ministers, 2006).

The first bill requiring the use of Open Source was discussed by the Bulgarian Parliament in 2003. It would have mandated all governmental institutions such as municipalities and regions, higher schools, medical institutions, non-profits and organisations receiving governmental funding to use Open Source and open formats within two years of adoption. There would have been an exception when OSS was justifiably not suitable for the specific purpose (EDRi, 2003). The bill did not pass and efforts to mandate the use of OSS have been delayed by more than ten years.

In recent years, the government has taken some steps toward the digital transformation of industry, through the main "Digital Bulgaria 2025" programme, which includes goals such as the digitisation of Bulgarian industrial sectors, accelerated development of eGovernment, increase of highly qualified ICT specialists, ensuring interoperability and strengthening cybersecurity (Ministry of Transport, Information Technology and Communications, 2019). Another programming document is a concept paper "Concept of Digital Transformation of Bulgarian Industry (Industry 4.0)" from 2017, that presents the goal of becoming a regional hub of digital economy through fostering innovation and introducing competitive services and technologies, as well as benefiting from new business models and processes of Industry 4.0 (Economic Policy Institute, 2018). Other developments include a cohesion policy project for SMEs to acquire new digital infrastructure, and an upcoming 5G strategy (European Commission, 2020). These documents refer to openness as a desired value in digital policies - and the implementation of such policies in Bulgaria - yet do not mention it specifically.

When it comes to the institutional dimension, Bulgaria does not have an agency to deal with Open Source matters; however, it has increased and harmonised some of its efforts in overseeing the digitisation of public services and Bulgarian industry.

The Ministry overseeing digital policies in Bulgaria is the Ministry of Transport, Information Technology and Communications, working on ICT policies in the fields of cybersecurity, Open Data, broadband connectivity, standardisation and others. It is responsible for the overarching National Programme "Digital Bulgaria 2020" and "Digital Bulgaria 2025", and the implementation of EU programmes and strategies.

The body responsible for policies, rules, and regulation of eGovernment within the ministry is SEGA (The State eGovernment Agency), a separate entity funded by the state budget that has been operating since 2016. It performs activities related to issuing and introducing policies in the field of eGovernment, planning the budget, coordinating sector-related policies and overseeing their implementation. The Agency also maintains central registers to meet the eGovernment requirements, a state private cloud and communication network used by the public administration (State eGovernment Agency, n.d.).

In the past, civil society organisations were openly advocating for increasing the importance of OSS and its uptake within the government and industries. No significant civic sector activity has been focused on OSS in Bulgaria for the last couple of years, although some software-oriented organisations, such as the Bulgarian Association of Software Companies, clearly voice their interests both in the country and abroad (BASSCOM, n.d.).

The organisation that has contributed to the inclusion of Open Source within public procurement in 2016 in Bulgaria was Obshtestvo (The Society), an independent group of software experts, programmers and developers who campaigned for software designed for the state and paid by taxpayers to be publicly owned and developed in a transparent manner (Obshtestvo, n.d.). Volunteers were developing OSS, promoting the use of Open Data and explaining the merits of OSS to policy-makers, businesses and users through meetings and online materials. It had not, however, precluded the use of proprietary software, being of the opinion that not everyone has to migrate to open solutions and instead should focus on fulfilling the specific needs of the situation. The group seems to have ceased activity soon after the amendment for which they advocated was included in the Electronic Government Act, with no significant engagement since 2017.

Historically, the Bulgarian chapter of the Internet Society established in 1995 had been the first organisation involved in promoting OSS and Open Standards in the country. Activities included raising awareness around the benefits of the use of the Internet in the country, promotion, development and education around Free and OSS, as well as eGovernment initiatives. Although the organisation is still carrying out a part of its activities, it has not been very active since 2008(ISOC Bulgaria, n.d.). The Internet Society, as a global organisation with national chapters, has recently seen new chapters emerging and reviving their activities; however, the Bulgarian chapter has not been active in the last ten years.

Current policy actions

In 2016, the Bulgarian government passed a landmark amendment concerning public procurement and OSS in its Electronic Government Act, originally adopted in 2008 (State e-Government Agency, 2016). It required public administrations which procure the development, upgrading or implementation of information systems and electronic services to include the provision that the source code “must meet criteria for Open Source Software” within the terms of reference of public procurement procedure.

The latest version of the Act, effective on 29.11.2019, states that (State e-Government Agency, 2019):

> **Art. 58a.** In the preparation of technical specifications for public procurement for the development, upgrade or implementation of information systems or electronic services, the administrative authorities must include in the specifications the following requirements:
>
> 1. in the cases when the subject of the contract involves the development or upgrading of computer programs:
>
> (a) computer programs must meet the criteria for open source software;

(b) all copyrights and related rights in the relevant computer programs, their source code, the design of the interfaces and the databases whose development is the subject of the contract must arise for the contracting authority in full, without limitation in their use, modification and distribution;

c) the repository and version control system shall be used for development.

The law does not differentiate between the various levels of in-scope administrations (i.e., regional, central and public bodies such as ministries), meaning that all administrations are equally expected to implement it. Other provisions that the law encompasses include open data, accessibility and interoperability requirements. It also established the new State e-Government Agency (SEGA) in 2016, responsible for national policies regarding eGovernance and good practices in the field. According to the law in its newest form (in force from November 2019), public officers could be held responsible for failing to comply with the guidelines and could face a financial fine in case of a repeated non-compliance, however, no reports of the enforcement of that rule have been found.

The Electronic Government Act is accompanied by the Ordinance on the General Requirements for Information Systems, Registers and Electronic Administrative Services which was adopted in 2017 and provides more detailed instructions regarding its implementation (Council of Ministers, 2017). It determines terms, procedures and general and technical requirements for electronic administrative services. Those include formats of electronic documents, electronic archiving practices, duties and responsibilities of officials, access restrictions, standards and others.

The Ordinance specifies licences under which the source code and documentation shall be made publicly available (including the EUPL, GPL 3.0, LGPL and AGPL licences), and that the projects should be available in a source code repository which public agencies should be using. The document specifies that access to this repository should be open and free of charge, should allow for an unlimited number of project repositories and that a copy of the repository should be available through the GitHub platform. Contractors providing software for public agencies are required to use the repository in their daily work and improvements could be suggested by anyone. However, as of April 2020 (during more than two years since its establishment) the official GitHub repository serving this purpose, administered by the State e-Government Agency, has only seen a handful of contributors with several months of lack of any activity (State e-Government Agency, 2018). Oversight over the implementation of the Act and the Ordinance is coordinated by the chairperson of the State Agency for Electronic Governance, whose responsibilities include filing annual reports with the Council of Ministers and commissioning periodical compliance checks.

According to a former advisor to the deputy prime minister, the introduction of the amendment concerning Open Source was motivated in large measure by several vulnerabilities that were being found in governmental websites. Such a situation might have been a result of the lack of oversight, or in expiring contracts, but the underlying issue was the belief in “security through obscurity” that clearly had not worked in the past, according to an expert.

Some ICT experts participated in a series of meetings with representatives of the Bulgarian Parliament to discuss the potential inclusion of Open Source within the 2016 Act, and attempted to educate officials about the nature of OSS. Despite the final incorporation into the text, according to some, many politicians had not been convinced of the possibilities that OSS brings and still perceived it as a less secure solution for the digitisation of governmental services.

The amendment passed, as there has been an internal push from some officials who did believe in the possible positive impact of OSS, and a small advisory team was dedicated to this issue as a priority. The advisory group was disbanded when the Prime Minister tendered his resignation in 2016 following his party's defeat in the presidential elections, which resulted in early parliamentary elections the next year. The advisory group's work was not continued in the next mandate and the group has not been convened again since then.

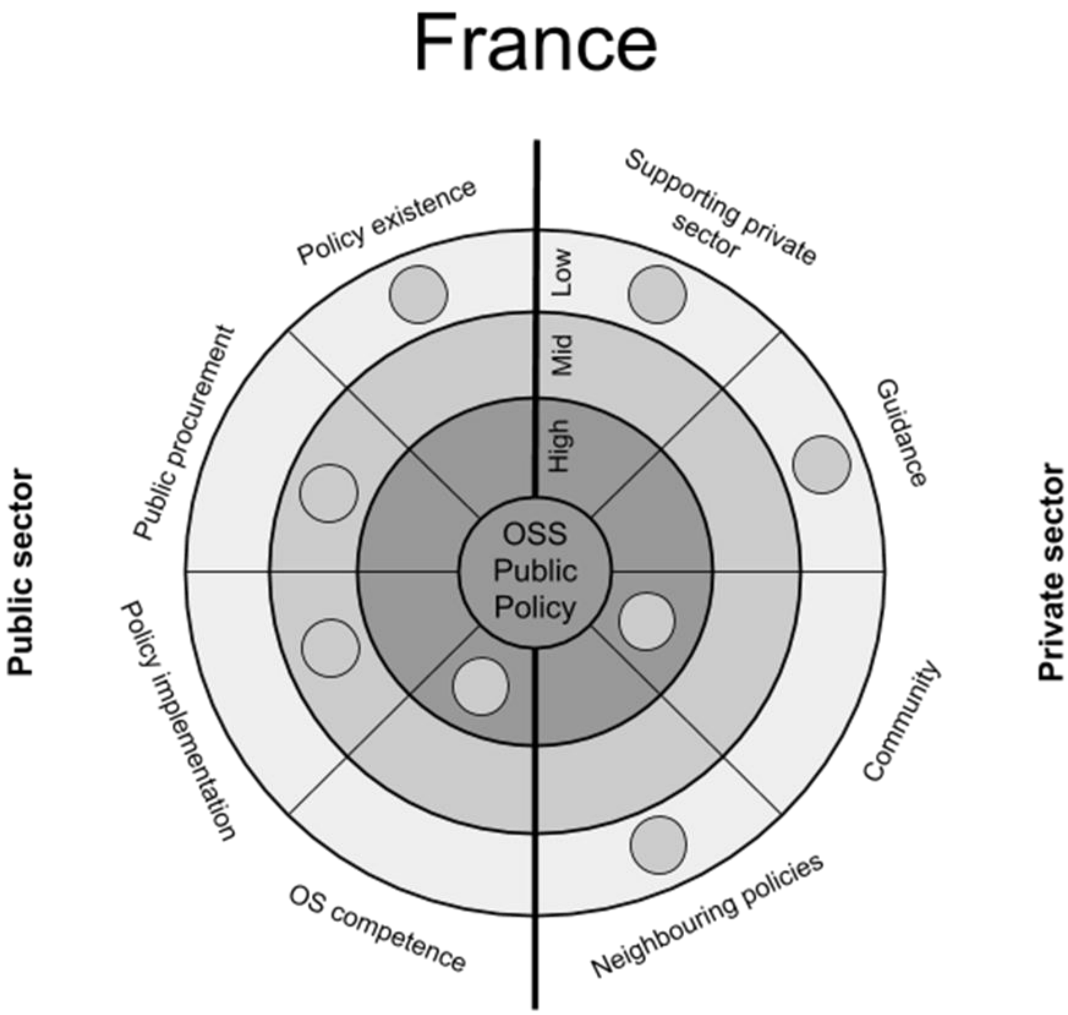
Opportunities and challenges

Bulgaria has a good record in transposing EU legislation and in proposing numerous policy initiatives and regulatory strategies in various areas; however, implementation seems to be lacking. The country experiences issues in enforcing compliance with laws and regulations that are being bypassed or disregarded, according to several rankings (European Commission, 2018). Frequent changes of governments add to the number of policy actions, but not necessarily to long-term planning or to ensuring their positive impact. Open Source is an instance of a tool that has been brought up by policymakers several times (though usually in relation to the public sphere) since 2003, and finally explicitly required to be used by public agencies in 2016, but no practical implementation has followed.

There are several structural, political and economic reasons for this reluctance to implement the law in practice, and for procuring OSS, in Bulgaria. Firstly, few stakeholders participating in public procurement fully understand the provisions of the Act and accompanying Ordinance, and what they entail. In such an environment, it might be easy for public officials to overlook such provisions and disregard their implementation, as no real consequences result from failure to ensure their execution. Scarcity of resources within public administrations and lack of an Open Source agency within public structures on any level add to the lack of accountability. Secondly, many companies in the country are unwilling to publish their code, as they prefer to collect royalty fees and generate revenues per unit. The third, overarching, factor is a lack of trust toward OSS in the country as seen by experts working on the law, which is being perceived as less secure than proprietary solutions. Many governmental officials in Bulgaria seem to agree with this perspective, disregarding the difference between sharing infrastructure and disclosing data, as well as the benefits of potentially more rapid detection of vulnerabilities and improving systems' security.

In spite of this lack of trust regarding OSS, it is nevertheless required by the current law within public procurement procedures. Lack of implementation remains a crucial issue, for assessing both the role of Open Source within Bulgarian policy-making, and the level of industry's uptake related to the policy. The amendment of the Electronic Government Act in 2019 which introduced more liability for not enforcing its provisions might improve the level of implementation among public agencies; however, in light of the low level of regulatory quality in the country, this is far from certain. The use of Open Source by public administrations might serve to cut down governmental spending on software, promote its uptake in the private sector and offer a range of possibilities to Bulgarian businesses, especially SMEs that are characterised by a lower level of digitisation.

France



Policy context

France shows significant involvement in leveraging Open Source for its public services, as well as neighbouring openness principles such as Open Data and sharing public agencies resources.

On a national level, Open Source policies fall under the auspices of the Interministerial Directorate for Digital Services (Direction Interministérielle du Numérique, DINUM), which has a separate entity responsible for Open Data and Open Source in its structure: Etalab - the French Taskforce for Open Data.

Etalab was established in 2011 to support digitisation efforts with Open Source within the French government (Etalab, n.d.). It is highly engaged in promoting the use of Open Source, with several initiatives such as Blue Hats ("a movement for public interest hackers") and several partnerships (Etalab, 2018). In February 2020 it signed a partnership agreement with ADULLACT, the Association of Developers and Users of Free and Open Source Software for Public Administrations, which brings together dozens of educational institutions, governmental agencies, associations and companies (Adullact, n.d.).

Open Source tends to get political attention in France, more than was observed in other Member States where it is often considered from a more technical perspective. For instance, in the French Senate, the first report of the Commission of Inquiry on Digital Sovereignty (Commission d'enquête sur la souveraineté numérique), presented in

November 2019, considers Open Source as an important part of the conversation on digital sovereignty and urgently calls for a discussion on the topic within the Ministries (La Commission d'Enquête sur la Souveraineté Numérique, 2019).

Each year since 2007, April, an independent organisation promoting Open Source in France, has proposed a Free Software Pact (Pacte du Logiciel Libre) to the candidates in local and national elections in France (April, 2007). In 2020, municipal elections were to have been held in France from 15 to 22 March, but the second round was called off due to the COVID-19 crisis. The pact, if signed by the candidate, signifies his or her willingness to encourage the use of open technologies, placing Open Source and open formats on the forefront of candidates' digital policy efforts. 2020 Pact was signed by 44 candidates from around the country (Candidats.fr, 2020). The previous edition of the Pact was signed by 501 signatories during the legislative elections, which indicates the high standing of Open Source on the political level. While the signature by a candidate of the Pact does not indicate his or her full understanding or commitment to the issue, it does show that encouraging Open Source might be seen as increasing candidates' chances in the eyes of voters.

Current policies

Several different Open Source policies have been adopted in recent years in France. Circulaire 5608, a landmark law, was adopted by the French government in September 2012 (Secrétariat général du gouvernement, Direction interministérielle des systèmes d'information et de communication, 2012). This law aimed to promote the use of OSS by demanding that all departments of the French public administration: consider OSS when procuring software; and consider procuring new OSS or open-sourcing existing software when making major revisions to existing applications. One tool used by Circulaire 5608 is that the country's public administrations are to conduct a thorough and systematic review of free alternatives when building and revising ICT infrastructure and applications.

The main aim of Circulaire 5608 is to realise the cost benefits associated with avoiding the licensing costs of proprietary software. It recommends reinvesting between 5 percent and 10 percent of the funds saved by spending them on contributing to the development of OSS and therefore improving the procured software for everyone.

In a 2019 study, Frank Nagle identified that Circulaire 5608 had increased the number of contributions to OSS from France, "creating a social value of $20 million per year" (Nagle, 2019). He assessed the law as highly beneficial in terms of both social value and increasing national productivity and competitiveness. The results include a 9% - 18% yearly increase in the number of IT-related startups, a yearly increase in the number of IT employees of 6.6% to 14%, as well as a 5% to 16% yearly decrease in software-related patents. This study is analysed more thoroughly in the economic analysis section of this report, where a closer look is taken at the quantitative model used and exact numbers derived in the research. It showed the far-reaching influence of Open Source public procurement policies, both in terms of volume and the number of industries, companies, and citizens affected.

Historically, France has been highly involved in Open Source and it is not showing signs of reducing its involvement. There have been two major legal developments in OS policies in France following Circulaire 5608: the Digital Republic Law (Loi pour une République Numérique) of 7 October 2016, accompanied by Decree no. 2017-638 of 27 April 2017 which tackles the issues of software licences (Décret n° 2017-638 du 27 avril 2017 relatif aux licences de réutilisation à titre gratuit des informations publiques et aux modalités de leur homologation, 2017).

The Digital Republic Law (Loi pour une République Numérique) of 7 October 2016 promotes open data, data portability, open access, accessibility and privacy on the national level (LOI n° 2016-1321 du 7 octobre 2016 pour une République numérique, 2016). It requires openness from simulation software used for governmental services and encourages

France's public administrations to use OSS. According to this law, software source code is an administrative document that has to be communicated and (where possible) to be reused. Although an extensive impact study was conducted for the purposes of creating the law, its focus is on open access to governmental data, and it does not put emphasis on software (Projet de Loi pour une République numérique, 2015).

Before this law was implemented, the French Administrative Court of Appeal had stated that source code developed within administrations can be considered as a public, administrative and reusable document, which has been confirmed by the Digital Republic Law. The law creates an obligation for public bodies to share openly and gratis their data bases while preserving anonymity and industrial secrets, as well as an obligation for private bodies to share data concerning public utility. Article 16 encourages public administrations to use Open Source solutions and open formats.

The overarching French policy for digitisation of public services, the Plan for the Transformation of Public Procurement 2017-2022 (Le plan de transformation numérique de la commande publique) aims at simplifying public procurement processes, increasing their transparency and interoperability and facilitating their governance (Ministère de l'économie et des finances, Direction des Affaires Juridiques, 2016). Although it does not list Open Source as one of the means, under Action 18 it focuses on guiding respective authorities in opening their datasets of general interest and pinpoints the importance of open, interoperable public data.

On 15 May 2018, DINSIC published The Contribution Policy for Free Software of the State (Politique de contribution de l'Etat aux logiciels libres) in order to support French administrations in their Open Source efforts. It also aims at encouraging public bodies to contribute to Open Source code within their respective missions (DINSIC, 2018).

Public administrations in France are active in sharing resources with other agencies and bodies. This includes a dedicated guidance for public administrations in France that wish to open up their code and use Open Source (Etalab, n.d.-a). This guidance encompasses not only sharing where to find open code that has been developed, and legal guidelines, but also personalised help in specific cases on technical and legal matters, provided by Etalab advisers. This help is connected to the Blue Hats movement, gathering those interested in using Open Source within the French government. Tchap, an Open Source, encrypted instant messaging app has been developed as a safe alternative to commercial messaging apps and made available to public servants for internal communication (Dussutour, 2020). It is also being used to facilitate the exchange of information around adopting OSS in the public sector, exchange of experiences and issues around the subject.

Etalab shares public sector Open Source initiatives on its dedicated site, compiling repositories from several organisations such as the Beta Gouv (a governmental network of start-up incubators aiming at improving public services), the National Cybersecurity Agency of France, INRIA (the French National research institute for the digital sciences) and Lutece (an OSS portal engine allowing the rapid creation of dynamic websites or applications) (Etalab, n.d.-b). Available repositories are grouped and presented in an accessible manner, consisting as of January 2021 of more than 6,500 repositories and providing clear statistics on organisations involved, languages used and licences.

Other resources shared by Etalab within the French public administration are APIs in three categories: on public services, about individuals as a one-stop shop for citizen's personal data, and about enterprises. Citizens can find APIs with publicly available data on enterprises on a separate site.

While the French government is exceptionally involved in sharing Open Source knowledge and resources within the public sector, it is not as developed in terms of industrial policies encouraging the uptake of Open Source by the private sector. Although there are no explicit public policies regarding the private sector, the promotion of OSS within the public administration in France has some impact on its uptake and on educating the public on the opportunities and features of OSS.

As in other countries, there are no policies openly addressing OSH. However, a movement within the Ministry of Ecology aims at developing a law on Right to Repair which might help bring the issue of OSH into public debate.

Opportunities and challenges

In France, there seems to be a tendency of gravitating towards domestically located or developed solutions. The notion of "digital sovereignty" seems to be present in the public debate and Open Source tends to be easily connected to the term, which is not always seen in other Member States. While in Germany there seems to be a strong link between digital sovereignty and Open Source, in other countries such as Poland, this connection doesn't seem to have been developed yet.

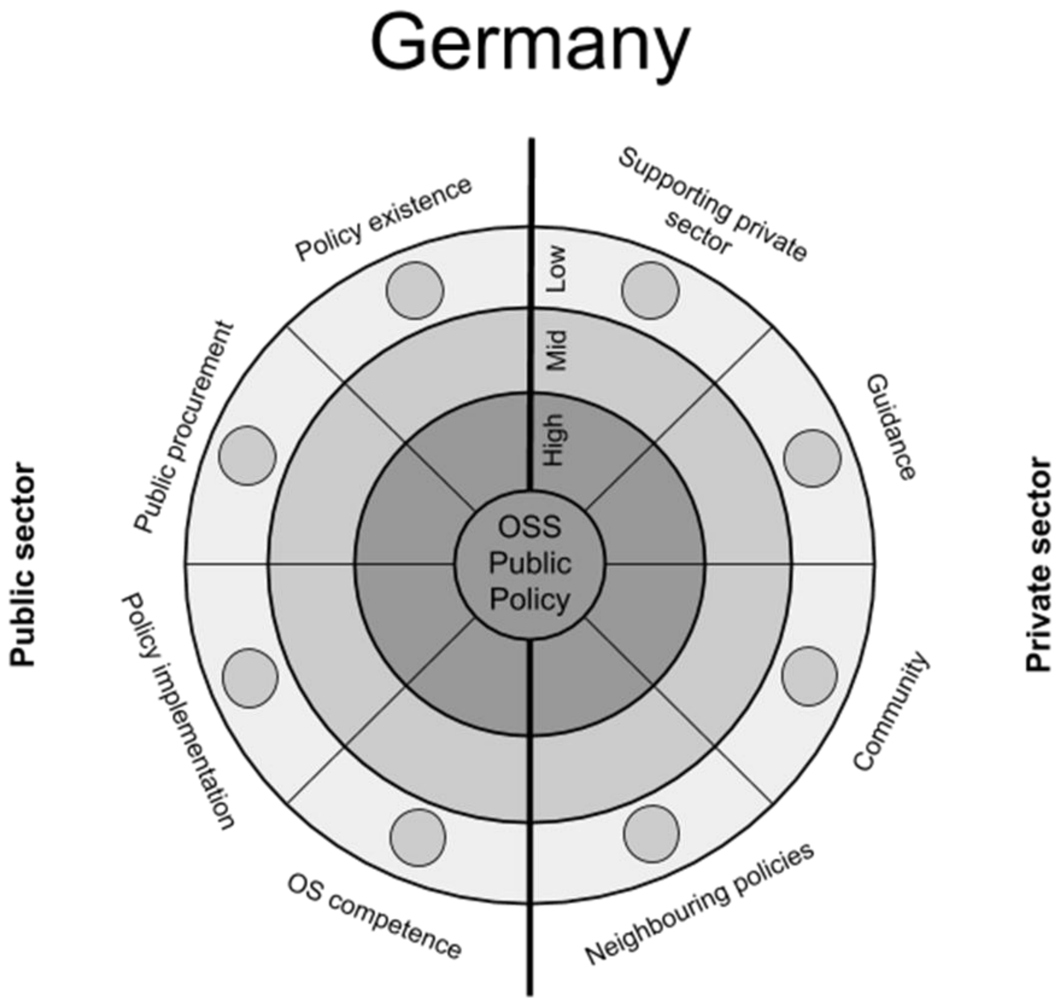
The French CNLL association (the National Free Software Council, fr: Union des Entreprises du Logiciel Libre et du Numérique Ouvert) represents the interests of more than 300 French Open Source companies. It is also a source of market research on industrial uptake and the Open Source ecosystem in France. As the CNLL states, it has been pushing for years for establishment of a 'true industrial policy for OSS' and regularly publishes white papers and studies on the industrial uptake of Open Source in order to bring the practical landscape closer to the policy-making environment (CNLL, n.d.) So far, there has not been a specific industry-focused policy regarding OSS on the national level in France.

The last study conducted for CNLL in 2019 states that in the EU, the Open Source market experienced strong yearly growth: from 8.6% in France, to 8.2% in Germany and 9.6% in a select number Western, Northern and Mediterranean EU Member States (CNLL, 2019). It also found out that the French Open Source market grows faster than the IT market itself, which reflects the fact that OSS requires more tailored IT services and that Open Source is heavily used in the development of rapidly growing innovative technologies (such as cloud services, AI). The report points out employment opportunities related to OSS and foreseen growth in its use among companies, based on a survey conducted for CNLL among French Open Source companies. Although the study shows optimistic forecasts for Open Source in France, the report has some limitations; those include taking into account only EU15 Member States, unknown data sets and a methodology that had not been shared with the public.

Regarding the French government's strong credentials in Open Source policies, one might think that it will continue developing and leveraging the potential of openness in the digital space and infrastructure. All the efforts of the public sector in France do not seem to be in vain, as a growing number of organisations and communities implement new programmes, activities and share resources. Some of these organisations focus on industrial partners and such businesses are also providers of IT services to the public sector.

There is a strong emphasis on Open Source in French digital policies. While not much support for the private sector aiming to adopt Open Source is offered, high involvement of the government in animating communities and sharing practices in the public space seems to have a positive impact on the private sector, as Frank Nagle established in his research. Even though there is no supporting policy for industry, the uptake and developments of OSS in the private sector seem to be relatively high in France. Coupled with a developed ecosystem of independent organisations supporting Open Source companies and projects, as well as a strong position in the European market in terms of innovating on openness principles, the question arises whether Open Source policies targeted at the private sector are necessary for it to thrive.

Germany



Policy context

Germany's interaction with OSS from a governmental perspective is complicated and exists within the complex institutional framework of competences split between the federal, state and municipal level. On a number of dimensions, Germany has had OSS initiatives, with different aims.

In the past, the Federal government has at times taken a coordinating role, though the jurisdiction of the Federal government is limited. When the Federal government took such a role, it was usually during times where an OSS-friendly government was in power and as such, when that government was replaced, these activities would then be stopped or even reversed. When a supportive government was in power, Germany would often be in a leading position toward Open Source support, yet when the government changed it would sometimes fall back to having no action at all. As such, the government's attitude towards Open Source has been characterised by a lack of consistency and by changeable support.

The early 2000s was a period of extensive activity, in the areas of coordination, adoption and support. A new role in the Federal government was formed to coordinate IT projects in the Federal administration, which would later publish "Letter No. 2/2000 Open Source Software in the Federal Administration", which would document best practices for the adoption of OSS for public administrations (Bundesstelle für Informationstechnik, 2000).

A year later, the Federal Department of Economy and Technology published "Open Source Software, A Guide for Small and Medium-Sized Enterprises" and thus became active in supporting the private sector with OSS, aiming to achieve increased competitiveness and digital transformation for its industry. A year later the German Parliament approved a resolution promoting the use of OSS as a way of ensuring competition to those proprietary companies which dominate the sector (CENATIC et al., 2010).

During this time, the Federal administration also procured Open Source extensively. A year after the signature of a deal with IBM and SuSe, over five hundred public entities in Germany were using OSS on their computers. Under this deal, IBM granted a rebate to the price of its hardware if it was ordered with the Open SuSe operating system from the Nuremberg company, SuSe. A high number of institutions have at some point been in the process of migrating to OSS. Examples include The Federal Ministry of Finance, the German Aerospace Centre, the Federal Ministry of Foreign Affairs, the German public company Deutsche Bahn, the Monopoly Commission, Air Traffic Control and the German Federal Institute of Geoscience and Natural Resources (Blau, 2003).

Some of the German Federal states (Länder) have their own policies, and a number of cities have migrated to OSS solutions and have adopted related policies. A number of Federal ministries also have had projects employing OSS, yet some of these projects have ended, resulting in a return to proprietary software.

For example, in 2018 the Land of Schleswig Holstein decided completely to migrate all of the public administration to OSS solutions, and to phase out all closed source software (Krempl, 2018). And, of the many cities that have migrated to OSS, the most well-known is Munich, yet that city has a mixed history with OSS, as it decided to migrate back to a closed source solution (Krempl, 2017), possibly because of lack of coordination and lobbying (Riehle, 2019). Yet, in 2020 the city announced a further change of course and made commitments to an effort of adopting more OSS again (Bantle, 2020).

Current policy actions and institutions

As opposed to many other countries, in Germany there is no centralised policy on OSS, and none governing the public procurement, internal use and re-use of OSS or support for OSS as a tool aimed at the software and IT sector. In Germany, a relatively disparate number of actors on different levels have made steps toward the adoption and support of Open Source, and in recent years a dynamic situation has developed under the banner of increasing digital sovereignty; however, a coordinated and effective approach is missing in Germany. Due to the strong emphasis of federalism within the German governmental system, this country report will place special emphasis on the actions of the different levels of government.

When it comes to re-use of software within the public sector, the situation is framed through the complex organisation of IT providers in Germany. Looking first at the Federal level, there is no strategy which aims at maximising the benefits of Open Source for the public sector on the level of the federal institutions of Germany.

Although increased centralisation of IT services on the Federal level has been an aim of decision makers in recent years, this process is still incomplete as of 2020; and the central IT provider for the Federal level “Federal Information Technology Center” (ITZ-Bund) which was created in 2016 only provides services to a smaller number of ministries and agencies, while other public authorities continue to create and run their own internal IT infrastructure. Formally, there is an OSS competence centre at ITZ-Bund aiming to “support OSS at the Federal administration”, yet interviewees have noted that this competence centre does not exist anymore and never had the political support nor resources to have a lasting impact on how OSS is used. Besides this organisational issue, the stated benefits of OSS being “reduced cost and image-gains” indicates only a limited understanding of the potential benefits and challenges of OSS when this initiative was still active (ITZBund, 2020).

When looking at public procurement in Germany, in most cases IT services are procured on the municipal, state and Federal level through semi-independent, publicly-owned IT providers, which are in charge of procuring and running the IT infrastructure for one or more public authorities. For example, on the municipal level, sometimes one provider will only be responsible for one municipality, yet in others a number of municipalities will be supplied through a shared provider. The situation is the same at the state level. On the Federal level, each Ministry and organisation makes its own IT decisions and only limited unification exists. To coordinate these providers, associations (such as Vitako for the municipal providers) exist (Vitako, 2020).

Figure 8.3: OSS related procurement initiatives in Germany

The Federal CIO provides “EVB-IT” templates, which IT providers are to use for all typical ICT procurements (Der Beauftragte der Bundesregierung für Informationstechnik, 2020). Thus, these templates are currently the most direct tool which the Federal government has to influence how and what ICT is being procured in Germany by public authorities. Legal assessments which have been performed on these EVB-IT templates have concluded that while they do not make procurement of OSS or OSH impossible, they have been drafted with proprietary software in mind, and thus procuring OSS or OSH through them requires additional knowledge and steps. In an attempt to mitigate this to some degree, in 2012 the German CIO published in an OSS migration guide, focusing on legal issues; but interviewees have noted that this document never reached practitioners and the inherent issues with the EVB-IT templates remained (Die Beauftragte der Bundesregierung für Informationstechnik, 2012). As such, in Germany the potential for supporting the local economy through public procurement is left formally untapped. The German Open Source Business Association (OSBA) has developed guidelines for procurement officers intending to buy OSS (Jäger, 2018). In addition, the German cybersecurity authority (BSI) requires support contracts to be made when procuring software, which is not well aligned with more diverse support solutions typical for OSS (Der Beauftragte der Bundesregierung für Informationstechnik, 2020).

Clearly the need to find and follow these guidelines requires knowledge of their existence, as well as the determination to follow the complex instructions. Thus, it cannot be said that Germany has a pro Open Source procurement policy.

Some Federal states have adopted legislation that prefers Open Source over proprietary software: examples are Thuringia, Bremen, Hamburg (Krempl, 2020) and Schleswig-Holstein (Bauduin, 2020), with the latter planning to migrate to an entire Open Source digital infrastructure by 2025. These plans usually come from governments under progressive leadership, yet with Open Source having become mainstream in corporations, preconceptions about Open Source are being reduced across the political spectrum, as shown for example by the CDU Digitalcharter.

Evidence of the new direction (also on the Federal level) in Germany is the "Service Standard" which the Federal Ministry of the Interior developed in 2020 as guidance for the implementation of the revision of the law regulating citizens' access to digital governmental services. The service standard builds on six main pillars, one of them "Openness", encompassing open standards, Open Source and re-use (Bundesministerium des Innern, für Bau und Heimat, 2020):

> "By making free software available, it can be reused and adapted by others - e.g. to specific regional conditions or other factors. Openness and re-use can refer to the source code of the code as well as to the open source architecture, data, conception and documentation of the project. A prerequisite for publication is the use of a free licence that defines the legal framework for subsequent use, modification and distribution. On the one hand, the re-use and adaptation of free and open source software can reduce the costs of administration, whilst on the other hand, it offers the possibility to collaborate with other interested parties outside one's own institution." (own translation)

Looking at industrial policy, the German government has multiple programmes aimed at supporting technology-led growth for companies, especially small and medium enterprises (SMEs), a company size very prevalent in Germany. These companies are often integrated into deep and wide supply chains and thus rely on cooperation with other companies to provide their products and services.

Thus, the two main German industrial development programmes, the Central Innovationprogramme SME (ZIM) of the Ministry of Economy (Bundesministerium für Wirtschaft und Energie, 2020) and the programme SME-Innovative of the Ministry of Education and Research (Bundesministerium für Bildung und Forschung, 2020) focus on linking SMEs with either other SMEs or academic partners to develop innovative solutions.

Currently, the potential of Open Source is not represented in these programmes, yet Open Source as a modular, collaborative tool to develop solutions is well-matched with the economic reality of German industry. In addition, Open Source is an important tool to mitigate the existing digital skills-shortage in the development of solutions through the re-use of existing libraries and modules, and thus its potential is being missed in industrial development programmes.

Opportunities and challenges

There are clear signs that on the Federal level in Germany the potential benefits of Open Source are gaining understanding. Within the umbrella of digital sovereignty, Open Source is often cited as an important enabler. Notable initiatives here are for example GAIA-X, which is planned to be built on open technologies (Federal Ministry for Economic Affairs and Energy, 2020), the recent study commissioned by the Ministry of the Interior analysing the dependence on Microsoft products (PwC Strategy&, 2019) and the new digital charter of the conservative government party CDU which cites "Open-X" as the new paradigm for German technology policy (CDU Deutschland, 2019). Yet so far none of these initiatives has produced any tangible change and so at this point they thus offer more promise than reality.

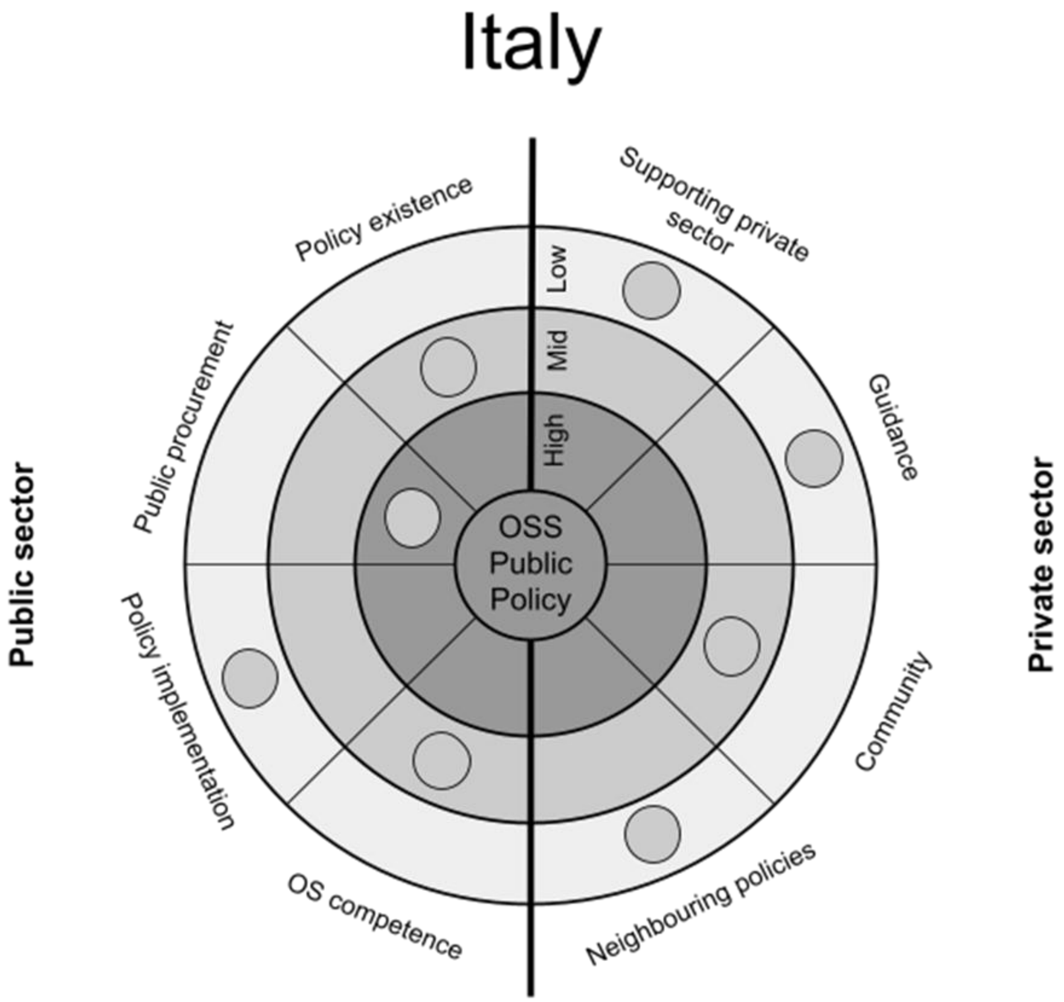
Most German states rely themselves on a publicly-owned IT provider which procures and runs infrastructure for the state. Some states even have multiple IT companies for different tasks.

Noteworthy is the solutions provider of the north, Dataport, which covers six states and has made the topic of digital sovereignty one of its core aims. In the context of this, Dataport created a fully Open Source, cloud-based office software suite, accessed through a browser, under the project name "Phoenix" (Dataport, 2020). This suite aims to provide all standard office software (meaning groupware, communication tools and collaborative editing and storage). The important administrative processes used by public administrations will only be analysed and migrated at a later point and the project thus does not represent a switch to an entirely Open Source stack. The suite integrates mostly domestic software offerings, such as Open-Xchange, Nextcloud and OnlyOffice. Although Dataport plans to run the software for its public clients, it is however working with the community on integration as well as the further development of the suite, which will be provided as a reference solution back to the community and can thus be adopted by other public administrations. If this project succeeds, Dataport could help provide an important template for other providers in an area where requirements tend to be uniform across authorities.

On the municipal level, there are a high number of IT providers, with many being responsible for just one municipality. A study for the German Ministry of the Interior investigated Open Source solutions on the municipal level and found that a number of cities are already implementing Open Source solutions. One of the findings of the study was that municipalities are somewhat restricted in their possible purchasing decisions due the current public procurement laws (Der Beauftragte der Bundesregierung für Informationstechnik, 2020). While municipalities do not have the power to make procurement rules, there is some level of organisation at the municipal level with the municipal IT provider Vitako. The importance of coordination becomes evident in this field, as without a coordinating body the sharing and re-use of solutions, and thus reaping one of the advantages of Open Source, has a lower likelihood of success.

As an association, Vitako is making plans to support the increased uptake, sharing and re-use and collaborative development of Open Source among its members. In June 2020 it announced plans to develop "one place for public sector code", in cooperation with OSBA as well as the associations of the cities and counties, the Ministry of the Interior and two Federal states. While plans are still in the early stages, Vitako hopes that such a platform will enable strong scaling and network effects for developing mature software, sharing solutions and increasing choice for IT procurers (Krempl, 2020; Open Source Business Alliance & Vitako, 2020).

Italy



Current policy actions and institutions

Today, the main eGovernment law of the Italian Republic, the “Codice dell’Amministrazione Digitale” (CAD) features a preference for Open Source, aimed at taking advantage of OSS for the public sector.

Articles 68 and 69 of the CAD are relevant for Open Source. Both articles have been adjusted frequently over the years. Since its enactment in 2005, the CAD has been modified 37 times; a preference for OSS was introduced in August 2012 and since then Articles 68 and 69 have been modified 4 times.

Article 68 regards activities to be performed before implementing a public procurement.

Article 69 regards the distribution of code developed by the public sector or by providers according to specifications of public administrations (custom software).

Article 68

The crucial adjustment to Article 68 was done through Law 134/2012, approved by the Italian Parliament on August 7, 2012. This added a preference to procure Open Source solutions over proprietary solutions, based on a comparative assessment. Article 68 paragraph 1, today states (translation from Italian based on Aliprandi & Piana, 2013):

August 2012	September 2018
Public administrations shall acquire computer programs or parts thereof as a result of a comparative assessment of technical and economic aspects among the following solutions available on the market: • *(a) software developed by the public administration;* • *(b) reuse of software or parts thereof developed by the public administration;* • *(c) free or Open Source Software;* • *(d) proprietary software under a licence;* • *(e) software which is a combination of the above.*	*Public administrations shall acquire computer programs or parts thereof in compliance with the principles of cost-effectiveness and efficiency, investment protection, reuse and technological neutrality, following a technical and economic comparative assessment of the following solutions available on the market:* • *(a) software developed by the public administration;* • *(b) reuse of software or parts thereof developed by the public administration;* • *(c) free or Open Source Software;* • *(d) use a cloud computing service;* • *(e) proprietary software under a licence;* • *(f) software which is a combination of the above.*

Point (d) on cloud computing was added three months later, through Law 294/2012, approved by the Italian Parliament on December 17, 2012. Interviewees indicated that adopting cloud solutions has become a priority for public administrations and that this has presented issues for smaller service providers. The principles under which software should be evaluated have also been changed over time, today aiming for a total-cost-of-ownership approach which also takes indirect costs (such as vendor lock-in) into account.

The parameters of the required comparative assessment are specified following the first paragraph. The main issues of the Italian law stem from a lack of implementation, to which both frequent adjustments and unclear drafting might well have contributed. The initial versions have been criticised for being "far from clear" and too narrowly focused on price.

Lawmakers did attempt to introduce more clarity by adding further explanatory remarks to the listing in the law with further revisions. This has evolved (as has the list) over the years to become more specific. The table below shows the evolution of the explanatory remarks on the "comparative analysis of solutions", (translation again adapted from Aliprandi and Piana 2013 and own translation):

August 2012	September 2018
Only when the comparative assessment of technical and economic aspects demonstrates the impossibility of adopting open source solutions or any other software solution already developed (at a lower price) within the public administration system, the acquisition (by licence) of proprietary software products is allowed. The assessment referred to in this paragraph shall be made according to the procedures and the criteria defined by the Agenzia per l'Italia Digitale, which, at the instance of interested parties, also provides opinions about their compliance.	*1-bis. To this end, before proceeding with the purchase, public administrations, in accordance with the procedures set out in the code referred to in Legislative Decree no. 50 of 2016, make a comparative assessment of the different solutions available on the basis of the following criteria:* • *(a) total cost of the program or solution as the cost of purchase, implementation, maintenance and support;* • *b) level of use of open type data formats and interfaces as well as standards able to ensure interoperability and application cooperation*

	between the different information systems of the public administration; ● *(c) supplier's guarantees regarding security levels, compliance with data protection regulations, service levels taking into account the type of software acquired.* *1-ter. Where the technical and economic comparative evaluation, according to the criteria set out in paragraph 1-bis, shows justifiably that it is impossible to access solutions already available within the public administration, or free software or open source code, appropriate to the needs to be met, the acquisition of proprietary computer programs is permitted through the use of a licence.*

With further adjustments, the provisions increased the factors that public procurers could take into account when making a procurement decision. Today the text approaches a total-cost-of-ownership calculation, by taking into account costs such as maintenance, interoperability issues and cybersecurity.

The legal interpretation (per Aliprandi and Piana, 2013) concludes that according to this new law, "the procurement of proprietary solutions (or of cloud services for that matter) is an extrema ratio, available only if previous [Open Source] solutions fail" and show themselves to be inadequate.

In the initial version of 2012, the "Agenzia per l'Italia Digitale" (AgID) was tasked with specifying the exact criteria of the assessment and when exactly no viable Open Source solution is available, allowing the procurement of a proprietary piece of software. Yet such guidance was only issued in May 2019 as "Guidelines on the acquisition and reuse of software for public administrations" (Agency for Digital Italy & Digital Transformation Team, 2019) and without such guidance on how to calculate procurement decisions, the actual implementation of the Article remained low (Nagle, 2019; Montegiove, 2016). It will be necessary to evaluate the impact of the new guidance at a later point.

Interviewees consider the new guidance as a crucial step. Previously, public procurers were missing the tools to implement the law. The law and the guidelines could be further fostered to enable public procurers to take into account additional factors, for example positive externalities such as the creation of technological know-how and increases in technological independence that can improve the bottom line of the assessment for OSS. Neither the law nor the guidelines take into account the potential benefit of mutualisation of cost between different public authorities, when developing solutions together.

Article 69

Since the re-formulation of Article 69 in 2016, the CAD has joined Article 68 as the second of the most important provisions advancing Open Source within the Italian public administration. Article 69 obliges public authorities to publish the source code of software that has been developed either by the public administration or for the public administration and to which they own the rights under an Open Source licence. The aim is to give other public administrations the opportunity to re-use and customise the software for their needs.

August 2016	September 2018
1. Public administrations which are the owners of computer solutions and programs created on specific indications of the public client, are obliged to make available the relevant source code, complete with the documentation and released in the public repository under an open licence, for free use to other public administrations or legal entities which intend to adapt them to their needs, except for justified reasons of public order and security, national defence and electoral consultations. *2. In order to facilitate the reuse of computer programs owned by public administrations, pursuant to paragraph 1, in the project specifications or specifications it is provided, where possible, that the ICT programs and services specifically developed on behalf and at the expense of the administration comply with the technical specifications of SPC defined by AgID.*	*1. Public administrations which are the owners of computer solutions and programs created on specific indications of the public client, are obliged to make available the relevant source code, complete with the documentation and released in the public repository under an open licence, for free use to other public administrations or legal entities which intend to adapt them to their needs, except for justified reasons of public order and security, national defence and electoral consultations.* *2. In order to facilitate the reuse of computer programs owned by public administrations, pursuant to paragraph 1, in the specifications or in the project specifications it is provided, unless this is excessively onerous for proven technical-economic reasons, that the contracting administration is always the owner of all rights to the information and communication technology programs and services developed specifically for it.* *2-bis. For the same purpose referred to in paragraph 2, the source code, documentation and the relative technical functional description of all the IT solutions referred to in paragraph 1 are published through one or more platforms identified by AgID with its own Guidelines.*

Article 69 has also evolved through legislative changes, and since December 2017 obliges AgID to identify one or more platforms on which public authorities can publish their code, in order to enable the easier sharing and discoverability of code. The law is somewhat vague, as it seems enough for AgID to identify a third-party code-sharing platform such as GitHub. In practice, today Developers Italia (AgID & Dipartimento per la Trasformazione Digitale, 2020), developed by AgID and the Digital Team (now part of the Minister of Technological Innovation and Digitalisation), fulfils the role of acting as a code catalogue for both Open Source code developed by the public sector, and Open Source code made available by third parties for use by the public sector. Developers Italia only catalogues code and provides links to a third party infrastructure which hosts the code.

The guidelines developed in 2019 by AgID which detail how Article 68 should be implemented also detail the implementation of Article 69.

In Italy, Open Source policy is tightly connected to the digital transformation of the public sector. Today, the main institutions are AgID, the Italian Digital Agency and the Ministry of Technological Innovation and Digitalisation, into which the majority of the previous Digital Team was absorbed under the name of “Dipartimento per la Trasformazione Digitale”.

The Digital Team (Team Digitale) was created in 2016 to provide “the ‘operating system’ of the country, a series of fundamental components on top of which build simpler and more efficient services” can be built in reaction to a “digital emergency” of the Italian public sector. Its initial mandate only lasted two years, but was extended until the end of 2019.

With a relatively small and focused team of about 30 to 40 staff, it provided solutions that other public administrations could re-use and slot into their infrastructure to provide working templates for their digital transformation. As a re-use agency, the team also acted as a de-facto Open Source office for the country, with a strong Open Source identity as part of the manifesto of the organisation. Team Digitale also acted as a consulting service in regard to Open Source and the procurement of Open Source by the public sector. Yet, it was not its role to implement CAD Articles 68 and 69.

In 2019, the Italian government decided to not renew the mandate of the Digital Team but instead that it should be absorbed by a new Ministry for Innovation. It is understood from interviewees that many staff members of the Digital Team did not switch over to the Ministry, due to differences in the direction the Ministry should take. Even though there are questions about the commitment of the Ministry toward Open Source, one activity which the Ministry is pursuing to help Open Source competences within the different levels of the public sector and to improve the sharing and re-use of solutions is to create regional Open Source competence centres that would advise the regions and municipalities. Currently there are already two existing regional competence centres.

AgID, the Italian Digital Agency was founded in 2012 and entrusted with carrying out a number of coordination and certification tasks within the Italian government on a national, regional and municipal level. As such it is an agency that executes or clarifies, but does not create policy and has a technical focus. The agency was tasked with clarifying Articles 68 and 69 of the CAD. Today, there are a number of issues with the division of labour between the Ministry and the AgID.

In August 2020, AgID published the “Piano Triennale per l’Informatica nella PA”, a document outlining the targets for digitalisation of the public administration until 2022. The document contains many references to sharing and adopting Open Source solutions (l’Agenzia per l’Italia Digitale & Dipartimento per la Trasformazione Digitale, 2020).

Opportunities and challenges

One interviewee working in the private legal domain of IT law described the laws in Italy as “fantastic”. Yet Italy has received criticism from different directions regarding its Open Source efforts (Nagle, 2019; Hillenius, 2013; Montegiove, 2016). What explains this gap between legal status and experienced reality?

Literature and interviewees point toward the lack of implementation as the main issue of Italy’s disappointing Open Source policy outcomes. The successful implementation of new policy requires awareness, competence and active political support among those charged with implementing the new rules. In the case of Italy, data would indicate that at least the first two requirements were not sufficiently fulfilled.

The changes to the new law were made in steps from 2012 onwards, and adjustments were frequent. Fundamentally, in the field of public procurement Open Source procurement is a niche, and constant changes to the legislative framework have the potential to confuse procurement officers who are not specialised to the same degree and in many cases are charged with procuring all manner of products and services. As such, interviewees indicated that awareness of the new top-down policy for Open Source preference was very low amongst public procurement officials. This does not yet account for an awareness of the latest changes to the law, which in turn might just motivate procurement officers to procure perceived “safe options” that have been procured in the past.

Further, beyond simple awareness of new laws and any possible change to them, public administrations require support in implementing them correctly. Italy has 22,000 public administrations, all individually procuring IT solutions. The law only outlines the very basic requirements, yet public procurement is a highly complex procedure, subject to many legal requirements. As in Germany, without clear implementation guidelines, procuring Open Source, which has monetary mechanisms different from those which apply to established proprietary software, is difficult to reconcile with existing practices. Interviewees indicated that procurement officers simply didn't know how to perform the required "comparative analysis of conclusions" foreseen in Article 68 of the CAD in the absence of the guidelines from AgID. These guidelines were only published in May 2019, thus almost seven years after the new procurement preference came into force. It is therefore currently too early for a complete assessment to be made of the impact of the guidelines on the implementation of the procurement rules.

The fact that AgID did not provide these important guidelines earlier is unlikely to result from a lack of motivation within the organisation to produce them; however, accounts indicate a lack of political and organisation support. The law adopted by the Italian Parliament initially gave AgID only a somewhat unclear mandate, yet the Italian government did convene a working group early in 2013 to define the guidelines. This group included stakeholders from the involved vested interests, but was concluded without any result being published.

Lastly, the CAD does not foresee specific measures to enforce the rules in case of non-compliance, for example by penalties wielded against the responsible public procurement authority. Such strict enforcement does not seem to exist in any territory, but could increase the level of implementation. In addition one interviewee pointed out that procurement law (whether European or Italian) is difficult to enforce in practice, as case law created broad exceptions.

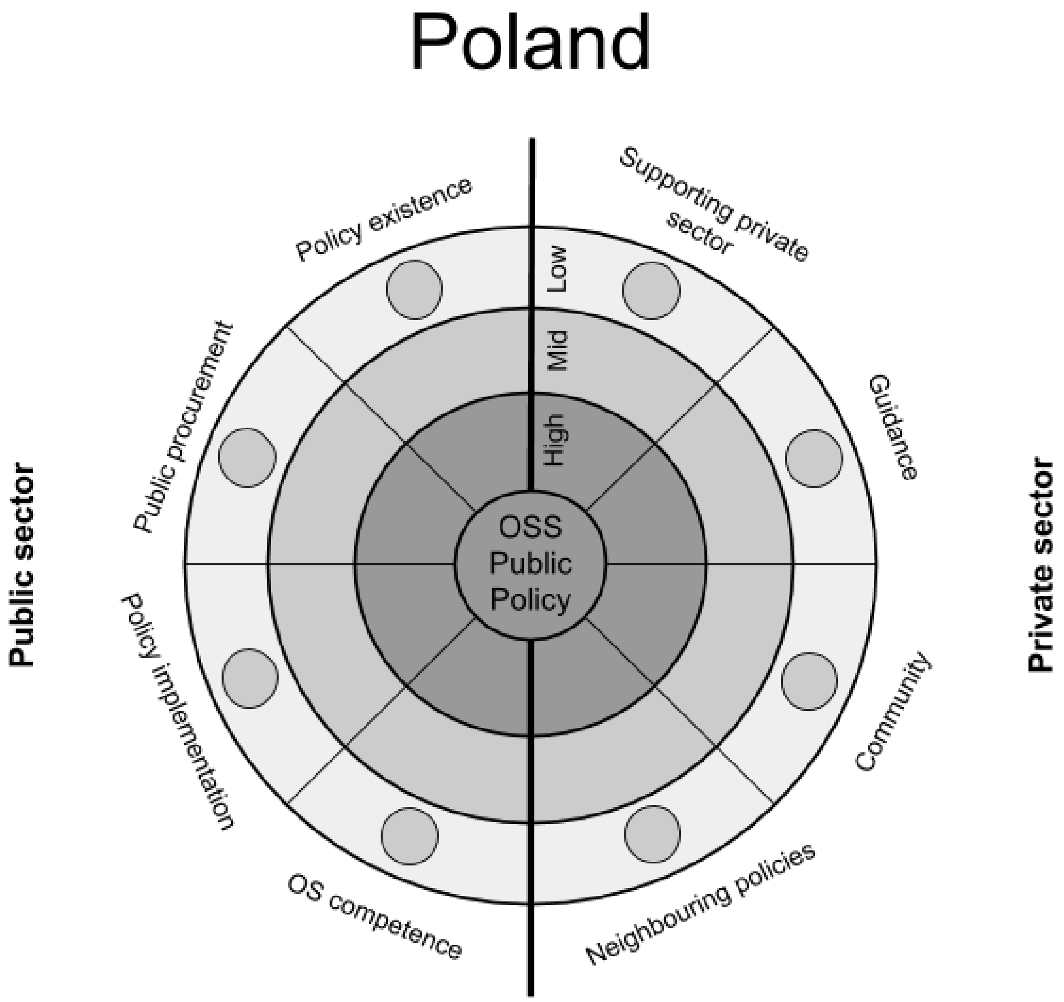
As previously mentioned, the guidelines published in May 2019 are designed to address this lack of implementation of the Open Source preference in public procurement. The guidelines were drafted by AgID with the goal of taking into account the actual procurement processes of public administrations and of providing "ready-to-use" templates that would not only explain all important concepts required and guide procurement officers point-by-point through the process, but also allow them simply to attach the prepared documents to their procurement process without much additional work.

To help public procurers to find suitable OSS and in order to support the implementation of Article 69 of the CAD (on sharing and re-use of software developed by Italian public authorities), the former Digital Team (now within the Ministry of Innovation) and AgID created Developers Italia. This platform enables public authorities and private companies to include their software in a catalogue of software suitable for use by public authorities. The platform is technically decentralised and scrapes information from third party software hostings, encoded in a prepared format, to be displayed on the platform. Currently it provides basic information on the software, who maintains it, a link to the code and documentation and which public administrations already use the software. One previously perceived issue which the platform has contributed to solving is the concern of public administrations that if they provide their software, they might be responsible for the provision of support to other public authorities the platform also lists the contact details of private support providers.

It is hoped that Developers Italia could lead to additional business for companies and public authorities supplying OSS. As of July 2020, about 129 pieces of software were listed in the catalogue, of which 110 are provided by public authorities and 19 by private companies, and these solutions have been used 630 times. One interviewee reported increased interest in the products of companies which provide their solutions on the platform.

Some regional public administrations have started to form communities around software projects (in some sense like consortia). These communities pool resources in developing, supporting and sometimes running software.

Poland



Policy context

The Polish government has been active in modernising public services, promoting open data, digitising industry and increasing investments in research and development over the last couple of years. However, the country is not known to be a digital champion in Europe and its interest in Open Source policies and their possible impact remain limited.

According to an analysis conducted during the Open Source Days in 2018 by Linux Polska, nearly all Polish companies use some kind of Open Source, citing its flexibility as a main reason for adoption. However, few of them specialise in leveraging Open Source as their main business model (Open Source Days, 2019). Yet, there is little research on the role of Open Source in the booming ICT sector in the country. The Polish IT sector is growing each year - by 7.2% in 2018 alone - and as the Polish Agency for Enterprise Development (PARP) highlights, this is largely due to the qualifications of the highly skilled IT workforce in the country. Interestingly, as much as 55% of the Polish IT market is constituted by sales of IT equipment, while software development makes up only 16%. Thus software might not be an immediate focal point for policymakers, Open Source even less so.

At a national level in Poland, the body responsible for Open Source would have been the Ministry of Digital Affairs - which (however) never had a unit or an agency responsible solely for Open Source (Cyfryzacja KPRM, n.d.). In October 2020 the Ministry of Digital Affairs was incorporated by the Chancellery of the Prime Minister and ceased to exist as a separate entity, operating under the name “Digital Affairs – Chancellery of the Prime Minister”. An organ that focused on Open Source the most in the recent years within the Polish government was one of the working groups within the Council for Digital Affairs in the Ministry, active from 2016 to 2018.

The Council for Digital Affairs is the internal think-tank at the Ministry of Digital Affairs providing external expert knowledge to the policy-making processes. The Council consists of a number of working groups in each term, focusing on particular subjects related to digitisation. Current working groups (for the 2019 - 2021 term) work on infrastructure and cloud, digital competencies, AI, cybersecurity and technologies (including 5G, blockchain, Internet of Things). Within all the publicly available documentation of the Council since its first meeting in February, there is no mention of Open Source or openness of code in any form (Cyfryzacja KPRM, 2020).

While the government has not taken much action on Open Source, civil society is not very active either. In the past, there have been a number of organisations in Poland with the main goal of analysing and promoting the positive impact of the uptake of Open Source; however today there is only one group currently in revival which focuses on this topic.

Internet Society Poland is a civil organisation that has significantly added to the debate on Open Source and open standards in the country. Established in 2000, its activities were put on hold in 2008 and it has been in the process of renewal since late 2019 (Internet Society Poland, n.d.). Even though the renewal of the organisation was interrupted and slowed down by the COVID-19 crisis, it nevertheless can now point to significant names among its board membership and collaborators, and it will start accepting new members in the near future.

Another Polish organisation which focused on OSS was the Free and Open Source Software Foundation (Fundacja Wolnego i Otwartego Oprogramowania, FWiOO), active from 2007 to 2015, which brought together several smaller initiatives and has been the most notable civil society organisation advocating for FOSS and working on Open Source policies (Fundacja Wolnego i Otwartego Oprogramowania, 2014). FWiOO has created several reports on subjects such as Open Source in public procurement and its state in the current Polish procurement law, open licences, technological and legal aspects of public procurement processes and it has tackled subjects such as interoperability, digitisation of schools, digital rights and open standards (Fundacja Wolnego i Otwartego Oprogramowania, n.d.).

FWiOO has also commissioned a quantitative study, conducted in 2010 by Pentor Research International, on the usage of Free and Open Source Software in the public administration (Pentor Research International, 2010). It analysed the prevalence of FOSS usage within public administrations on national and regional (voivodeship) level, FOSS quality, demand for such software, reasons for implementing OSS, and barriers stopping agencies from using it. The survey covered more than 100 respondents and found out that 90% of administrations had FOSS installed on at least one computer within an agency; however, this was usually a computer used by the IT staff. This survey also found out that the most common reasons for the adoption of FOSS were insufficiency of funds to buy proprietary software, and future cost reduction. The most significant barriers for using FOSS, as indicated by surveyed officials, were: the need to provide training to employees, security and data privacy concerns and a long decision process between different levels of public administration that accompany implementing more “unusual” software.

In Poland there are other civil society organisations for which Open Source could be of interest, such as Centrum Cyfrowe (which supports open culture and Creative Commons), Fundacja ePaństwo (which focuses on open government and open data), and Panoptykon Foundation (which opposes digital surveillance and protects digital rights) (Centrum Cyfrowe, n.d.; Fundacja ePaństwo, n.d.; Panoptykon, n.d.). All of these organisations were asked to contribute their voice for this research. However, Open Source is not a crucial field of activity for any of them at the moment. Some of them pointed to the lack of any such debate on the national level, the absence of any interest from policymakers, and a feeling that this may not be the most burning issue in the current digital ecosystem - as well as citing lack of subject-matter expertise.

The Polish government is showcasing activity regarding Open Data through legislative texts such as the Act on the reuse of public sector information (2016), which fully implemented the PSI Directive, amended for the last time in 2019, which will now be replaced by the Open Data Directive that has to be transposed into national legislation before July 2021 (Chancellery of the Sejm, 2016).

It has taken significant steps toward making more governmental data available and transparent through actions related to the Central Repository of Public Data (data.gov.pl), which allows any public body to publish its data and currently provides the data of more than 100 public agencies in Poland; the repository is under expansion with initiatives such as a current (July 2020) public consultation (Centralne Repozytorium Informacji Publicznej, n.d.). It is apparent that Open Data is a field of high interest for the government, alongside digitisation of public services, ICT education, expanding infrastructure in the country and implementing Digital Single Market goals.

The Act on the Computerisation of the Operations of the Entities Performing Public Tasks from 2005 outlines the standards to be complied with in ICT projects procured for public use and the National Interoperability Framework adopted in 2017 on standards enabling interoperability of data within public registries (Rada Ministrów, 2017; Chancellery of the Sejm, 2005). Although most of the document assumes that proprietary software is being procured, a number of clauses useful for the procurement of OSS are included, specifying the licensing conditions and features that a procuring agency has to aim to achieve.

There have not been any significant legislative moves regarding Open Source policies in Poland or any other instruments for supporting it. Currently, no specific unit or officials are known to be working on the subject.

Current policy actions

The most recent action related to Open Source within the Polish Government was the establishment of the working group on “Openness of data and publicly funded software” within the 2016-2018 term of the Council for Digital Affairs (Cyfryzacja KPRM, 2018). The reasoning behind the creation of this group, as stated by its members, was to promote Open Data that gathered some traction and the issue of OSS that “basically nobody works on currently”, which shows the lack of maturity of the discourse on Open Source in Poland.

The aims of the working group included assessing the approach to OSS in public procurement in Poland, analysing policies related to OSS in selected countries to draw lessons for national legislation, legal analysis of licensing models, and their impact. These goals were to be implemented into a set of recommendations for public agencies procuring software and possibly policy recommendations proposing legal changes, with a long-term positive influence on innovation, increase in the number of public-private IT ventures and cost reduction for public agencies.

Moreover, the working group conducted a public consultation, to cover issues of costs and benefits of using Open Source in public administrations, business models supported by Open Source and possible advantages for the Polish economy. Unfortunately, the results of the consultation are nowhere to be found in the public repositories of the Ministry.

Over the course of its existence, the working group is understood to have developed two documents. Although neither document has ever been shared publicly, it was however possible to access copies of the two documents for the purposes of this study.

The first document, “Licensing of publicly funded or co-funded software. Preliminary assumptions’ was finished in November 2018 and covered the types of software licences, and their impact on procuring authorities in terms of costs and control over governmental and citizens’ data (Rada ds. Cyfryzacji, 2018a).

The second (complimentary) document, “Licensing of publicly funded or co-funded software - recommendation of the Council for Digital Affairs” is based on the report on licensing schemes, consultations, analysis and discussions within the working group, and lists some of the recommendations which were developed (Rada ds. Cyfryzacji, 2018b); those included:

- While procuring the development or purchase of publicly (co-)funded software, the issues of copyright and of access to source code should be addressed. Access to full documentation and its accordance with open standards influence the use of such software, possible fixes and additions in the future as well as interoperability.
- Software costs are not limited to initial implementation cost, but include maintenance, improvements, adjustments and ensuring interoperability. Without access to the source code, there is uncertainty regarding such costs and there are risks associated with the use of such software.specially while citizens’ data, national security and the long-term stability of IT systems are in play, these are major risks.
- Software-as-a-Service solutions require rigorous verification of the long-term security of data, as well as of the future possibility and costs of switching service providers.
- For the above reasons, the Council recommended including access to source code and documentation, used formats and interfaces, complex cost analysis and control over the use of data to the requirements within public procurement procedures. Using proprietary solutions should be allowed only in duly justified cases, and the burden of proof should be on the procuring authority.
- It is not acceptable that the interaction between the citizen and the State requires the use of software or a module from a specific provider.
- Regardless of the licensing model chosen, software must be able to export data in a well-documented format, the implementation of which is not limited by someone else’s exclusive rights, so allowing it to be transferred to other IT systems, and allowing access to archived data after a long period of time.

Moreover, the Council suggested liberalising Polish copyright law, to enable the use of software which has not been developed and distributed by copyright holders for more than 20 years. The current legislation indicates this period as 70 years and shortening it would enable legal access to data saved by information systems not in use for years, or their reconstruction.

Developments within the working group and the two documents created within the Council for Digital Affairs took a step towards a more mainstream adoption of Open Source in public services and provided a solid ground for further developments. However, the working group finished its term at the end of 2018 and has not been renewed or replaced since then. Neither of the two reports was ever shared with the public or otherwise published in any way. No response has been received from the Council for Digital Affairs and the Ministry to requests for comments on the reasons behind why either report was abandoned and its conclusions not published.

In Poland, the National Cloud (Chmura Krajowa) is a noteworthy project in the cloud space; this is a national multi cloud venture, inaugurated in 2018 by Poland’s largest bank PKO Bank Polski and the Polish Development Fund, as a way to digitise businesses and the public administration (Chmura Krajowa, n.d.).. It has secured the involvement of several partner companies, with Microsoft having invested over $1 billion in the project, and Google Cloud being a strategic partner. In the context of other big cloud ventures in Europe, more specifically the Gaia X initiative, it does not seem to declare openness as its core value. This partnership is planned for seven years and involves training over 150,000 professionals, educators and students on: management of the multi cloud solution, AI, Big Data, the Internet of Things and other related topics. It is one of the biggest technological investments in Poland and includes building a data center, providing Microsoft Azure services, business intelligence, data analysis as well as modern workplace modules.

Opportunities and challenges

In recent years, there has not been much debate around stimulating Open Source through public policies in Poland, and so future support for open digital solutions in Poland is not highly promising at this point. If the recommendations of the working group of the Council for Digital Affairs were taken forward, a different policy landscape for Open Source in Poland might be seen. The question of implementation is a separate one: as many countries that have adopted some policies on Open Source in the public sector have not seen much practical implementation by public agencies - and neither have there been results in the private sector.

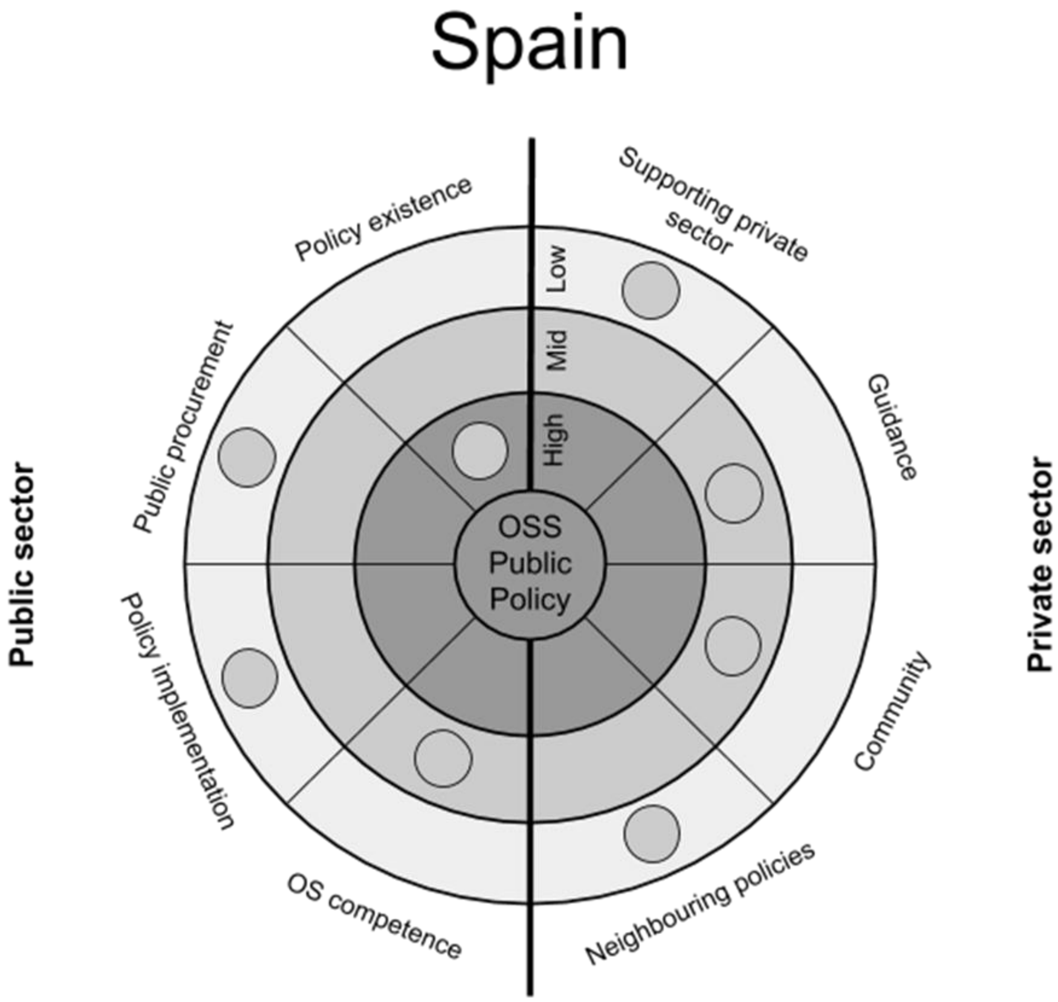
In Poland, no substantial action has been taken in order to advance the uptake of Open Source in the private sector through public policies and other instruments, such as funding schemes or regional development funds. There are some instances of European or nationally-funded projects that cautiously encourage tendering competitors to implement Open Source. For instance, the National Centre for Research and Development, a governmental research agency, distributes funding that favours Open Source, such as its “Fast Track” (“Szybka Ścieżka”) programme (The National Centre for Research and Development, 2020). The programme provides funding for SMEs and Consortia within the European Smart Growth Operational Programme for innovative ventures, and it is foreseen as likely to award more funds to those applicants who plan openly (or freely) to distribute the results of their work via OSS licences and indicate as much in their proposals.

In the Polish public sector, singular local initiatives are emerging, such as the city of Gdańsk, which puts the “policy of openness” at the forefront of its smart city strategy, including where possible Open Source solutions, in its Operational Programmes 2023 (published in 2015) (Operational Programme Development Team, City Hall in Gdańsk, 2015). If such a strategy proves successful, other cities could follow the lead, yet it remains to be seen whether there will be more adoption of OSS on a municipal level of the public administration.

Recently, the Ministry reached out to different stakeholders for their input to the Data Consultation conducted by the European Commission, where Open Source could be one of the themes, as it is an important factor in the notion of digital sovereignty. The lack of civil society organisations working on the issue currently surely explains or is consistent with the absence of focus on Open Source in the public discourse in Poland. Not many academic publications in Polish have been devoted to Open Source in recent years, while those which do exist are largely practical guides relating to the use of a particular piece of open software, overlooking the more strategic dimension of the subject. For Open Source policies to be developed, there is a need for understanding its features and of the opportunities which it might bring to public services as well as to the private sector. As a lack of such understanding is observed, it follows that educating the public and officials on nature and promise of Open Source seems crucial if any relevant policies are to be adopted in the future.

As Poland scores well below the EU average on digitisation and is currently reliant on its low costs of labour, preferential conditions for foreign investment and educated workforce for economic input in the ICT sector, it is in need of creating a different competitive advantage. Long-term, the country would have to strengthen its innovation potential and foster other solutions that might support catching up with its Western neighbours.

Spain



Policy context

By 2005, 98% of the Spanish public sector used OSS "to some degree", taking the highest position of the surveyed countries in Europe (CENATIC et al., 2010). It is thus clear that already early on, before a widespread central government policy on Open Source adoption in Spain came into effect, government authorities were adopting OSS in their organisations, and the Spanish government's IT departments were aware of the potential benefits of adopting Open Source. Spain has never adopted a stated preference for the use of Open Source, yet through a relatively complex set of legislation on eGovernment and regional bottom-up initiatives it has created a distinctly positive environment for OSS within Spanish public policy.

Legally, one of the first important steps was the 2007 Act guaranteeing electronic access by citizens to public services (eGov Law 11/2007), which focused on the re-use of software among public administrations. This Act featured a number of rules which opened the door for OSS. Articles 45 and 46 allowed public administrations to Open Source their applications for the purpose of re-use of solutions by public administrations (if they owned the intellectual property rights to them) as well as obliging them to maintain updated registers of their re-usable software in cooperation with the (to-be-created) Technology Transfer Centre. In addition, Article 4 uses open standards as a tool to establish technological neutrality as a basic principle within the context of the law.

In Spain before this (in 2005) the National Government's OSS Group, created by the Higher IT Council for the Promotion of the Electronic Administration, adopted a set of recommendations advising the use of OSS in the Spanish administration. The following year, CENATIC, a public entity in charge with promoting the adoption of Open Source by the Spanish government, was created (Metzger, 2016). CENATIC is the Spanish Government's only strategic project promoting awareness and use of OSS (CENATIC et al., 2010). While CENATIC was merged into Red.es in 2013, the unit still provides its services today as a competence centre (Red.es, n.d.). In a 2007 resolution, the Spanish Parliament had urged the central government to use OSS (CENATIC et al., 2010).

According to CENATIC, in Spain most OSS projects in the administration have been carried out at the Autonomous Administration level (similar to regions, bigger than provinces). At the regional and local level, a number of authorities have passed legislation that would favour the usage and procurement of OSS, particularly in the field of education (Garro, 2016). One relevant project tendered by the regional government of Valencia is gvSIG. The project was tendered from the start to be made available under an Open Source licence and a first version was released in 2004, with co-financing by the EU. The tool remains in use and development today, not only in Spain but across the world. As development continued, the project was handed over to a community association (the gvSIG Association) and is now being developed by the community. This is a good example of how Open Sourcing a project has led to the creation of a real community around a project initiated by the public sector.

A number of Spanish regions (for example, those of Catalonia, Aragon and Asturia) and municipalities have also created a number of Linux distributions, as was typical in the early 2000s. It is clear that some regions felt the need to follow the example of other regions when creating these multitude of Linux projects. Yet, these projects rarely thrived for very long, and very few remain today. With similar needs across public administrations and only small communities around each regional Linux distribution, it is apparent that this model provided relatively few advantages from Open Source, while at the same time forcing the regions to invest in the development of their own fork of a well-known distribution.

Current policy actions and institutions

In 2015, Spain introduced Law 40/2015 of 1 October on the Spanish Public Law Legal System, which is the successor to the eGov Law 11/2007. Articles 157 and 158 set the rules regarding Open Source. Although this Law does not go as far as actively mandating or preferring OSS, it does establish three main guidance principles:

- it reminds public administrations of the option to re-use existing solutions between public administrations;
- it obliges public administrations to create a repository for subsequent re-use, with the option to use the repository of the Technology Transfer Centre of the Spanish Central Government; and
- it obliges public administrations to release software solutions under an Open Source licence.

Also relevant is the provision seventeen of Law 57/2007, aimed at digital content without intellectual property restrictions, which introduces a degree of copyleft (obligation to re-distribute under the same conditions), as the provision asks for a licence to be chosen which facilitates study, copy and redistribution under the same terms (Commissioner for Technology and Digital Innovation, n.d.).

Complementary to the 2007 eGov Law and its successor Law 40/2015, Royal Decree 4/2010 uses the avenue of eGovernment again to concretise the usage of OSS within the public sector. Article 16 of the Decree establishes the conditions to be applied to software solutions intended for re-use, specifically on the condition that the derivative work retains the conditions of the original, meaning a degree of copyleft is introduced. The Article further makes a recommendation to use the EUPL (European Union Public License), while not excluding the option to use another licence which guarantees the same rights. The exact wording of the Law is (translation by the city of Barcelona):

1. In terms of the applications certified as open source, administrations shall use licences that guarantee that the programs, data or information shared:
    1. Can be executed for any purpose.
    2. Allow for the source code to be consulted.
    3. Can be modified or improved.
    4. Can be redistributed to other users either with or without changes, provided that the derivative work preserves the same four guarantees.
2. To this end, they shall procure the use of the European Union Public Licence, without prejudice to other licences that guarantee the same rights as those set out in sections 1 and 2.

Article 17 of the Decree specifies the conditions under which the repositories introduced by the 2007 eGov law are introduced. Specifically, the Decree imposes a duty to consider solutions available to public administrations that may fully or partially satisfy the needs of the new requirement, and it also clarifies the conditions under which solutions are published in the repositories (Commissioner for Technology and Digital Innovation, n.d.).

When it comes to public procurement, there is no law specifically favouring OSS in Spain. The relevant Royal Legislative Decree (3/2011) considers commercial off-the-shelf (COTS) software to be a supply, while custom-made software is considered a service to the public sector. In the latter case, the service provider (developer) is obliged to transfer the rights to modify or customise the software to the public administration, unless otherwise established in the administrative specification. In addition to this, the aforementioned Royal Decree 4/2010 requires public administrations, before procuring a new solution, to consider existing solutions available through the repositories (Commissioner for Technology and Digital Innovation, n.d.).

Besides the central government's role, Spain is well known for a number of public initiatives adopted by regions and cities, successfully employing OSS. One example is "Consul", software which was developed by the city of Madrid for citizen consultation and is now being re-used in 18 countries around the world (Hillenius, 2018). The City of Barcelona is in the process of adopting software that is mostly OSS, with 70% of the city's software budget being invested in OSS (Offerman, 2017). Also, since 2017 the city has had a strategy on technological sovereignty and an implementation guide on how to achieve this, based on a new Technology Code of Practice (Commissioner for Technology and Digital Innovation, n.d.).

From a policy perspective, two non-exhaustive examples in Spain are the region of Andalusia and the Basque region. In 2005 Andalusia adopted an order promoting the use and re-use of OSS, as well as re-use through the creation of repositories. A 2012 Decree of the Basque region operates in a similar way. Even though the City of Barcelona is switching its software infrastructure to Open Source, there is no public policy which requires the adoption of Open Source for public institutions, yet the existing re-use and interoperability requirements favour Open Source (Commissioner for Technology and Digital Innovation, n.d.).

The Open Source and Re-usable solutions service within Red.es (known until 2013 as CENATIC) acts as a national competence centre for OSS toward the public sector, offering guidance in cooperation with the General Secretariat of Digital Administration (SGAD) of the Ministry of Finance and Public Function (MINHAFP) (Red.es, n.d.). Public officials can contact the service to receive advice on how to build OSS solutions from top to bottom. Among the services listed below, the SGAD also offers a Publishing and Licensing Guide for public officials.

- Advice on compatibility of Open Source licences and associated components;
- Selection of the appropriate Open Source licence as a step before the release of a solution;
- Recommendations for Open Source licences, according to the set of components that make up the solution;
- Technical advice related to the generation of releasable solutions;
- Advice on how to make effective the distribution of a solution as Open Source: creation of packages, licence compliance, etc;
- Operation and integration of Open Source communities;
- Questions concerning the intellectual property rights aspects of Open Source solutions.

Working in coordination with the aforementioned service, the Technology Transfer Centre (TTC) is in charge of creating and maintaining the national repository of Open Source solutions, created under Law 40/2015 (Royal Decree 4/2010). The portal provides information on projects, services, semantic assets, regulations and solutions that are being developed in the field of e-Government. Its usage is obligatory in Spain for the units of the central government, and it is also available to public administrations at the lower levels of the Spanish state. Its main objectives are (Portal de Administración Electrónica, n.d.):

- To create a common software and services repository for reuse in public administrations.
- To create a common knowledge base on the various technical solutions (regulations, services, semantic assets, infrastructure, developments, etc.) in the field of eGovernment.
- To create a space where experiences can be shared and cooperation can take place in the field of eGovernment.

In addition, using GitHub, the collaborative development of applications of the public administrations is facilitated. Any administration can publish its free software project and create a development community around it.

The TTC also interoperates with a number of repositories on the regional level (such as Analusia, Catalonia and Extramadura), as well as the EU's JoinUp. In 2018 another cooperation with the Inter-American Development Bank (IADB) and the government of Spain started the federation of the respective software repositories, in order to enable the usage of solutions across borders (European Commission, 2018).

Opportunities and challenges

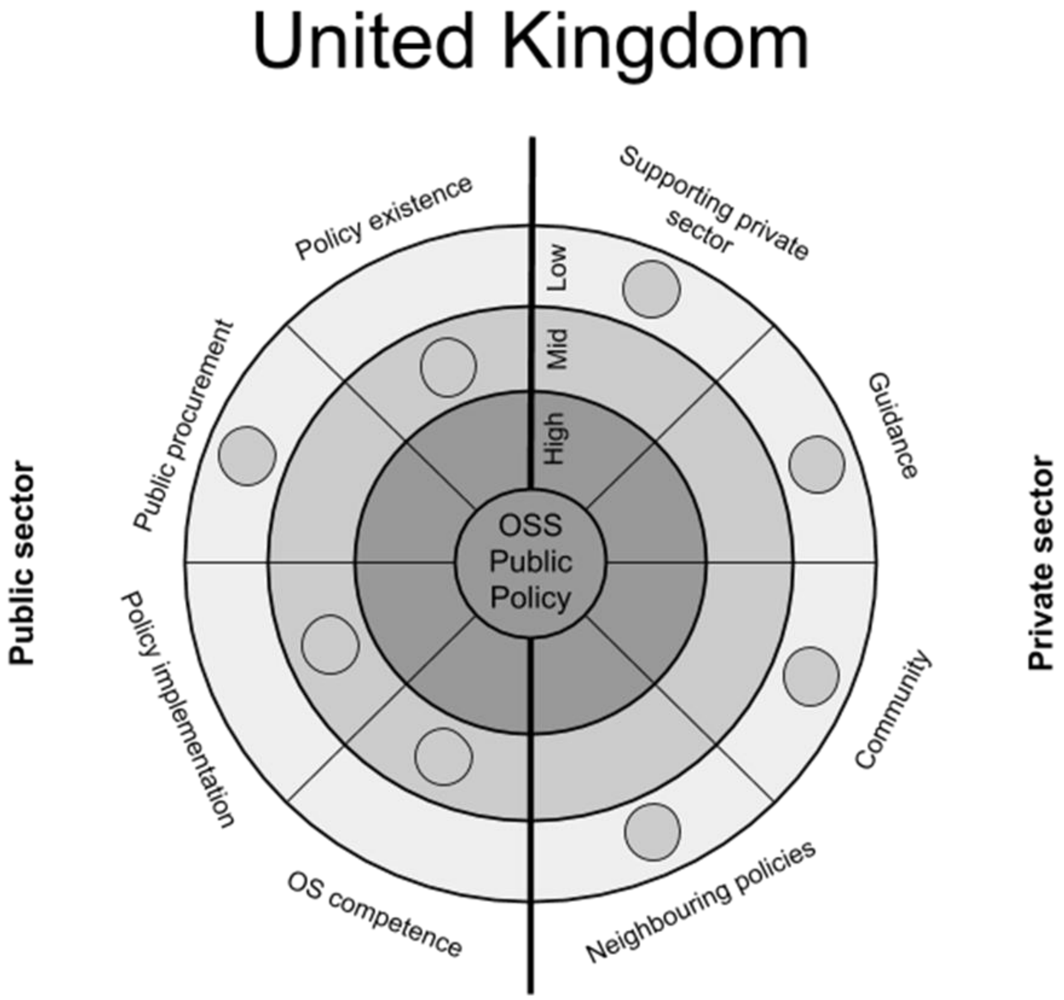
Historically, the main aim of the Spanish public administration in its usage of Open Source Software was to reduce the costs of IT procurement (jserrano, 2019). This was true even before the economic recession at the turn of the decade, and the lasting economic impact of the recession has left cost reductions high on the agenda for the Spanish central government. Today, Spain is underinvesting in technological development and while recognising the struggle for technological independence, the discussion has not gained the same traction as it has in other EU Member States. The understanding is that it will have to cooperate and pool resources, most notably with others in Europe, where there are the strongest connections to possible partners, besides the Latin American world (Ortega Klein, 2020).

Yet, a 2016 study concluded that technological leadership and understanding within the political class in Spain is low. From the step of problem definition to agenda setting, to the formulation of possible solutions, policy making is dominated by public servants who try to take opportunities where they present themselves to introduce their possible solutions. At the central government level, OSS has thus been mostly promoted from the technical perspective, by civil servants who are invested in Open Source. The potential of Open Source, especially aspects further than the aspect of cost savings, as an important tool in the technology industry is not well understood on the political level and it is not featured in a meaningful level on the digital political agenda, which in itself does not play a high role on the political agenda. As such, desired outcomes are seldom either well defined or assessed.

Political decision makers in Spain tend to engage in impromptu, informal decision making. Especially in large organisations, a so called garbage can model was observed, where decisions do not follow a bigger strategic consideration, and the dynamic between problems, actors, opportunities and solutions is in flux. A lack of impact assessment, analysis and evaluation in the run-up of a decision was identified. At the same time, previous decisions, such as the variety of laws enabling the re-use of Open Source decisions and within procurement do not seem to have been reviewed by political decision makers (Garro, 2016).

g. Public policy actions around the world

United Kingdom



Policy context

The UK Government maintains that it first set out its policy on the use of Open Source in 2004, yet an earlier 2002 publication by the Office of Government Commerce (OGC) is known (Cabinet Office, 2011). At the time the OGC formed part of the UK Government's Treasury, but it moved in 2010 across to the Cabinet Office, before it was disbanded in 2011; the OGC was in charge of issuing guidance to improve the efficiency of public procurement. In this role, it provided guidance on how government in the UK should treat Open Source from a procurement perspective. In its guidance, OGC instructed public sector organisations to "consider OSS solutions among proprietary ones [...] on a value for money basis", though it also said to "avoid lock-in to proprietary products" and instructed organisations to obtain the necessary rights relating to custom solutions to make them available for reuse (Office of Government Commerce, 2002).

In essence, these basic principles remain in effect today, even after having reiterated in the different subsequent permutations of UK Government policy. In 2004, the Cabinet Office e-Government office published the same principles outlined by the OGC, and referred to more detailed guidance issued by OGC (Cabinet Office, 2004).

Interviewees indicated that the new government which came into power as from 2010 made a significant push for open technologies within the public administration, connecting Open

Source to Open Standards, and - in the succeeding years - having pushed forward a number of initiatives.

In February 2009, the previous government had already published a new Government Action Plan that went further than the previous procurement-focused guidelines. The Action Plan continued existing language, yet also matured the UK Government's approach to Open Source. Examples include considering indirect benefits of Open Source (such as flexibility and re-use) when comparing OSS and proprietary software, "embed[ding] an 'Open Source' culture of sharing, re-use and collaborative development across Government and its suppliers", as well as "ensure[ing] that there are no procedural barriers to the adoption of Open Source products (Lord, 2009).

Following a period of public consultation, this Action Plan was updated in 2010 to improve its implementation effectiveness. The new Action Plan also prescribed a number of key actions, including "All about Open Source: An Introduction to Open Source Software for Government IT". Open Standards principles were also featured in the Action Plan (Cabinet Office, 2010). This was again reiterated in the 2011 Cabinet Office Government ICT Strategy, in which open technologies featured heavily, committing again to the creation of a level playing field for the procurement of Open Source solutions. This initiative was primarily motivated by a push to reduce government spending on technology, a paradigm that continues (Cabinet Office, 2011).

Following this document, the Cabinet Office and Home Office issued an explainer document titled "All about Open Source", first published at the end of 2011 and revised in 2012. The document aimed at educating public officials about Open Source, focusing on debunking myths and answering common questions (Cabinet Office & Home Office, 2012).

Current policy actions and institutions

Similar to the United States, the United Kingdom's policy on Open Source has focused on aspects internal to the government and has not sought to prescribe rules onto the private sector. Nonetheless, there is no comprehensive United Kingdom government Open Source policy, although the UK has had a number of policy initiatives and can look at the achievements of its policies.

Possibly the most impactful concrete policy forms part of the Cabinet Office's control of expenditure (referred to as 'spend'), and thus represents a procurement policy. The spend control applies to all UK central government departments, as well as to bodies controlled by central government departments. Specifically, in the space of IT, the spend control principles need to be applied to "digital spend over £100,000 and technology spend over £5 million" (Cabinet Office, 2020). When spend controls apply, the Technology Code of Practice needs to be adhered to (Government Digital Service, 2019). Point three of this Code of Practice obliges central government departments to be "... open and use Open Source". The policy makes an ardent case for Open Source and its benefits for the government, but stops short of requiring the purchasing of Open Source, as procurers are only obliged to "Give equal consideration to [OSS] when you choose technology" (Government Digital Service, 2017).

The other typical UK government Open Source policy area of making code available for re-use is covered by the Service Standard for public services, which (at point 12) requires public authorities to "[m]ake new source code open", in order "for people to reuse and build on" the code. The Service Standard additionally asks public authorities to publish code in an open repository and to retain ownership of the associated intellectual property rights, so as to make it available for re-use under an open licence (Government Digital Service, 2019). The Service Manual specifies the requirement and provides more detailed guidance on how to implement the requirement (Government Digital Service, 2017).

Today, according to GitHub, in the UK some 63 central government departments and 29 local councils publish their code on the code sharing platform, with many authorities publishing very frequently, indicating that the government's push to publish code for re-use has been met with some success.

In the UK, the Cabinet Office, in concert with the Crown Commercial Service (CCS), is together with GDS (Government Digital Service) the most important public authority for Open Source.

The Cabinet Office is involved mostly in its role for the improvement of public procurement, government transparency and as coordinator of cross-departmental policy (Cabinet Office, n.d.). In this role, it has published most of the past Open Source policies, which apply across the government as a whole.

The CCS is an executive agency in charge of public procurement, being an interlocutor to suppliers, but also drafting procurement policy and developing guidance; it recently revealed a website that is not within the GOV.UK framework (Crown Commercial Service, n.d.).

GDS is the United Kingdom's digital agency and develops digital solutions for the government. It also administers all ongoing Open Source relevant policies, meaning: the Cabinet Office's spend controls for digital and technology, the Digital Service Standard, the Open standards Principles and the Technology Code of Practice (Government Digital Service, n.d.).

GDS can be considered the Open Source office of the United Kingdom, due to its driving position in respect of Open Source and open technologies, its involvement with the Open Source community, where it represents the UK Government at the Linux Foundation, W3C and Unicode, also in an effort to highlight and normalise the value of the involvement with the Open Source community. Yet, according to interviewees from within the UK Government, the aim of the government is not to have a centralised authority on Open Source, but to have decentralised competences spread across the different government departments. Most departments are said to have such in-house competences. While not formalised, officials who are known to have strong competence on Open Source are consulted when drafting different kinds of digital policy.

Together with the UK Ministry for Housing, Communities and Local Government (MHCLG) in July 2018 GDS formulated the Local Digital Declaration, which specifies 'development in the open' as one of 6 Principles, and commits to the Service Standard (a set of 18 criteria to help government create and run good digital services) as well as a published technology code of practice, aiming to widen their application to the local government level (Ministry of Housing, Communities and Local Government, 2018). As of the end of 2020, the Declaration (which was endorsed by 45 co-publishers) had been adopted by some 241 signatories.

Within the British health care system (the National Health Service, or NHS), a separate entity NHSX was founded early in 2019 with responsibility for setting national policy and developing best practice for NHS technology, digital and data, including data sharing and transparency - i.e., to support the digitalisation of the system. (The X in the name refers to "user experience"). NHSX is committed to using open technologies, such as Open Source and open standards in its work, and is also a member of the Open Source patent pool Open Invention Network (OIN) (NHS England, n.d.).

Opportunities and challenges

The United Kingdom Government's strategy included the introduction (first in 2012) of a set of its own heavily influential Open Standards principles, which have now been revised, in

2015 and then in 2018. Interviewees indicated that these principles aimed to tackle the issue that the government could not prescribe what local and regional governments were permitted to buy, yet the government could set standards and as such could require the usage of open standards. As per the wording of the current Open Standards Principles, "Open Standards are one of the most powerful tools we have to open up government. They make it possible for the smallest supplier to compete with the largest. They make data open for any citizen to audit. They unlock the transformative power of open source software." (Cabinet Office, 2018).

This shows that the UK Government aims to achieve a number of goals with its pursuit of open technologies, both aimed internally and externally, including the support of local SMEs and intensified use of Open Source, as OSS tends to favour implementing open standards and as such standards-based procurement requiring open standards favours Open Source. Except in relation to public procurement, there are no other rules in the UK that support the private sector regarding Open Source uptake, education or guidance.

The potential of Open Source and its re-use was also used when the UK Government created a "'one-stop-shop" for digital government services, as well as a common platform for all government websites, GOV.UK. This platform is built on open technologies and most components are being developed on GitHub under the MIT License. Similar to the Italian government template, GOV.UK provides a common basis and slot-in templates for government units to adopt on their websites, so that departments can easily add services to their website. GOV.UK was developed by GDS and has been adopted by all government departments, meaning that all central government websites run on the same platform and use common components. GOV.UK is considered a success for GDS and the UK Government, having been adopted by other governments, driven by the Open Source approach (Derek du Perez, 2019).

Brazil

Policy context

In Brazil, the story of OSS (though the concept of Free Software is also prevalent there) is primarily one of the past and not of the present. Brazil may be one of the countries in the world with the most vibrant Open Source communities, being a country where Open Source has permeated not only the technology but also cultural sector. Open Source became part of a wider push of the Lula government to establish knowledge commons, where information, data, and content are collectively owned and managed by a community (Birkinbine, 2016). The goal was "to democratise and universalise access to information and knowledge through the use of new technologies" (CENATIC et al., 2010), because it was perceived that value generation in Brazil was not flowing toward Brazilian hands, but to multinational companies.

Since 2003, the Brazilian government has taken many steps in the area of policy and institutionalisation to enable the open sourcing of both public and private software technologies.

Even before the Lula government of 2003, a Presidential Decree in 2000 formed an inter-ministerial working group with the aim to develop policy options to enable universal access to governmental services, with OSS being proposed as one option on this path (CENATIC et al., 2010). Around this time, a number of cities and municipalities made a decision to switch to OSS, primarily for economic reasons. Estimates at the time concluded that across the country, nearly $200 million per year were spent on licensing fees to Microsoft alone and by switching $120 million of those could be saved. While the first initiative came from cities and states, the success drew the attention of the central government and when Luiz Inácio Lula da Silva (Lula) of the left-wing Workers' Party came to power in 2003, Open Source became a priority of the central government, taking the leadership role (Birkinbine, 2016).

In the following years, the government pursued the creation of new institutions and internal policies, but did not adopt more sweeping changes to public procurement law. The first major formal step was the creation of Technical Committees with the purpose "to coordinate and shape the implementation of OSS projects and actions". Open Source communities were invited to join the discussions of the Technical Committees with the aim of creating a Strategic Plan for OSS Implementation within the federal government. This plan set the guidelines for the migration process and recommended 29 policy actions. The implementation of the plan and coordination with the Open Source community was given to the Institute of Information Technology (ITI), running the OSS Brazil project. First five ministries would migrate to Open Source to gather experience and provide a case study for other public entities (CENATIC et al., 2010). During this time the Brazilian government prepared several studies and publications, including a migration reference guide on how to adopt OSS, based on the EU's IDA Open Source Migration Guidelines and a study on the copyleft LGPL (GNU Lesser General Public License) licence, making it the official licence for governmental use (Furtado de Magalhães Gomes et al., 2015).

Open Source was also included in the Digital Culture programme of the Brazilian government (Cultura Viva), which was launched by the Ministry of Culture in 2005. Within the programme, education and digital campaigns were provided through OSS, with the programme matching Open Source experts with projects in the cultural sector which wanted to use digital technologies.

Between 2004 and 2005, the National Institute of Information Technology (ITI) prepared a draft presidential decree that was supposed to reverse the current legal standard to prefer proprietary software and to promote the migration of public administrations to OSS in four areas: operating systems for servers and desktops; office software; Internet browsers; and email. Similar to other laws around the world, proprietary software could still be procured, but had to be justified. Yet, because of disagreements within the government on how to take the issue forward, the proposed decree was never approved (Cassino, 2019).

It took some time until another attempt at a procurement law was launched. In the meantime, the Brazilian bureaucracy would continue its migration efforts and expand Open Source offerings. In 2007 an Open Source re-use software catalogue was created under the name of "Brazil Public Software Portal". It structured available software for re-use and identifying relevant service providers (More on the portal later.)

In 2010, the Lula government tackled the issue of public procurement again and adopted Instrução Normativa MP/SLTI No04 (Normative Instruction No. 4), a binding resolution. Article 11, section 2 specified that when government authorities made public procurement decisions, they would need to consider the availability of OSS in general, and software that is available in the Brazilian Public Software Portal. OSS should be used when considering budgets and if proprietary software is procured, this has to be justified. Though literature suggests the norm is binding, interviews indicate that in reality it has no binding effect and is just a recommendation from the Ministry of Economy. The norm was challenged before Brazil's Supreme Court, the Supremo Tribunal Federal (STF), asserting that it was giving preferential treatment to a single company, but the court upheld the law (Birkinbine, 2016). Similar laws were also enacted in some Brazilian states and cities. According to interviewees, "hundreds" of laws were enacted on the different levels of government, favouring Open Source. Interviewees indicated that 2010 can be considered the peak of

Open Source policy in Brazil, with a levelling off happening after, as many of the most involved bureaucrats then left the government.

With the end of the year 2010 the Lula government ended; even though his successor came from the same party and had been Lula's chief of staff, the Dilma government never displayed the same conviction toward Open Source. When in 2016 the new government signed a new decree (Decree No 8,638) on a new Digital Governance Policy, it revoked the 2003 decree creating the Technical Committees, which had been an important part of the bureaucracy's work on Open Source and had created the frame for coordination between Ministries in order to advance Open Source. Open Source was not even mentioned in the Digital Governance Policy, and thus the bureaucracy's impetus toward Open Source was lost (Cassino, 2019).

Current policy actions and institutions

Today in Brazil, the 2010 norm around software procurement (which favours Open Source) is the most relevant existing legislation at the central government level, although interviewees point to a relatively muted practical effect. OSS in Brazil has completed a journey from a grassroots level movement to becoming a policy priority of the central government and, after ten years of attention from central government, is going back to becoming a more decentralised movement.

A 2010 survey among Brazilian public institutions showed the status of OSS adoption in the categories of E-mail, internet servers, information systems, desktops and office suites. The survey identified that universities and agencies with a technology mission were furthest along with their Open Source transition; and, whilst most Ministries had made some transition, smaller agencies that had no significant technological background had the lowest adoption rate. In general, e-mail, information systems and internet servers were the categories where the transition was successful, while desktops and office software were seldom migrated to OSS (Software Livre Brasil, 2010).

In June 2020, far-right President Jair Bolsonaro's government proposed a Provisional Measure (MP 983/2020) on Open Source Software to Congress, stating in Article 8 (interviewee translation):

> "The information and communication systems developed or whose development is contracted by bodies and entities of the direct, autarchic and foundational administration of the Powers and constitutionally autonomous bodies of the federal entities are governed by an open source license, allowing their use, copying, alteration and unrestricted distribution to all bodies and entities covered by this article."

As the text has not been voted on yet, it remains only a proposal. Besides this, many of Brazil's 5,500 cities have local laws which favour OSS in public procurement.

The Brazilian Software Protection Act mandates (in Article 9) that "the use of computer programs within the country will be subject to the license agreement". As mentioned before, the GPL License was defined as the main licence to be used, later joined by the Creative Commons GNU GPL (CC-GNU-GPL-BR). These licences were translated into Portuguese by the state IT company SERPRO (Metzger, 2016).

Although Brazil never had a formal governmental Open Source office singularly in charge of advancing and coordinating the government's efforts around Open Source, the government did create a small number of organisations which took on specific tasks within the overarching effort toward the adoption of OSS. Among those are the National Institute of Information Technology (ITI), the Committee for the Implementation of Software Livre (or

CISL) and Serpro, the state IT service provider. In addition, the President's Chief of Staff took a directing role within the effort as a whole.

The role of the National Institute of Information Technology (ITI) in Brazilian Open Source is almost one of happenstance. Until the Lula government came to power in 2003, the agency was in charge of the state's cryptography and certification systems, and received little attention. The new government had to appoint a new President and chose Sérgio Silveira, who said (about his having been offered the post): "I don't know exactly what the ITI is, but I'm going there to implement software livre". He spoke to Open Source people in the country who saw the opportunity to use ITI to become a spearhead for the adoption of Open Source. Silveira wanted to use ITI to locate competent personnel and to craft a national OSS strategy. When he agreed to become President of ITI, he received agreement from the President's office to support him in this mission (Shaw, 2011).

Closely connected to ITI was the CISL, the Committee for the Implementation of Software Livre. It served with an explicit agenda-setting function, in order to activate and connect to the network of Open Source advocates. It brought together stakeholders from different organisations, such as Ministries, private companies, agencies and advocates. The first main output was a strategic planning document issued in 2003 and endorsed by Lula. The main recommendation was to create a federal committee tasked with Open Source adoption, headed by Silveira (Shaw, 2011).

The state IT services company Serpro, which is the self-described "largest Information Technology company providing services for the public sector in the world" (Serpro, n.d.), was deeply involved in the management of the Open Source transition in the Brazilian public sector. Interviewees indicate that Serpro was the main source of know-how on Open Source and played an important role due to the many technical experts working within the company. One of its main contributions was to create a migration manual for OSS, which interviewees indicated was very important to give public administrations the necessary knowledge for a successful migration. Serpro also developed an Open Source strategy for its own organisation and formed an advisory committee where Open Source activists were invited to take part. It also runs the e-PING interoperability programme, providing Interoperability Standards for Electronic Government. The programme provides a minimum set of assumptions, policies and technical specifications on the use of information and communication technology, required to provide the technological and regulatory basis for interoperability of services. The programme uses open technologies, yet is not binding (Metzger, 2016).

The Brazilian Public Software Portal (Governo do Brasil, 2020) is more than just a catalogue of solutions, though this service is also offered; users can also submit requests for software to meet the needs of their local community. Besides this, the portal allows communities to be formed around existing software or a new software need, in order to collaboratively develop the software. Even though this platform was founded as long ago as in 2007, only 69 pieces of software are available on it. This is possibly influenced by the fact that software on the platform has to be licensed under the GPL v2 and thus, some software is ineligible (Birkinbine, 2016).

The portal was reformed in 2013 with the aim of increasing the integration of functions of the portal and to have more software hosted, by allowing more licences. To achieve the first goal, the portal was made more centralised to have development shift from external sites such as GitHub to the portal, in order to increase control over the software and reduce reported surveillance through United States institutions. It is questionable how successful the reforms were, as usage does not seem to have increased significantly since the reform. This might also be caused by the government's reduced emphasis on Open Source (Birkinbine, 2016). In addition, interviewees noted that even though all government was supposed to publish its software on the portal for re-use, this has clearly never become a widespread practice.

Opportunities and challenges

Two aspects may be the most notable in the case of the Brazilian Open Source movement. First, unlike in many countries where economic reasons prevailed, Open Source in Brazil was motivated first and foremost by a belief of software as a commons and thus it was viewed from a more shared ownership point of view. Second, the adoption of Open Source was not a top-down political project, but brought up from civil society and technical experts so that it was institutionalised and graduated to some level of politicisation.

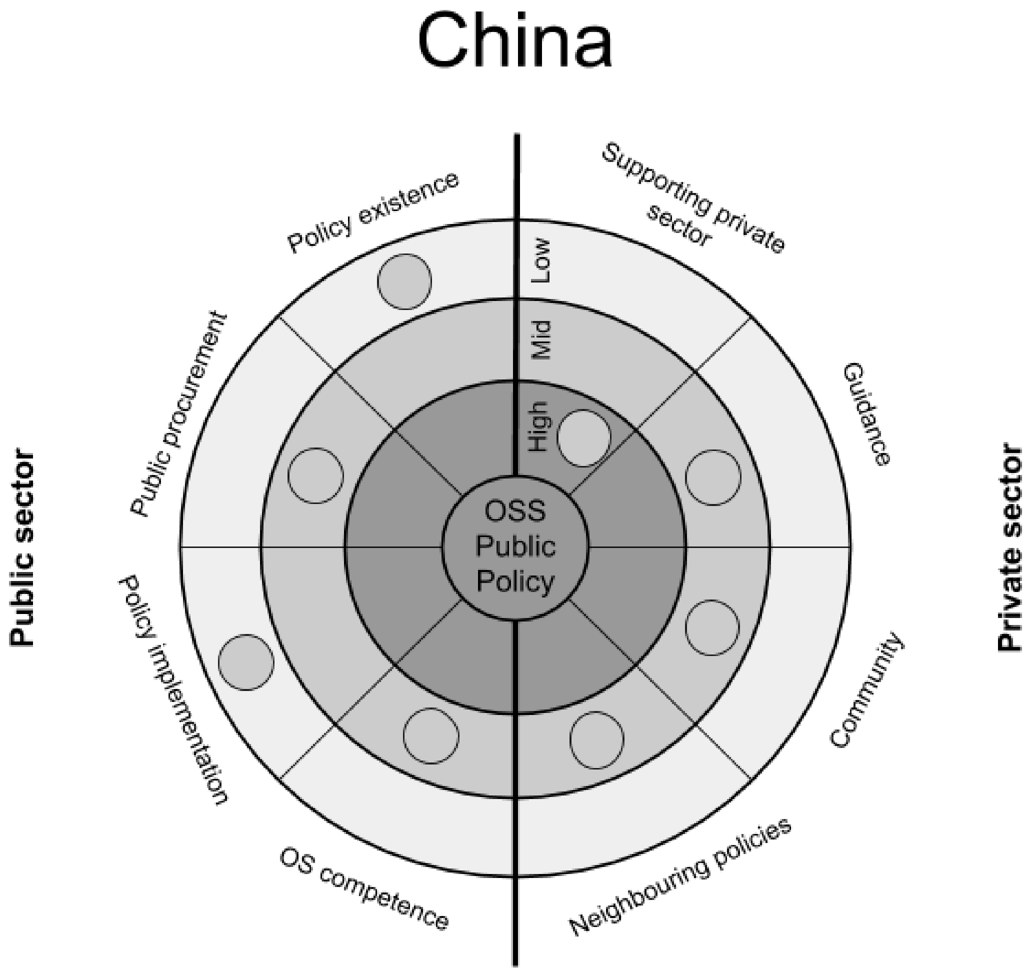
In the early 2000s, the term "technological sovereignty" was already used in Brazil by activists who wanted to have more control over the software which they and their government used. As opposed to a majority of countries where (from a political ideology perspective) Open Source communities tend to be either apolitical or libertarian, in Brazil Open Source communities tend to be characterised by a strong sense of common ownership for the common good. Open Source was seen as one part of the strategy to achieve a sovereign digitalisation in the areas of national education, economic growth, autonomy, and development. Based on this, a local software industry was created and fostered by the federal government.

The networks formed by civil society and technical experts proved to be the spark that made the Open Source movement in Brazil into a political force. Literature refers to elite networks of "insurgent experts" that were working within political, technical and educational institutions to mobilise collective action. These networks engaged strongly with the government party, the Workers' Party, adapting their messaging to the ideology of the party, framing OSS as a counter-hegemonic alternative to the dominant market-based logic, in order to ensure political support for the issue. Supporters were consciously provoking (foreign) proprietary companies in order to achieve a higher level of politicisation of the issue, and so increase its role in the political agenda-setting cycles (Shaw, 2011).

Besides the aspect of Open Source within the public sector, in Brazil the government also saw the potential to promote a home-grown software sector, independent from international suppliers. The state IT company Serpro supported many companies in their adoption of Open Source, not only for its usage but also as system integrators and software developers, through publications as well as through procurement. These activities had political support from the leadership of the Workers' Party, as it was well aligned with their broader political goals of self-sufficiency and their negative view of multinationals and their impact on Brazil (Shaw, 2011). At the same time, interviewees indicated that, as in other countries, the government did not manage to foster a software sector that was able to provide the supply required to meet the demands of the government from the perspectives of quantity and quality. Most companies remained small, often just with one employee, unable to supply what the government needed, and thus never managed to grow. Thus, many times even when public administrations wanted to rely on Brazilian-produced or Brazilian-integrated OSS this was not possible or practical, and the question of how effectively to support the professionalisation of the Brazilian software industry remained open.

Internally, the high level of institutionalisation within the Brazilian government (through the ITI, the CISL and Serpro) played an important role in effectively coordinating not only the inputs toward the political level, but also the reactions to political inputs, and thus ensuring an appropriate response as well as taking advantage of the opportunity structure in place. The cooperation of technical experts who were acting as policy entrepreneurs and the bureaucracy was an important factor in carrying the OSS conviction into Brazil's Ministries and agencies. Yet, interviewees indicated that as toward the end of the 2000s more and more of these policy entrepreneurs left the Brazilian public administrations for work within the private sector, Open Source in the Brazilian government lost its impetus. Even with the level of institutionalisation which had been achieved within the Brazilian government, without those individuals advocating internally for the issue, Open Source fell off the policy radar of politicians, who lost interest in the topic as a whole. It is thus not surprising that when policy was revised by the Dilma government in 2016, Open Source was not even considered and was forgotten (Cassino, 2019). This shows that the issue of continued support for a policy issue cannot be solved entirely through institutionalisation; individual conviction is also required in order if the issue is to remain on the political agenda.

China



Policy context

There was little written information available to the study team about the policy formation process in China, and information on output is limited. Thus, expert input is the main source of information in this area.

Opinions diverge on whether in China the private sector or the public sector was responsible for the first push toward Open Source. This question, while applicable in a Western context, is less relevant in the Chinese context. Although privatisation has given Chinese companies more flexibility and freedom, the government's involvement continues to extend well beyond holding financial stakes, especially in industries which the government considers strategic.

Yet, applying this dichotomy as best as possible, it seems that while the major corporations got engaged with Open Source around the turn of the decade, the Chinese government's involvement had started already in the early 2000s and for a long time was the driving force behind any OSS push in China, an area with which the private sector did not engage significantly, as industries tended to be less focused on research and development, but more on industrial production.

Yet the Chinese government had already early on seen the potential for economic development, increased technological independence and security in OSS. As such, the Chinese government implemented a "resolute interventionism" (CENATIC et al., 2010) in its usage of Open Source.

The push for technological independence is not a new development within Chinese industrial policy. Although historically China was a technological leader, this advantage had been lost by the 18th century, and the Chinese government felt the consequences of this disadvantage in the following years. The information age was built on Western technologies, language and standards, and China thus had to approach technology on the terms of those in control of those technologies. This has created a long-standing motivation for China to achieve more control over strategic technologies.

The government has supported the expansion of development communities and the use of Open Source within the administration through central government planning. Early on, for China, Open Source meant Linux and it focused on replacing the proprietary Microsoft-dominated desktop with a self-developed alternative, which later became to be known as Red Flag Linux, but was already founded in 1999. Red Flag Linux was part of the bigger Asianux project, along with Miracle Linux in Japan and Haansoft in Korea. As part of the Chinese government's strategy, new computers were required to be sold with an operating system, and the use of software produced in China was encouraged.

Like so many other government-led Linux distributions, and even though by the year 2010 its usage was mandatory in all government agencies, Red Flag Linux eventually was discontinued, as it offered relatively little advantages over COTS or existing Open Source operating systems and it thus achieved little market penetration outside of those entities which were required to use it even though its usage was mandatory in all government agencies by the year 2010 (Muncaster, 2014). The last version of the overarching Asianux project was released in 2015 (Asianux, 2019).

In the private sector, Huawei was the first major Chinese company to begin looking at Open Source strategically around 2010, in a bid to become more competitive on a global scale. To increase its Open Source capacity, Huawei built up an Open Source Programme Office (OSPO), improved its IP handling capabilities and started getting involved with international companies and organisations experienced with Open Source.

For a long time, one factor holding back the development of Open Source in China was its difficulties connecting with the global Open Source communities, which predominantly communicated in English. Interviewees also indicated cultural differences between the public and direct Western Open Source communities and Chinese communities, where addressing issues one to one, away from public view, is the norm. Apart from the practical issue of time zones, differences in the increasingly synchronous Open Source development environment, this has historically created challenges for Chinese developers existing within Western Open Source systems, as it could leave them in unproductive situations.

On the other hand, some interviewees indicated that Chinese culture is also well suited to an Open Source development method. Chinese developers are used to a collectivist, collaborative working approach, moving quickly from project to project, building on previous work and without an emphasis on reinventing the wheel - improving development speed.

Current policy actions and institutions

Generally, the Chinese government is heavily involved in setting the direction for industrial development. China's five year plans play a high-level role in this, in coordination with other relevant high-level strategies, such as the Made in China 2025 plan, with both the Ministry of Industry and Information Technology (industrial policy) and the Ministry of Science and Technology (R&D and innovation) being responsible for concrete policy formation in the technology domain. These Ministries are supported by a number of research institutes / government think tanks. Relevant here are the Industrial Internet Special Working Group, the Instrumentation Technology Economy Institute, the China Center for Information Industry Development and the China Academy for Information and Communications Technology (CAICT) (Arcesati et al., 2020).

When it comes to the adoption in China of Open Source within the public sector, interviewees indicated that there is no uniform policy applicable to all government units, with significant regional differences present.

On the national level, the main Ministries relatively regularly publish communications regarding Open Source - announcements, opinion pieces and papers - which are generally favourable in view. Yet, the Ministries do not create legislation and there are for example no formal procurement or re-use policies in China. One reason given for this is that the Ministries do not have the necessary evidence to argue an explicit pro Open Source policy. The Ministries are known to fund projects involving the development of Open Source.

CAICT, which was identified as the main agency in China which sets Open Source policy, is a child agency of the Ministry of Industry & Information Technology (MIIT). CAICT is expected to have thought leadership on the topic of Open Source in China and in that role creates guidance. In China, the line between formal policy (regulation) and policy advice is fine; interviewees indicated that CAICT's advice is considered "not optional" by those within the government's influence, especially in the case of strategic industries.

Research conducted by CAICT is not usually released to the public. It has in recent times also begun to investigate Open Hardware more in-depth to assess its potential. CAICT is in a role to create standards and best practices for the government, though this role is not formalised.

In its role as the governmental organisation with the highest understanding of Open Source, CAICT will also attend Open Source conferences and act as a connection to the community by organising its own Open Source conferences. Yet, CAICT still does not take up the role of an Open Source competence centre, at least not formally.

In addition to CAICT and the overarching role which it has taken up, there are also industry-specific research agencies, some created under the MIIT and some in companies with significant government influence. In many cases, leadership of state companies may have roles on committees of the relevant ministries and communication is very regular. The role of the research bodies is to help shape consensus.

On the lower levels of government, there are also some significant regional differences. The coastal, highly digitised provinces (e.g., those of Zhejiang, Guangzhou and Guangdong) have a very favourable stance regarding the adoption of OSS, as they compete for funding through national programmes, based on their innovative potential and thus need to ensure to stay connected to trends. Yet provinces with a lower level of technological exposure are often not engaged on the issue at all (Xu 2020).

Away from the public sector, the Chinese government is very directly involved with many educational institutions as well as private and semi-private companies in which it has a stake. In the technology-driven sectors, the Government has given private actors the freedom and its blessing to use Open Source as a strategic tool in both digital transformation, innovation and technological independence.

China has supported the creation of public-private partnerships with the aim of increasing capacity and of promoting Open Source. This has happened on the national level, with a number of industry associations, in the education sector and internationally.

In 2005, the Chinese government supported the founding of a university alliance spanning 70 members, called the Leadership of Open-Source University Promotion Alliance (LUPA). This foundation has resulted in more than 300 universities and schools offering courses on open technologies. A similar initiative was launched in the same year as the Guangdong Linux Centre, which - along with 27 universities - created the Guangdong Leadership of Open-Source University Promotion Alliance (GDLUPA) (CENATIC et al., 2010).

Internationally, China is connected to a number of organisations in Asia. The Ministry of Industry and Information Technology supported the establishment of the Open Source Software Promotion Alliance to encourage the development of China's OSS industry and to create links to other countries in Asia with similar aims regarding Open Source (Lewis, 2010). Similarly, the China OSS Promotion Union (COPU) was founded under the leadership of the Ministry. COPU, together with the Ministry, represents China at the Northeast Asia OSS Promotion Forum - an organisation founded by the competent Ministries of China, Japan and South Korea to coordinate, collaborate and exchange on Open Source projects that touch all three countries. This collaboration is happening within a greater context, which is sometimes referred to as the "Kanjisphere", a distinct Chinese-Japanese-Korean techno-linguistic zone. The forum also engages with private enterprises, research institutes, and educational organisations (Japan OSS Promotion Forum, 2013).

Opportunities and challenges

As a country involved with technology, China also has history as a hardware producer - typically as a "factory" for foreign companies. That many of the products produced by Chinese factories were unattainable for those producing them was one of the main motivators of the Chinese government to pursue a technologisation of its industry, placing a greater focus on software (CENATIC et al., 2010).

In 2000, China's 10th five year plan intended to transform the country from a consumer of IT services to a producer (Government of China, 2000):

> "[I]nformatization [sic] is the key in promoting industrial advancement, industrialization and modernization. Therefore, national economic and social informatization should be the first priority. Putting effort into promoting national economic and social informatization is a strategic action in the fulfilment of the whole modernization construction plan."

This trend was echoed in the following plans, such as by the 2010 plan's aim of "moving coastal regions from being the 'world's factory' to hubs of research and development, high-end manufacturing, and the service sector" (Government of China, 2010) and the 2015 plan to "move up in the value chain by abandoning old heavy industry and building up bases of modern information-intensive infrastructure" (Government of China, 2015). Here, additional industrial policy in the form of Made in China 2025 or China Standards 2035 are also relevant, and follow broadly the same strategy of climbing further up the value chain and relying more on either domestic or Open Source solutions in order to gain independence.

This was commented on by Lisa Caywood, not only as a matter of economic development, but also as one of national security: "China has very solid historical reasons for avoiding dependency on foreign tech without some access to (yes, I'll say it) the means of production. So do former subjects of various Euro empires, but for China that issue is at the core of the modern state" (Asay, 2019). Proprietary software was considered unstrategic and subject to capture by foreign interests and thus Open Source was one of the tools the Chinese government favoured when addressing this issue.

Even considering China's construction and production prowess, China remains dependent on foreign technology providers, as 90 percent of chips necessary to meet domestic demand are being imported and over 90 percent of high-end industrial software used in China is of foreign origin - usually provided by companies like SAP, Microsoft and Salesforce. In addition, leaving high-profile cases aside, much of the manufacturing remains low-tech (Arcesati et al., 2020). Mitigating these strategic dependencies has been a strategic aim of the Chinese government for years, only increased by the current trade tensions.

Open Source plays a role in this effort, for example in the development of the new national digital currency; yet while it is built on Open Source technologies, it also needs to be recognised that the resulting product is not Open Source, and that for the Chinese government Open Source can be classified mostly a means to an end: there is no an inherent affiliation to the philosophy of Open Source such as plays a role in some EU and South American government decisions. It would therefore be wrong to expect the Chinese government to push toward Open Sourcing all technological development.

Yet, while in China the culture of contributing back (upstream) has for some time remained somewhat underdeveloped, this is changing with increasing exposure to international Open Source communities and an increased buy-in to the steps necessary to reap the benefits of Open Source in the long term. The Chinese government has also agreed to a "cooperate to compete" approach, meaning that it is willing to make compromises for the sake of cooperation in order to achieve its goals.

Open Source is considered as one of the pieces within a mix of tools to achieve the goal of rapidly developing technologies, such as AI and Cloud, which the Chinese leadership has designated as key. With this, the government is also directing Chinese companies to become more active in Open Source, domestically and internationally.

The Ministry of Industry and Information Technology actively tracks the involvement of Chinese companies (especially that of major companies), in Open Source communities, and seeks to increase Chinese representation in those communities as well as in standardisation organisations (Guanyu, 2019). There is satisfaction that China has become the second biggest origin of contributions on GitHub after the United States (Zihe, 2019).

Table 8.9: China's involvement in Open Source foundations

Foundation	Membership	Chinese enterprises	International enterprises
Linux foundation	Platinum member	**2** (13%) Huawei, Tencent	15
	Gold member	**3** (18.8%) Baidu, Alibaba, WeBank	16
Apache software foundation	Platinum sponsor	**1** (10%) Tencent	10
	Gold sponsor	**1** (11.1%) Huawei	9
	Silver sponsor	**3** (27.2%) Baidu, Alibaba,	11
OpenStack foundation	Platinum sponsor	**2** (25%) Huawei, Tencent	8
	Gold sponsor	**10** (50%)	20
Eclipse foundation	Strategic member	**1** (10%) Huawei	10

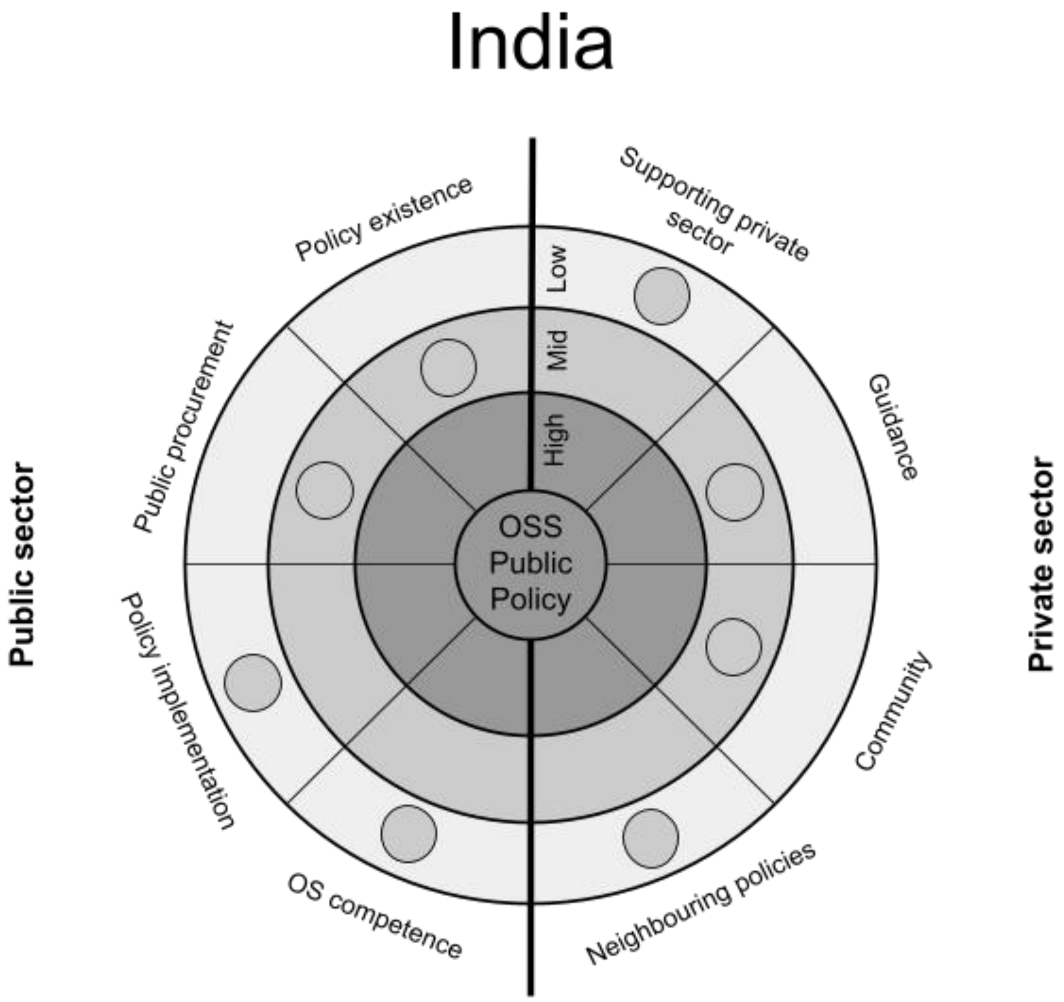
The Chinese government is also intensifying support for domestic Open Source communities in projects the results of which can be used more easily by the majority of developers who are not comfortable with English and by smaller companies. Examples are OS China and Gitee.com (which, by focusing on the Chinese market alone, has become the second biggest OSS hosting platform).

With the increasing trade uncertainties, concerns - about being involved in foundations, projects and licences governed by United States law - have taken hold. In response, China is pushing for more domestic governance and licences. Huawei was reported to have been involved in founding a domestic Open Source foundation early in 2019, as a reaction to GitHub having limited access to certain parts of its service in the ongoing trade dispute, although interviewees did indicate that no serious Open Source foundation exists in China as of yet. (China Daily). Some Open Source organisations are thus choosing to move their governing jurisdictions away from the United States in order to enable continued cooperation with Chinese organisations.

Indeed, early on the Chinese government appears also to have realised the relevance of OSH for its technological sovereignty. Having anticipated the United States' ability to restrict Chinese companies' access to chips produced by non-Chinese companies (not only American but also South Korean or Taiwanese), the government helped to found the "China RISC-V Alliance", which aims to increase the development and adoption of the Open Source architecture in China, and so reduce reliance on Western-controlled x86 and ARM architectures. The first resulting special-purpose chips are already in production by Chinese companies. (Meinhardt 2020)

To enable the fast development of technologies, the Chinese government will often designate lead companies in a technological field and task them with the development of national standards which are to be followed by the rest of Chinese industry. The Chinese government will also try to create a set of three companies in competition with each other, in order to make these companies efficient within the domestic market and so prepare them for international competition.

India



Policy context

In the public's consciousness, the Indian people are tightly connected to the software industry. Thus, it is clear that India must have had some historical success in creating at least the perception that it is a tech-savvy country (Folz, 2019).

The concepts of Free and Open Source Software only emerged in the 1980s, and early Open Source policy in India cannot be understood without an understanding of IT policy. Indeed, back in the 1960s the Indian government (in particular the Department of Electronics (DoE)) followed an interventionist industrial policy toward the software sector; thus to some degree the Indian government understood early on the economic value for India of having its own software industry. This is evidenced by three main policy actions of the DoE in the 1970s:

- the creation of the Electronics Corporation of India Limited (ECIL), as "infant-industry protection" and a deterrent for international embargos;
- increasing the minimum required level of domestic ownership of international IT companies' subsidiaries established or operating in India;
- the introduction of the Software Export Scheme of 1972, which provided financial support for the Indian software sector, with the first resulting exports to third countries happening from 1974 on.

Whilst the degree of success of these measures is difficult to ascertain objectively and subject to debate, the export scheme especially is credited with having significantly influenced the creation of the Indian domestic software supplier market in earnest. The first Indian company to take advantage of the scheme was Tata Consultancy Services, which used the scheme to establish its international presence (Saraswati, 2012).

The interventionist policy paradigm remained dominant throughout the 1970s and 1980s, producing industrial policy which aimed at achieving a technologically independent and self-sufficient Indian economy, based on the concept of Swadeshi. Policies aimed at increasing the economic output for technology-based companies were described as "pro-business rather than pro-market" (Guha, 2008). Yet, a boost in domestic demand for consumer goods required that the Indian economy needed to be opened to some level toward the international market. At this point Indian technology companies were not able to compete internationally, and the government was thus cautious to expose them to international suppliers on the Indian market. In an attempt to achieve the two Indian policy goals of protecting local industry and providing more consumer goods, the government decided to liberalise the import of raw materials, production machinery and intermediaries. Computer kits without software were imported to be "made in India" and to run on Indian software. This led to a huge increase in revenue for the domestic technology economy (Saraswati, 2015).

This policy of liberalisation under the New Industrial Policy increased in the 1990s, eventually leading all major tech hardware producers in India to stop their own production on account of having become uncompetitive. Companies employed different strategies to deal with this. Some stopped their business, whilst others embraced foreign investment and became resellers for major Western suppliers such as HP and Dell. Some others pivoted their business from hardware to software and formed some of the most promising software companies of the time. The low labour costs, good English skills and technical skill of Indian software developers gave these companies a competitive advantage and led to a successful, highly export-oriented Indian IT services industry. It was also during the 1990s that OSS gained attention in India. Still influenced by the self-sufficiency paradigm, in 1988 the Indian government required that all computers procured for the Indian government should run on UNIX systems, and this was supplemented with Linux systems when these became available. While in the private sector misconceptions around OSS remained, many universities were embracing OSS such as Linux for its low cost and technical advantages over proprietary software at the time and formed Linux User Groups (LUGs) (Folz, 2019).

Table 8.10: Influence in India of Science & Technology policy cultures during different phases

Year	Political-Bureaucratic	Industry- Market	Academic	Civic
1947–1970	++	-	±	
1970s	+	-		-
1980s	+	-		±
1990s	±	++		±

Legend: ++: very high influence | +: high influence | ±: moderate influence | -: low influence, Source: Krishna (2001), p. 4

With the turn of the millennium, awareness of OSS started to jump from academia to some government officials, even in higher positions. Although the Indian national government had no official OSS policy at this point, some pockets within the government started to favour procuring OSS over proprietary software. At the same time, Indian software companies were still able to take advantage of their strong competitive positioning acquired in the 1990s. Indian software engineers soon became a major part of the image of the country.

Yet by the mid-2000s, international IT suppliers increased their market presence in India and began establishing themselves in the economic, political and public life of the country. Parallel to this, the Indian IT sector continued to grow, though increasingly growth shifted away from Indian to international companies, disrupting a more balanced distribution. Thus although the Indian software sector as a whole remained of considerable size, domestic companies played a smaller role. Two major factors can be identified as having contributed to this development. First, international IT suppliers began to hire away large swathes of senior and distinguished employees of Indian IT suppliers, thus leaving them with junior and less capable staff, crippling their ability to compete on complex and high-value contracts, inhibiting growth. This changed the trajectory of the Indian software market. Indian companies, starved for talent, transitioned to providing basic services (such as call-centre outsourcing) and thus lost the opportunity to become major software providers. Second, replacing government-led initiatives, investment in policy-advocacy and market research allowed a conglomerate of international IT suppliers to shape Indian IT policy, somewhat hiding the increasing weakness of Indian IT suppliers from policy-makers and establishing themselves as the sole source of industry software policy guidance. This has changed the trajectory of the Indian software market.

In turn this affected OSS policies in India. A latent positivity regarding potential cost savings had developed across the political spectrum in India, yet supporting OSS publicly was seen as dangerous for local IT companies, which were dependent on international IT suppliers, many of which at that point being primarily proprietary companies.

In the ten years up to the adoption of the 2015 preferential OSS public procurement policy, the Indian government seems to have followed a loosely structured course which did not support OSS directly, but instead focused on increasing know-how and awareness within the public administration through technology and OSS-focused public institutions. At the centre of this effort were the National Informatics Centre and the C-DAC (Centre for Development of Advanced Computing), under which the NRC-FOSS (National Resource Centre for Free/Open Source Software) was founded.

Current policy actions and institutions

The most important existing public policy relating to Open Source in India is the Digital India programme adopted by the Ministry of Communication & Information Technology (Meity) in 2014 (Ministry of Communication & Information Technology, 2014). The Digital India programme features the “Policy on Adoption of Open Source Software for Government of India” (Ministry of Communication & Information Technology, 2015).

The Policy sets out the goal for the policy as:

> “Government of India shall endeavour to adopt Open Source Software in all e-Governance systems implemented by various Government organizations, as a preferred option in comparison to Closed Source Software (CSS).”

To define OSS, instead of referring to either the Free Software Foundation or to Open Source Initiative definitions, a modified definition of the Free Software Foundation’s definition was used.

The scope of this policy extends to all units of central government in India when performing public procurement of software. State governments may choose (but are not required) to adopt the policy themselves. Per the law, when replying to any request for proposals (RFP), potential suppliers need to justify any offer which is not OSS-based, and procurement decisions should be based on specific criteria which include “strategic control” and “life-time costs”.

The set-out policy outcomes of the policy are:

- to provide a policy framework for rapid and effective adoption of OSS;
- to ensure strategic control in e-Governance applications and systems from a long-term perspective; and
- to reduce the Total Cost of Ownership (TCO) of projects.

Estimates determined that in 2012, the procurement of IT made up around 50% of Indian governmental procurement budgets (Consumer Unity & Trust Society, 2012). As such, the potential impact of this policy on the Indian software market is clearly significant, but it still depends on many factors such as implementation rigour and flanking measures that aim to build the necessary capacity of Indian IT suppliers to match supply with demand.

Interviewees indicated that the level of uptake of the Indian procurement policy is “patchy”, and highly dependent on the level of knowledge which an individual procurement officer has. This situation is made possible as the policy foresees no enforcement instrument, and as there is no instrument to support unaware or unwilling procurement officers in implementing the policy. Additionally, most public software procurement is being made by the 29 separate states in India, which have their own individual diverging policies, and thus the level of knowledge around Open Source at the political level is relevant.

A 2015 study focusing on a sample of seven Indian states revealed highly diverging uptake, with a mix of proprietary desktop and non-desktop software in use. Interviews conducted for this 2015 study revealed a lack of information and misconceptions around the quality of OSS as the main reason for the non-uniform results (De’, 2015).

In addition, interviewees credit international IT suppliers with influencing policy makers toward not taking steps to increase the adoption of OSS, with the aim of reducing orders to local IT suppliers. International IT suppliers are said to have used their affiliations with major domestic IT suppliers in order to exert pressure on policymakers, questioning whether corporations and partnerships could continue if India were to turn away from their products. For years, this has reportedly held back a policy which already had support in principle within the administration.

Looking back at the potential impact of the procurement policy, policy uptake was one issue; yet another issue reduced its impact significantly. Even with the non-uniform uptake at the national and state levels, according to interviewees based on the procurement law demand for OSS solutions increased. Yet the local software sector could not match the increased demand with a local supply of OSS solutions.

A number of reasons have been put forward to explain why the Indian software sector did not grow with the increased demand for OSS. In the background section, the context of these factors was investigated in more detail. Two other main factors can be identified here: lack of access to qualified personnel, and the small size of the average Indian IT supplier.

In the 2000s, the increase in foreign direct investment was mirrored by an increase in the dominance of international IT suppliers over the Indian software market. Few domestic companies of a size sufficient to rival either the product catalogues of international IT suppliers or their perceived attractiveness as employers. Indian software developers in general prefer to work for an international IT supplier instead of for a smaller local company, and this has severely hampered the growth of the Indian IT sector. Interviewees clarified that while there is a great deal of business available to Indian IT suppliers, the domestic market is far too small to satisfy the demand and public procurers are hesitant to buy from SME-sized companies.

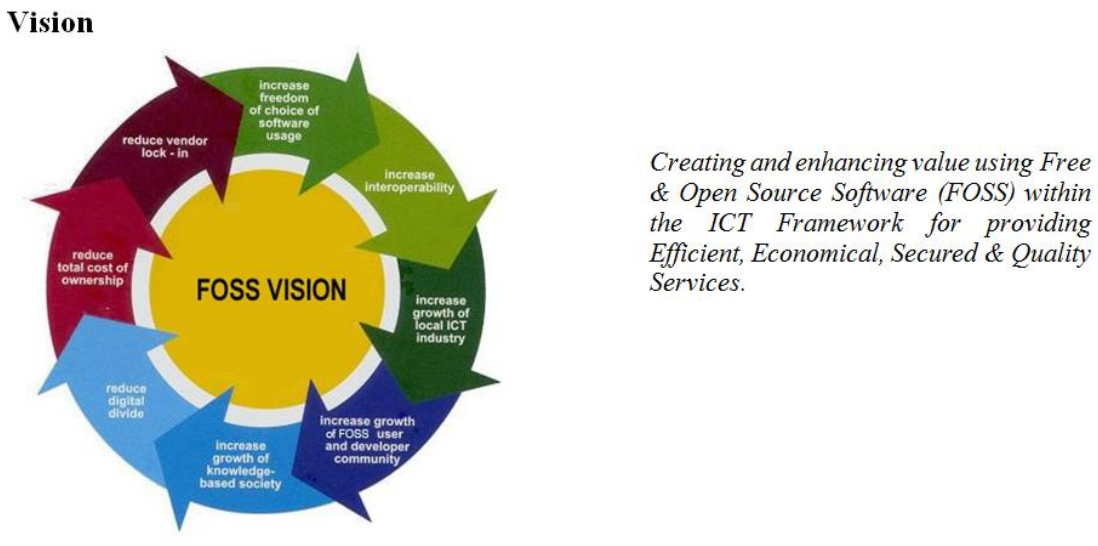
A number of public institutions in India are involved in the policy dimension of OSS. Among them are the Ministry of Electronics and Information Technology (Meity), the National and the C-DAC (Centre for Development of Advanced Computing), under which is the NRC-FOSS (National Resource Centre for Free/Open Source Software). Consistently, the efforts of these institutions have focused on the public sector.

Meity was the Ministry responsible for the introduction of the OSS public procurement policy of 2015. Before July 2016 the Ministry, still only a department of the Indian government, noted as follows in relation to its OSS policy (Ministry of Communication & Information Technology, 2016):

> “Department of Electronics & Information Technology (DeitY) has taken many initiatives for promoting and fostering the adoption of Free & Open Source Software (FOSS) in view of various inherent advantages like increasing interoperability, developing local capacity/ industry, reducing costs, conserving foreign exchange, achieving vendor independence, enabling localization and reducing piracy/copyright infringements. India’s strength in Information Technology can be further utilized to develop products using FOSS which will help in bridging the digital divide with significant cost savings and facilitate the creation of a knowledge society. Indian industry/SMEs can benefit from the liberal licensing norms of FOSS which enables software to be freely modified and distributed.”

Whilst clearly these goals have not been updated since the introduction of the procurement policy, they mirror the strategic goals evident in the policy of the Indian government. The Indian private sector is mentioned only at the end of this policy statement, and this reflects the priorities which the Indian government sets. The private sector is usually only indirectly affected in the Indian government’s OSS efforts, for example by the procurement law, but is never the direct addressee of the Indian government’s policies, nor is it the target of institutions which the Indian government has set up.

Figure 8.4: Meity’s FOSS Vision



Over the last 20 years, the C-DAC has possibly been the main Indian national institution involved in OSS policy. Already in the early 2000s it was involved in one of the first projects to increase OSS capability of the Indian public sector, to set up infrastructure for OSS together with the Indian Institute of Management of Bangalore and IBM, which provided a majority of the funding for this project. This project ended after three years, and led to the founding of the National Resource Centre for Free/Open Source Software (NRC-FOSS) in 2005.

The NRC-FOSS was put under the supervision of the C-DAC and existed until its funding ended in 2012. It had the goal of “bridging the digital divide as well as strengthening the Indian Software industry” by networking a broad number of governmental, academic and industry in order to develop and spread OSS in India. The NRC-FOSS was planned to have three phases, of which (due to its having been defunded) it was only able to implement two.

In the first phase, the Centre was supposed to introduce FOSS courses at universities, but only managed to convince twelve lecturers to start teaching OSS to their students. According to one of the directors of the organisation, those students who took the course saw improved hiring rates, but its impact remained low. The second action of the first phase was to develop an India-centric Linux-based operating system. The Bharat Operating System Solutions, or BOSS Linux was released in 18 of 22 official languages of India, but remained a small project and therefore was not able to convince those who had not already been convinced by the marquee Linux-based operating systems.

The relative lack of success of phase 1 negatively impacted the Centre’s ability to build coalitions and stakeholder buy-in for the follow-on projects of phase 2, which encompassed the creation of a Master’s programme, as well as translations and improvements to existing OSS. Although these actions were reasonably successful, trust in the organisation had eroded and funding was denied for phase 3 and thus for the Centre in general (Folz, 2019).

According to interviewees, government institutions in India do not: internally share solutions; license them under an OSS licence; utilise repositories; or nurture their private OSS communities. This is in relative contrast to the stated goals of a number of institutions and initiatives, and shows that even with efforts for over twenty years, the Indian government has not managed to create an Open (Source) culture within its own institutions.

Opportunities and challenges

From a strategic point of view, the adoption of FOSS in India has focused on the aspects of cost-savings, support for the local economy and customisations for the Indian market. Intangible benefits such as the fostering of entrepreneurial digital skills, sharing capabilities across departments, reducing vendor lock-in, improving data security by having full control of data, increase in transparency and improvements to e-government capabilities and decision-making have played a smaller role.

India is a developing or emerging country, and so the potential for cost-savings in IT expenses can play a higher role in considerations than it might in some developed countries. Yet, the economic impact should not be underestimated, as the first results of a 2015 study for the Indian Institute of Management Bangalore concluded. A “conservative” estimation in this study concluded that, taking into account the total cost of ownership, by migrating Indian primary and secondary schools to OSS the software budget could be reduced by $1.3 billion, potentially freeing up spending for other priorities (De’, 2015).

The same 2015 study also highlighted the potential which an OSS migration could have for the local economy, from the perspective of supplying and supporting software locally. As OSS allows every able company to integrate and support software, Indian policymakers are aiming for the 2015 public procurement policy to move revenue to domestic companies.

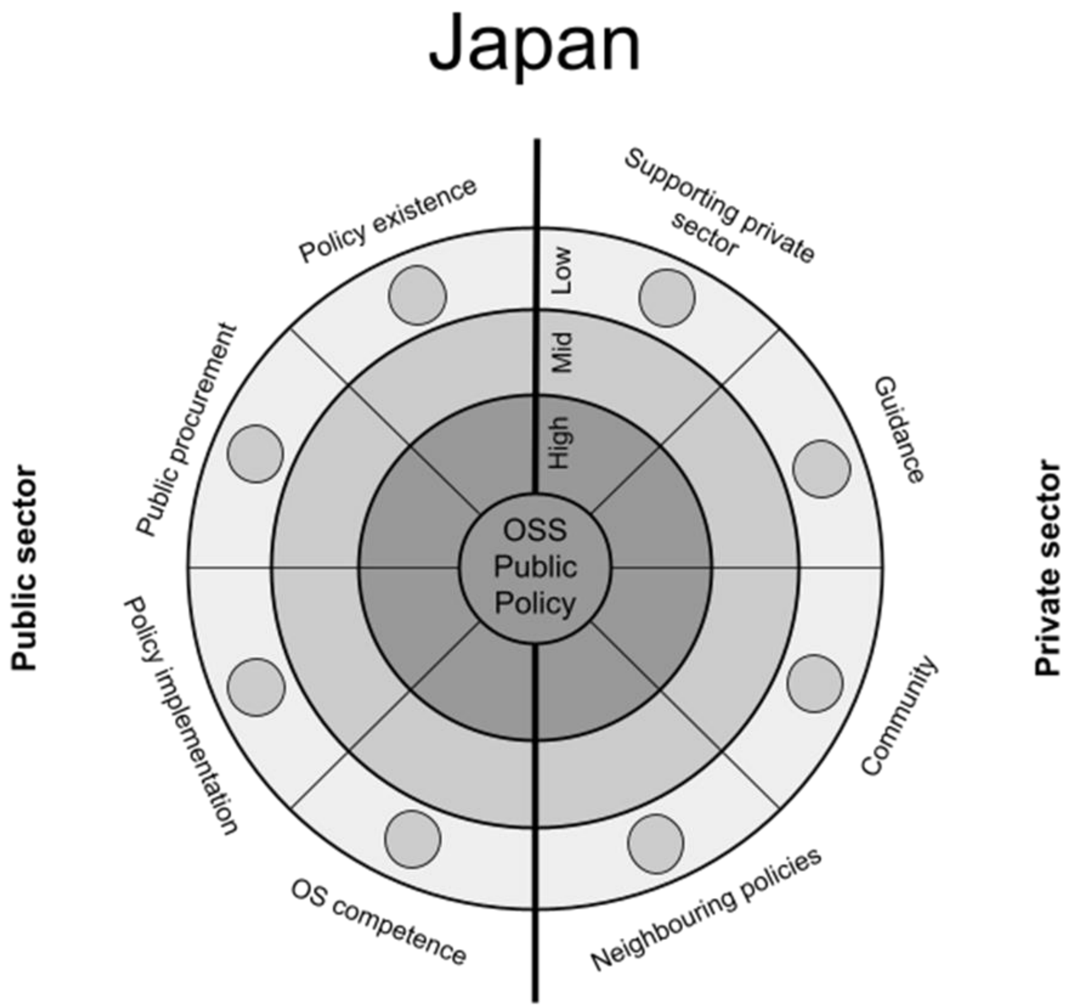
In India, a third factor is driven by the country’s unique language diversity. India has 22 official languages and (according to the 2001 census) an additional 122 “major” languages. Many international software companies do not see the economic value of making the necessary investment to support this Indian language heterogeneity. Yet, in the case of proprietary software, locals are legally barred from translating software themselves. OSS makes it possible for anyone with the necessary expertise to translate software and to provide this translation to the community (Babu, 2011).

In fact, this language diversity has been a major driver for developing skills through OSS, a crucial intangible benefit which OSS offers. In an interview, a previous government official (II2) shared that many teachers in India acquired OSS skills because they translated software that was not available in their teaching language so as to make it useful for their classes. Many taught themselves basic to advanced coding skills in this task, and quickly realised the immense potential of OSS. More importantly, the many teachers with coding skills acted as multipliers to their students, spreading the knowledge of coding and OSS skills to them.

Apart from the main tangible benefits which Indian policymakers pursue, these policymakers aim to achieve some other intangible benefits. Yet, interviews have shown that there is no indication that policymakers are pursuing these goals through any means other than procurement policy and institutional awareness-raising. Having surveyed recent technology-related legislation, such as on cybersecurity, artificial intelligence and high-performance computing, no specific attention is being given to OSS or to OSH. It is conceivable that, as OSS has become mainstream, the implementation of such technologies is being expected without any specific mention being made of them (Folz, 2019).

According to interviewees, the BJP-led Indian government under Narendra Modi which has been in power since 2014 has not changed OSS policy outcomes in very specific ways. Although OSS is not a part of the major discourses within the party or government, it has still led to changes in the motivation behind those policies. The BJP-led government places greater emphasis on nationalistic considerations, and sees OSS as a way to attain technological independence from foreign powers. This is supposed to give the government wider room for manoeuvre and emphasises the national economic interest.

Japan



Policy context

As can be seen in other Asian countries, the role of central government in the early adoption of Open Source in Japan was crucial, in the absence of early adoption by the private sector (compared to the United States or within the EU), either as users or producers of OSS. In the early 2000s the Japanese government was concentrating on investigating and evaluating the effects for the Japanese economy of adopting OSS, from the perspectives of technological independence, economic development and security. Japan joined China and South Korea in 2003 by signing a multi-million cooperation agreement on the joint development of non-Microsoft software products. Open Source was a core component in this agreement (Chae & McHaney, 2006).

The initial focus was on Linux derivatives for the Asian market, which would be better suited for the specific needs and requirements of the CJK (China, Japan and South Korea) countries. The Japanese government also worked with international suppliers (such as IBM), together with local partners, to deploy Linux based operating systems, such as for the government payroll (CENATIC et al., 2010). By adopting Linux, the government hoped to halve the running costs of about $7 billion (Kshetri & Schiopu, 2007).

In the same year, the Japanese Ministry of Economy, Trade and Industry (METI) published a report “On Usage of Open Software: A Guideline for its introduction”. In the report, Linux was framed positively and guidance - on how to adopt Linux and on accompanying legal issues - was included. When the Ministry of Internal Affairs and Communications (MIC) adopted a new e-municipality system in 2004, it added Linux as a choice of operating system for municipalities (CENATIC et al., 2010).

Yet for some time the private sector remained relatively inactive regarding OSS, with the Japanese government pushing for industry to digitise its business and become more software-focused. The Japanese government supported this with some vigour (Asay, 2008).

An important step toward increasing understanding of Open Source was the creation in 2006 of the OSS Center organised by the Information-Technology Promotion Agency (IPA), an agency under METI. The OSS Center has financially supported the adoption of OSS within Japanese municipal government under the "Open Source Software use infrastructure agenda". However this was held back by an unsustainable financing model and the low availability from local industry in Japan of support services for OSS. Although the policy succeeded in creating a small number of IT suppliers in Japan which competed with foreign suppliers, it neither created a vibrant OSS market nor did it result in the long-term adoption of Open Source within Japanese municipalities. The OSS Center has also offered technical information, in cooperation with major IT vendors (Noda & Tansho, 2010). According to interviewees, the OSS Center published a number of guides, such as on Open Source licences. The OSS Center was closed in the early 2010s and no new organisation has followed in its footsteps.

Similar to other countries, after many initiatives in the early 2000s, in Japan the level of attention paid to the adoption of Open Source in the public sector reduced somewhat. Yet, unlike in the United States and within the EU, concerns around technological independence remained active; accordingly, interviewees indicated that even though headlines around thousands of government computers migrating to Linux reduced, the general push toward the adoption of Open Source for industry remained.

Current policy actions and institutions

In line with the close collaboration with the other two CJK states, Japan does not have an explicit Open Source procurement or re-use policy, and focuses its Open Source activities on industrial support and technological independence.

Interviewees indicated that although there have been attempts to implement a policy of favouring OSS in public procurement, on the national level none has succeeded. The Ministry of Internal Affairs and Communications is in charge of guidance regarding procurement, through the Basic Policy for Public Procurement of Information Systems. Although this policy does not have any rules which directly discriminate against OSS, the guidelines do not contain or mention any of the aspects which level the playing field for OSS as against proprietary software, such as considering the total cost of ownership (TCO) or taking into account possible indirect benefits from OSS, such as re-use and the support of the local economy. Even so, the current situation is an improvement, as until 2005 proprietary software was explicitly preferred over OSS by Japanese law (Metzger, 2016).

According to interviewees, the Japanese regions follow the guidance of the national level closely and do not have different rules regarding the public procurement of software. A few municipalities have a practice of procuring OSS, in order to support local and regional software companies. Among them are the cities of Fukushima and Matsue. Both municipalities have high adoption of LibreOffice, and Matsue encourages the development of software in Ruby, for which it hosts the Ruby Biz Grand Prize, giving an award to a company that utilises Ruby, promoting it around the world. The prefectures of Nagasaki and Shimane used the switching of IT contracting to OSS as a way of ensuring that local and regional software development companies would receive project funding, and to reduce dependence on major IT suppliers (Noda & Tansho, 2010). Interviewees have indicated that while the government encourages Open Data in research, the open sourcing of own developments is not the norm, and there are no rules which specifically encourage this. In the context of the COVID-19 pandemic, some developments have been open sourced and Open Data has been used in order to disseminate information more quickly.

The Japanese Ministry of Economy, Trade and Industry (METI) is in charge of a number of digital policy areas. Unlike other similar Ministries in Asia, METI does not have a specific software policy department tasked with industrial software policy, but instead has generic IT industry and innovation departments (Ministry of Economy, Trade and Industry, 2018). METI has a strategy for the digital transformation of Japanese society and its economy, which ties together many currently evolving technological areas, such as artificial intelligence, IoT, data and cloud with the goal of a “Society 5.0”, where the border between the “physical” and “cyberspace” becomes erased. In this, METI does not seem to place any specific emphasis on OSS or on OSH, though it is known that the Japanese government has supported digitisation of the Japanese industry through Open Source. As part of the Digital Government action plan, a transition from proprietary solutions to “shared or standard service” is envisioned (Hiramoto, 2018). While there are an IT Strategy, Data Strategy, Digital Government Strategy and Open Data Strategy, there does not seem to be an overarching Open Source strategy within the Japanese government today, either with an internal or external scope (Commerce and Information Policy Bureau, 2019).

Under METI is the Information-Technology Promotion Agency (IPA), which focuses mainly on software issues, such as cybersecurity, emerging technologies and IT education. The IPA represents Japan at the North East Asia OSS Promotion Forum, and in the past has been involved in policies supporting businesses to adopt OSS; however, according to interviewees, in recent times it has switched its focus more to standardisation as opposed to OSS. This is also true for one of the focus areas, eGovernment, which has been a significant focus for the organisation.

On the private side, as the main Open Source business association, the Japan OSS Promotion Forum (JOPF) represents the interests of industry engaged with OSS as the main Open Source business association. Its membership is mostly composed of companies, with a few other associations, universities and the IPA (Information-Technology Promotion Agency) making up the rest. There are only 14 “regular” members, as opposed to the 112 “general” members. Of the regular members, only two (RedHat and Synopsis) are not headquartered in Japan. The Ministry of Economy, Trade and Industry and the Ministry of Internal Affairs and Communications are observers. JOPF has organised around four committees and three working groups. The committees are in charge of investigating the state of Open Source in specific verticals (social media, mobile, big data, cloud, AI and IoT). There is also a publicity committee, which is aimed internally at disseminating the latest knowledge around Open Source. The working groups are around technical questions, standards & certification and business promotion. Whereas the committees create a link to Open Source communities, the working groups are linked up with the North East Asia Open Source Software Promotion Forum.

As the Japanese government no longer provides any guidance and support for licensing, the private sector has taken over some of that responsibility. The Open Source License Laboratory (OLL) is a member non-profit organisation, which conducts research on OSS licensing, OSS usage methods and licensing properly to utilise OSS; the aim is to promote healthy use of OSS in order to achieve a higher utilisation of OSS in Japan and to develop the software industry (Open Source License Laboratory, 2020).

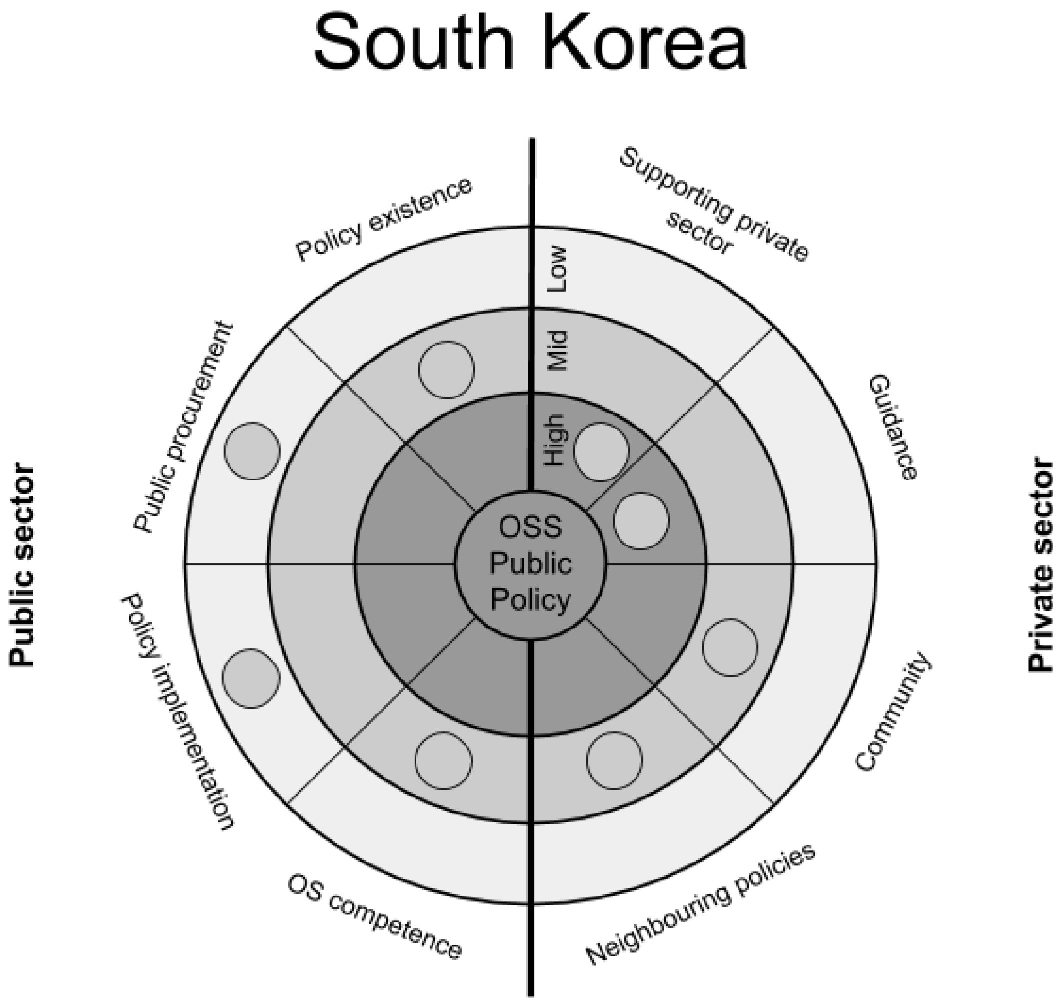
Opportunities and challenges

In Japan, a reversal between the public and private sectors’ involvement in Open Source can be observed. Interviewees indicate that already before the 2000s the Japanese government was the first government in Asia to realise the potential of Open Source to enable their strategic goals of technological independence, increased digitalisation of industry and reduced cost. The government thus took a leadership role within Asia and CJK countries.

The government worked very closely in this time with major Japanese companies in order to coordinate and disseminate the approach. Interviewees highlighted the roles of Mitsubishi, Hitachi and Toyota. The Japanese government reacted to a perceived lack of digitalisation within the Japanese economy and dependence on foreign suppliers for critical digital technologies when pushing for Open Source technologies. In the first phase, the government tried to stimulate the development of the technology sector through public procurement of OSS, such as Linux. From 2003 on, direct industrial support joined this effort, where the government promoted OSS to Japanese IT industry, in an effort to increase software development and exports. In 2006, the OSS Center institutionalised this effort together with programmes within the IPA. Interviewees indicated that ¥7 billion was spent on the encouragement of developing OSS and education efforts within companies and universities. This lasted until around 2012, when the government decided that industry no longer required this kind of support and shifted its focus, first to cloud computing and then to artificial intelligence. Much of the institutional support thus was stopped or handed over to the private sector. The aim with these technologies was still to develop a Japanese IT industry that would be able to develop and host these technologies.

Open Source was to some degree a new approach for Japan and its companies, as the country had enjoyed the protective privilege of an island nation and the policy options that come with this. What major Japanese companies were familiar with though was sharing development between companies. The major Japanese companies were (and are still today to some degree) organised in so called keiretsu, where they share development costs, support each other in opening up markets and financing new business opportunities. Thus, the concept of collaborating in certain areas where there is mutual benefit was far from foreign. The Japanese hardware and computer industries, likewise, saw a need to become less dependent on proprietary technologies that could be taken away from them, and thus welcomed the push of the Japanese government (CENATIC et al., 2010). In the context of the keiretsu, Open Source represents another way to share development, yet in a different framework. Nonetheless, keiretsu can be considered akin to “inner sourcing”, where companies open up development inside the company, without sharing the results outside of the company. Interviewees also indicated that Japanese companies contribute back upstream less than their South Korean or Chinese counterparts, even though Japanese companies generally entered the Open Source world as one of the first in Asia and today are considered to have a strong profile when it comes to how OSS development works.

South Korea



Policy context

Similar to many countries around the world, the first policy actions of South Korea revolved around the adoption of OSS alternatives to dominant proprietary office software on government computers, and thus focused on reducing vendor lock-in. For example, in 2002 the South Korean government announced the migration of 120,000 computers (i.e., about 23% of all government computers) to Hancom Linux, a distribution maintained by the South Korean software company Hancom. Further announcements were made in 2004 and 2006 for smaller Linux migration projects, and in 2005 government authorities would even receive financial support for a switch to OSS. The success of these initiatives today is in question, as (per interviewees) 90% of the government's installed desktop computers run on a proprietary operating system. More impactful actions might have been the early support for OSS for industry and education. In 2004, the Ministry of Information and Communication announced a plan to foster the nation's OSS industry, with the aim to promote the national ICT sector and with that to support the local economy. Already early on the South Korean government sought to increase its Open Source capacity, for example, by joining the Linux Foundation in 2004 or by signing an agreement with Brazil's National Information Technology Institute (ITI) in order to exchange information on experiences with OSS (CENATIC et al., 2010).

In 2008, the eGovFrame project was launched in order to create a standardised development framework for eGovernment projects, managed by the National Information Society Agency and the Ministry of Public Administration and Security. This framework was going to be built on open technologies and especially OSS (Kim & Teo, 2013). Creation of this framework was overseen with a formal structure with members holding different roles and an eGovFrame Center had been established in 2010 in order to provide support for developers and users.

Early on, the government also pursued Open Source solutions for the education sector; for example, the South Korean Ministry of Education launched the OSS-based NEIS (National Educational Information System) project. This system is intended to be a unified and centralised platform for all student data, enabling schools to access and share information on-line as part of the Korean educational system's modernisation plan.

NEIS was part of an overarching effort by South Korea's IT Industry Promotion Agency (KIPA, today NIPA) to invest and standardise Open Source solutions for use by the public and private sectors, which would be developed by domestic software companies instead of by foreign multinationals (Mereness, 2006). One activity feeding into this was the Open Source Software Promotion Group, which was active between 2002 and 2006 in the creation of an action plan for KIPA (CENATIC et al., 2010).

Already in 2007, the South Korean government published an "Open Source Software License Guide", which is still being updated. The government aimed to help software developers and companies to fully understand the terms and conditions of typical OSS licences (Metzger, 2016).

Even before this, in 2000 South Korean industry organised itself within the Korean Linux Council, renamed in 2006 as the Korea Open Source Software Association (KOSSA). While privately organised by industry, with over 200 member companies, both domestic and foreign, the government partly finances the activities in an effort to encourage Open Source uptake within the private sector (Korea IT Times, 2012). The Association runs the Open Source Software Learning Community, which provides professional online and offline training in Open Source technologies. The main purpose is to provide support (compliance, governance), education (organise field trips around the world with member company employees) to members and act as an opinion control tower. KOSSA gathers the opinions of companies and gives it to the government; and the government always consults KOSSA (Korea Open Source Software Association, 2010).

Universities were also used to enable the training of more transferrable digital skills not specific to one particular product, where industry together with universities created centres of excellence, one example being the Linux Hub Centre at Seoul National University (Mereness, 2006).

Due to the mixed level of English skills, another focus supported by the Government was the adaption of documentation for important Open Source projects. The most important might have been the Korean Linux Documentation Project (KLDP), a project that has been active since 1996 and today still hosts an active community (Korean Linux Documentation Project, n.d.).

Current policy actions and institutions

Open Source policy in South Korea is tilted toward industry support and questions of copyright and licensing. Whilst especially in the Western world Open Source is led by the private sector, in South Korea it is the government which has been leading the way toward a higher emphasis on OSS. Public procurement and re-use of software within the public sector plays a secondary role.

In order to achieve this, the South Korean government uses governmental institutions to disseminate information. The Ministry of Science, ICT and Future Planning (MSIP) sets the overall direction for software policy development. Below that is the National IT Promotion

Agency (NIPA), which is in charge of developing South Korea's software industry, with a $360 million annual budget. It uses market research, university education development, marketing, direct business support and international cooperation to fulfil its mandate. While the focus of the agency is on software, with one unit specialised in 3D printing, the agency also covers emerging hardware markets. It maintains a number of international offices, including in Silicon Valley, in order to help South Korean businesses (such as start-ups) to gain access to know-how and foreign markets. One of the main aims of the agency is to support the "softwareisation" of existing industries (National IT Industry Promotion Agency, 2019). Open Source plays a major role in this and to support this, NIPA also hosts the Open Source Software Competence Plaza (OSSCP).

The Plaza has an annual budget of $12 million, and aims to be a full service provider of support for companies wanting to take advantage of OSS. Amongst the services which it offers are (National IT Industry Promotion Agency, 2017):

- Technical consulting;
- Revising digitalisation plans;
- Providing OSS solution, licensing, governance and company guides;
- Verifying OSS licence choices;
- Inspecting code for vulnerabilities;
- OSS governance consulting;
- Maintaining a data hub for OSS R&D tasks;
- Discovering and surfacing successful OSS case studies; and
- Hosting OSS seminars.

Apart from the competence centre itself, the Plaza also offers a learning community for individuals and companies interested in Open Source, a yearly award for outstanding usage of OSS by a South Korean company, and KOSSLab, an Open Source incubator. KOSSLab selects 30 projects a year to support, through networking, community development and financial aid. The Plaza also takes part in the yearly Northeast Asia OSS Promotion Forum of CJK countries (China, Japan and South Korea) (National IT Industry Promotion Agency, n.d.).

As well as NIPA's and OSSCP's direct focus on industrial policy support, the Korea Copyright Commission (KCC) sets aside $3 million per year in its mission to promote OSS licence compliance and governance. The KCC provides extensive guidance to South Korean companies, small and large, in order to ensure they conform to licence terms and have low transaction costs when engaging with OSS. The KCC translates popular licences into Korean to make adoption easier, and has also developed its own, jurisdiction-specific licences, such as the Korean Open Government License (KOGL) and the Korean Creative Commons License. Experts indicate that their "Open Source License Guide" was an important step in supporting major South Korean technology companies in embracing Open Source, as they had a readily available resource to help them in their transition. The guide explains the legal risks of OSS licences, how to deal with licence violations, IP infringement caused by third parties and risks related to IP management (Metzger, 2016). Within the Open Source License Information System (OLIS), the KCC also developed a software program (CodeEye) to identify and inspect whether a product contains OSS. With this, (licence) dependencies and issues can be identified before a commercial product is released and any Open Source material is distributed. CodeEye consulting also suggests modules and libraries that a company could use to support its product stack (Open Source License Information System, 2016). In 2018, the KCC dealt with 149 cases.

As previously mentioned, procurement policy or re-use policy (an aspect which in Western countries tends to form the core of Open Source policies) is not as high a priority for South Korea's policymakers. Although the Ministry of Strategy and Finance has issued a guideline on budget preparation which mentions the possibility of procuring OSS, no preference is stated for OSS (National IT Industry Promotion Agency, 2016). Apart from this, the Software Industry Promotion Act gives each governmental institution the power to enter into a separate contract for any software products designated by the Minister of Science, ICT and Future Planning. Based on the frequent procurement of OSS by public administrations in South Korea, it would appear that no significant hurdles exist in local procurement laws hindering the procurement of OSS, even if no explicit preferential treatment exists for OSS (Metzger, 2016).

The re-use of governmental work, including software, was added to the South Korean Copyright Law in 2013 as Article 24-2. Governmental works (to which the government owns all rights) can be freely re-used by everyone, including the government. The law also leaves the option for the government further to incentivise the re-use of governmental work. The government maintains a database, containing OSS product information and source code that is in scope for the law (Korea Copyright Commission, 2013).

Opportunities and challenges

In a 2018 presentation, Kyungwon Rho (Director General, Software Policy Bureau, Ministry of Science, ICT and Future Planning) laid out the South Korean government's approach to Open Source. Within the context of the government applying focus on the key areas of Artificial Intelligence and Cloud for industry, the government realises that these domains rely heavily on OSS. In line with this, the government is thus investing heavily in understanding OSS, in order to make the right policy decisions and to be able to support industries of different sizes, from small to big. This ties into the general strategy of creating a "software centric society" and becoming the "best country for running a software business" (Rho, 2018). Rho's successor, Dohyun Kang, called "Open Source software [...] the basis of all activities" (Kang, 2019).

To achieve this, the South Korean government follows four core principles:

- Openness;
- Participation;
- Cooperation; and
- Sharing.

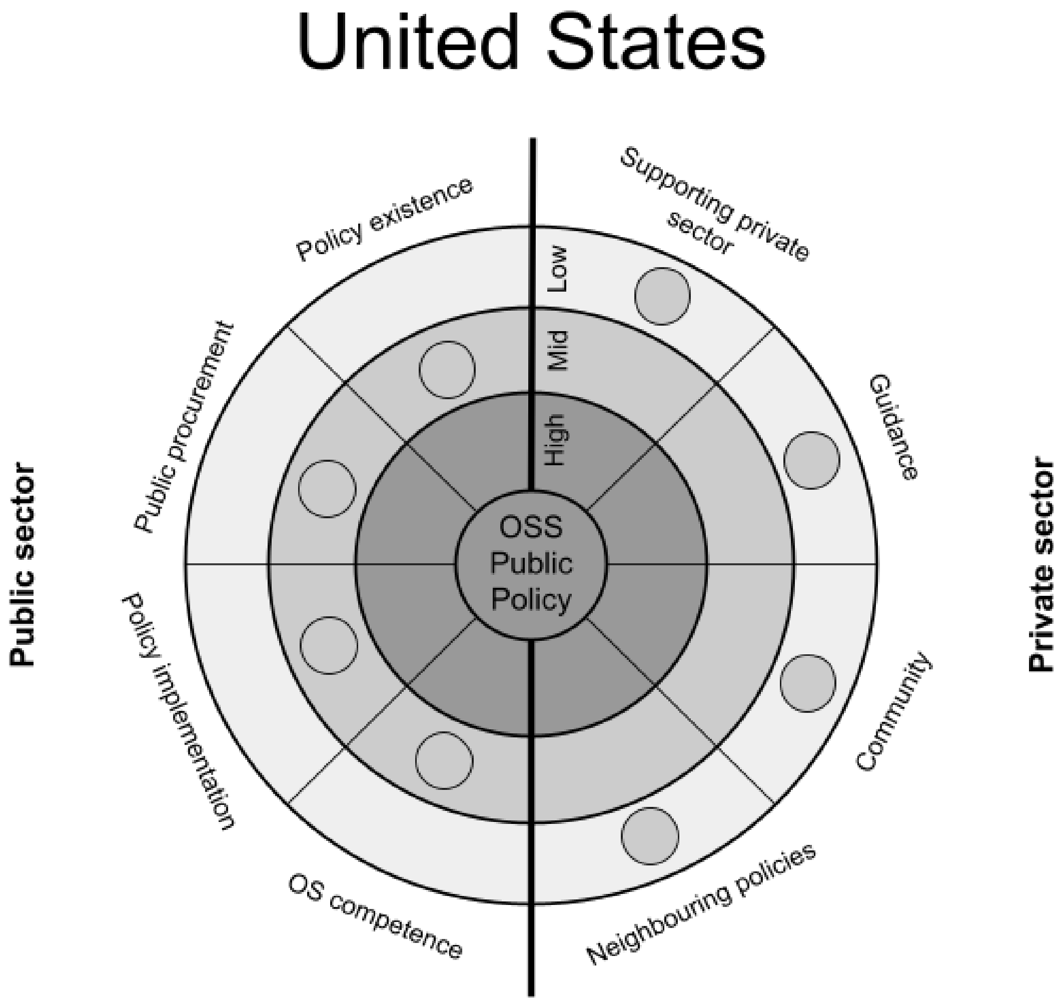
More specifically, the South Korean government aims to support the global development of the OSS ecosystem in order to enable greater take-up by South Korean industry. As described above, the government provides extensive guidance and support to industry on the legal aspects of Open Source. And lastly, it aims to spread an Open Source culture within its own organisation and toward industry through improved education of developers, teaching Open Source skills and close collaboration with industry. One interviewee indicated that the South Korean government is not yet sharing its own developments as well as it could be, and that there is still work to be done toward enabling a more transparent culture within the South Korean government.

It is clear that the South Korean government is pursuing a strategy of economic development when supporting OSS. Yet (similar to the position of other Asian countries) the aspect of technological independence is an important motivator.

Major South Korean companies, such as Samsung and LG, have improved their Open Source knowledge significantly in the last ten years, and today are strongly connected to global and domestic Open Source communities. While in the past these majors concentrated on using Open Source code and integrating it, this has evolved into contributing back to projects and communities. Examples are Tizen OS and WebOS (bought from HP/Palm) - which also reflects the attitude of majors to the acquisition of existing technology through buying companies or their technology. According to Jeongmin Woo, Korea Open Source Software Promotion Forum, the South Korean OSS market has had a compound annual growth rate (CAGR) of 20% over the last five years, being worth 278 billion Korean won in 2019 (Woo, 2019). The major companies play an important leading role, with many smaller companies watching these conglomerates closely, not least as many are closely integrated into the supply-chains of the major players.

The South Korean government has been supportive of this, one example being the creation of the Open Source Software Competence Plaza (OSSCP), as a company cluster, among other clusters. The aim of the South Korean government is to create a national technology stack that can produce in line with fourth industrial revolution expectations, which requires as few components exclusively controlled by foreign suppliers as possible. Due to the fact that the licence terms and conditions associated with public Open Source projects restrict access to the technology, it is difficult but not impossible (e.g. Android) for suppliers, even if they are the lead developer, and thus Open Source is a good fit for South Korea’s strategic aims. The South Korean government is aiming here for a “pure” South Korean approach, with all components coming from companies based in South Korea. The South Korean government is though not exclusively supporting Open Source, while there are still some migration projects happening within the government, these are preferably “Open-Type Operating Systems”, so not fully Open Source, in order to give the government more control. Examples are Harmonica OS, GooRoom OS and T-Max OS. Also, in December 2019 the Ministry of Interior and Safety launched a study to ascertain security threats stemming from such “Open-Type Operating Systems”.

United States



Policy context

In the 1980s, the US government followed the major trends of the software industry when adopting custom, proprietary software. Government contracts were very important for the private sector, especially in these early years, as the government was one of the few entities with the financial ability to procure expensive systems and thus government procurement, especially by the Department of Defense (DoD), has determined products' successes and failures. According to estimations, the US DoD was the largest purchaser of custom software in the USA (Mowery & Langlois, 1996). The 1990s brought a shift toward proprietary commercial-off-the-shelf (COTS) products, in a bid to reduce development cost - though this shift brought with it issues of vendor lock-in and increased integration cost. The Technology Transfer and Advancement Act of 1995, under which Congress directed Federal agencies to include private sector (as compared to "government unique") standards – including software standards - aimed at reducing vendor lock-in. While the dominance of proprietary COTS software on the desktop in the area of operating systems and productivity software remains to this day, the 1990s also introduced OSS to the infrastructure and back-end of the US Federal government, and thus the acceptance and understanding of Open Source within the Federal government improved (Castle, 2020).

In the early 2000s the situation was markedly changed in the private sector, with some of the major international, US-based software companies investing heavily in OSS and its promotion as well as its legal protection. In the public sector, a report by MITRE Corporation, a non-profit manager of federally-funded research and development centres, discovered significant usage of OSS within the US DoD; Bollinger's (2003) study summarised:

> "The main conclusion of the analysis was that FOSS software plays a more critical role in the DoD than has generally been recognized. […] One unexpected result was the degree to which Security depends on FOSS […] imply[ing] that banning FOSS would have immediate, broad, and strongly negative impacts on the ability of many sensitive and security-focused DoD groups to defend against cyberattacks." (p. 2)

In 2004, the White House Office of Management and Budget (OMB) published Memorandum M-04-16, with the main aim of reminding Federal agencies of the possibility of procuring OSS and further considering "the total cost of ownership including life cycle maintenance costs, the costs associated with risk issues, including security and privacy of data, and the costs of ensuring security of the IT system itself", when procuring software (Burton, 2004). The 2004 Memorandum clearly did not go as far as recommending or requiring the procurement of OSS by Federal agencies, but the reminder around total cost of ownership, security and privacy can be seen as an implicit endorsement of OSS, albeit without any prescribing effect.

The 2004 Memorandum had not structurally changed the situation of Open Source usage in the US public sector, as the mix of Open Source back-end and proprietary front end continued and to some degree still continues to this day. Another factor leading to the comparatively higher use of large proprietary software in the public as compared to the private sector is the degree to which some Federal and state agencies continue to employ legacy systems for reasons of inertia and budgetary constraints.

In the past, lawmakers had proposed the inclusion of Open Source approaches as part of legislation regarding public health databases, such as in 2008 and 2009, but it appears that US lawmakers have not approved legislation featuring Open Source, with a scope toward either the public or the private sector (Lewis, 2010). On the Federal agency level, a number of initiatives were launched; for example the Open Source Electronic Health Record Agent project was formed in 2011, in cooperation with the Department of Veterans Affairs (Alsaffar et al., 2017).

Current policy actions and institutions

In the USA, public policy which takes Open Source into account focuses exclusively on the public sector.

The main Open Source policy of the US Federal Government was adopted in 2016. The United States Chief Information Officer, a political appointee of the President, embedded within the OMB, published Memorandum M-16.21 ("Federal Source Code Policy: Achieving Efficiency, Transparency, and Innovation through Reusable and Open Source Software") (Scott & Rung, 2016). White House Memoranda are valid until revoked and, at the time of publication, this Memorandum continues to be in effect.

The White House policy applies to all major agencies of the Federal government, instructing them to create policies based on the Federal Source Code Policy, which aims both at stimulating the Federal government increasingly to procure software that is Open Source and at encouraging the re-use of custom software procured by the Federal government for the purposes of another public administration within the Federal government.

As things currently stand, when Federal agencies procure software, a majority of code is being custom developed for the public administration, from the bottom to the top of the software stack (Castle, 2020). The Memorandum thus concentrates on custom-generated code, stating that "Agencies must obtain sufficient rights to custom-developed code to fulfil both the Government-wide reuse objectives and the Open Source release objectives outlined in this policy's pilot program" (Scott & Rung, 2016). The aim is only to procure new custom-developed software if firstly no software is available for re-use within another Federal agency, and secondly if no existing commercial solution is available.

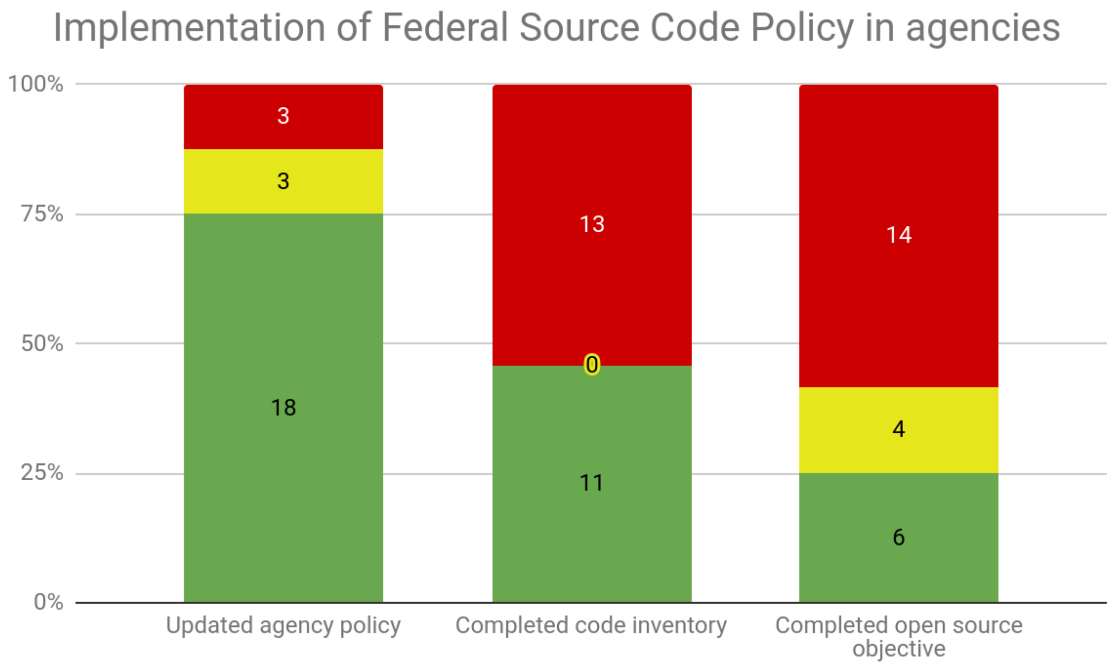
To be able to re-use existing solutions, these need to be made readily available. The Federal Source Code Policy directs all agencies to publish some custom-developed code as Open Source. Initially, for the first 36 months after publication of the Memorandum, agencies are instructed to make available at least 20% of newly developed custom code. The "pilot program" has expired and was not renewed. To leverage their investment of public funds, agencies are instructed to make their Open Source code available to all other agencies through an "inventory". The code was required to be made discoverable on the code.gov platform, in order to enable discovery.

As the Federal Source Code Policy obliges the major federal agencies to adopt their own Open Source policies consistent with the Federal Source Code Policy, with the responsibility for policy-making and implementation relegated to the agencies themselves, code.gov (the platform which is run by the GSA (General Services Administration)) keeps track of the progress of agencies on their implementation of the policy, on three tasks (code.gov, n.d.):

1. **Updated agency policy**: Agencies must update their policies to be consistent with the Federal Source Code Policy.
2. **Completed code inventory**: Agencies must inventory all new custom code created after August 2016 (notwithstanding exceptions enumerated in the Federal Source Code Policy).
3. **Completed Open Source objective**: Agencies must open source at least 20% of all new custom code created after August 2016.

Results to date have been mixed, as only six of the 24 agencies have achieved compliant status, fulfilling all requirements. 17 are partially compliant, fulfilling at least one requirement (usually that of having a policy), while most the results are more negative when it comes to having completed the inventory of code and specifying how much code has been published under an Open Source licence. The digital agencies GSA and 18F also have explicit policies for the publishing of all code as OSS (Shive, 2019; 18F, n.d.). Numerous agencies in the USA publish their projects under an OSS licence. The figure below provides an overview (code.gov, n.d.).

Figure 8.5: Implementation of Federal Source Code Policy in agencies



Legend: Green = fully compliant; Yellow = partially compliant; red = non-compliant

Opportunities and challenges

Outside of the heavily government-led areas of defence and military technology, the US government typically does not set the direction for industrial sectors, and a common sentiment specifically in the USA is that the government should not “pick winners” or control technological outcomes. The technology sector moves fast and there are questions whether governmental actions, which are subject to democratic control and require legitimacy building, are best positioned to engage in making those decisions.

Partly for this reason, the US government has historically focused heavily on funding research and development (R&D) in many areas. Yet, the question remains as to where to spend that money, as funding specific projects can still result in picking commercial winners. Funding basic research that has a high number of applications, facilitating cooperation among companies to work on common issues and investing in the infrastructure necessary for companies to succeed is one way to approach R&D funding. In that case, the crucial factor becomes which company is able to commercialise a specific technology the fastest (Branscomb, 1992). Here, a role for Open Source is apparent, as it is one model to facilitate collaboration across companies and one which has become dominant in the software industry. Thus, Open Source competence is a crucial skill for companies in the USA to achieve the immediate and successful integration of technology into their products.

The US approach to industrial policy is also true for the software sector. In the early days of the software industry, support from the US military was an important factor in the built-up of the American software sector, a factor that set it apart from most other nations. Notable here is the involvement of the Advanced Research Projects Agency (ARPA) in spearheading software projects of relevance to the US military, such as improvements to GNU/Linux, and the ARPANET, the effective precursor of the internet. The other major factor in the early development of the software industry was the organisational and financial support of the US government through its Federal policy for software research and education at US universities. The US government supported the creation of study programmes and invested heavily in the digitalisation of universities and their programmes, at one point providing half of the total funding. In 1967, the White House created the Office of Computing Activities within the National Science Foundation (NSF), which re-focused governmental spending on supporting computer education at universities, producing a surge in doctoral programmes. The military involvement in education was an important factor too, as ARPA funding was (as of 1990) the basis for the PhDs of 26% of the faculty in the 40 leading US university departments of computer science (Mowery & Langlois, 1996). The immense role of Federal funding for the strong software sector of the USA becomes clear through a study which concluded that during 1950-1980, of the 45 software advances deemed as breakthroughs that originated in the US, 18 were funded by the Federal government (Flamm, 1988).

An example of when the USA engaged directly in industrial support policy is the case of Sematech - a non-profit public–private consortium, partly funded by the government, partly funded by the private sector, which was founded in 1987. The main aim of Sematech was to overcome the high barrier of R&D required to stay competitive in the semiconductor industry by pooling R&D resources. In 1985, Japanese companies took the majority of market share in semiconductor sales, having relied on the keiretsu model for Japanese industry to coordinate R&D. In contrast, US industry was on the verge of collapse. The US government realised the value of the industry for the country and the strategic advantage R&D pooling offered. Under Sematech, the US semiconductor industry sent engineers to work on issues common across competitors within the US industry. These engineers would then bring those solutions back to their companies, where they would be implemented in their products (Whetsell et al., 2020). This example also shows the role of antitrust policy and the value of making possible research cooperation. While the evolution of the modern model of OSS development cannot be traced directly back to this antecedent, the resulting benefits are roughly analogous. And unlike the Sematech model, which was not widely replicated, the formation of corporate-sponsored OSS projects has exploded.

Today, Sematech is considered a success; and in its heyday, contributing to the return of the 1990s the US semiconductor industry had regained its top position within the semiconductor market, and Sematech was one of a number of factors which led to this. In the USA, similar organisations, such as The National Alliance for Advanced Transportation Battery Cell Manufacture and the SunShot Initiative are modelled around Sematech and intend to reap the same benefits for the battery and solar energy industries respectively (Hof, 2011). Yet Sematech suffered initially from organisational issues, squabbling over the direction of the initiative, and mistrust on sharing insights. Open Source licensing aims to reduce the transaction cost of sharing research and development, creating an incentive structure which favours cooperation where it is beneficial to everyone and to go alone where it is beneficial to a company. OSS therefore has the potential to achieve similar policy objectives, with less organisational and legal friction and a lower level of government monitoring and oversight.

Looking at the inception of the US software industry, according to Mowerey and Langlois defense-related spending by the US government played a more significant role than it did in the semiconductor industry. The influence US Federal agencies had on the early development of the software industry was in some sense unique, yet at the same time reduced throughout the 1990s, as the industry itself clearly achieved the scale and economic dynamism to chart its own direction, not being reliant or even welcoming Federal direction and funding (Mowery & Langlois, 1996).

h. The merit of Open Source for cybersecurity

The merit of Open Source for advancing cybersecurity may not be immediately intuitive. Both sides of the debate, one advancing the opportunities, the other the drawbacks of Open Source within the field of cybersecurity, tend to identify the misconception that their side of the debate is being dismissed. Those unconvinced advance the argument that with access to the code or plans to the makings of a piece of software or hardware, those who have an interest in compromising the technology, would have an easier time in finding its weaknesses. Yet on the other side, proponents of Open Source argue that only in an open setting can users and experts pore over the code to find vulnerabilities.

For many years, both sides have exchanged arguments, in some cases motivated by a number of factors, such as financial interests and technical merit. An initial survey of our experts shows that the answer to this question could prove to be nuanced. Independent research indicates both the arguments of the critics and the proponents possibly hold merit in the real world. For example, a study conducted by cybersecurity researcher Ross Anderson (of the University of Cambridge's Computer Laboratory) asserts that "[i]n a perfect world, and for systems large and complex enough for statistical methods to apply [...] whether systems are open or closed makes no difference in the long run." (Feller et al., 2007). This shows that there is not a simple answer in this area, as the issue is more complex than the question of Open Source vs proprietary, and depends on many other factors.

It is necessary to understand clearly the role of OSS and OSH in relation to cybersecurity in general. This is based on existing research and expert interviews. Both the methodology employed within the policy impact analysis to understand current policy actions and impacts within cybersecurity, as well as the methodology from the case studies, which also covers cybersecurity cases further, can be used to investigate the impact of OSS and OSH on cybersecurity.

European Union policy

The European Commission has made cybersecurity one of the most important focus areas in supporting the digital transformation in the EU. It is tackling this issue with a number of policy initiatives.

The first comprehensive cybersecurity strategy of the European Commission was released in 2013 under the title "An Open, Safe and Secure Cyberspace" (European Commission, 2013). Part of this strategy was the establishment of the European Cybercrime Centre at Europol (Europol, n.d.) and the introduction of the proposal for the Directive on security of network and information systems (NIS Directive), which came into force in 2016, representing the first EU legislation on cybersecurity. The NIS Directive's aim is to improve the resilience of critical infrastructure against cybersecurity attacks (European Commission, 2016). The cybersecurity strategy was reviewed in 2017 and complemented by the Commission's European Agenda on Security 2015-2020.

In 2017 the EU cyber diplomacy toolbox was adopted in order to support other countries in increasing their resilience against cybercrime. Stemming from this is also the 2019 cyber sanctions regime, first applied in 2019 (European Commission, 2020). To increase the security of mobile networks, following a coordinated assessment with Member States, the European Commission adopted the 5G toolbox in 2020, aiming specifically at 5G infrastructure and supply chain with strategic and technical measures. The European Electronic Communications Code (EECC) contributes to EU cybersecurity policy by providing important definitions and provisions general cybersecurity measures (European Commission, 2018).

The European Union Agency for Cybersecurity ENISA was created in 2004 as the European Network and Information Security Agency. Its mandate significantly evolved in 2019 when the Cybersecurity Act came into force, made its mandate permanent, increased its budget and gave it the responsibility to develop European cybersecurity certifications for products, processes and services (European Commission, 2004; European Commission, 2019).

The latest action of the EU is the adoption of a new cybersecurity strategy, which concretely introduced a proposal for a revised NIS Directive and announced incoming proposals for increased resilience in IOT and within EU institutions. The revised NIS Directive now makes a distinction between essential and important infrastructure and adds possible enforcement fines to the scope (European Commission, 2020).

None of the EU's legislative instruments tackling cybersecurity take specific account of open source software or hardware in their provisions. In fact, open source is not mentioned at all in the legislative texts. Though some provisions touching on technical transparency and vulnerability disclosure seem to approach methods also made possible by open source software and hardware.

Discussion on the potential

Within the expert community, a consensus has developed that if used correctly Open Source has the potential to be a security enhancer for cybersecurity-relevant systems (Lynch, 2015). Well known cybersecurity expert Bruce Schneier has written many times about how he sees openness as the way to improve cybersecurity in ICT (Schneier, 2004). The German government has used open sourcing as a tool to address concerns aimed at Huawei's supply of infrastructure for 5G networks (Busvine, 2018). In the Open Source world, the most secure solution is considered full openness, from hardware to software, in order to ensure that there are no unknown or unwanted factors within the product's code and plans (Pearce, 2018).

One of the main advantages of Open Source regarding cybersecurity is its auditability, as the code evidently is open for inspection. This aspect is especially important in the area of safety-critical uses. It is relatively easy to hide vulnerabilities and backdoors in proprietary software, by reducing the level of security of the software as vulnerabilities can compound and even if a vulnerability is ostensibly only known to few, the past has shown that it is often known and exploited by more. For this reason, in areas where software requires the trust of users, consumers, businesses and governments alike, open sourcing the security relevant parts for an independent audit has become good practice in areas such as messaging. Yet, the security audit does not necessarily have to be conducted by a specialised service. Open Source components are everywhere and get re-used. Those who use the software, whether or not on any company's payroll, can inspect the code and assure themselves that the code is safe before integrating it into a product. If bugs are found and fixed, typically all users of the code will benefit from this. This openness, allowing anyone to contribute, is made clear by what is known as Linus's Law, which states that "given enough eyeballs, all bugs are shallow" (Raymond, 1999).

One issue which remains even with auditability of code is that of whether the source code and the final compiled product are the same. It is possible, even though only very rarely found, that a finished product is not identical with the code from which it was built. With OSS, less trust is necessary than in the case of proprietary software, as the source code can be inspected; yet as it can be difficult to ensure that the compiled code and source code are identical, even with OSS some trust toward the chain of compiling and distributing software is necessary when using a finished product. For advanced users, such as companies, compiling the product code oneself is an option (Hofferbert, 2018).

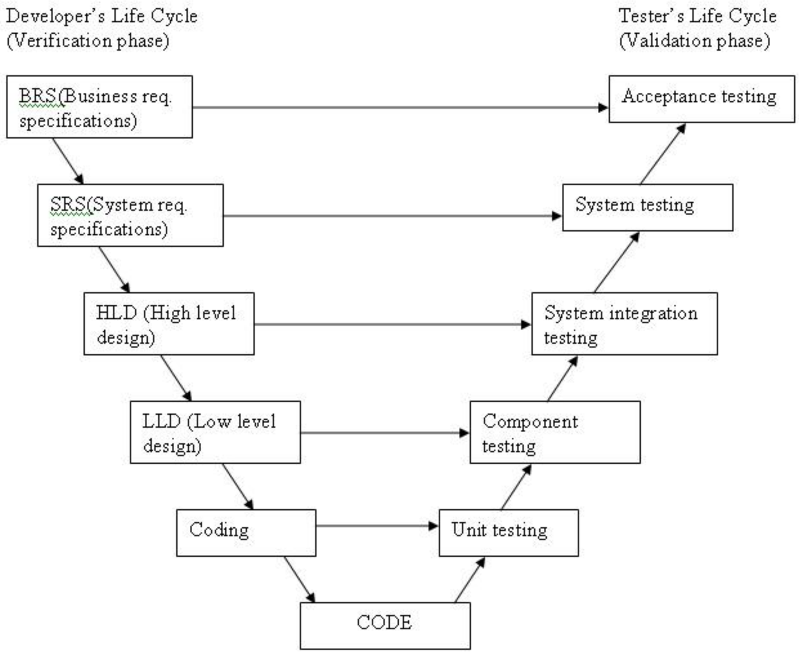
Another inherent benefit of Open Source is the ability to fork a project. Forking means copying a project's code and creating a separate project based on this code. In many cases forking is employed if there are significant disagreements regarding the direction of a project, leading to the project being split and separate versions being developed independently, although often many links remain. When it comes to cybersecurity concerns, forking can play an important role in achieving a continued or re-achieving a high level of security. Both OSS and proprietary software may at some stage be abandoned by their original developers, yet when proprietary software becomes "abandonware", short of reverse engineering there are usually very few options available for keeping the software up to date and safe.

On the other hand, OSS can be forked if a maintainer stops work on a project (or a new maintainer can be assigned, as there are no copyright ownership issues to deal with). An example of this is TrueCrypt, an encryption software project for files or disks, which was a standard software until 2014, when the maintainers announced that development had ceased. As TrueCrypt was source-available software (distinct and more restrictive than Open Source), the project was forked by multiple new maintainers. Today, VeraCrypt has become the de facto successor project and continues the development of this security critical software, with new issues often being fixed within a day of their first being identified. This option is especially important in any situation where the software in question is an important component which has been integrated (on multiple occasions) into other software (Hofferbert, 2018).

Practical opportunities and challenges

There are different ways to develop software, serving different goals. OSS is considered a highly dynamic, innovative way for the collaborative development of software. The foundational Open Source literature The Cathedral and the Bazaar by Eric S. Raymond coined the phrase "Release early. Release often." (Raymond, 1999), and this is representative of the idealised Open Source development model, which is agile, where constant iteration leads to frequent releases. In an iterative model, development can begin with a part of the project, can evolve quickly and does not have to conform to strict specifications at the beginning. Now, considering the goal pursued with this, to be able to try new code and features quickly, this is a paradigm well aligned with that goal. Yet, when it comes to safety-critical code, this approach reveals challenges. The potential of Open Source has been discussed to find vulnerabilities quickly, yet when there are constant releases, the risk increases that issues are overlooked in quality assurance and might even snowball when they connect to potential additional vulnerabilities.

Figure 8.6: The V-Model (Source: http://tryqa.com/what-is-v-model-advantages-disadvantages-and-when-to-use-it/)



A V-model is a development approach that places an emphasis on process and requires the clear identification of requirements and testing and with this demonstrates some potential issues which an idealised Open Source approach can have with safety-critical code. A V-model focuses on verification and validation of requirements and components within the larger system. All steps of the planning and development process are verified against the requirements of the project. In the second part, the developed code is tested as a single unit, as a component within the project, then integrated into the target environment and lastly tested as a whole system. This development requires more time and clear requirements toward the project, as this development mode does not react as flexibly to changed requirements, yet the validation phase typically corresponds better to safety requirements. The V-model is often employed in safety-critical areas such as medical or aeronautical applications (Pressman, 2015).

OSS is often used as a component within a larger piece of software, either Open Source itself or proprietary, understanding its interaction within the software it is integrated with and the larger system it is deployed within is important. Yet, the iterative development approach, with its frequent changes, is not well suited to these requirements. Yet, though Open Source developers typically prefer an agile development model, it is not bound to one specific model. Thus, in situations where safety-critical code is being developed, the way in which it is developed needs to be evaluated, taking into account necessary review requirements and processes. On this basis, code developed by hobbyists and not maintained professionally, might therefore not be appropriate for inclusion in any project which demands high security requirements. Open Source organisations such as the Linux and Eclipse Foundations, and companies organised within and outside them, have reacted to the spread of Open Source components in security-critical environments and have started a number of projects aiming to improve security within Open Source, through improving tools and processes to strengthen Open Source within security critical environments (Stewart, 2019).

Maintenance is another important aspect which should be considered when developing and using Open Source components. As was previously discussed, almost no software developed today is not dependent on Open Source components. Such components often provide base functionality which has been successfully solved in a previous project. Yet these components are not just developed once and then never touched again. They need to be continually maintained and updated to remain useful and to fix any bug discovered in the code. Otherwise, programs that rely on that code will reflect the same vulnerabilities that an integrated component shows. This work needs to be done by people. There are examples of technologies which are supported by companies, consortia and foundations which are actively developed and maintained based on commercial interests. Linux is surely the most prominent example, but there are other examples (such as the machine learning framework Tensorflow or the container orchestration software Kubernetes) where companies finance the development and maintenance of an underlying technology because it is in their interest.

Yet, not all important Open Source projects are supported by deep pockets. A prominent example is OpenSSL, which is an OSS library running on around ⅔ of all Web servers to ensure secure communication. Until 2014, OpenSSL was maintained by one full time developer and a number of volunteers. Even though OpenSSL was critical to the security of a majority of the Web's traffic, the level of resources flowing into the project was completely insufficient to ensure the level of reliability and testing necessary for OpenSSL. The technical details of the now infamous Heartbleed bug of 2014 are not relevant here; suffice it to say that it allowed an attacker to obtain (inter alia) the private keys of servers and users' passwords. The vulnerability stayed unreported for two years, and there are instances of it having been exploited to gain access to systems. It has been called "the worst vulnerability found (at least in terms of its potential impact) since commercial traffic began to flow on the Internet" (Steinberg, 2014).

However, here the strengths of Open Source also surfaced, as the issue was fixed in very little time by a team at Google. In the case of proprietary software, vulnerabilities sometimes stay unfixed for a long time, and if the owner of the code does not choose or wish to fix the code, no one else can. In this case, even though the software was crucial to huge commercial interests, those relying on it for a security-critical function were free-riding on third party labour that was not sufficiently funded to fulfil such a role, until it was too late. As such, taking again the famous Eric S. Raymond quote on Open Source, "given enough eyeballs, all bugs are shallow", and without enough eyeballs those bugs will not be discovered (Eghbal, 2016).

OpenSSL is only the tip of the iceberg. Maintenance is an issue for all software and affects Open Source in the same way it does proprietary software. Establishing clear responsibility is an open issue with OSS in critical production environments, as many important projects are positioned in between being small community projects and those big enough to attract corporate support.

In addition, some maintainers feel uncomfortable with an influx of corporate support, worried about outside influence changing the project, leading to a situation where they will provide free labour maintaining a project and accepting change requests toward their software from companies. As a result, burnout has become a significant issue within the Open Source community. Mitigation means introducing more paid labour for the maintenance of projects on which significant dependencies exist.

Open Source has certain advantages and disadvantages when it comes to delivering more cyber-secure products. Yet, it should also be considered that at the end of the day the collaborative, innovative potential of Open Source applies to cybersecurity as much as it applies to all other computing areas. For instance, when Mozilla (the producer of the popular Firefox Open Source browser) was shipping a browser that could not go a single major release without a critical vulnerability, it developed Rust, a programming language that would place an emphasis on security by creating code that would be secure-by-default and worked with a fail-safes in mind.

The language worked well for Mozilla and the browser's migration toward Rust is progressing, creating a more secure version of a program that is the number one vector for attacks. Other companies were interested in Rust's potential to make code more secure too, yet it did not have all the features they needed for their use case. Today, Rust is being collaboratively developed by Mozilla and other companies such as Microsoft and Intel, with more features being added to the language, thereby making it more useful for everyone and thus enabling the entire industry to create more cyber-secure code. Today Rust is one of the languages most beloved by programmers, and it continues to grow fast in popularity (Hu, 2020; Levick, 2019; von Leitner, 2020). In February 2021 the development of Rust was handed over to an independent foundation (Williams, 2021).

Finally, it should be considered that Open Source has cybersecurity-enhancing properties that if used correctly can make software more secure. Yet, as cybersecurity is not mainly a product but a process, the most important factor is how the code is being maintained.

i. Open Source and transparent, unbiased AI

Artificial Intelligence is often defined as an umbrella term for various techniques having the same characteristics as human intelligence and embedded in a machine, system or a network (Li & Du, 2017). The essential meaning is turning input of given data into the desired output through a series of an extensive set of operations carried out on data fed into an AI model. As AI is a complex term defined by different trajectories, paradigms and technologies, it will be not focused on what constitutes AI. More importantly for the purposes of this study, all AI implementations rely on software and a lot of it is Open Source.

Even though not as new a field as thought - the term “artificial intelligence” (AI) was first used in 1956 - AI has gathered increased attention on all levels and among strikingly diverse groups (Abate, 2017). A large breakthrough was observed with the creation of sophisticated Machine Learning (ML) algorithms able to process large volumes of data and improve over time, as well as developments in deep learning, a subset of ML, that imitates the architecture of the biological neural networks of the brain.

According to the Artificial Intelligence Index Report 2019, the volume of peer-reviewed AI papers has grown by over 300% from 1998 to 2018, global investment in AI start-ups has increased in the last ten years at an average of 48% per year, and interest on the part of policymakers has grown significantly (Perrault et al., 2019). With such an observed rate of growth, many technological, ethical and legal questions are arising, and those include questions around topics such as transparency and opaqueness, bias and discrimination, innovation and regulation, openness and competition and others. Transparency can be defined as disclosure of information, which encompasses dozens of different types of data, such as intended use of AI, source code, limitations, laws, and human-readable explanations. In this chapter, the role of Open Source in ethical and unbiased AI has been focused on, as it is often perceived as a way to increase trust in, and the speed of development of AI systems, as well as the uptake of AI.

Most algorithmic systems form a part of larger integrated services and devices, such as personalised newsfeeds or autonomous vehicles using large data-sets to train the algorithms. For instance, in facial recognition, large annotated data sets containing millions of photographs are initially labelled by humans. For the development and implementation of AI solutions, usually such large data sets, appropriate to a project, are a cornerstone on which other layers can be built. Obtaining data sets is not an easy task and obtaining data sets which provide proportionate representation of different groups or features is even more challenging. Acquiring structured datasets and developing Artificial Intelligence and Machine Learning models is often a time-consuming and expensive task, thus the benefits of Open Source development model are being leveraged by commercial and non-commercial players.

In this context, bias is a systematic error that can place underprivileged groups at a disadvantage. Several types of bias can be found in training data, such as: historical, representation, measurement, behavioural and others. But there is also the distinction between bias which has its roots in datasets, and bias which stems from the algorithms themselves (Mehrabi et al., 2019). Although bias has been extensively studied in fields such as facial recognition systems and recommendation systems that directly face the users, the issue of bias encompasses a wide variety of applications such as recruitment processes, chatbots, medical procedures, criminal risk assessment. There are several efforts to overcome these biases, of which releasing software used for AI models as OSS is one, including realising toolkits that aim at supporting mitigating bias as Open Source (Bellamy, 2018). Openness could be a way to verify bias and take control over it; however, it is not certainly sufficient as a means.

Openness in AI

Openness in AI development, just like in any other digital domain, carries many different meanings. Those include Open Source code, open science, open data, general openness principles of a company regarding safety and others. As this study focuses on OSS and OSH, this chapter puts emphasis on these components, however, other layers should not be disregarded in discussions about the ethics and bias of AI.

There are claims (some dating back to 2007) that few researchers have been openly sharing their code related to machine learning (Sonnenburg et al., 2007). Some have called for more openness in research and development of AI in order, for instance, to accelerate research and its reproducibility, while some caution against hasty developments which might result from increased openness (Bostrom, 2017). What it is described below is that in current reality, many do open up their AI developments on different layers, including those of interest for this study.

Throughout the years, openness in AI emerged as either an industry standard or a goal called for by researchers or the community. One instance is the healthcare domain, in which open science, open data and Open Source are pinpointed as ways to make healthcare research more transparent in different applications, such as ophthalmology research or medical prediction, as well as a way to overcome fears about AI-based data analysis and clinical decision systems in healthcare settings that might potentially bring future benefits (Kras et al., 2020; Calster et al., 2019; Paton & Kobayashi, 2019).

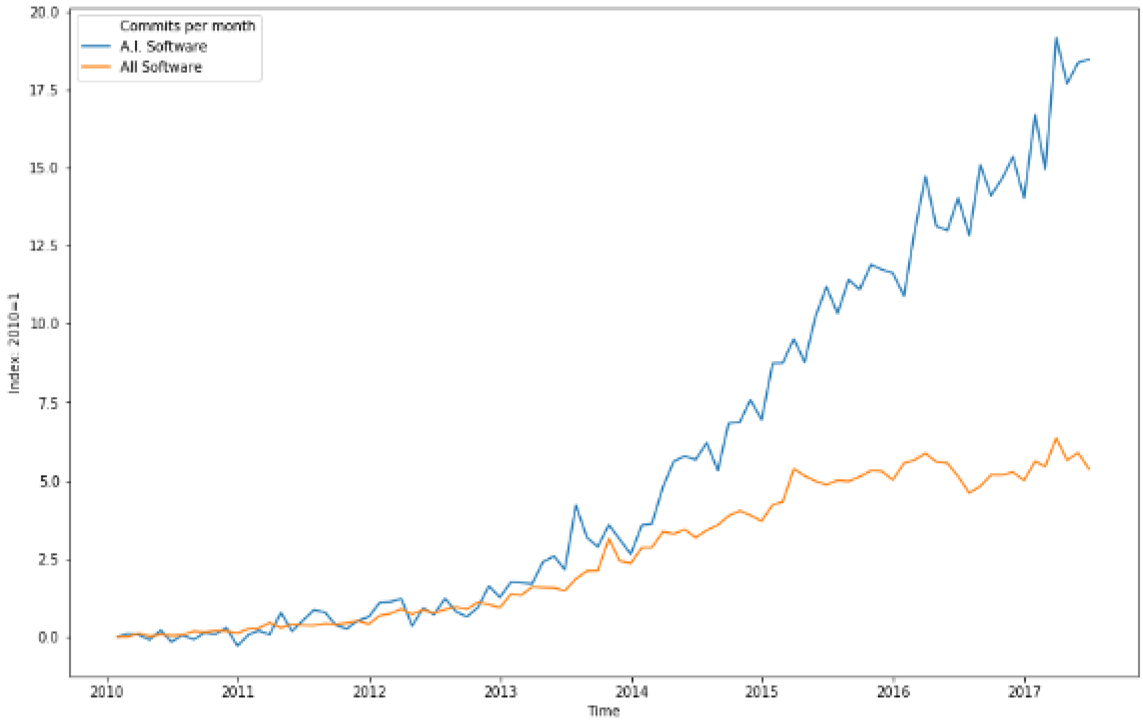
Several commercially-backed or funded Open Source initiatives exist in the space of AI development, often with a focus on ethics such as: the non-profit OpenAI, launched in 2015 with Microsoft as an investor (OpenAI, n.d.), IBM's AI Fairness 360 toolkit, aimed at detecting and removing bias in machine learning models (IBM Research Trusted AI, n.d.); or the H2O, an Open Source data science and machine learning platform used by over 18,000 organisations globally (H2O.ai, n.d.). These are just some examples of a few larger Open Source ventures in the AI sphere; many more are being created or released every day.

Several key components are needed for a working implementation of AI. Those include initial datasets (so training data depending on the purposes of a project), frameworks and libraries that applications are built on (such as Python libraries and the popular python framework Scikit-Learn or Tensorflow from Google), APIs offering services such as text classification or sentiment analysis (often coming from big cloud providers such as Amazon Web Services or Microsoft Azure), customer-facing AI applications (Siri and Alexa, recommendation engines), as well as the underlying hardware able to process large volumes of data (such as CPUs and GPUs).

Software in AI

A recent OECD Working Paper, published in May 2020 (Baruffaldi et al., 2020) discusses research into the issue of OSS in AI development. This OECD paper, similarly to the quantitative analysis of this study, uses GitHub data (so, an OSS repository) among its data sources in order to assess technological developments in the studied area, that of AI-related software. The paper concluded that the number of AI-related projects has been growing since 2010, and that since 2014 the number of commits per month has grown about three times as much as the overall number for all Open Source Software projects on the platform.

Figure 8.7: Commits to AI Software vs all Software (Source: Bruffaldi et al. 2020)



Moreover, it indicated that the most commonly used programming language used for AI repositories was Python, and that the most common subjects of these OSS development projects included: image recognition, deep learning and text mining. This data shows us that there has been considerable growth and interest in Open Source AI projects. Different benefits and features of OSS projects have been discussed in other parts of this study, but they are very well-applicable to AI.

As mentioned, AI systems are usually based on large datasets and large amounts of code. This makes it difficult to own and control them by a single person or entity. Open Source allows organisations and individuals to examine an algorithm, investigate its effects and improve it, which can have a positive impact on both the algorithm’s accuracy as well as its fairness, and the merit of transparency through collaborative development. The problems of data, system and outcome opacity of such systems and decision-making processes have pushed numerous stakeholders to strive and push for greater transparency and less bias in AI developments. Opening software is one of the ways to improve these features, however, in order to be transparent, an AI system often needs to be not only Open Source, but also operate on trustworthy data sets, which poses its own regulatory, technical and privacy challenges (Mayernik, 2017).

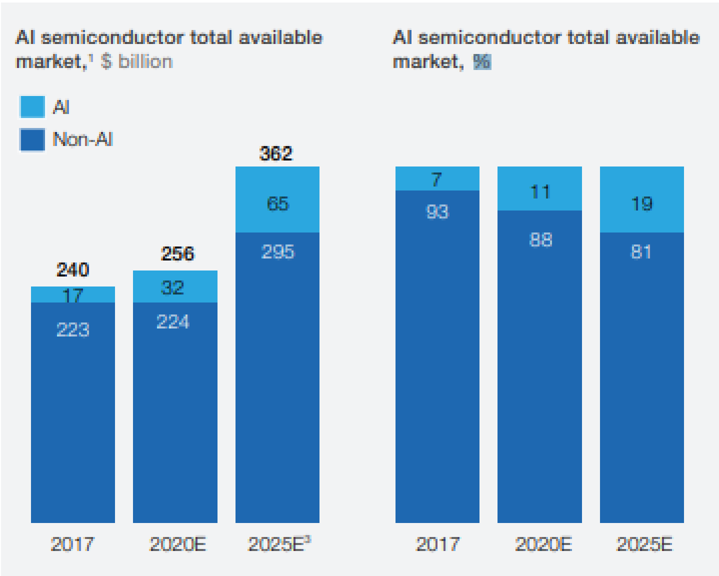
Different companies and governments put different weight on highlighting the role of Open Source in AI development. In some countries, dedicated bodies covering this area can be found, such as the China AI Open Source Software Development League which was set up in 2018 and supports the China Electronics Standardization Institute (CESI) under the Ministry of Industry and Information Technology. The League published a report on AI Open Source Software (AOSS) in 2018, in which it points out to the USA’s leading position in AOSS development, which according to the report is a home base for groups/main developers of 66% of global AOSS, while China to only 13% (China Artificial Intelligence Open Source Software Development League, 2018).

It also outlines three main types of AOSS maintainer, namely: companies, research organisations and foundations. The country is focusing on independently researching and developing AOSS for locally useful functions, such as data processing in China’s languages or speech recognition, as well as implementing AI solutions in industrial applications. An interesting concept that seems currently to be spurring attention in China is the industrialisation of AI, which should not be mistaken for using AI in industrial settings. It indicates the transition from the bottom-up, individual-focused development of AI to the production of “AI” in a repeatable, professional-based manner - so, for instance, going from tools built by individual university students to industry-run systems such as TensorFlow (Ding, 2020).

Hardware in AI

Testing AI models is a resource intensive task that requires serious computing power which often comes with requirements of flexibility, customisation possibilities, interoperability, speed, particular purpose and other features. Those conditions make it an interesting area for OSH that allows higher cooperation and makes adaptations and integration of diverse building blocks easier. AI infrastructure as such includes integrated circuits, computer systems and cloud services that enable and improve the performance needed for AI tasks, such as training deep learning models.

Figure 8.8: AI semiconductor market (Source: McKinsey 2018)



In 2018, a McKinsey report stated that AI applications present the best business opportunity for semiconductor companies that have been in the sector for decades due to the fast growth of the market and growing market demand for AI-enabling infrastructure (McKinsey, 2019). As per the recommendation of the report, such companies “must undertake a new value-creation strategy that focuses on enabling customised, end-to-end solutions for specific industries” and the prediction was made that by 2025 AI-enabling semiconductors could account for almost 20% of all demand in the sector and could reach even $67 billion in revenues, capturing almost half of the AI stack in terms of the value of innovation. Foreseen growth includes all different areas of hardware used for AI purposes, in: computing (both in data centers and in edge applications); memory (both high-bandwidth and on-chip memory); storage; and networking. How does OSH fit into such promising forecasts?

While, as discussed above, many companies and organisations openly share their AI software, some of them open up their infrastructure design used for AI. Those include Facebook, Google, NVIDIA and many others (Lee & Wang, 2018; Lattner & Davis, 2019; NVIDIA, n.d.). In addition, several projects are focused on OSH for AI applications, such as: French GreenWaves, based on an ultra-low-power RISC-V processor aimed at executing neural networks inside battery-operated IoT sensors; Antmicro's deep learning enabled edge hardware; or Arduino, promoting its board for AI applications (GreenWaves Technologies, n.d.; Antmicro, n.d.; Arduino, n.d.). Although there are not yet any comprehensive studies on the role of OSH in AI, based on the diversity of uses and applications of OSH projects developments in this area might be seen in the future.

Policies

As in many areas of technology, policymakers around the globe are trying to keep pace with technological innovation. Private sector is presenting a very high development rate in terms of new AI systems and several ethical and policy documents are being developed in order to ensure proper implementation of such systems, often referring to certain values, trustworthiness, and benefits of such solutions or no harm. Another highly debated issue of AI systems is their safety and liability and how policymakers can ensure that such systems can operate safely and guarantee user protection.

A study of the global AI ethics guidelines landscape from September 2019 states that, at the time, there were 84 such guidelines in the world (Jobin et al., 2019). The USA had the highest number of such documents, followed by the EU, and almost 90% of them had been published after 2016, in a large share by private companies and governmental agencies. The most prevalent principle connecting almost all of the researched guidelines is that of transparency (as a way to minimise harm and improve AI, as well as for trust and legal reasons).

Another source analysing and categorising AI ethics guidelines is the AI Ethics Guidelines Global Inventory run by a German non-profit AlgorithmWatch, that consists of more than 160 guidelines (AlgorithmWatch, n.d.). Among them, eight are binding, while the vast majority remain in the sphere of mere recommendations. Many national policymakers are in the process of developing their own AI strategies for areas such as ethics, innovation, industrial uptake and research. On the European level there has been a large increase in a number of policymaking actions related to AI in all different institutions and on different levels. Here, a look at significant European policies will be taken to indicate what is their approach to Open Source.

One of such initiatives is the High Level Expert Group (HLEG) on Artificial Intelligence, which was convened in 2018 by the European Commission (European Commission, 2020). The HLEG first published its Ethics Guidelines and then the Policy and Investment Recommendations, both aimed at supporting the HLEG's general objective of helping in the implementation of the European Strategy on Artificial Intelligence (High-Level Expert Group on Artificial Intelligence, 2018).

In its Guidelines, the HLEG lists seven key requirements for making AI trustworthy, among which transparency is listed (that does not point to Open Source as a way to achieve such a requirement). Moreover, in the requirement of accountability, the report states that desired auditability of AI systems "does not necessarily imply that information about business models and intellectual property related to the AI system must always be openly available".

While the HLEG's Guidelines do not mention Open Source, the Policy and Investment Recommendations from June 2019 put more focus on the issue. The recommendations state the need for supporting the development of Open Source AI software libraries in order to foster digital independence in the EU, with accompanying initiatives such as the AI Digital Innovation Hub network (High-Level Expert Group on Artificial Intelligence, 2019). Providing researchers and companies with up-to-date OSS and support could contribute to building a strong European competence in the field of AI, as well as securing support mechanisms for commercial developments of hardware and computing infrastructure for connected devices and the Internet of Things. Moreover, the HLEG states that "the AI cybersecurity policy should be user-centric, systemic and anchored in open and pluralistic processes", and Open Source is an enabler of such.

According to the paper, the public sector can play a significant role as an enabler of ethical AI advancements, with the aid of instruments such as the Tallinn Declaration on e-Government, creation of European annotated and trustworthy public non-personal databases to develop and train AI solutions available for companies, civil society and research institutes, increasing investments in pan-European initiatives in the field, and establishing an appropriate governance and regulatory framework.

The most important and awaited policy action on the European level in recent years was the White Paper on Artificial Intelligence - A European approach to Excellence and Trust from the European Commission, published in February 2020 (European Commission, 2020). As the title suggests, the White Paper on AI sets out two aspects of AI development in Europe: Trust and Excellence. The paper introduced concepts such as high-risk and non-high-risk AI applications that would be subject to different regulatory treatment, as well as brings up the need for a uniform regulatory and investment approach across the EU Member States, in order to leverage the full potential of the EU single market. It does not explicitly refer to Open Source as such a leverage, however it points to limitations of scope of existing EU legislation that should be addressed, namely the open issue whether stand-alone software (not a part of a final product or subject to specific sector rules) falls under the EU product safety legislation as the current framework applies to products and not to services.

As the White Paper sets out, European excellence in research and deployment of AI will be enabled through a set out outlined key actions, including updating the 2018 Coordinated Plan on AI, facilitating the creation of AI excellence and testing centres, setting up a new public-private partnership in AI, data and robotics, investing in educating and upskilling the workforce to develop AI skills and promoting the adoption of AI by the public sector. All of these actions can bring opportunities to OSS and OSH ecosystems and companies,

The February 2020 White Paper was complemented by the Public Consultation on Artificial Intelligence, which ran from February until June 2020 (European Commission, 2019), and which gathered extremely high interest: the European Commission has received over 1,200 individual responses and written inputs. A majority of respondents agreed with most of the actions planned by the Commission in its "ecosystem of excellence" package, including initiatives such as working with Member States, upskilling, focusing on SMEs, partnerships with the private sector and promoting uptake of AI in the public sector. Around 42% of respondents requested a new regulatory framework on AI and only 3% thought that current legislation is sufficient, while over 80% of all submissions agreed with mandatory requirements laid out in the paper, such as clear liability and safety rules, informing about the nature and purpose of AI systems, human oversight, and ensuring the quality of datasets. About 60% of respondents expressed agreement with a revision of the existing Product Liability directive in order to adjust it to cover AI systems, which is currently being looked into by, among others, the European Commission's Expert Group on Liability and New Technologies and articulated by the Report on safety and liability implications of Artificial Intelligence, the Internet of Things and robotics, published in February 2020.

The Report addresses the need for a clear and predictable legal framework and presents several challenges posed by the current, fragmented legal landscape in the EU. While risk assessments are performed before placing a product on a market, there could be a new risk assessment taking into account important changes throughout a product's lifetime, allowing for more human oversight and ensuring safety of its autonomous behaviour. For a successful ex-post mechanism of enforcement, transparency of algorithms needs to be addressed - and Open Source Software is one of the elements useful for increasing transparency of algorithms and processes accompanying them.

The Product Liability Directive's revision could clarify the scope and provide a clearer framework both for users and producers of AI systems, as they pose unique challenges due to their autonomy and opacity. The risk is especially high with devices using AI that are present in public spaces such as autonomous cars and services used by a broad public such as traffic management systems. There is yet to be a harmonized framework on this issue in the EU, which would clearly establish limitations to responsibility in the hand of creators of AI systems, while providing possible compensation schemes for those who have been harmed or treated unfairly by an AI system.

The European Commission is not the only European institution to bring the subject of AI questions to the table. The European Parliament has a number of files regarding the use, development and implementation of AI, most of which have been discussed in plenary in September 2019, as well as other, more overarching policy initiatives with a wider scope (such as the Digital Services Act) which have several touchpoints with Artificial Intelligence.

Although before the COVID-19 pandemic AI had been very high on political agendas throughout Europe, it is however possible that the COVID-19 health situation had an impact on the speed and future of the regulation of AI on the European level, as political focus has certainly changed. While the use of Open Source in AI developments is high in both software and hardware layers and the possibilities for AI developments in the open are numerous, not many policy initiatives point to Open Source as a significant element of an AI landscape that would be characterised by transparency and lack of bias. Yet, it is noteworthy that many such initiatives are non-binding and still in early phases of development and/or consultation of experts and the public. Therefore, it seems difficult to state what exact role policy makers see for Open Source in this domain and with regards to bias and transparency.

The topic of Open Source, bias, and transparency in AI through the policymaking lenses is worth exploring more in detail. If used well, AI can enable user-driven innovation, which not only includes technological innovation of all different sorts and in a plethora of domains, but could also possibly help in overcoming issues and challenges related to Artificial Intelligence.

AI in public services - a Polish case

AI systems can be used for a plethora of applications, and many of them find their place in the public sector. As it is the case in many EU Member States and on the European level, legal uncertainty around the use of Artificial Intelligence in public services raises many questions. For example, in Poland it has caused concern and a number of voices were raised regarding the use of AI-based solutions for, among others, blocking accounts of companies suspected of tax evasion, automated fining for traffic offences, profiling the unemployed and distributing allowances, assigning school places and assigning judges to specific cases (Random Case Allocation System). This last application caught the attention of the ePaństwo Foundation, as the allocation system was shown to contain several bugs and irregularities, which resulted in an unjust allocation of human resources to cases.

The Foundation, as well as an auditor controlling the court in Toruń, tried to get access to the algorithm and the source code of the system (Izdebski, 2020; Sąd Apelacyjny w Gdańsku, 2018). In both cases they were not granted access by the Ministry of Justice (which is responsible for the system), either to the source code or to its results. In its decisions, the Ministry has consistently refused to make the source code available, explaining that the source code is a text in a specific programming language and thus is subject to copyright, thus such technical information does not fall under the right to public information. Additionally, the Ministry did not agree to make the reports containing the results of this algorithmic system available, on the ground that this data has also been qualified as technical information, and so not subject to disclosure by the authorities (Škop et al., 2019). This clearly points to the problems related to the lack of legal certainty related to AI systems and their components, especially in their public sector applications. For example, it is highly possible that source code would be released in France if a similar case emerged, as publicly-funded source code is regarded as public information and citizens can request access to it. These issues should be explored on the EU and Member States level in order to provide a more trustworthy and even ground for AI innovation which could be highly beneficial, if used well.

j. Open Source Hardware policies

Only a limited number of sources is available that tackle the issue of OSH policies (just as is the case with the economic impact analysis research), which shows that OSH is less prevalent in public discourse than OSS. There is a need for more research on the issue and monitoring of the developments in this sphere.

Expert and practitioner involvement will be crucial to fill the gap in the perceived absence of a lack of policies aimed specifically at OSH. Two factors are at play: first, the viability of transposing existing OSS policies in the realm of procurement and deployment - which should also envisage the effect of secondary policies like Life Cycle Costing (LCC) requirements specific for hardware. Second, it is crucial to consider the development of additional policies in areas which directly or indirectly affect OSH, such as intellectual property rights, standardisation policy, open standards implementation rules, as well as potential direct support for infrastructure, including fablabs and makerspaces.

One of the experts on this issue is Javier Serrano, who has published a draft paper “Why (and how) public institutions should release more of their hardware designs as Open-Source Hardware” (Serrano & Serrano, 2020). It points to possible benefits of common and shared designs for digital infrastructures and to repetitiveness of setting up such infrastructures, which could be avoided if policies and good practices were developed for OSH.

The paper proposes a number of ways for raising the profile of the OSH debate, especially among the research and development focused bodies of the public sector. Those include expressing a need for an OSH foundation based on examples of the Linux Foundation and the Apache Software Foundation for software which could take on a role of hubs for projects that would be provided with technological, legal and organisational guidance. There is a need for governance guidelines and templates that early-phase projects could build upon, more cooperation between different stakeholders and institutions, funding for research on unsolved problems, as well as for promoting OSH and educating policy makers on the benefits of this development model. The author finalises the paper with a call for feedback and contributions as the main goal of the document was to trigger the debate on this subject and share ideas for possible future policy-making.

Basing on discussions within the OSH expert group which has been convened, here are some of the concepts currently being explored within this landscape: the link between AI infrastructure and OSH and its possible place in public policies and research and development actions; different types of OSH and the possibility of placing them in realm of public policies; learning lessons from OSS foundations and governance models; lessons learnt from OSS for OSH; potential promising areas in the public sector for OSH; types of stakeholders that should be convened to facilitate the discourse; and many others.

9. Policy Recommendations

The need for successful digitisation in all areas of society has never been more clear. In March 2021, the European Commission has defined its goals for the digitisation of the European society in the 2030 Digital Compass as achieving:[19]

1. a digitally skilled population and highly skilled digital professionals
2. secure and substantial digital infrastructures
3. digital transformation of businesses
4. digitisation of public sectors

If harnessed, OSS and OSH can make critical contributions to achieving each of these goals. The necessity for the digitisation of European societies has never been more clear and insights from the different analyses conducted in the context of the different tasks allow to derive a set of policy recommendations aimed at achieving this. Before starting to go into the details of specific policy recommendations, arguments have to be provided for why a governmental intervention related to OSS and OSH is justified.

Following the rationale of market failures, our empirical results show that OSS has the properties of a public good (Eghbal 2016) or common good (Tirole and Rendall 2017), which generates significant positive economic externalities, i.e. contributions of 0.4% to 0.6% to the GDP in the EU. Since in addition some stagnation in the contributions to GitHub can be observed, which has recently been confirmed by Dorner et al. (2020), but also by the survey conducted by Nagle et al. (2020) and expressed by some interviewees in the context of the case studies, there is even more pressure to publicly support still the development of OSS code and not only the only emerging activities in OSH.

The conceptual starting point for the identification of necessary policy measures for the support of OSS and OSH in Europe are the functions of the innovation systems identified by Hekkert et al. (2007). This framework has also been used to derive policy measures for the software sector in Europe in the EU study "The Economic and Social Impact of Software & Services on Competitiveness and Innovation" (SMART 2015/0015) and the predecessor (SMART 2009/041), which already includes some recommendations to support OSS in all sectors of the economy and public administration. Eventually, the recommendations have been discussed with practitioners from the public sectors in the context of an online workshop conducted in December 2020 and subsequently - where necessary - adapted.

The policy recommendations addressing the European Commission are structured along three dimensions, corresponding to the main goal that the respective recommendation aims to contribute to.

19 https://digital-strategy.ec.europa.eu/en/policies/digital-compass

Table 9.1: Structure of the Policy Recommendations

A digitally autonomous public sector	Open R&D enabling European growth	A digitised and internationally competitive industry
• Building Institutional Capacity • Creation of Legitimacy • Strategic Intelligence	• Knowledge Creation • Knowledge Diffusion and Networking • Entrepreneurial Activities • Human Capital Development	• Financial Capital Development • Regulatory Environment • Market Creation • Open Source Hardware • AI, HPC, Software defined infrastructure • Sustainability

These goals are directly linked with the main strategies set out by the European Commission, such as the European Digital Strategy, the Digital Europe Programme, President von der Leyen's Political guidelines for the next European Commission, the Berlin declaration. These policy recommendations also take into account and aim to make a contribution to specific digital strategies, including the European approach to Artificial intelligence, the New Industrial Strategy for Europe, the European data strategy, the EU SME Strategy, the EU's 2020 Cybersecurity Strategy, and the Commission's approach to High-Performance Computing.

a. A digitally autonomous public sector

Building institutional capacity

Today, the scale of Europe's aggregate institutional capacity related to Open Source is disproportionately smaller than the scale of the value created by Open Source as shown in the economic analysis. In order to achieve Open Source policy at a scale of the findings in this study, i.e. up to 0.4% to 0.6% of GDP per year in the EU, it is a prerequisite to consider building institutional capacity to deliver it. This increased institutional capacity is as relevant for the European Commission, European businesses, as well as it is for public sector organisations, public research organisations and universities with Open Source strategies across the EU.

The private sector, at least when considering the large IT companies, has built up its institutional capacity (Hecht 2020) as the importance of Open Source has grown seen at the number of contributions and contributors, e.g. more than 260,000 located in the EU. While it is generally not advisable to mimic the private sector exactly, or to do what the private sector does, Europe at large should increase its institutional capacity in order to secure value from the vast innovative Open Source movement for its citizens.

It is necessary to take a holistic approach to digital policy supported by the insights of van Loon and Toshkov (2015) based on surveys among municipalities on adopting Open Source Software in public administration in the Netherlands, in particular the importance of boundary spanners and political commitment. The Commission is already active in several programmes, which support OSS, e.g., ISA² in DIGIT, EU FOSSA 2, the Open Source

Observatory (OSOR), JoinUp, and the EU Open Source Strategy (European Commission 2020). However, all these measures are currently fragmented and lack an overarching common purpose, which can both guide and pool resources to accelerate EU's and its Member States' digital transformation journey whilst creating more jobs and digital leaders in Europe.

Moreover, there were unintended consequences for OSSH based businesses, which stemmed from legislation under the Digital Single Market. A broader view requires all services of the European Commission to actively avoid unintended consequences, and to act towards strengthening the Open Source ecosystems and enabling European OSSH based businesses to succeed within it. There are fragmented responsibilities regarding digital policy. Consequently, there is still potential to improve the coordination of digital lawmaking, as it is a horizontal policy area, impacting most or all policy areas today.

A European OSPO network

The OSPO (Open Source Programme Office) supports and accelerates the consumption, creation, and application of open technologies. A large number of IT companies have adopted the OSPO (Hecht 2020) as best practice for internal Open Source management, and have over time sharing best practices via semi-formal networks. It is worth noting that reaching a point where an OSPO networks with OSPOs at other companies is a clear sign of maturity.

The OSPO is emerging as a fundamental building block and networking interface in the global institutional infrastructure of Open Source. As such, it should be considered as central to capacity building of European Open Source and eventually to the promotion of further contributions to Open Source and therefore GDP in the EU. Not just in the private sector, but also in the public sector and in academia, are clear signs of more OSPOs being formed, but it is still nascent.

The European Commission has established an OSPO in order to increase the institutional capacity of the European Commission internally, taking the lead in establishing OSPOs in government institutions. However, increasing the institutional capacity of the European Commission should be done in tandem with increasing the institutional capacity of European institutions across the Member States.

It is recommended to consider taking five steps to increasing European Open Source institutional capacity through a network of OSPOs:

- Giving the EC OSPO an external networking component
- Making the EC OSPO into the legislative coordinator for Open Technologies within the European Commission
- Identifying and mapping European OSPOs in existence in industry, public sector and academia
- Encouraging and building 20 OSPOs through a funding programme
- Creating and funding the EU OSPO Network.

Giving the EC OSPO an external networking component

It is recommended to actively use the EC OSPO as the Commission's external collaboration interface to different OSPO enabled institutions, within industry, research organisations and universities and across borders. As such, the OSPO can be seen as a sort of 'standardising' effort of institutionalisation meant to increase the 'Open Source' interoperability between diverse organisation which should help increase the sharing and reuse of best practices, source code and other digital artefacts between public as well as private institutions.

In order for the European Commission to secure the vast value of the Open Source ecosystem for European citizens, such a holistic vision of the internal and external work is a necessary starting point.

Making the EC OSPO into the legislative coordinator for Open Technologies within the European Commission

It is recommended to use the EC OSPO as an Open Source competence centre and legislative coordinator for open technologies. The OSPO thus would become a consulting body for cabinets, DGs and units drafting policy as Open Source and Open Technologies have shown to be the subject of unintended consequences of EU policy in the past.

The EC OSPO, as envisioned here, will act as networked component within the Open Source communities of industry, academia, civil society and public sector and thus would be perfectly positioned to surface the well-documented wealth of knowledge available in the communities when making policy decisions. In addition, with its network, the EC OSPO could be used to ensure public consultations reach the intended target groups.

Identifying and mapping European OSPOs in existence in industry, public sector and academia

It is recommended to give the EC OSPO the task to identify and map existing European OSPOs in industry, the public sector and academia, with the aim to exchange information and share best practices for a future European OSPO Network. Such an exercise could also identify on a continual basis what supportive action is needed and provide such services, such as licensing help, support in digitalisation, training sessions, etc. This model has been successfully applied in South Korea, where the government played an important role in providing incentives and support to increase software expertise in the technology sector.

Encouraging and building 20 OSPOs through a funding programme

It is recommended to investigate further potential levers that the European Commission and the Member States have to increase the uptake of OSPOs, not just among IT companies, but across different industrial verticals. It would be worth considering a goal such as “each FTSEurofirst 300 company to have an OSPO by 2030”.

For the public sector, it is recommended to leverage funding programmes such as Horizon Europe and Digital Europe to fund and support the formation of at least 10 OSPOs in European Government institutions to speed up the process of developing best practices for government. This could be done through a competition where for example EU cities and/or regions apply for funding and additional support to form an OSPO. Requiring them to also have a networked component could help lead-frog the maturity of the network of EU Government OSPOs.

For academia, it is recommended a similar approach as for the public sector, but taking the particular needs and demands of public research organisations and universities into consideration.

For both the public sector and academia, it is recommended to carefully consider the requirements of building OSPOs, in order to on the one hand being flexible enough to meet the diverse Open Source goals of the different organisations, while on the other hand maintain the networked component “standardised” enough to enhance organisational interoperability.

Creating and funding the EU OSPO Network

Finally, it is recommended to create a programme meant to network the EC OSPO, the identified OSPOs in industry, the public sector and academia, as well as the OSPOs formed with support from EU funding programmes in the public sector and academia. Specific subgroups for the different sectors can be considered, but this network could be used as the institutional backbone infrastructure to achieve Open Source policy at scale. This has been implemented successfully in the North East Asia OSS Promotion Forum, which brings together the competent ministries from China, Japan and South Korea, in order to coordinate actions. Such a network could also employ benchmarking efforts to provide incentives for more ambitious actions.

As a final point, it is recommended to support the mainstreaming of the term OSPO for reasons of semantic interoperability between diverse institutions. A network of OSPOs that speak the same language, have similar organisational structures, have similar competences and mandates would enable structured collaboration between the EC OSPO and other government organisations, research organisations, universities, Open Source foundations and private sector OSPOs across borders in Europe and beyond.

A European Open Source culture enabled by the EC OSPO

Policy analysis across the world has shown that creating awareness and buy-in of both the top-level political decision-makers and the public administration itself is an important requirement to be able to achieve successful implementation of policies and to inform successful policy formulation. It is recommended to use the OSPO to work toward a cultural shift toward open, also leveraging open innovation principles for working methods. A strategy that has shown itself to be successful to achieve this is to make appointments with Open Source expertise in key positions. At the same time, incentives need to be created to engage such individuals long-term within the public administration.

Creation of Legitimacy

Legitimacy is fundamental for the breakthrough of an emerging technological system, like OSH, but also for the further development of established technologies, like OSS. One opportunity to increase their legitimacy is to elaborate the role of Open Source in the recently started discussion about achieving digital autonomy and technological sovereignty. In parallel, there is a longer tradition to consider Open Source as a large part of the technical infrastructure of an information and knowledge driven society, which contributes - as shown in our economic analysis - to economic growth.

Promoting digital autonomy and technological sovereignty via Open Source

Calls for technology sovereignty[20] in general or digital sovereignty or autonomy in particular in Europe have become louder in recent years, even before the coronavirus pandemic. The optimism of recent decades concerning the interdependence of our economies and the further integration of global value chains has been challenged by recent growing geopolitical uncertainties and the threat of global trade conflicts. In the EU, but also in its Member States, these challenges have started a discussion about how independent a state or the EU must and can be with regard to critical technologies. It is obvious that there is a tension between the call for technology or digital sovereignty on the one hand, and the for decades

[20] For example, Edler et al. (2020) define "technology sovereignty as the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act, and to be able to develop these or source them from other economic areas without one-sided structural dependency."

or even centuries dominant economic model on the other hand, which stresses that global specialisation and the division of labor combined with free trade increases the welfare of all. Consequently, the EU as an economic area must consider the question of technology sovereignty carefully and in a differentiated manner.

Edler et al. (2020) propose different strategic approaches to secure technology sovereignty. First, it is first necessary to generate technology-specific knowledge using the classic instruments of research and innovation policy. This requires a critical mass of skilled people, which can in the short run be assured by hiring experts from outside the EU being endangered by several vulnerabilities. Therefore, this demand can in the long run only be satisfied by actually teaching the corresponding content at universities within the EU. In addition to this supply-side measure, public procurement can provide strategic incentives so that production capacities for the relevant technologies and the corresponding products will be created or ensured by the European ecosystem supporting Europe's digital sovereignty (FOSS4SMES 2019). Since the potential portfolio of technologies relevant for technology sovereignty is much too large, a specific division of labor is necessary, not only in the European, but in the international context. Through long-term research cooperation, bilateral, but above all multilateral research is conducted with partners who have the relevant complementary competencies in technologies identified as critical, which ensures joint access to these technologies and avoids one-sided dependencies. Finally, the development of open standards supported by many international companies, but also by OSS and OSH, is a specific form of collaboration beyond research, which can assure the access to technologies relevant for assuring technological and digital sovereignty (FOSS4SMEs 2018).

Most importantly, OSS and OSH provide control over technologies, as the public availability means access is difficult to restrict. In addition, they reduce the dependency on vendors of specific proprietary technologies and software, as highlighted in the results of the stakeholder survey. Software licensed under an Open Source license has shown itself to be resistant to international trade conflicts, as the availability to all parties must remain. Thus, Open Source Software can be seen as a defensive tool against trade conflicts. Finally, if standards, but also OSS and OSH, are combined with public procurement, it allows accessing a larger number of suppliers of the relevant technologies, and also assures long-term competition. However, the current debates about technological and digital sovereignty stress computing power, control over data and secure connectivity as the three inseparable pillars, e.g. by Thierry Breton, Commissioner for the Internal Market.

Consequently, it is recommended to integrate in the discussion about strategies to achieve technological, but in particular digital sovereignty and autonomy also OSS and OSH, which will also contribute further to their legitimacy within the EU. One concrete option to foster digital sovereignty could be the further elaboration of the Open Source Observatory (OSOR) owned by the European Commission to European OSS and OSH repositories in addition to GitHub, GitLab and other mainly US hosted repositories. In particular, the recommendation in FOSS4SMEs (2019) is supported, that the European institutions should consider supporting directories for OSS solutions so that European start-ups and SMEs can easily make use of the available OSS solutions suited for their needs and eventually to their commercial success.

Considering Open Source Software as public infrastructure

Although Eghbal (2016) argues that OSS belongs to countries' digital infrastructure and in our econometric analyses is revealed a significant impact to the GDP of the EU by the contributions to OSS, this is not yet reflected in the existing policy framework.

SDOs are already well-integrated into the European research and policy frameworks, while for OSS communities such integration is still at the beginning. Therefore, it is recommended to integrate OSS and their communities not only into the European research and innovation policies, but also via a regulation similar to Regulation (EU) No 1025/2012 on European standardisation into the more general policy frameworks, like the European Green Deal and European industrial strategy.

The public support of OSS foundations should be raised to a level comparable to the support provided to European SDOs, especially if they commit to a charitable cause and comply both to the relevant WTO regulations and the European guidelines to horizontal co-operation agreements.

Today, OSS runs a large part of the technical infrastructure of an information and knowledge driven society. OSS should be considered as an infrastructure of the information age of similar importance to highways and bridges (see also Eghbal 2016). It is worth investigating the benefit of public medium-to-long term investments into OSS infrastructure that supports EU policy goals, e.g. like the mentioned European Green Deal and European industrial strategy. It is recommended to further evaluate policy options for the EU to contribute directly to OSS. This may require changing the regulatory framework or establishing European OSS development organisations.

The acceptance of the public interest in the contributions OSS makes to the common good could justify the establishment of a European OSS development umbrella organisation. Careful consideration needs to be applied to avoid disrupting the upstream/downstream model peer production process that is based on self-identification. This can be avoided by selectively awarding competitive, time-limited grants similar to current research funding by the EU. Governmental and regulatory representatives should expect to be received as welcome contributors, but also to have to earn their merit in the communities like any other contributor. When developing policy measures aimed at fostering OSS development, sector specific experiences may not be generally applicable. In particular, the highly concentrated, regulated and politically influenced mobile communication sector may not be a useful yardstick for the development of general public OSS policy. Experiences from a plurality of highly innovative technology areas, like cloud-native computing, automotive platforms or programming languages that involve standards setting and implementation should be taken into account. Practices need to be developed that reflect the trend towards openness and transparency in general and the WTO requirements in particular.

Securing the health of the Open Source ecosystem

Clear and accepted definitions are important to secure legal certainty, keep transaction costs to a minimum and maintain a healthy ecosystem. Would the definition of OSS be called into question these inherent benefits would be threatened. OSS is defined by the Open Source Initiative's (OSI) Open Source Definition's (OSD) ten criteria. Free Software is defined by the Free Software Foundation's (FSFE) Free Software Definition, compromising of the four freedoms. When legislating, the majority of surveyed countries either refer directly to the Open Source Definition or copy the text verbatim into law.

It is recommended to clarify that Open Source Software or Free Software are defined by the Open Source Initiative's Open Source Definition and the Free Software Foundation's Free Software Definition respectively.

Strategic Intelligence

Strategic intelligence fulfils an important function both within an emerging technological system, like OSH, but also in an established technological system, like OSS, because it serves several purposes. First of all, it helps to guide the search for new and promising technological opportunities and application areas, which supports both, industry as well as policy, in better and timely strategic decision processes and eventually resource allocation. Secondly, a monitoring of potential technological options generates information that allows the identification of new technological and business opportunities. Finally, a permanent monitoring also offers the possibility to determine fields of action for policy makers and the opportunities to review existing measures.

Integrating the Open Source in European digital indicators

Our review of the existing literature and the challenges of our own efforts to collect data on OSS-related activities, but also the only emerging developments in the area of OSH have revealed significant gaps in the data. However, the new guidelines for collecting, reporting and using data on innovation released by the OECD/Eurostat (2019) included for the first time Open Source as a knowledge source. The results of the recent German version of the Community Innovation Survey confirm its relevant role as knowledge source not only for the information and communication sector, but for many companies across all industries and size classes.

Therefore, it is recommended to expand the focus on OSS in the short term and on OSH at least in the medium term to address further innovation related questions in the Community Innovation Survey. The findings from the survey can provide further insights to the most relevant and promising questions helping to promote contributions to Open Source and eventually economic growth in the EU. With the first results available for the EU, further initiatives in other OECD countries to collect similar data might follow, which might then allow international comparisons and benchmarks. These insights will help the EU to adjust and improve their OSS- and OSH-related policies in areas, where it is lacking behind.

Whereas, the data gap related to OSS and OSH can be addressed in the Community Innovation Survey, there is so far no other data related to OSS and OSH available. One option would be to investigate the possibilities to measure the efforts related to OSS and OSH based on companies' tax declarations. However, due to different approaches in the different Member States and the limited use of this option, even when it is available (Ghosh 2006), regular surveys among companies actively contributing to OSS and OSH are recommended. Although some of the required numbers, like the number of companies, value added or employment, are already existing for software companies in the classical statistical data, there is the need for an in-depth analysis of their specific OSS- and OSH-related activities and their use of OSS and OSH code. *It is recommended*, in particular Eurostat, that these surveys take place on a regular basis on the EU level to allow comparisons between Member States and to detect changes and new trends. In addition, it is recommended to include benchmarking on usage and competence of OSS in its regular DESI (Digital Economy and Society Index), recognising the important role OSS plays in the digitisation of the public sector and beyond.

Expanding the Open Source Observatory by components of strategic intelligence

Whereas large OSS-based companies have the funds and resources to conduct such monitoring exercises, small and even micro companies are lacking these opportunities. However, as our analyses have shown the major contributors to OSS and OSH is this group, which justifies a public intervention, because the result of such monitoring activities has the character of a public good. At first, there are incentives problems, which prevents this information from being produced by single private actors and freely distributed. Secondly, if the information is produced, then it is efficient to make it available to all interested stakeholders. Consequently, it is recommended to generate this information about future trends and opportunities related to OSS and OSH not only at the national level of the Member States, but at the EU level.

Consequently, it is recommended to expand the existing Open Source Observatory (OSOR) already owned by the European Commission to open its portfolio to include elements of strategic intelligence. OSOR serves already to exchange, but also access relevant knowledge. The focus on the use of OSS in public administrations across Member States should be expanded to the demand in the private sector related, and beyond Europe. However, the publicity of this platform is still limited indicated by its just around one thousand followers of its Twitter account. Therefore, it is recommended in a further step in addition to the recently established Open Source Programme Office (OSPO) as facilitator for all activities outlined in the Open Source Software strategy for 2020-2023 to promote the awareness of OSOR among public administrations, but also among the private sector, i.e. in particular SMEs and start-ups, and citizens such as academics and OSS enthusiasts.

b. Open R&D enabling European growth

Knowledge Creation

The creation and expansion of a knowledge base is at the core of emerging technologies and industries, because learning and researching are preconditions of innovation. Therefore, the creation of a knowledge base encompasses not only new basic knowledge through research and development, like OSSH. It also contains its diffusion not only among Public Research Organisations (PROs) and universities, but in particular among the private and the public sector via the related learning processes through the application of the knowledge, i.e. the OSSH code being an important part of the digital commons. As shown in our economic analysis, it eventually contributes to economic growth.

Following the user-driven innovation paradigm (e.g. von Hippel 2005), the learning and feedback processes by users gain more and more importance for the knowledge base in general, but in particular for OSS and OSH. Therefore, the border between knowledge or OSS and OSH creation and its diffusion becomes more and more fluid with a stronger impact of users on the creation of new knowledge and code through Open Innovation mechanism in general, but in particular by OSSH.

Increasing the level of public R&D funding of specific Open Source projects

Due to the significant positive externalities generated by OSS supported by the results of our econometric analysis, but also the stakeholder survey and the developer survey conducted by Nagle et al. (2020) revealing the value of the knowledge and skills that employees gain from contributing to OSS, public R&D funding is justified. The existing level of funding for OSS has been (Ghosh 2006) and is still limited for both OSS and OSH.

Therefore, it has to be expanded. Already, Yildrim and Ansal (2011) recommend specifically that academic research agendas should give higher priority to research about OSS development complemented by the suggestions of Heikkinen et al. (2020) related to OSH. In parallel, governments but also industry should fund academics that develop research projects on OSS and OSH.

Dude to the economic grwoth enhancing impact of OSS, it is justified and therefore recommended to expand the public funding of OSS- and OSH-focused research and development projects both in in the Horizon Europe to €1 billion per year, but also in the Digital Europe Programme, which can be justified by its significant impact on GDP. In this context, the funding ratio of 50% for OSS- and OSH-based organisations should be increased to 75% reflected in the related clauses in the Model Grant Agreement. To illustrate the success of such funding, it has to be highlighted that in 2016, Arduino was recognised by the Innovation Radar, a European Commission initiative to identify key innovations and innovators in EU-funded research projects, as ranking first among over 1,000 organisations (Cuartielles et al. 2018).

In addition to R&D funding, it is recommended to launch research awards or prizes for OSS and OSH communities or for students and academics, which generate innovative solutions to specific challenges, e.g. health or security, for the benefit of the society as such, but also addressing specific needs of the public sector or specific regional clusters.

Due to the large cross-border spill-overs in particular of OSS, there is a strong argument for providing R&D funding at the level of the EU and not only at the national level. It might be even more effective and efficient to concentrate the R&D funding related to OSS at the European level to exploit the existing positive externalities at a larger scale within the whole EU.

However, due to the public good character of OSS also regions outside the EU will benefit from the European funded OSS as shown by our analyses. Therefore, complementary to the pure increase of EU R&D funding for OSS, it is recommended to target the R&D funding in the sense that it should be linked to the specific objectives, e.g. of the European Green Deal and European industrial strategy.

Easing the access for SMEs, Start-Ups and Individual Developers to ICT-related Open Source funding

In addition to focusing R&D funding more to OSS and OSH related projects, the target groups of this funding are definitively SMEs or even microenterprises and start-ups, but even indivdual developers. Our analyses have revealed that these companies are responsible for the main share of contributions to OSS and that the contributions per employee are increasing with decreasing number of employees. Furthermore, Wright et al. (2020) show that the pool of OSS is pushing the creation of ICT-related start-ups, which is complemented by the results of the stakeholder survey revealing that in particular young micro organisations benefit from OSS. Taking these two observations together, it is recommended to exploit the virtuous cycle of supporting existing SMEs and active individual developers contributing to OSS, which itself is pushing the creation of further start-ups, via public funding of their R&D related to OSS. Related to OSH, experts in the field highlight the importance of larger companies with the necessary resources and production capacities. Therefore, it is recommended that companies being larger than SMEs should at least not be discriminated against or excluded by publicly funded programmes in the area of OSH.

Knowledge Diffusion and Networking

In contrast to knowledge creation, knowledge diffusion and networking are depending on cultural factors, which can in general only be influenced by soft policy instruments. However, their relevance for innovation and, therefore, growth is widely acknowledged. OSS and OSH have due to their openness all the requirements necessary for an effective and efficient diffusion of knowledge characterising them eventually as commons. Consequently, our empirical results reveal a significant contribution of OSS to the GDP of the EU.

Supporting incentives for publicly funded R&D projects to make their results open and accessible

Complementary to the expansion of public funding of specific OSS and OSH projects, the participants of all publicly funded R&D projects should have strong incentives to make their results accessible to all interested stakeholders, which is supporting the above-mentioned knowledge diffusion. This proposal follows Moedas (2016), who presents a vision of the future in 2030, where Open Source communities and scientists have pushed the EU offering free public access to all publicly funded research.

Reflecting the practical obstacles of making all research results of publicly funded R&D projects open access and taking into account possible incentive problems of industry, it is not recommended to make obligatory all results open access, but, rather, to provide strong incentives to do so. Therefore, it is recommended to expand the current Model Grant Agreement by the following paragraph:

"To the extent that research outputs consist of software or designs for hardware, beneficiaries should consider that the source code (for software) and designs (for hardware) is be made publicly available alongside the other research outputs, and under (in the case of software) the EU Public Licence or (in each case) another licence approved by the Open Source Initiative as complying with the Open Source Definition."

In addition, it is recommended to provide additional awards for uploading code in publicly accessible EU based OSS and OSH repositories (see the specific recommendation by Heikkinen et al. 2020). Here, the already existing Open Source Observatory (OSOR) operated by the European Commission could be used as a repository. It is also recommended to provide incentives in its funded R&D projects contributing to existing OSS and OSH projects equally to creating new projects. Unlike in the proprietary mode, Open Source inherently favours building on top of existing work, improving the outcome for all. Finally, there is always the challenge to maintain projects, i.e. the code should be available several years after the completion of projects (Nagle et al. 2020) like in the Software Heritage. Therefore, it is recommended to promote the OSOR as a platform where code created within public funded R&D projects should be uploaded.

Supporting the creation of Open Source platforms and networks in the EU

The role of platforms and repositories, like GitHub, for developing and using not only OSS, but also OSH, is crucial. An indication of the lower bound of their commercial value can be seen in the acquisition of GitHub by Microsoft for $ 7.5 billion in 2018. The objective of gaining and securing digital autonomy or sovereignty by the EU is also dependent on the independence of such platforms and repositories hosted in third countries. Governments around the world have successfully created networks and communities around their projects, leveraging the benefits of such communities in scale, maintenance and development for individual authorities and the wider ecosystem. Examples include gvSIG and Decidim in Spain, Integreat in Germany and Blue Hats in France. Therefore, it is recommended to support the development and maintenance of platforms and depositories, but also networks hosted in the EU.

Entrepreneurial Activities

Entrepreneurial activities are a crucial aspect of the emergence of new, like in the case of OSH, but also for the performance of already existing innovation systems, like for OSS, because these activities include the search for application of new technologies and potential business opportunities. Finally, despite the massive involvement of individuals and micro companies in OSS and OSH and the driving force of OSS for creating start-ups according to Wright et al. (2020), a lack of successful entrepreneurship is observed, especially in the form of young, high-risk, but strongly growing start-ups in the EU compared to the USA with its successful OSS-based platform companies.

Providing relevant education and establishing a culture to foster Open Source based start-ups

The study on the role of OSS for the creation of start-ups based on a large sample of countries by Wright et al. (2020), but also our own analyses have revealed that OSS makes significant contributions to the creation of IT-start-ups, i.e. more than 650 per year in the EU. The study by Wright et al. (2020) even shows that OSS-based start-ups are often "mission-driven" engaged in socially-impactful activities addressing different SDGs.

This positive relationship can be further promoted by providing entrepreneurial skills facilitating OSS- and OSH based start-ups, e.g. in the various Master programmes on entrepreneurship, but also in the ICT focused studies. This requirement is even more crucial, since the study SMART (2015/0015) identifies a lack of entrepreneurship in the European software sector due to lack of entrepreneurial skills of software engineers.

However, in the long run, a culture for such start-ups has to be developed. This needs long-term strategies and measures in addition to education, e.g. as an important component for sustainable business models. Therefore, it is recommended to encourage the Member States of the EU to actively promote OSS and OSH within the organisations in universities, e.g. centers for entrepreneurship, and public research organisations, e.g. technology transfer offices, being responsible for the support of entrepreneurship, because these institutions are the origin of a large share of technology-based start-ups. Furthermore, it is recommended to establish Open Source Innovator awards similar to the European Inventors Awards of the European Patent Office.

Promoting partnerships between small Open Source players, trusted intermediaries and larger companies

The insight from our analysis that in particular micro and small companies are responsible for the major contributions to OSS from the EU calls in addition to the above mentioned virtual network between them for additional schemes. In particular, measures that help start-ups based on OSS and OSH to team up with established and commercially successful companies can close the often mentioned gap between invention and innovation in the EU, which is also relevant in OSS and OSH. Ghosh (2006) already indicates one key reason for the weakness of the EU of deriving economic benefits from its massive contribution to OSS, which is also supported by our econometric results, in the weak investment of the large ICT companies with OSS-based micro companies or SMEs in contrast to US companies, like IBM or Microsoft. Such a more proactive strategy of partnering with OSS- and OSH- based companies and OSS or OSH communities can only be driven by the large European ICT companies themselves. It is recommended to support and encourage such partnerships through publicly funded measures. The partnerships might cover not only formal, but also informal arrangements.

Since OSS, but also OSH foundations play an important role in the whole ecosystem, it is recommended to support them by providing financial support, e.g. for their education programmes (see further details below), but also their collaborations with companies, in particular SMEs and start-ups. Their work should also be supported by subsidising their OSS projects that address specific needs of SMEs and start-ups located in the EU, but also those supporting the achievements of the Sustainable Development Goals (SDGs) or objectives of the Green Deal.

In contrast to several large US firms, which have built large platform-based business models often driven by OSS, such strategic approaches are still limited in Europe. One exception is for example the telecom provider Telefonica. Therefore, following the suggestion by Ghosh (2006) it is still recommended to support via wide reaching campaigns the awareness of the potential benefits for large firms at a strategic business level of cooperating with OSS communities and OSS-based start-ups and SMEs. However, public agencies at the national, provincial and local levels could follow the example of private firms and explore formal and informal partnership arrangements with OSS foundations and specific project communities to provide “localisations” and special purpose software systems for their own business management needs.

In SMART (2015/015), it is suggested that this could be done by establishing or supporting platform partnerships. For example, telecom operators located in the EU, like Telefonica, being already very active in OSS, should be supported in offering platforms, which new entrants can use to market their services. It is recommended to support this by promoting the approach of teaming up with trusted intermediaries, by funding the development of related OSS and by providing guidelines concerning operational roles in the OSS ecosystem. This approach is also relevant to secure the digital autonomy of the EU, which is endangered by the massive OSS engagement of the US located large platform companies. Our analysis shows that the US economy and therefore also these companies benefit significantly from the large contributions of European OSS developers and companies.

The Open Source Observatory (OSOR) owned by the European Commission serves already as a place where the OSS community can come together to publish news, find out about events, identify relevant OSS solutions and read about the use of OSS in public administrations across and beyond Europe. However, the publicity of this platform is still limited indicated by its just around one thousand followers of its Twitter account. Therefore, it is recommended to promote the awareness of OSOR, which efficiency has in parallel to be improved, among public administrations, but also among the private sector, i.e. in particular SMEs and start-ups, and citizens such as academics and OSS enthusiasts. Specifically, as the OSOR is already helping public sector bodies to increase their level of competence regarding OSS, it could be expanded to do similar activities for the private sector, monitoring current relevant developments, providing guidance for OSS adoption, development, creation of OSPOs, licensing support. As our analysis of policies reveals, these activities were already successfully performed by public sector bodies in South Korea.

Human Capital Development

The relevance of human capital for an innovation system is fundamental, in particular in the area of OSS and OSH, where the involvement of skilled personnel is key. There is evidence from our stakeholder survey and several other studies, e.g. BITKOM (2020), or papers addressing policy measures related to OSS, which emphasise the importance of education related to OSS. For example, the survey conducted by BITKOM (2020) reveals that the lack of skilled labour is the most important disadvantage followed by a lack of training opportunities preventing companies from using OSS. Especially innovation systems, like software in general and OSS and OSH in particular, are as a general purpose technology shaped by both, their own high dynamics as well as the continuous further development of their application fields. Due to the multidimensional dynamics, the continuous development of human capital in the area of software and OSS and OSH is an important factor for its long term development and performance.

Already Yildrim and Ansal (2011) recommend that professional training programmes should be provided by academia, incl. universities, but also the local software industry, including start-ups. Eghbal (2016) also suggests expanding the pool of potential contributors to OSS, which requires better education not only of employees in the private sector, but also of government officials. Based on this study's findings of the positive impact of the contributions to OSS by developers located in the Member States to the GDP in the EU, it is recommended to include OSS and OSH as topics into the European Qualifications Framework (EQF). It is a common European reference framework not only to make qualifications more consistent and transferable across different countries and systems, but also to integrate them into the portfolio of all qualifications of the EQF to exploit possible synergies.

Promoting the inclusion of Open Source (development, business models and licensing) in the programmes of Higher Education Institutions

Universities have long used Open Source to build their websites, create educational software, and improve access to learning tools and more. Although they are proficient at using OSS-based technologies, the majority of universities appear to be less active when it comes to offering teaching the benefits of OSS development to their students, i.e. there are not many classes focusing on OSS or even OSH in the EU. For example, among the almost 15,000 programmes included in the platform “study.EU” are only two referring to “Open Source” and none to “Open Source Hardware”. This is surprising, because there is a growing demand for OSS development skills, because employers want increasingly hiring developers who have experience working with OSS (Linux Foundation 2018:

https://www.linuxfoundation.org/publications/2018/06/open-source-jobs-report-2018/) supported by the lack of skilled personnel revealed by BITKOM (2020). Obviously, there is a gap in the market for education related to OSS, but probably also for OSH.

Since the Higher Education Institutions (HEIs) in the EU are not adequately meeting the demand for skilled personnel in the area of OSS, it is recommended to provide funds at the level of the EU to support the development of curricula (FOSS4SMEs 2018) focusing on OSS and eventually extended to OSH without prioritising any specific proprietary provider as already requested by Ghosh (2006). FOSS4SMEs (2018) point to the value of transferable and sovereign digital competences by moving away from not only vendor and product specific knowledge toward generic competences. The provision of funding at the level of the EU is justified at first by the cross border spillovers created by OSS within the whole EU as revealed in our analysis. Secondly, the mobility of software developers between the companies and consequently between the Member States is quite high, which generates further positive externalities, such as by the mobility of researchers within the European Research Area.

In order to exploit possible positive externalities between those HEIs, which have built up the described missing programmes and those HEIs interested in developing such a portfolio of courses, it is recommended to provide an opportunity to fund twinning projects under ERASMUS+ .

Finally, not only Master courses on OSS and OSH should be offered, but also further education programmes should include similar modules responding to the dynamic development in software in general and OSS and OSH in particular. A number of country governments have enabled the adoption of Open Source into HEI curricula, such as China, India and South Korea. Results were mixed, as similar to public procurement the awareness and culture need to be present for the uptake and impact to be significant. In addition to the HEIs, OSS foundations are already offering further education. Therefore, it is recommended to consider their support for their development of education programmes and services related to OSS and OSH.

Promoting entrepreneurial and management skills among Open Source based micro companies and SMEs

Complementary to the general gap of OSS- and OSH-related skills, the EU faces obviously a lack of management skills. The findings of our empirical analysis has revealed many micro companies contributing to OSS, which have problems to grow, because very few larger young companies are seen. One barrier is certainly the access to financing, incl. venture capital (see below). However, as addressed in other studies, like SMART 2015/015 or FOSS4SMES (2019), the actors in the European software sector face in particular a shortage of management skills.

Therefore, it is recommended to encourage the Member *States* to establish specific incentives for HEIs in general and business schools in particular to offer specific OSS- and OSH-focused management courses, e.g. as mini(MBAs) as already suggested in FOSS4SMES (2019), which also include modules not only about business development in general, access to finance, but also intellectual property rights, liability issues and opportunities in public procurement. These courses could also be developed in close cooperation with Open Source business associations, which have already working groups focusing on education.

Developing an EU Certification Scheme for individuals who have developed Open Source skills in particular fields

Since existing studies, the interviews and the stakeholder survey have revealed severe shortages in skilled labour, the promotion of education programmes is certainly one important approach to tackle this challenge. However, the effectiveness and efficiency of labour markets are depending on the level of transparency of qualifications and skills. Since there are very few Master courses dedicated to OSS or OSH and the skills are depending on the continuous contribution in particular to OSS, the skills of the individual developers are not transparent and difficult to assess by companies and organisations searching for skilled labour.

Therefore, it is recommended to develop an EU-wide Certification Scheme, which reduces the information asymmetry and increases the efficiency in the labour market for Open Source developers. These schemes could be developed and offered by HEIs, but also private certification bodies, which already offer certifications not only for organisations, but also for persons.

Increasing the diversity of Open Source contributors

Underrepresentation of women in the IT sector is a well-known fact, and OSS is not any different - some studies show that there are fewer women in OSS than in the software industry as a whole. In a report from 2006 only 1.5% of OSS contributors were women, compared to 28% in proprietary software (Ghosh, 2006). The most recent survey of more than a thousand OSS contributors globally had over 93% of men among its respondents, similar to other surveys of this type (Nagle et al., 2020).

This leads to lack of inclusion of women's experiences in analysing Open Source, especially such as barriers of entry to join different projects, accepting or rejecting code by female-sounding users, "volunteer" type of OSS contributions (especially at the beginning of developers' careers) that is expected to be in done in "free time" that women tend to have less of, often due to their caring duties (Nafus et al. 2006).

It is recommended to explore the issue more in depth in the form of a research project within Horizon Europe, as there has not been a comprehensive study on the issue that addresses all challenges and opportunities women face in regards to the OSS ecosystem. Some of the ways in which women might be able to participate in OSS more include: encouraging funding for OSS specific projects to civil society organisations that focus on gender balance in IT/STEM; promoting partnerships between OSS actors (foundations, projects etc.) and women's tech organisations; ensuring proper women's representation on official OSS events and conferences; encouraging to maintain gender balance in EC-funded projects in the area, such as selecting projects that positively include women in technical roles.

As diversity does not equate to gender equality only, it is worth exploring the issue of ethnic and racial diversity in the field and inhibitors of involvement for different public. Some OSS actors put efforts into increasing diversity in their projects and facilitating obtaining certain skills useful for OSS, such as the Linux Foundation's project offering 50 scholarships per quarter to black individuals who want to take the Linux Foundation certification programme, which can help them to participate more effectively in the OSS activities.

c. A digitised and internationally competitive industry

Financial Capital Development

Access to finance is one or even the most important factor for the economic development not only of start-ups, but also for small and medium-sized companies, i.e. also for OSS- and OSH-based enterprises.

Establishing tax incentives related to Open Source contributions

When the above targeted OSS- and OSH-based companies eventually grow successfully and start to generate significant revenues profits, tax incentives might come into play to secure sustainably their contributions to OSS and OSH, because they obviously generate significant positive spillovers for the economy of the EU. Related to start-ups not yet being profitable, tax breaks, i.e. a negative tax, should be also considered.

Already Ghosh (2006) and Eghbal (2016) ask for the provision of equitable tax treatment for the contributors of OSS. In detail, it is recommended to encourage all Member States of the EU to treat OSS and OSH contributions both by individuals and corporations as charitable donations for tax purposes based on the time spent writing the code. In some countries, like the USA, but also some Member States of the EU, this is already possible, but often not very well known among OSS- and OSH-based companies. Therefore, it is recommended in these cases to promote the awareness of such schemes to reach effectively among firms, contributors, foundations, but also tax authorities.

Establishing a European scheme for high-risk, R&D-intensive Open Source based start-ups including their growth phase

There are not many large European companies active in OSS and many of them are quite old, i.e. founded in the last century, compared to the USA. Although this “ageing industry” is a general tendency in the European economy (Philipon & Veron 2008), the impact is especially significant in the fast moving, high-technology industries (Veugelers 2009), like in software in general and OSS in particular. The aging phenomenon is not necessarily the result of the absence of entrepreneurial activities in the EU as seen in the large number of micro companies and SMEs being active in OSS compared to a small share of larger companies with more than 100 employees. Obviously a few years after founding most of the startups based on OSS in EU Member States develop not very dynamically. Related to the situation in OSH, the situation is even more dramatic. First, there are not many OSH-based start-ups in the EU. Secondly, a significant share is going out of business after their foundation. As it seems this growth issue related to OSS and the survival problem are not well addressed by policies in the EU, although there is a strong focus on SME policies in Europe (Philipon & Veron 2008).

A major issue for start-ups based on OSS is according to the insights from the interviews conducted in the context the case studies the access to financial sources. Therefore, the needs of such high-risk and due to the high share of labour costs R&D intensive startups, which aim at radical, innovative solutions, should be addressed.

Since 2018, start-ups and small and medium-sized enterprises that are based in one of the EU’s Member State or are established in a Horizon 2020 Associated Country can receive EU funding and support for breakthrough innovation projects with a market-creating potential as part of the Enhanced European Innovation Council (EIC) pilot. The Enhanced EIC pilot provides grant-only support along with blended finance, i.e. grants in combination with equity investment. The Enhanced EIC pilot’s stage funding helps to boost fast company growth and market-creating innovation. It also facilitates the scaling up of innovative companies by providing them access to Business Acceleration Services.

The Enhanced EIC pilot funds high-potential, high-risk innovation developed by SMEs through the EIC Accelerator Pilot, which offers Europe’s innovative entrepreneurs the chance to step forward and request funding for breakthrough ideas with the potential to create entirely new markets or revolutionise existing ones. The EIC Accelerator pilot provides full-cycle business innovation support including coaching and mentoring.

Consequently, at first, it is recommended to continue the programme and explicitly open the Enhanced EIC including the EIC Accelerator to applications from young, high-risk, R&D-intensive OSS- and OSH-based entrepreneurs to address the lack of venture capital in the European small business ecosystem (FOSS4SMEs 2019). Secondly, it is recommended that this funding opportunity of OSS- and OSH-based start-ups has to be made aware within the OSS and OSH communities, because from the so far more than 6.000 funded projects only 0.5% are related to “Open Source” and none to “Open Source Hardware”. Finally, it is recommended to launch financing instruments, like specific late-stage focused Venture Capital funds, for follow-up stages and measures that help these funded OSS- and OSH based start-ups to team up with established companies (see above).

Fostering the potential of (pre-)commercial public procurement to support innovative Open Source based companies

The public authorities are one of the largest procurers for software and services in the EU. Therefore, public procurement strategies can play a key role in the further development of OSS and OSH. In particular, public procurement in form of pre-commercial procurement can be used to foster the potential of OSS and OSH not only to save costs by switching from proprietary software to OSS, but also to target it towards addressing sustainable development in general or the Sustainable Development Goals (SDGs) in detail. In a number of cases, such as the United States government investment into software research at universities and start-ups has been a factor in creating an expansive software sector employing OSS.

The EU’s research and innovation programmes FP7, CIP and Horizon 2020 have been funding projects in which groups of procurers from EU Member States are jointly implementing Pre-Commercial Procurement (PCP) or Public Procurement of Innovative Solutions (PPIs), as well as coordination and networking projects that prepare the ground for future PCP or PPIs.

However, an analysis of the projects (European Commission 2019: Innovation Procurement: The power of the public purse) reveals that only very few projects deployed solutions as Open Source. One example is the DECIPHER PCP, which resulted in an Open Source connector for patients, doctors and relatives. Another example is PREFORMA PCP, which successfully delivered three new open-source standardised tools that improve the curation capacity with high digitisation accuracy and quality at reduced costs. The three Open Source conformance checkers developed in the project help memory institutions to validate incoming file formats and codecs against their standard specification, define custom policies, and build an efficient ingest workflow. These two examples show that pre-commercial procurement can result in successful Open Source solutions.

Therefore, it is recommended to fully exploit the potential synergies between pre-commercial procurement and both OSS and OSH in a more strategic and systemic way. In particular, the option to go for OSS- or OSH-based solutions should become more aware among the participants of both the PCP and PPIs, the same way as standardisation. Furthermore, it is recommended that funding requirements should be reshaped towards favoring OSS- or OSH-based instead of proprietary outcomes, because of their positive spillover effects and the potential to counter lock-in effects linked to proprietary software can be avoided for public authorities.

Finally, pre-commercial public procurement can be also one way to stimulate the start-up scene in Europe, because it might relieve in particular start-ups based on OSS of the need to offer a ‘perfect’ software product or service in order to be competitive. Moreover, once a new OSS-based product or service is procured from this target group is successfully deployed in the public sector, this serves as a demonstration for its other customer groups by offering free credentials or reputation.

Regulatory Environment

The regulatory environment has a great significance not only for the emergence of a technological system of innovations, like OSH, but also for its further development as in the case of OSS. The regulatory framework conditions impacts functions and elements in many ways. Most obviously, it has an impact on the infrastructure and framework conditions (system elements) and on the entrepreneurial activities, mobilisation of resources and market creation (system functions). It encompasses a broad variety of issues ranging from topics as outlined in the recent overview by McEntaggart et al. (2020), but also includes SME policies and access to finance to intellectual property rights (IPR). While some of these topics like the SME policy, the support of high-risk start-ups and venture capital are clearly addressed at a horizontal level, other topics like IPR can have specific issues related to software, e.g. in the discussion on changing the conditions for software patents at the beginning of the century (e.g. Blind et al. 2005).

Complementary to the governmentally set regulations, voluntary standards issued by institutions following specific WTO rules or being accredited by governmental organisations, like ministries, are the results of self-regulatory processes mainly driven by industry, but also other stakeholders, like NGOs, unions and other organisations representing specific societal interests. Europe providing level playing conditions and having a reliable and trustworthy regulatory environment has shown to increase interest by Open Source organisations and foundations, of which some have moved to Europe in 2020. Companies in Asia tend to prefer Europe-based organisations over US-based ones as the risk of exclusion is perceived to be lower. This could be leveraged to make Europe the center of Open Source development and governance in the world. Europe would profit from increased digital skills and regulatory influence on software supply chains.

Clarifying the liability regime for individual developers of Open Source Software and Hardware

High risk of liability hampers innovation, because in particular innovative products and services might be accompanied by unknown and higher levels of risk. Liability issues have been named as obstacles to use and in particular to contribute to both to OSS and in particular also to OSH, e.g. in the area of medical devices developed to tackle the challenges of COVID19.

Although the most recent report on the implementation of the EU legislation (European Commission 2018) acknowledges the challenges for product liability related to digitisation, the Internet of Things, Artificial Intelligence and cybersecurity, the role of software in general and OSS or even OSH are not mentioned. Since OSS and OSH are relevant for security issues, but also AI, they are at least indirectly relevant for product liability.

Therefore, it is recommended to increase legal security by clarifying the liability regime, e.g. in the framework of the EU legislation on liability for defective products, in particular for individual developers of OSS, but also of OSH, because the existing clauses seeking to exclude liability which can be found in almost all OSS and OSH licenses provide a false sense of security to developers. First, they are of questionable enforceability, bearing in mind both domestic legislation in Member States, and EU legislation such as the General Product Safety Directive. Second, there is no direct nexus between ownership of intellectual property and liability for its content, so it is possible that there is no opportunity for a developer to apply an exclusion clause in any event. Although it is clear that the consumer of unsafe products needs the right to claim against actors in the supply chain for loss or damage caused by that product (as exemplified by the General Product Safety Directive), it is recommended that consideration needs to be given to the extent to which it is appropriate that liability should extend to individual developers contributing to designs or code which are then incorporated into products and placed on the market. Furthermore, it should be considered whether the product is supplied to consumers, intermediaries or non-consumer entities such as business or public sector organisations.

Increasing the security level of Open Source Software

Complementary to liability regimes, which try to increase incentives for investments in safety and security issues, the allocation of resources for these activities can be publicly supported. Since Nagle et al. (2020) reveal that contributors to OSS spend very little of their time responding to security issues, but would appreciate bug/security fixes, free security audits, and simplified ways to add security-related tools for their OSS projects. Complementary, a significant share of companies surveyed in the BITKOM study state security-related advantages, e.g. the stability and low error susceptibility of OSS, through regular and timely updates. However, companies are ambivalent towards the IT security of OSS, because some of them perceive disadvantages due to security gaps and error susceptibility. Since the investments for increasing the security level of OSS might be suboptimal due a limited private willingness to pay, additional incentives to increase investments in security related efforts are needed.

In addition, OSS has become an important component of the digital public infrastructure. OSS components are used both by both the private and public sector in mission-critical functions, yet the continued security and functioning of these components is currently underfunded, representing a possible market failure. Here, the public sector has an important role to ensure that this public good remains available. The European Commission has performed first positive steps in this direction with the FOSSA bug bounty programme. Yet, this project was only a pilot project with a limited scope and budget. It is recommended to consider expanding the FOSSA bug bounty programme into a permanent facility to identify and tackle risks to widely used OSS and eventually OSH. Specifically, it is recommended to implement a safe harbour for researchers taking part in bug bounty schemes by formalising a set of template terms and conditions for the operation of a bug bounty schemes backed by legislation which ensures that those researchers provided that they adhere to the terms of the scheme, do not find themselves liable for civil or criminal proceedings under copyright or data protection law, or for unauthorised access to computer systems.

In addition, the role of OSS and OSH is currently not reflected in EU policy making. None of the recent European Commission policy initiatives on cybersecurity take into account OSS or OSH, while the benefits of using OSS and OSH as a tool to increase the level of security in products and services is clear. Among these benefits are the auditability of codes and schematics, perpetual possibility to improve and patch code, ability to fork a project to address issues and continued support and prevention of abandonware. The European Commission has made progress in increasing the share of OSS in its own or procured software. It is recommended to consider this strategy also for critical infrastructure within the private and public sector, either by incentivising or requiring increased adoption of OSS in those components.

In particular, it is recommended to consider making regular audits of critical software mandatory and provide the results publicly to ensure uptake by the development community. For companies maintaining critical infrastructure based on software, an Open Source Programme Office should be encouraged by law, in order to ensure OSS components used in the software stack are appropriately monitored and updated by the company. The European Commission could also consider the usage of marks and seals to indicate good practice maintenance of software.

Further, portions or entire components of OSS projects prone to vulnerabilities should be rewritten to produce substantially more secure results. Due to the observed underinvestment by the private sector and the positivce externalities of secure OSS, it is recommended to establish public funding opportunities for individual developers, but also for companies, which have the internal resources to perform security checks, e.g. via the funding provided for cybersecurity within the Digital Europe Programme. In addition, best practice in secure software development should be identified and promoted. Secure software development should be now included in the education programmes offered by HEIs, but also be taken into consideration in the hiring or continued professional development of OSS developers. Badging and mentoring programmes, but also the influence of respected OSS contributors should be utilised to encourage projects and their contributors to develop and maintain secure software development practices. Eventually, OSS projects should be encouraged to incorporate security tools and automated tests as part of their continuous integration of code, even as part of their default code management platform.

Improve the interface between OSS and standardisation

Although standardisation has been mentioned as an opportunity to promote OSS by Ghosh (2006), specific recommendations have not been elaborated. From Blind and Böhm (2019) it is also known that the interface between OSS and standardisation needs to be improved. The reasons are manifold. First, the governance schemes in standard development organisation (SDOs) and OSS communities are different. Furthermore, in SDOs heterogeneous stakeholders with an overrepresentation of larger and patent-holding companies are active, whereas OSS communities are typically characterised by smaller companies and also by independent software developers. Finally, the IPR regimes serve different purposes in SDOs as compared with OSS communities. However, legal compatibility is a necessary, but not a sufficient condition for possible collaborations of SDOs and OSS. Although conflicts are reported, licensing incompatibilities are in most collaborations not a relevant problem in practice (see case studies in Blind and Böhm 2019). In general, SDO and OSS communities describe their mutual interaction despite some trade-off leading to a reduced speed of development as fruitful and productive, but the collaboration is only at a very low and emerging level.

Since the relevance of standardisation has been emphasised in the context of OSS in both the interviews and the survey, those recommendations by Blind and Böhm (2019) are reiterated, for which now additional empirical evidence is available. Therefore, *it is recommended to policy makers in the Member States and the European Commission* in particular to promote OSS in addition to standardisation as a further channel of knowledge and technology transfer, e.g. as an explicit dissemination channel for Horizon Europe projects, because from the German edition of the Community Innovation Survey (Rammer 2020) it is known that OSS and OSS communities are an important source of knowledge for companies irrespective of their size. In addition, the interface between OSS and standardisation has at first to be clarified and then further promoted. For example, whereas OSS is acknowledged to be relevant for the development of Artificial Intelligence (AI), the standardisation roadmap on AI released by the German Standardisation Institute DIN does not take the role of OSS for AI in general and the interface between standardisation activities and OSS not comprehensively into account.

Promoting Open Source in European public procurement

As elaborated by Blind and Böhm (2019), in improving the effectiveness and efficiency of public procurement, governments have already looked at standards as a way of reducing the cost-of-ownership of certain products and the risk of lock-ins covered by proprietary or de facto standards. In the EU, this has led to specific measures in the area of public procurement. For example, public procurement must comply with Directive 2014/24/EC, which differentiates between formal standards and other technical specifications developed by private organisations. For the latter, a description of functional requirements and use of technology-neutral specifications is additionally encouraged. Art 23(1) of the Directive requires that "[t]echnical specifications shall afford equal access for tenderers and not have the effect of creating unjustified obstacles to the opening up of public procurement to competition". Therefore, standards should not be used in a discriminatory fashion that is unjustified by the subject matter of the contract. The key element in EU public procurement law is a requirement that public authorities procure software or other technology systems by referencing open standards (as opposed to proprietary technologies). In addition to cost savings in purchasing these standard based products, standards might reduce costs of document format incompatibility and conversion.

Whereas standards are already explicitly mentioned both in the procurement directive and in the more recent communication on making better use of standards in public procurement for building open ICT systems (European Commission 2013a), neither software in general nor OSS in particular are mentioned. However, Nagle (2019a) proves the positive impact on demand for OSS by a change in France's technology procurement policy that required government agencies to favour OSS over proprietary software in an attempt to reduce cost. This increase in contributions to OSS by French developers led to benefits for France that increased its national productivity and competitiveness by increasing the number of firms using OSS, the number of IT start-ups, and the amount of IT labour, and decreasing the number of software related patents.

Therefore, it is recommended to explicitly include OSS in public procurement policies, e.g. in updating the public procurement directive or the public procurement strategy taking into account the specific needs of OSS based SMEs (FOSS4SMEs 2019). In particular, the total cost of ownership, including exit costs and considering the added-value due to the reusability of OSS solutions, should be considered. Complementary, discussions with policy makers and practitioners in the public sector revealed the need for guidelines for public procurers how to procure OSS based products and services, which is complemented by the need to proactively pull OSS into the public sector, whereas the sales teams of classical vendors have already strong incentives in pushing their proprietary software.

The policy analysis in a number of countries such as Brazil, India, Germany, Italy and Bulgaria has shown that effective guidance for public procurement is crucial to achieve a positive implementation of any new rules. Public procurement in IT is complex and thus without this guidance, public procurement officers tend to react only slowly or not at all to evolving rules. These cases also showed the importance of fostering an Open Source culture within the organisation, in order to on the one hand implement laws, but on the other hand reap the benefits of Open Source that go further than code.

In order to promote procurement of OSS across Europe, it is recommended to develop guiding material on how to procure OSS aimed, at leveling the playing field, promote learning between national procurers, but eventually also competition between OSS based companies and other organisations, like research institutes and universities.

Considering Open Source in future revisions of European copyright and patent legislation

Although there are no significant concerns raised by the interviewees in the context of the case studies or by the respondents to the stakeholder survey, the recommendations by Blind and Böhm (2019) related to the role of OSS are not only specified, but also expanded to OSH in the context of the existing IPR framework. The current regulatory frameworks both related to copyright, but also to patents do not reflect the relevance of software as such and OSS in particular.

Therefore, it is recommended to consider OSS, but also OSH in future revisions of European copyright and patent legislation, bearing in mind that such legislation will need to be implemented within the context of binding international agreements, such as TRIPS and the Berne Convention.

OSS and OSH are available under a number of different licences and different licensing mechanisms, but the specific licensing selection cannot be influenced directly by European or national Intellectual Property law. However, possible problems can be avoided or mitigated by undertaking pro-active consultations with OSS and OSH stakeholders. There continues to be a need for EU policy makers to understand better the various differences of OSS and OSH based business models from established business models or licensing frameworks. For example, current licensing models for both OSH and OSS retain some uncertainties in scope arising from applicable copyright law, and these issues should be considered in future revisions of the recently approved Directive on copyright in the Digital Single Market. Another example, the European Patent Convention does not include a reference to software or even OSS as sources of prior art, although the interface between patents and software in general and OSS in particular is going to become more relevant with the further digitalisation of technology and industry.

In particular, it is recommended that:

- an “orphan works” provision is implemented for open source code, facilitating re-licensing code where the copyright owners cannot be traced;
- wording is included in copyright legislation excluding APIs and programming languages from the scope of copyright, following the judgment of the CJEU in SAS v World Programming (and consistent with the effect of the US Supreme Court’s judgment in Google v Oracle);
- a provision is introduced into patent law requiring that reference implementing code set out in a patent must be released under an appropriate open source licence (consistent with the the fundamental bargain underlying the patent system that the patent holder receives a limited monopoly in exchange for opening the implementation to the world, to facilitate understanding, research and study).

Exploit the synergies between Open Source and Open Data

OSS and OSH occupy overlapping domains, and the third body of open innovation, open data, interacts with both of them. The European Commission established database right as a sui generis form of intellectual property protection for certain databases, and one consequence is that databases which are subject to this right must, in order to be open data, have an appropriate licence attached to them. There are a number of open licences which are either specifically designed to apply to data, or accept that data should be included within the categories of information covered. These include the Solderpad Hardware License (Solderpad.org), the Community Data LIcense Agreements (sharing and permissive) (https://cdla.dev/) and the Open Data Commons Open Database License (ODbL) (https://opendatacommons.org/licenses/odbl/).

Open technologies in both software and hardware frequently rely on data sources to operate. This is true of machine learning algorithms, which can require large amounts of training data, and web services which rely on services such as mapping data. In fact, there is an increasing number of data sources available through APIs which are available on an open licensing model (for example, Openstreetmap is available under the ODbL and is relied on by a vast number of services).

The utility of open data may depend, to a large extent, on the ease with which that data can be reused and combined with other data, and to that end, Open standards have a significant role to play, regulating not only the format of the data in question, but also the processes that have gone into its collection, and the APIs though which it is accessed and disseminated. For example, opencorporates.com provides a unified interface to data held on companies in company registries throughout the world (nearly 200,000,000 companies) and presents them through a unified API (https://opencorporates.com/info/our-data/).

There is also an overlap between what counts as software and hardware, on the one hand, and data on the other. For example, software may rely on lookup tables associating ISO country codes with the country names, and hardware designs may include a netlist which is essentially a database listing the interconnections between components in an electronic circuit.

Finally, data has the additional challenge that it may contain personal information which creates tension between the rights afforded to data subjects over their personal data and the rights granted by open data licensing.

It is not within the scope of this report to cover this in detail, but any policy consideration or recommendation which relates to OSSH should also bear in mind the interrelationship between OSSH and open data, and ensure that the impact of the open data dimension is addressed.

Market Creation

For emerging technological systems, like OSH, but less OSS, the creation of a market is a crucial precondition, because it impacts all other functions of the innovation system, like entrepreneurial activities as well as the allocation of human and financial capital. Therefore, competitive markets are also a major source of innovation in technology and business. Consequently, significant barriers and failures affecting the creation or function of markets have to be addressed.

Considering Open Source in competition and platform policies

Since the improvement of the interface between standardisation and OSS based on previous studies has been suggested (e.g. Blind and Böhm 2019), and also confirmed by the insights from the interviews and the stakeholder consultation, this coordination approach has been expanded to competition policy in general.

Therefore, it is recommended to create a level playing field between SDOs and OSS communities to foster innovation, and encourage synergistic interaction between them. This requires creating exchanges between the evolutionary selection process in OSS communities and the formalisation within SDOs, but also may add additional obligations, like working with multi-stakeholder platforms or OSS communities to follow to minimal obligations related to governance norms, e.g. following WTO principles, that support the long-term viability of the OSS development model. This is in line with a recommendation by Nagle et al. (2020) to transfer OSS projects to foundations with neutral governance to ensure diversity of organisations and control of influence. If OSS foundations become dominant platforms, they have the responsibility to ensure that their rules do not impede free, undistorted, and vigorous competition according to the recommendations proposed by Crémer et al. (2019). Since, meanwhile half of the developers surveyed by Nagle et al. (2020) are paid by their employer to contribute to OSS, there are also concerns related to the consequences on competition.

Policy makers have provided substantive guidance on the legal boundaries and requirements applicable to the substance of IPR policy choices of SDOs with the safe harbour approach defined in the guidelines to horizontal co-operation agreements (European Commission 2011). No such guidance exists with regard to OSS communities, in particular of the role of OSS and OSH umbrella organisations. It is recommended to investigate at first the need for such requirements, which might be limited by the constant threat of forking, and then eventually developing specific requirements for horizontal co-operation to be applied for OSS and OSH communities, in particular foundations.

Therefore, it is recommended to explicitly consider Open Source in competition and platform policies. For example, Open Source was not mentioned in the last edition of the annual report on competition policy. The proposed Digital Services Act's broad set of objectives means that many different kinds of services fall within its scope. The OSS community relies heavily on platforms that allow developers to collaborate, by developing, reusing and sharing software. These platforms may be relevant for certain elements of the Digital Service Act and it is recommended to the co-legislators to consider Open Source stakeholders (both users and providers of these services) and gather their input so as to understand how the proposed rules may achieve their intended objectives, as well as avoid unintended consequences for software development.

Since, in particular, AI is an important technology affecting the development and growth of many digital markets and platforms and - as revealed by the stakeholder survey - OSS is used in the context of AI, the role of OSS should be acknowledged in the competition-related approaches towards AI. For example, OSS is not an obstacle, but rather a facilitator for companies to enter competitive markets also based on AI. However, the large platform providers challenging competition policies and authorities also make use of OSS contributions for the development of software they use for developing their platform architectures and ecosystems. Consequently, Open Source has a multi-faceted role for competition. Therefore, it is recommended to explicitly consider Open Source in the further discussion and development of competition policies in general and platform policies in particular. Consideration can be given to excluding from the ambit of Article 101 of TFEU arrangements between entities provided that they have as their primary aim the development of OSSH and they meet a set of basic requirements for transparency, openness and participation.

Considering Open Source explicitly in SME Policies

Complementary to these rather new developments in the competition in digital markets, it is recommended to consider Open Source in SME policies, as many contributors to Open Source are micro companies and SMEs. However, according to the stakeholder survey, the smaller companies are, the more they benefit from OSS, whereas Nagle (2018) reveals the positive productivity effects for companies contributing to OSS being biased strongly to larger companies. Therefore, there is a strong economic rationale to support more SMEs and micro companies related to an involvement in OSS communities, but not necessary to their entry, since the entry barriers are low. This is not necessarily the case so far as OSH is concerned. It is recommended a systematic approach to supporting OSS- and OSH-based SMEs and micro companies following the ten principles of the EU's Small Business Act for Europe (SBA), which provides a wide range of pro-enterprise measures to guide the design and implementation of SME policies.

The pillars of the SBA are:

- Responsive government: Is the overall operational environment conducive to business creation and risk-taking? Is the framework for SME policy responding to the needs of small and medium entrepreneurs?

- Entrepreneurial human capital: is the formation of entrepreneurship key competence and the development of SME skills part of the public policy setting? It is approached in a gender-sensitive way, supporting women's entrepreneurship?

- Access to finance: How available is external financing for start-ups and SMEs? Have specific policy instruments been introduced to make it easier and cheaper for small entrepreneurs to obtain funds to start and grow their businesses?

- Access to markets: Are SMEs able to sell their products and services to clients in domestic and foreign markets? Can public policies make it easier for small entrepreneurs to enter new markets?

- Innovation and Business Support: Can SMEs obtain advice and technology to remain competitive and increase their productivity? Is the government fostering a more innovative SME sector?

Within the public policy analysis, success cases and failures have been observed in the public sector's attempts to support the SME sector. Successful examples can be seen in India until the mid 2000s and France, where a supportive regulatory environment, public procurement and government protection enabled significant SME growth and scale. Yet, in all cases the effect remained limited, as international growth requires global competitiveness and governments' willingness to shield the domestic market from international entrants is typically shown itself to be limited. Cases such as Brazil and India from the mid 2000s show a domestic software sector that decayed in the face of international competition.

d. The next revolution: Open Source Hardware

In addition to the recommendations around liability, made above, which are similarly applicable to OSH and OSS, there are other potential inhibitors in development of OSH. A lack of consistency is noted across the patent systems in the EU in their treatment of exemptions for the implementation of patented inventions in the course of research, for non-profit activities, or for personal use.[21] This may impact OSH development in areas as diverse as 3D printing and silicon design. The cost of determining whether any particular activity is subject to patent protection is notoriously expensive and uncertain, and our direct recommendation is that steps are taken to harmonise the exemptions throughout the European Economic Area to provide a safe harbour for actors who may potentially infringe patents (often inadvertently) in research, for non-profit activities or for personal use, while recognising the rights of patent holders to benefit from their legitimately-granted monopoly in a commercial context.

The interaction between Open Source technologies and regulation is complex, especially where safety is concerned. In theory, at least, in the domain of software, it is possible for an actor wishing to make use of an Open Source project in the regulated domain, to take every component of the code, obtain its source code, and review that code for any bugs, errors or vulnerabilities. Thus, if software malfunctions in a car, aeroplane, pacemaker or cell tower, it is possible to re-build and trace the potential source of the error, whether it is in the software itself, or in the toolchain used to create it, should all be Open Source. Software is made of 1s and 0s. Hardware is made of atoms, and any hardware design (open or not) will consist of components (for example, capacitors, chips, screws, bearings) described at a much higher level of abstraction (Katz 2012). This means that an OSH design is not as easily replicable as an OSS design, because each of the individual components may themselves need to be traced to locate the source and cause of the defect.

Regulators will typically place the onus on an organisation seeking to deploy a product or place it on the market to obtain a certification for it covering specific aspects of its design and performance. This certification is typically expensive and tends to mean that only larger organisations are able to participate in the process. This creates a barrier to entry both for small organisations and to Open Source communities. It makes it difficult for Open Source Hardware companies to participate in this context, both because of the costs involved, but also because the release early, release often methodology of Open Source is often incompatible with the certification process. It also inhibits entities from experimenting and modifying certified products for fear that the experimentation will bring the product outside the scope of the certification.

[21] https://www.wipo.int/edocs/mdocs/scp/en/scp_15/scp_15_3-annex1.pdf

While it is certain that consumer safety and environmental factors are of paramount importance, it is recommended to fund a project to develop innovative regulatory mechanisms (such as the approaches being considered in relation to white space spectrum deployment).[22] The areas of regulation to be considered should include medical, radio frequency and automotive.

It is noted that a barrier to the development of Open Source projects is the availability of tooling, both in the physical sense (e.g. mills, lathes, presses, workspaces) and in the digital sense (e.g. design software, compiler toolchains, simulators, debuggers). In the world of Open Source Software, much of the tooling is either now itself Open Source Software (and therefore available free of charge), or is available at very low cost (e.g. Apple's XCode development environment). In the world of open hardware, the same is not true. As noted below, for silicon design, much of the software required to design, simulate and test the silicon is proprietary and expensive, but this is still activity which can take place in the digital domain, and there are increasing moves to make Open Source toolchains available. However, for physical items, there is no avoiding the necessity at some point in the development cycle to make the physical entity in question. Although for some very simple and small items 3D printing may allow rapid prototyping, there may be a need for the availability of services which enable simple items to be rapidly fabricated as a service either as a one-off or in small volumes. In the domain of printed circuit boards, for example, such services exist throughout the EU, but the most advanced of these operations are based in China, mainly Shenzhen, and examining ways in which these and similar services can be developed should be a policy goal.

In line with the previous recommendation, fablabs and makerspaces can play a role in lowering the barriers to development of open hardware by making tooling available to a wider range of individuals. Alongside this come important roles in knowledge and skills transfer and community.

The development of centres of excellence consisting of partnerships between academia, research institutions and the private sector can deepen much of the excellent work which is already being undertaken in the EU in the area of open hardware, by both promoting research, development and knowledge transfer of the technologies themselves, but also by attracting and developing skills, and investigating which modes of co-operation can be most effective, as well as normalising open development methodologies. The UK has recently confirmed it wants to accelerate its UK ARPA programme, itself based on the original US project of that name, but also emulating the success of public private partnerships along a model similar to that used in the USA for space (e.g. SpaceX) and potentially for fusion power. One area of research in Open Source Hardware which could be investigated is that development of a standardised intermediate language for silicon chip development. It has been noted that development in chip technologies has been inhibited by the heavy involvement of incompatible proprietary languages promoted by the various EDA (Electronic Design Automation) companies (although Verilog does act as a low level standard). The implementation of a single intermediate language (which subsequently compiles to Verilog) would present an opportunity not only for designs to interoperate more freely, but for this to operate as a platform for greater language abstraction. It would also allow the development of more advanced applications of FPGA technology, such as systems which dynamically reconfigure their FPGAs in real time. Europe has a number of successful and innovative open silicon initiatives (e.g. OpenCores and OpenRISC), but the innovation tends to be

22 https://www.researchgate.net/publication/224244913_TV_White_Space_standardization_and_regulation_in_Europe, https://www.europarl.europa.eu/EPRS/EPRS-Briefing-554170-Radio-Spectrum-FINAL.pdf

further commercialised in the USA and China, and a centre-of-excellence initiative would tend to reduce this leakage of European innovation and encourage digital autonomy.

e. Domain specific recommendations

Complementary to the general recommendations derived from the functions of the innovation system, also a set of policy recommendations is derived for several domains based on the results of the different analyses.

Artificial Intelligence

The digital transformation of the economy and society is progressing very rapidly. In this context, artificial intelligence (AI) is gradually emerging as a general-purpose technology that could have far-reaching effects in several sectors and cause radical changes in value chains and business models. As revealed by our analyses, micro and small companies have no problem entering these new AI dominated markets and make significant contributions to OSS, which is also an option for OSS based AI. Furthermore, the agility of the OSS based development process allows both a fast and low-cost implementation of AI solutions independent from vendors having a large market power. Finally, OSS solutions can provide the often called for transparency of the AI relevant software. In order to exploit these opportunities, it is recommended and Member States to provide funding opportunities for OSS developers, but also companies, e.g. via the Digital Europe Programme. However, so far the AI related documents published by the European Commission, e.g. the White Paper (European Commission 2019) do not mention the potential of OSS for the further development of AI. Further, it is recommended to consider provisions in EU Copyright and database legislation (along similar lines to those recommended for APIs and programming languages above) clarifying the extent to which models developed by deep learning systems can be subject to intellectual property protection, and the extent to which pre-existing bodies of material can be used to train AI algorithms. Existing text and data mining provisions fail to recognise that such activities frequently make use of the dataset at a very high level (being not so much concerned with the content of the dataset, but the relationships between items within them, and that a category of access and analysis is exempted from the necessity to obtain a licence, even for commercial purposes). Similarly, the scope of protection for computer-generated works should be harmonised across Member States, with a view to avoiding anomalies such as the copyright in a work generated by software outlasting the copyright term of the underlying software which generated it.

High Performance Computing

High performance computing operates at the edge of technological advancement, and in addition to the role of open hardware and software in the datacentres which house HPC technology, at a more fundamental level, Europe must compete with the EDA (electronic design automation) companies and silicon foundries based mainly in the USA, China and Taiwan. The importance of both FPGAs and ASICs in cutting-edge areas of HPC such as neural nets highlights this. There is an opportunity for the EU to take the lead in silicon chip design languages, but this is inhibited by the fact that the chips on which these design languages are implemented are generally manufactured overseas. FPGAs are increasingly becoming hybrid devices, containing a dedicated ASIC portion with functionality such as a processor cores, combined with a general purpose FPGA array. These chips are themselves largely designed and manufactured overseas, and research should be undertaken into what the effects of this reliance on overseas technology currently has on innovation, autonomy and economic activity within the EU, and how those factors can be improved.

Specifically, it is recommended to launch a standard request (mandate) to the European standardisation bodies to develop a European standard of a bitstream format to decrease reliance on individual vendors of specific FPGAs, and ways to increase innovation in the development of the underlying FPGAs (as opposed to the code used to configure them).

Software defined infrastructure

Interviewees from our case study research indicate that differentiation in communications infrastructure is tending to move from hardware to software. In other words, there is a trend towards generic hardware which can be configured using gateware and software. A network device which consists of a number of a network interfaces and a microprocessor based controller which defines the protocols and data flows implemented by and between the interfaces can be dynamically configured to act as any number of network interface devices such as routers, switches, multiplexers and so on. This principle can be extended to other devices, such as servers and even, with the implementation of software defined radio, wireless communications. Thus a single device can be configured to act as a 3G or 4G base station, and, with the correct software, firmware and gateware, even 5G and, potentially, as yet undefined standards such as 6G. The advantages of this commoditisation include capital cost reduction, decreased maintenance costs, the ability to provision new technologies remotely without physically swapping out the hardware, ease of deployment and maintenance in remote and harsh environments, ease of addressing vulnerabilities and bugs, reduced environmental impact (by embracing reuse of appropriate components and the circular economy).

Projects such as the Open Compute Project and MyriadRF exemplify this approach. In common with many open hardware projects, the hardware elements (i.e. the physical circuitry) are designed in a traditional closed design team and then released to the world, under a form of open (or, in the case of the Open Compute Project, quasi-open) licence, when the initial design is ready for deployment, Stirling and Bowman (2020), define this as the Open When Ready (OWR) model. However, the software is typically developed using a classic Open Source model (defined by Stirling and Bowman as ODH: Openly Designed Hardware). The Bazaar model (Raymond 1999) applicable to Open Source Software, is equally applicable to ODH, and, in contrast to OWR, allows the full power of distributed collaborative development to emerge. As the hardware allowing the implementation of software defined infrastructure becomes more commoditised, and the functionality and differentiation moves into software, this means that the Bazaar model starts to become increasingly applicable. Further, although components such as processor cores are widely regarded as hardware, where they are implemented in FPGAs, the code implementing them (written in a hardware description language) becomes amenable to the Bazaar/ODH model of development (this was noted by our interviewee for the MyriadRF project, and there are distinct communities, operating in different modes, around the hardware, the FPGA code ("gateware") and the firmware/software). Thus our policy recommendations recognise that OSSH lie on a spectrum between softwareness and hardwareness, with gateware lying close to software on that spectrum, with the consequence that recommendations for Open Source Software will also apply to Open Source Hardware, especially where the hardware in question lies on the software end of the soft/hard spectrum.

The implications for this sector are that, as the functionality of hardware becomes more defined by software (including firmware) and software-like hardware code (gateware), the improved efficiencies and opportunities arising from the Bazaar/ODH model apply and therefore many of the policy recommendation applicable to Open Source Software also apply to those forms of hardware, such as gateware, which are amenable to the Bazaar/ODH model.

It is recommended that any policies adopted around OSS recognise that they may be equally applicable to OSH, particularly OSH which lies towards the software end of the hardwareness spectrum. In particular, these policy recommendations would include those already made in this report as follows:

- the establishment of an OSPO or network of OSPOs
- Intellectual Property Rights recommendations
- procurement recommendations
- liability recommendations.

f. Sustainability

The negative impact of the ICT sector on emissions and other measurements of climate impact has become more apparent. At the same time, digitalisation holds the potential to contribute significantly to the sustainability of our societies. Specifically, OSSH have an indirect impact on the consumption of resources, for the simple reason that they discourage the duplication of effort. When developing OSSH, industry agrees on common components in software and hardware that can be reused. In software, this leads to reduced effort which is necessary for digitalisation, thus achieving earlier positive externalities of digitalisation. In hardware, shared open source components could be produced in highly optimised processes, thus reducing the environmental impact. As an engine of commoditisation, both OSH and OSS result in moving the differentiation motivation higher up the value chain.

The Open Compute Project demonstrates that applicability of OSH characteristics into the hyperscale server and data centre sector makes it easier for the purchasers of data centre infrastructure to demand increased standardisation, lower power consumption and the ability to recycle components such as power supply units.

Software components available under an OSS license can be adjusted to increase compatibility and work with existing hardware, thus reducing the need to replace hardware purely on incompatibility basis. For most use cases in ICT, the performance requirements for hardware are not cutting edge. Using OSS has shown to enable the continued use of hardware components in areas where such requirements are low well beyond their intended lifecycle and thus reduce obsolescence. This approach would reduce usage of raw and rare materials.

Similarly, software defined infrastructure technology, which is facilitated by open technologies (see section above) has the potential to allow individual hardware units to be repurposed for multiple purposes, thus not only reducing Waste Electrical and Electronic Equipment (WEEE), but also allowing in-place hardware configuration and reducing the environmental footprint of transporting the equipment and deploying personnel.

Where suppliers are required to continue to provide maintenance services and spares, the release of design materials and source code for software can relieve them of that requirement in appropriate circumstances. In the case of firmware, this would likely be a licence with the characteristics of GPL-3.0, which guarantees to the consumer the ability not only to access the source code, modify it and re-compile it with modifications, but for many devices, provides the information necessary to re-install the firmware once recompiled. Such availability would facilitate the growth of re-use markets.

Open source designs could also be utilised to increase transparency of products in regard to their energy usage in production and during use. A transparent market allows producers to charge more for sustainable products, as customers who are aware of the negative environmental externalities of ICT, will be better positioned to recognise and select 'green' and upgradable products and services, thus avoiding adverse selection.

Designs that are open source would also increase the ease of (automated) disassembly and thus conditions for recycling. Transparency of the designs would enable the analysis of exact steps necessary to disassemble a product while reducing e-waste and increasing the recyclability of products.

Therefore, additional funding in support of OSSH projects is recommended, if they provide supplemental “green” benefits. The following specificactions are recommended:

- Support the initiatives established under the “right to repair” banner, by implementing maintenance and repairability requirements, which could be satisfied through the release of design materials and source code under an appropriate OSSH license. Companies unable to provide maintenance and repairability themselves could, through this measure enable third parties to increase the lifetime of their software and hardware products;

- Take into account existing OSSH solutions when digitising processes and products, in order to minimise the effort and time needed to reap the positive externalities of digitalisations;

- Support the commoditisation of software and hardware components under an OSSH license;

- Use the release of design materials and source code to increase the transparency of products, in order to enable customers to make more informed choices about the environmental impact of their purchases;

- Mandate the release of design materials and source code for products that have reached their end of life to enable the continued support by third parties and improve the recyclability of these products;

- Implement research to further analyse the impact of OSSH on the circular economy, with particular emphasis on establishing its environmental footprint, including energy usage and reduction of waste, with a view to best targeting policies to those areas of OSSH most likely to have the best impact.

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11. Acronyms

AGPL: Affero General Public License

AI : Artifical Intelligence

API : Application Programming Interface

ARM : Advanced RISC Machines

ARPA : Advanced Research Projects Agency

ASIC : application-specific integrated circuits

BE : BetterEvaluation

BSD : Berkeley Software Distribution

CAGR : compound annual growth rate

CC-BY-SA : Creative Commons Attribution-ShareAlike

CERN : Conseil Européen pour la Recherche Nucléaire

CII : Computer-implemented inventions

CNC : Computerized Numerical Control

COCOMO: Constructive Cost Modell

COSS : Commercial Open Source Software

COTS : commercial off-the-shelf

CPU : central processing unit

CRM : Customer Relationship Management

CSS : Closed Source Software

DG CONNECT : European Commission Directorate for Communications Networks, Content and Technology

DIGIT : European Commission Directorate General for Informatics

DIY : Do It Yourself

DOLS : Dynamic OLS

EC : European Commission

ECI : Economic Complexity

EDA : electronic design automation

EEA : European Economic Area

EFTA : European Free Trade Association

EIC : Enhanced European Innovation Council

EIF : European Interoperability Framework

EOSC : European Open Science Cloud

EQF : European Qualifications Framework

ERASMUS : EuRopean Community Action Scheme for the Mobility of University Students

ERP : Enterprise Resource Planning

EU : European Union

EUIPO : European Union Intellectual Property Office

EUPL : European Union Public Licence

EUR : Euro

EUROSTAT : European Statistical Office

EXGR : Gross exports

FE: Fixed effects

FOSH : free and Open Source Hardware

FOSS : Free and Open Source Software

FPGA : Field programmable gate array

GCC : GNU Compiler Collection

GDP : Gross Domestic Product

GDPR : General Data Protection Regulation

GPL: [Gnu] General Public License

GPU : Graphics Processing Unit

HDL : hardware description language

HEI : Higher Education Institution

HPC : High Performance Computing

HTTP : HyperText Transfer Protocol

ILO : International Labour Organization

IMF : International Financial Statistics

IoT : Internet of Things

IP: intellectual property

IPR : intellectual property rights

ISA: Instruction Set Architecture

LCC : Life Cycle Costing

LGPL : Lesser [formerly Library] General Public License

LP : Labour Productivity

LUG : Linux User Groups

MBA : Master of Business Administration

METI : Ministry of Economy, Trade and Industry

MFF : Multiannual Financial Framework

MFP : Multifactor Productivity

ML: Machine Learning

NACE 2 : Statistical Classification of Economic Activities in the European Community

NGI : Next Generation Internet

NGO : Non-governmental organisations

ODH : Openly Designed Hardware

OECD : Organisation for Economic Co-operation and Development

OLIS : Open Source License Information System

OSD : Open Source Definition

OSH : Open Source Hardware

OSOR : Open Source Observatory

OSPO : Open Source Programme Office

OSS : Open Source Software

OSSH: Open Source Software and Hardware

PCB : printed circuit boards

PCP : Pre-Commercial Procurement

PPI : Public Procurement of Innovative Solutions

PSI : public sector information

PSS : product-service systems

RHEL : Red Hat Enterprise Linux

ROI: Return on Investment

SAAS : Software as a Service

SDG : Sustainable Development Goals

SDO : standards development organisations

SME : Small and Medium Enterprises

SQL : Structured Query Language

STEM : science, technology, engineering and mathematics

SWOT : Strengths, Weaknesses, Opportunities, and Threats

TCO : Total Cost of Ownership

TFLOPS : One Trillion Floating Point Operations Per Second

TFP : Total Factor Productivity

TRIPS : Agreement on Trade-Related Aspects of Intellectual Property Rights

UNESCO : United Nations Educational, Scientific and Cultural Organization

VC: Venture Capital[ist]

WDI : World Development Indicators

WTO : World Trade Organization

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13. Annex to Econometric Analyses

Table A.1: Impact of OSS Commits on Total Factor Productivity (FE)

	(1) All	(2) EU	(3) Other
Log capital stock	-0.05641***	-0.06962***	-0.08843***
	(-2.73)	(-2.70)	(-2.93)
Log employment	-0.48225***	-0.50659***	-0.65485***
	(-6.99)	(-6.60)	(-4.63)
Log payments for use of IP	0.02068***	0.01993**	0.06314***
	(2.61)	(2.28)	(3.45)
LD.Log R&D expenditures	0.02739	0.05371	-0.25160**
	(0.75)	(1.41)	(-2.18)
LD.log R&D expenditures by ROW	0.67581***	0.87039***	-0.13109
	(3.56)	(4.01)	(-0.43)
D2.Log transnational patent applications	0.01525***	0.01868***	-0.00192
	(3.94)	(4.36)	(-0.26)
D.Log GitHub commits	0.00982**	0.01079**	-0.01177
	(2.30)	(2.42)	(-0.90)
D.Log GitHub commits by ROW	-0.13455***	-0.17187***	0.03026
	(-8.21)	(-9.26)	(0.99)
Constant	8.48179***	9.01494***	12.27003***
	(7.26)	(6.68)	(5.23)
Observations	576	457	119
R^2	0.253	0.323	0.274
N_g	34	27	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Impact of OSS Contributors on Total Factor Productivity (FE)

	(1) All	(2) EU	(3) Other
Log capital stock	-0.08459***	-0.11114***	-0.10241***
	(-3.94)	(-4.12)	(-3.25)
Log employment	-0.49663***	-0.52746***	-0.65538***
	(-6.90)	(-6.44)	(-4.68)
Log payments for use of IP	0.01744**	0.01808*	0.06830***
	(2.10)	(1.94)	(3.72)
LD.Log R&D expenditures	0.01326	0.03574	-0.29883**
	(0.35)	(0.88)	(-2.58)
LD.log R&D expenditures by ROW	0.33022*	0.44746*	-0.12728
	(1.66)	(1.93)	(-0.43)
D2.Log transnational patent applications	0.01041**	0.01306***	-0.00078
	(2.46)	(2.74)	(-0.10)
D.Log GitHub contributors	0.00978	-0.00003	0.04964*
	(0.64)	(-0.00)	(1.89)
D.Log GitHub contributors by ROW	-0.07896***	-0.09163***	-0.04213
	(-3.48)	(-3.56)	(-1.03)
Constant	9.54002***	10.48084***	12.57817***
	(7.88)	(7.35)	(5.38)
Observations	576	457	119
R^2	0.187	0.230	0.294
N_g	34	27	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Impact of OSS Commits on Multifactor Productivity (FE)

	(1) All	(2) EU	(3) Other
Log capital stock	-0.08459***	-0.11114***	-0.10241***
	(-3.94)	(-4.12)	(-3.25)
Log employment	-0.49663***	-0.52746***	-0.65538***
	(-6.90)	(-6.44)	(-4.68)
Log payments for use of IP	0.01744**	0.01808*	0.06830***
	(2.10)	(1.94)	(3.72)
LD.Log R&D expenditures	0.01326	0.03574	-0.29883**
	(0.35)	(0.88)	(-2.58)
LD.log R&D expenditures by ROW	0.33022*	0.44746*	-0.12728
	(1.66)	(1.93)	(-0.43)
D2.Log transnational patent applications	0.01041**	0.01306***	-0.00078
	(2.46)	(2.74)	(-0.10)
D.Log GitHub contributors	0.00978	-0.00003	0.04964*
	(0.64)	(-0.00)	(1.89)
D.Log GitHub contributors by ROW	-0.07896***	-0.09163***	-0.04213
	(-3.48)	(-3.56)	(-1.03)
Constant	9.54002***	10.48084***	12.57817***
	(7.88)	(7.35)	(5.38)
Observations	576	457	119
R^2	0.187	0.230	0.294
N_g	34	27	7

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Impact of OSS Contributors on Multifactor Productivity (FE)

	(1) All	(2) EU	(3) Other
Log payments for use of IP	0.02022	-0.00089	0.06190
	(0.12)	(-0.00)	(0.18)
LD.Log R&D expenditures	-0.57500	-1.43856	6.38451*
	(-0.31)	(-0.66)	(1.79)
LD.log R&D expenditures by ROW	-2.95279	-4.25354	0.39727
	(-0.49)	(-0.57)	(0.04)
D2.Log transnational patent applications	0.28569**	0.31778*	0.09564
	(2.06)	(1.89)	(0.40)
D.Log GitHub contributors	0.21704	0.73846	-3.20867***
	(0.40)	(1.18)	(-2.80)
D.Log GitHub contributors by ROW	-2.56735***	-3.19163***	1.55110
	(-3.51)	(-3.73)	(1.04)
Constant	1.06076	1.48165	-0.09485
	(0.28)	(0.34)	(-0.01)
Observations	357	255	102
R^2	0.120	0.136	0.181
N_g	21	15	6

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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