World of
Open Source

Open Source Innovation as a Potential Lever for Economic Recovery

Insights from a Linux Foundation Challenge Session
at the 9th World Open Innovation Conference

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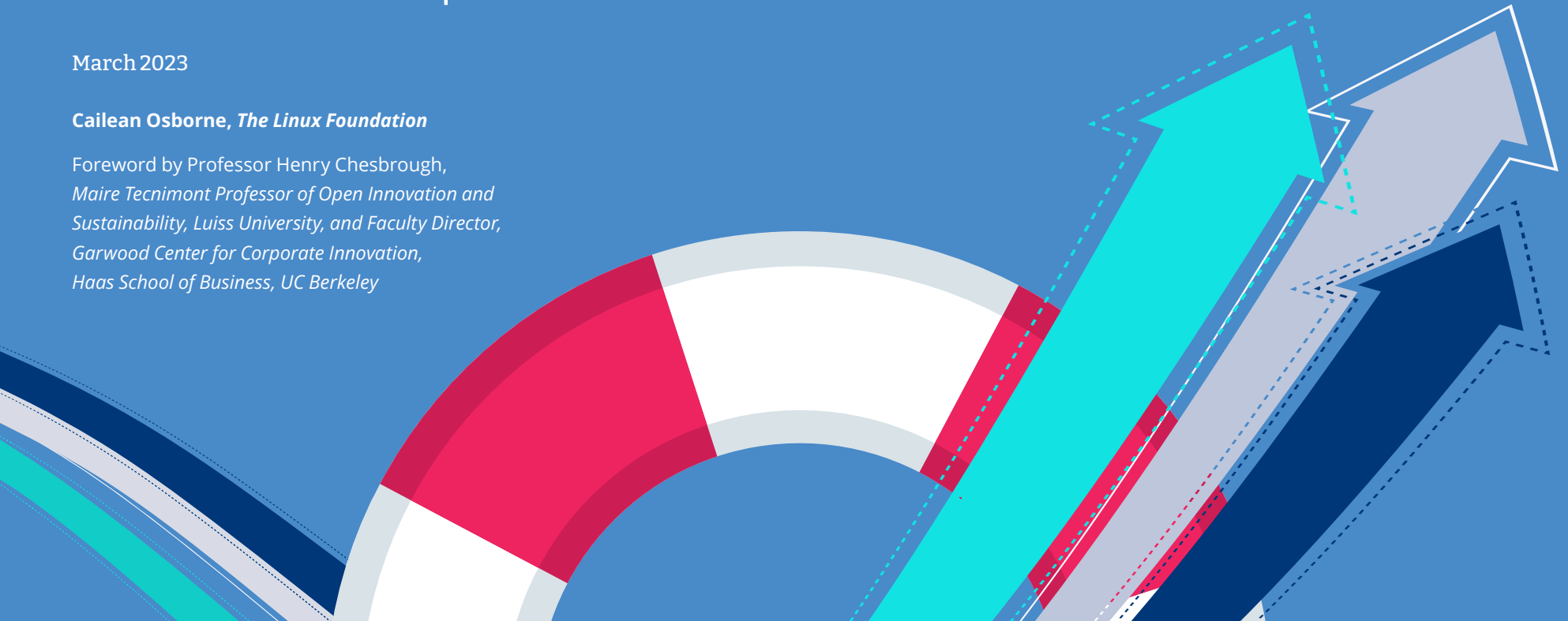
Open Source Innovation as a Potential Lever for Economic Recovery

Open source software is a low-cost, high-quality alternative to closed source software for digital innovation, especially during an economic downturn.

Open source has financial and efficiency benefits, as well as longer-term organizational benefits.

Open source innovation may have the greatest impact in developing economies by enabling new modes of economic participation.

Open source supports the development of **cost-effective public service delivery solutions** and tackles long-standing vendor lock-in problems.

Institutional barriers, such as lack of leadership, policies, and investment, are holding back the potential of open source in the public sector.
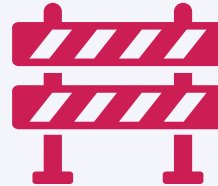
Education about the benefits of open source innovation is needed to scale open source participation across society and the economy.
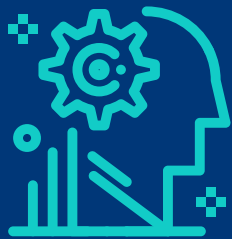
Open Source Program Offices help to encourage an "open source mindset" within organizations.

Open source is a key part of our global digital infrastructure. Like any type of infrastructure, we need to invest in its development, maintenance, and security.
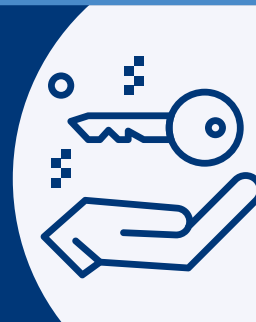
Organizations from various sectors should work together to fund the open source communities building and maintaining our digital infrastructure.

Open source innovation is an effective approach to building shared solutions to global problems.

Organizations that benefit the most from open source software should reciprocate their fair share to open source communities in order to ensure their sustainability.
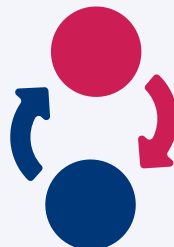
Companies can support open source communities in many ways, including funding or encouraging their employees to contribute during working hours.

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Foreword

Over a year ago, Hilary Carter, SVP for Research & Communications at the Linux Foundation (LF), contacted me about engaging with the LF. The LF has been driving the Linux kernel specifically, and open source software (OSS) more generally, for more than two decades. That led to a series of activities over the past 12 to 14 months that have culminated in this report, based on a challenge posed at the recently concluded World Open Innovation Conference (WOIC). The WOIC started eight years ago in 2014. While the participants in the WOIC were generally aware of the LF, there was little interaction between these groups until the ninth meeting of the WOIC that took place at the Technical University of Eindhoven (TU/e) in November of 2022.

It will help readers of this report to know a little more about the context for this challenge at this conference. The plan for the WOIC was to bring scholars who studied innovation (and open innovation in particular) in closer contact with one another AND with organizations that were using open innovation in their work. This connection between theory and practice is sometimes tenuous in the study of innovation, as academics can trap themselves in their own siloes, while people in the industry also find it hard to access academic research.

The WOIC was a sincere effort to create a meeting space where both sides could engage readily with one another. Our hypothesis was two-fold: 1) that academic scholars had much to learn from organizations engaged in leading-edge open innovation practices and 2) that busy managers would benefit from being exposed to some of the cutting-edge research being conducted on open innovation.

When Hilary Carter reached out to me, I immediately realized that the LF was an organization that should be much better known by my fellow scholars. While the early days of Linux are generally known and appreciated, many of my colleagues (and I, for that matter) were not well aware of its current activities, nor did we understand the scope of its impact. For these reasons, Hilary and I proposed a challenge session to the organizers of this year's WOIC, led by Prof. Marcel Bogers and his team at TU/e.

This report contains the results of this challenge session. In my personal view, these results strongly validate both aspects of the above hypothesis. More generally, the LF and OSS are now playing an increasingly vital role in the development of technology and innovation. And, as many of the OECD economies face the prospect of a significant recession in 2023, that may provide an impetus to further adoption and use of OSS as a cost-effective response to shrinking budgets.

The second part of the hypothesis will not be fully tested until there has been enough time for those who participated in the challenge session to update their own research plans to incorporate more open source technology into those plans. But the LF received some useful insights during the challenge session based on existing research findings.

Perhaps the most salient insight in my mind was the opportunity to link the advance of OSS (and an open innovation mindset) to pursuing global grand challenges, as exemplified by the Sustainable Development Goals.

I am hopeful that this challenge and report will form the basis for further community engagement and interaction. We have much to learn from one another, and we are pursuing quite similar social objectives and outcomes from our work.

Professor Henry Chesbrough
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Executive summary

On November 15 and 16, 2022, the 9th Annual WOIC convened experts from academia, industry, and government in Eindhoven, the Netherlands, on the topic of "The Human Side of Open Innovation."[1] The Linux Foundation led a challenge session on "Open Source Innovation as a Potential Lever for Economic Recovery." As digitization is an attractive strategy to combat economic pressures, Hilary Carter of the LF invited participants to discuss the role that OSS could play during the current economic downturn. Carter made the case that organizations across sectors should consider several benefits presented by OSS when they design and invest in their digital strategies. This report summarizes the primary takeaways from the roundtable discussions:

1. **OSS is a low-cost, high-quality alternative to closed source software for digital innovation:** By adopting OSS, organizations in the public and private sectors can reduce costs when their budgets are shrinking. OSS should thus be an attractive choice when organizations plan and implement their digitization strategies. However, participants acknowledged that OSS does not come "off the shelf," and often organizations struggle to "package up" OSS into high-performing digital products or services, which requires in-house technical expertise, investments, and OSS-friendly policies, amongst others.

2. **OSS has potential in the public sector but faces many institutional barriers:** OSS can support the development of cost-effective solutions for public service delivery and tackle vendor lock-in problems. However, common roadblocks to OSS adoption in government include the lack of OSS leadership, OSS policies, investment, and technical expertise. It will require a combination of technical expertise, cultural shifts, and investments to realize the potential of OSS in the public sector. The establishment of Open Source Program Offices (OSPOs) can be an effective way to facilitate OSS cultures in the public sector.

3. **OSS is digital infrastructure, and we must invest in it:** OSS is a key part of our global digital infrastructure that anyone can use, modify, and innovate on top of. Like any type of infrastructure, we need to invest in its development, maintenance, and security. Since the challenge session, think tanks across Europe and North America have made similar arguments about the urgency of funding OSS as digital infrastructure. The German government's Sovereign Tech Fund,[2] Open Tech Fund's FOSS Fund[3], and the E.U.'s Next Generation Internet initiative[4] are promising policy developments in this direction.

4. **We should build more OSS as shared solutions to societal problems:** OSS can be an effective approach to developing shared solutions to societal and environmental problems. One area may be climate technology, considered a "recession-proof" domain of the technology sector, which in 2022 received more venture capital investment than in previous years, and it has support from government budgets, such as the new U.S. climate bill. This represents a major opportunity for OSS developers to build and share OSS in the common interest of tackling climate change.

5. **Education will be key for scaling open source participation and adoption:** A key roadblock to increasing participation in open source amongst organizations, which are not already active adopters or contributors to OSS, is a lack of institutional knowledge about how to get involved in a manner that is cybersecure, sustainable, or beneficial. There is a need for education about the economic value and security of OSS and more broadly the "open source mindset" to increase open source participation. The establishment of OSPOs can be an effective way to facilitate such cultural shifts within organizations.

6. **Companies must reciprocate their fair share to OSS communities to ensure their sustainability:** There is widespread concern amongst developers that companies disproportionately benefit from OSS without adequately reciprocating to the developer communities. Participants highlighted the need for companies to provide adequate levels of support to the OSS projects that they rely on and benefit from. Companies can support OSS projects in many ways, from sustained funding to technical contributions.

Introduction

Economic uncertainty abounds, as a third of the global economy is expected to be hit by recession in 2023 in the wake of rising energy prices, high inflation rates, and waves of layoffs taking hold across sectors. Economists suggest that investing in innovation can be a strategic opportunity during the economic crisis and, according to commentators, decision-makers in the public and private sector are designing digital innovation strategies to navigate the current economic climate. In light of this context, the LF advocates that open source innovation presents a number of benefits and opportunities. However, as such a view is to be expected from an organization whose remit is to support open source collaboration, delegates from the LF Research team sought to test our assumptions with an audience of innovators, academics, and practitioners who specialize in open innovation. Given the current climate, there was no better time to solicit expertise on whether, how, and why our assumptions on open source as a potential lever for economic recovery and resilience would be validated.

On November 15 and 16, 2022, the ninth Annual WOIC convened experts from academia, industry, and government at the High Tech Campus in Eindhoven, the Netherlands, to exchange insights on "open innovation."[5] The conference focused on "The Human Side of Open Innovation,"[6] including keynotes, panels, and challenge sessions on topics ranging from the value of OSS to the measurement of open innovation. Hilary Carter and Cailean Osborne from the LF's Research team led a challenge session on "Open Source Innovation as a Potential Lever for Economic Recovery," where stakeholders from startups, multinational corporations, academia, and various governments discussed the role that open source innovation could play as a potential lever to stimulate recovery and resilience during the current economic downturn. This report summarizes insights from the session, highlights six themes that emerged during the roundtable discussions, and draws parallels with other research we have published to date. The report concludes with actional steps that organizations can take to capitalize on the benefits of OSS as they navigate the economic downturn.

Challenge session

Every year, the WOIC convenes stakeholders from academia, industry, and governments to exchange insights on open innovation. Challenge sessions are a key part of the conference's collaborative spirit, where speakers invite attendees to brainstorm a particular problem and come up with new ideas or potential solutions. The LF's challenge session on "Open Source Innovation as a Potential Lever for Economic Recovery" included approximately twenty conference delegates and ran for one hour and 15 minutes.

Challenge session introduction and goals by Hilary Carter

The LF's Hilary Carter opened the challenge session by painting a picture of the economic downturn. At the time of the event (November 15 to 16, 2022), economic uncertainty abounded, as Europe was heading into winter in the midst of rising energy prices, high inflation rates, and waves of layoffs taking hold in many sectors. In January 2023, the IMF announced its forecast that a third of the global economy will be hit by recession in 2023, with economic slowdowns expected in the USA, E.U., and China.[7] The bite of this economic climate is being felt across sectors, including the technology sector, ranging from tighter investor appetites increasing the precarity of startups to an unprecedented slowdown of spending on digital advertising and cloud computing.[8]

Carter invited participants to consider how organizations may use OSS as a potential lever to tackle and, where relevant, remain competitive during this economic downturn. Carter cited recent studies that suggest that investing in innovation can be a strategic opportunity during economic crises. For instance, the Harvard Business Review suggests that digital transformation can lead to lower costs, higher productivity, and better customer experience, amongst others.[9] Similarly, McKinsey & Co.'s research shows that companies that invested in innovation in past economic crises delivered superior performance post-crisis.[10]

In the context of this industry research, business leaders are in a position to invest in digitization. The CNBC Technology Executive Council Survey found that more than 75% of technology executives expect to spend more on technology this year, with a focus on cloud computing and artificial intelligence.[11] "If they've learned anything from past downturns, it's that technology is not a cost center but rather a business driver," the CNBC survey reports. Similarly, the Chief Information Officer Survey by J.P. Morgan Chase found that IT budgets are on track to grow by 5.7% in 2023, which is a stark comparison to the widespread budget cuts during the pandemic.[12]

Carter made the case that organizations from all sectors ought to consider the benefits presented by OSS when they design and implement their digitization strategies in the wake of shrinking budgets. The benefits of OSS are manifold, including cost savings (OSS is free), speed (immediacy of use, modification, and development), code quality (according to the adage, "Given enough eyeballs, all bugs are shallow"[13]), mitigation of vendor lock-in (organisations attract and retain talent when they endorse OSS-friendly cultures).[14] Indeed, with roughly 70% to 90% of any software stack consisting of OSS, the ability of organizations, including companies and governments, to innovate faster and at a higher level of quality is frequently due to their adoption of OSS components.[15]

Carter concluded by emphasizing that the LF aims to advance the global effort to grow open source innovation initiatives and raise awareness of how organizations can capitalize on the value of OSS.

Academic reflection by Dr. Paul Wiegmann

In his academic reflection, Dr. Paul Wiegmann made the case that it is key to consider non-economic factors that led us to the current economic situation and define its context. COVID-19 had a major economic impact, e.g., by lockdowns stopping business activity

worldwide and disrupting supply chains. Just as the world is moving out of the pandemic, geopolitical crises like Russia's attack on Ukraine have caused inflation and energy shortages. All of this is happening against the background of the ongoing climate emergency.

As we tackle the economic crisis, Wiegmann argued, we must also take note of wider societal and environmental problems, as root causes of the economic crisis are likely to relate to them. He referred to the UN's SDGs, which cover both economic and non-economic challenges. They represent a global consensus about pressing issues that humanity must resolve. In this spirit, we should take a societally-focused approach to digital innovation.

Wiegmann invited the participants of the challenge session to consider how open source innovation can contribute to realizing the SDGs and to reflect on the extent to which digital innovation with such a focus could help resolve the economic crisis.

Roundtable discussions

Following the presentations, participants formed roundtables to discuss the following questions:

- What role can open source innovation play as a potential lever to stimulate economic recovery?
- What do we need to do to realize the potential of open source innovation in the economic crisis?

Six major topics emerged in the roundtable discussions, which we summarize below.

Open source as a low-cost and high-quality alternative for digital innovation

OSS is a low-cost, flexible, and high-quality alternative to closed source software for digital innovation. Participants agreed that this should make OSS an attractive alternative to the development and / or procurement of proprietary software at a moment when organizations must cut costs to survive the economic crisis. By adopting OSS, organizations can reduce costs and free up capital, which they can redirect elsewhere. Participants underlined that in previous recessions, we did not have the digital infrastructure and tools to disseminate, modify, and adopt OSS quickly and cheaply. Therefore, the benefits of OSS as a means to combat the anticipated recession are yet to be observed. According to some of our participants, not all regions of the world were experiencing the same inflationary shocks as Europe and North America—a point which challenged the roundtables' understanding of economic downturns being a global phenomenon. These participants went on to suggest that OSS may have the greatest potential in developing countries by making technology accessible to stakeholders who may otherwise not be able to afford costly closed source software and therefore enabling new modes of participation in the global digital economy from these regions. However, regardless of region, the participants agreed that a key challenge for OSS adoption is the "packaging up" of OSS into digital systems and services, a process that requires in-house technical expertise and OSS-friendly policies within organizations.

Open source has potential in the public sector but faces many institutional barriers

Participants discussed the potential of OSS in the public sector by enabling cost-effective IT solutions for public service delivery. Governments across the globe tend to procure software solutions rather than build in-house solutions due to a lack of institutional capacity, policies, or expertise. The result is that governments tend

to be subject to vendors' costly proprietary software, licenses, and maintenance. Participants mentioned that federal and state governments in India build OSS solutions into IT systems because it cuts costs and allows for bringing in multiple partners simultaneously. Participants suggested that the Indian government may be able to share lessons and guidance with other governments around the world. Finally, participants suggested that OSS developer communities could work toward developing OSS solutions for governments to reduce problems associated with vendor lock-in. It will require a combination of technical expertise, cultural shifts, and financial investments to realize the potential of OSS in the public sector. The creation of OSPOs can be a great way to do this. For instance, the European Commission's OSPO[16] is a promising development in this direction.

Open source is a key part of our global digital infrastructure, and we must invest in it

Participants agreed that we should not view OSS only in monetary and efficiency terms. Instead, there must be a greater recognition of the value of contributing to shared systems and tools, which developers across the globe can contribute to and innovate on top of, regardless of their use cases, and where the dividends may come later. In other words, we should treat and invest in OSS as a key part of our global digital infrastructure. These arguments resonate with wider developments in the OSS policy landscape. Nadia Eghbal has compared OSS to critical transportation infrastructure,[17] whose maintenance is largely performed by unpaid volunteers.[18] Similarly, in its Mobilization Plan, which outlines the need for $150M of funding for solutions to the ten major problems facing open source security, the Open Source Security Foundation notes that, "Open source software is a form of digital public good, creating wealth and capability for society as a whole in a continuously-renewing form."[19] Since the challenge session, think tanks such as Open Future[20] and the Atlantic Council[21] have made similar arguments on the need to fund the maintenance and security of OSS as critical digital infrastructure. Furthermore, in the last year, bespoke funds have been established

with precisely this aim, such as the German government's Sovereign Tech Fund[22] and the Open Tech Fund's FOSS Fund.[23] These new funds join other notable funds, such as the European Commission's Next Generation Internet initiative, which has funded over 800 OSS projects since 2018.[24] These developments underscore an increasing recognition across policy and industry circles that, as we rely on OSS, we must treat it and fund it as critical digital infrastructure.

Open source as shared solutions to societal and environmental problems

Participants agreed that OSS presents a way for developing shared solutions for societal problems. One area may be climate technology, which is thought to be a "recession-proof" domain of the technology sector. According to Bloomberg, "2022 [was] on pace to eclipse every other year in venture-capital fundraising," with the trend being particularly "amplified" for climate investing.[25] Furthermore, more public money than ever is going toward the development of novel solutions to address global warming. For instance, the new U.S. climate bill provides $370 billion in climate spending and includes incentives for nascent technologies for solar and wind power, amongst others.[26] This represents a major opportunity for OSS developers to build open source solutions in the common interest of tackling climate change. One place where such open source innovation is taking place is LF Energy, which hosts over 20 OSS projects focused on advancing the transition to clean energy.[27]

Education about the benefits of open source is needed to increase adoption

There is a need for more education and awareness-raising to cultivate an "open source mindset" amongst organizations that to date have not been adopters or developers of OSS. A key roadblock to increasing the use and development of OSS by organizations across sectors is a lack of institutional knowledge or capacity about how to contribute to OSS development or adopt OSS sustainably and securely. More broadly, there will be a need for education about the value of OSS and the "open source mindset"

to increase participation in and adoption of OSS. The LF's research reports[28] and educational materials[29] play an important role in educating diverse stakeholders about the promise and practicalities of OSS. For example, the TODO Group's 101 Course on OSPOs[30] provides practical information ranging from the basics of OSS to building an OSPO. Participants also agreed that OSS communities can play an important role in this equation by sharing the wealth of knowledge, skills, and guidance amassed and shared by the diverse stakeholders in their communities.

OSS communities need reciprocation from companies to ensure sustainability

While the private sector has made substantial investments in the creation and maintenance of OSS, participants highlighted that OSS developers are often concerned or frustrated that companies benefit disproportionately from OSS and do not always contribute back their fair share to the developer communities. As Priyanka Sharma, the General Manager of CNCF, has remarked publicly, "Unless you're among the top-tier funded OSS projects, sustainability relies on community."[31] Participants discussed the need to design fit-for-purpose mechanisms to ensure organizations that

benefit from OSS support OSS communities. This discussion resonates with Ashwin Ramaswami's (2023) recommendations about how companies can support OSS maintainers.[32] Ramaswami suggests that companies should fund work that may be more mundane but important (such as continuous integration pipeline improvements or security audits) and invest in documentation development. Ramaswami also recommends that companies should continue to allow their employees to contribute to OSS during working hours. Companies should not just submit pull requests and put all the work on maintainers to review them; they should train their employees to become maintainers, community organizers, or code reviewers in the future. That being said, as OSS projects attract more contributors that have employers who pay them to contribute, they should also ensure that they maintain sufficient transparency around the level of corporate involvement and funding in the interest of safeguarding community interests. Maintaining transparency and clear governance mechanisms can help ensure OSS projects develop according to community interests while also benefiting the utmost from the valuable technical and financial support that companies can provide.

Resonance with key findings in the "World of Open Source: Europe Spotlight 2022"

The key themes resonate with the findings on OSS trends and priorities in Europe in our recent research report with Scott Logic, a UK-based software consultancy, "World of Open Source: Europe Spotlight 2022."[33] With insights from quantitative surveys and qualitative interviews with developers, the research report describes the "state of open source" across Europe and builds a comprehensive picture by examining open source consumption, contributions, challenges, motivations, and opportunities. Below we summarize four conclusions.

Imbalance between OSS use and contributions by organizations

A significant proportion of respondents indicated a lack of a clear policy concerning contributing to OSS at their organization or simply did not know the policy. In contrast, very few respondents saw the same challenges when consuming OSS. This gap widened further in some sectors, such as telecommunications, the public sector, and finance. The result is that organizations tend to

"take" more than they "give," which challenges the sustainability of OSS projects. The damaging effects are experienced most visibly through high-profile security incidents due to a lack of open source maintenance. Less visible effects include a growing unease within many open source communities. This finding concurs with the roundtable discussion about the need for organizations to give back more to OSS communities. Our research expands on this point. While making technical contributions is one way of "giving back," many organizations can begin by creating and socializing institutional OSS policies, which can encourage an OSS-friendly culture and mindset within organizations.

Clear open source leadership within organizations pays dividends

The route to unlocking value from open source goes far beyond simply creating the right policies. We found that organizations with a structured approach to open source via an OSPO, or simply visible leaders who support OSS, tend to have an organizational culture that encourages and empowers employees to contribute to open source. We found that organizations at the two extremes of the scale (<10 or >10,000 employees) tend to have an OSPO or visible leader, while mid-sized organizations tend to lack both. There is clear potential for these organizations to follow in the footsteps of small or large organizations, creating an OSS leadership structure that empowers and supports their employees. For organizations interested in establishing an OSPO, we recommend that you consult the TODO Group's Resources and Guidelines[34] to help you advance your OSPO journey.

The public sector is failing to capitalize on open source

We are increasingly seeing open source consumption formally prescribed by national and international government bodies across Europe. Much of the public sector's code is now shared in the open, primarily for transparency reasons. A neat example is the European Commission's code.eu,[35] a code development platform for open source projects shared by E.U. institutions. However, despite the consumption policies and increasing number of public sector-founded projects, the public sector remains an outlier across many aspects of our research. There is little inner source activity, which indicates a lack of collaboration between public sector organizations and a lack of a clear contribution policy, which potentially suggests an overly narrow appreciation of open source's value and that it is simply a mechanism for the transparency of work rather than for collaboration and collective value creation. With the public sector having so much to gain from open source, much must happen to create a cultural shift. Policies that simply mandate consumption and the "sharing of code'' miss much of the value OSS offers.

Open source can be an apolitical key to fostering digital sovereignty

Digital sovereignty is high on political agendas across Europe. North America drives and owns much of our digital world in terms of the products, services, and infrastructure we depend on. There is a clear need to create and sustain the mechanisms that will enable Europe to plot its own course in the digital world. Our survey findings reinforce the notion that open source is a powerful mechanism for innovation, collective value creation, and ultimately bringing the vision of the "digital commons" to life. There are strong beliefs that industry standards and interoperability benefit the most from open source and that there should be further investment in open source alternatives to technology monopolies. Open source exists and operates beyond politics, which inclusively drives value for all. It breeds digital products and services that anyone can use, ensures space for constraint-free innovation and collaboration, and it creates rich environments for skills and capability development.

Conclusion

The insights from our challenge session on "Open Source Innovation as a Potential Lever for Economic Recovery" at the ninth WOIC in Eindhoven, the Netherlands, from November 15 to 16, 2022, validated our hypothesis that open source is the valuable economic lever that we, at the heart of open source project communities, understand it to be. At the same time, the session provided a valuable perspective, particularly from Dr. Wiegmann, that innovations can be both financially impactful and purpose-driven. It also challenged our understanding of economic downturns being a global phenomenon. According to some of our participants, not all regions of the world were experiencing the same inflationary shocks as Europe and North America.

Overall, two overarching themes stood out to us during the round-table discussion. First, while OSS presents many benefits, it does not come "off the shelf;" organizations must have a combination of technical, institutional, and financial capacity to capitalize on OSS's potential. The establishment of OSPOs can be an effective way to facilitate such institutional changes. Second, OSS forms a key part of our digital infrastructure, and we must invest in its development, maintenance, and security. Since the challenge session, similar arguments have been made by think tanks such as the Atlantic Council and Open Future. The establishment of OSS-focused funds, such as the German government's Sovereign Tech Fund, the Open Tech Fund's FOSS Fund, and the European Commission's Next Generation Internet initiative are promising developments in this direction.

We can draw out three actionable next steps from the key themes that emerged during the challenge session, which you can take as you develop and implement your digital strategies for navigating the economic downturn:

1. Whether you're in the public or the private sector, begin to use OSS—it's a low-cost, flexible, and high-quality alternative to closed source software.

2. Establish an OSPO to provide OSS leadership, create clear policies around OSS consumption and contribution, and encourage an OSS-friendly culture within your organization. We recommend that you consult the TODO Group's Resources and Guidelines to help you advance your OSPO journey.[36]

3. Invest in the developer communities building the OSS that you depend on in order to ensure security and sustainability. OSS is a key part of our digital infrastructure, whose development, maintenance, and security needs investment. There are many ways that you can contribute to OSS as an organization, including by funding communities or encouraging your employees to contribute during working hours.

We hope that the insights and actionable next steps from the WOIC challenge session are useful for OSS practitioners and policymakers. The LF aims to advance the global effort to advance the open source movement and raise awareness of the value and promise of OSS, especially in the wake of the current economic downturn.

About the author

Cailean Osborne is a researcher at the Linux Foundation and a Ph.D. Candidate in Social Data Science at the University of Oxford. Cailean supports LF Research with research projects on open source software trends and LF Europe with regional growth. Previously, Cailean was the International Policy Lead at the U.K. Government's Centre for Data Ethics & Innovation. Cailean's interests are in public interest computing and the digital commons.

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Acknowledgments

Endnotes

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