THE LINUX FOUNDATION | Research

Open Source for Sustainability

How Projects under the Linux Foundation Are Helping to Advance the UN Sustainable Development Goals

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Open Source for Sustainability

WHY THE UN SDGs?

The United Nations Sustainable Development Goals (SDGs) target specific global crises so that multi-stakeholder networks can help to meet them through their collective ingenuity.

DIGITAL ASSETS & SDGs

Digital public goods, including open standards, open source software, open content, open AI models, open data, and open hardware, are vital to attaining the SDGs.

OPEN HARDWARE & SDGs

Open hardware specifications & designs such RISC-V enable hardware reproducibility and efficiencies in energy & computing power.

OPEN STANDARDS & SDGs

The standards development process is a community's means of reaching an agreement, which is a step toward the global adoption of digital public goods.

OPEN CONTENT & SDGs

Open content developed by LF Training and Certification can help nurture the talent that is "structurally missing in a sustainability and developing economic context."

—CLYDE SEEPERSAD

AI, INNOVATION & SDGs

Developers could mitigate concerns, build trust, increase collaboration, and ultimately spur innovation by releasing their AI models under open source licenses.

GOAL 1: NO POVERTY

The Bakong project, sponsored by the National Bank of Cambodia and codeveloped by Hyperledger Foundation member Soramitsu, has made the country's mobile payment system accessible to its unbanked population.

GOAL 2: ZERO HUNGER

AgStack's field boundary dataset, AI modeling, and software applications help farmers use data to manage their water, fertilizer, and workers more effectively to improve yields.

GOAL 3: GOOD HEALTH & WELL-BEING

IBM's Call for Code initiative has supported projects that deploy alternative digital infrastructure during emergencies, such as the ClusterDuck Protocol's sensors and communication networks.

GOAL 4: QUALITY EDUCATION

With LF free courses and open content, learners can access practical training, pursue certifications, and use their new skills and knowledge in the open source ecosystem.

GOAL 5: GENDER EQUALITY

LF projects such as ASWF, CHAOSS, R Consortium, FINOS, OpenJS, and RISC-V host DEI working groups that combat bias and advance minority representation in their communities.

GOAL 6: CLEAN WATER & SANITATION

Botanical Water Technologies uses Fujitsu's Hyperledger Fabric service to mark the collection, filtering, refining, selling, delivery, and use of water otherwise wasted in agricultural production processes.

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GOAL :7 AFFORDABLE & CLEAN ENERGY

To reduce waste, LF Energy projects such as Operator Fabric, PowSyBI, SOGNO, and Grid eXchange Fabric coordinate energy sources, operators, grid data, and smart devices.

GOAL 8: DECENT WORK & ECONOMIC GROWTH

Internet Security Research (ISR) of the ISR Group reduces barriers to secure communication over the Internet so that people can learn, work, and contribute digitally to the economy without worrying about their privacy.

GOAL 9: INDUSTRY, INNOVATION & INFRASTRUCTURE

CNCF formed worldwide to shift to a cloud computing model in support of the development of the critical building blocks of this new digital economy.

GOAL 10: REDUCED INEQUALITIES

LACChain, run on Hyperledger Besu, gives Latin American businesses access to peer-to-peer transaction technologies, creating opportunities to level socioeconomic disparities while increasing personal protections.

GOAL 11: SUSTAINABLE CITIES & COMMUNITIES

The Civil Infrastructure Platform team creates OSS components for embedded systems to meet the requirements of modern municipal infrastructure such as energy distribution, wastewater management, healthcare provisioning, and communications.

GOAL 12: RESPONSIBLE PRODUCTION & CONSUMPTION

With 3MF Consortium's open specification for 3D print files, innovators can send their files to any system, supporting additive manufacturing's reduction of waste and fuel.

GOAL 13: CLIMATE ACTION

OS-Climate's data commons and analytical tools to measure risk and resilience allow investment managers to make investment decisions based on a company's alignment with net zero goals.

GOAL 14: LIFE BELOW WATER

OS-Climate wants to see their Data Mesh blueprint expanded into biodiversity data, making it a key enabler in the identification of risk & adaptation investment in marine ecosystems & other biodiversity hotspots.

GOAL 15: LIFE ON LAND

Smart Parks' OpenCollar uses Zephyr technology in its embedded trackers to catch poachers and collect evidence to take legal action against them.

GOAL 16: PEACE, JUSTICE & SECURITY

Open source projects such as Five-Fifths Voter, Open Sentencing, and Truth Loop are content platforms that address bias and discrimination in the judicial and regulatory systems.

GOAL 17: PARTNERSHIPS FOR THE GOALS

The LF hosts mission-critical pieces of technology in a neutral, collaborative way, made "uniquely possible because of the scale at which we can operate."

—SUMER JOHAL

LINUX FOUNDATION & THE SDGs

The LF manages a massive portfolio of digital public goods & provides the legal structures, funding sources, tools, growth mechanisms, & governance models for measuring community health that make sustainable development possible.

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Foreword

The spirit of open, inclusive innovation for which the Linux Foundation is so well known is exactly the spirit we will need to achieve a sustainable future.

Our global goals are ambitious, and we are right to be ambitious. The challenges facing humanity are of a scale that demands decisive global action. We are achieving remarkable breakthroughs that could accelerate our progress, but our success will be measured by how far and wide our innovations improve lives for the better.

I have no doubt that this report will inspire yet more contributions to open source projects for good, projects that ITU will always be pleased to support. As the UN specialized agency for information and communication technologies, ITU fosters collaboration to support innovation on a global scale.

Our diverse global membership includes governments, industry players, academia, and international and regional organizations. We are also supporting new partnerships and creating opportunities for everyone to influence our work with collaborative frameworks such as AI for Good.

We want our work and its outcomes to include everyone. We aim to be a valuable partner to all innovators working towards a better world. We share this philosophy with the Linux Foundation.

Standardization and open source projects can make powerful, mutually reinforcing contributions to sustainable development, but this work is driven by a strong will to come together and build consensus on the way forward. We need to continue putting more minds to this task.

ITU and the Linux Foundation offer trusted, neutral platforms to stimulate the collaboration and partnerships that we know to be essential to our global goals. Our processes ensure that all participants' voices are heard. I urge you to make your voice known.

Bilel Jamoussi
Deputy-Director Telecommunications Standardization Bureau (TSB), International Telecommunication Union (ITU)

Introduction

In 1987, the United Nations published its first definition of *sustainable development*—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs," with a call for managing the effects of our "technology and social organization on environmental resources … to make way for a new era of economic growth."[1]

Since Linus Torvalds' release of the Linux kernel in 1991, the Linux community has cultivated an approach to developing *open source software* (OSS) and other public digital assets that has sustained not only the kernel but over 850 other types of projects, many of them useful in addressing our planet's greatest challenges. It's all about shared resources, a digital commons with tools and structure, that has become vital to the functioning of 80–90 percent of all software used today.[2] (A 2023 sample of OSS put that figure at 96 percent.[3]) Around the world, businesses, governments, and nonprofits depend on open source to deliver essential services to their constituents.[4]

This research digs into the sustainability of free and open digital assets and their use in sustainable development. By *sustainability*, we mean a digital technology's "viability over the long term—whether people use it, whether a community has formed around it," and whether its stewards consider the contexts in which their projects live and these assets are used—and the impact of those applications on people's lives and the planet's livability.[5]

Background and Research Questions

In 2017, the UN Global Compact reported that digital technology—particularly open source—would be instrumental in achieving the UN Sustainable Development Goals (SDGs), unlocking an additional $2.1 trillion in annual revenue for the technology sector alone by 2030.[6] We wanted to understand where the projects and programs hosted by the Linux Foundation (LF) fit into these sustainability efforts. This research explored three questions of the projects under the LF umbrella.

- First, does the project's open source asset (whether standards, software, data, content, model, or hardware) help its users to make progress toward one or more of the UN SDGs? In answering this question, we applied the categories of digital assets in the UN "Road Map for Digital Cooperation" and focused on discrete use cases launched, in development, and proposed.[7]
- Second, does the project or its organization itself help to advance one or more of the UN SDGs? In answering this question, we explored the documented efforts of each project community, its maintainers and contributors, and its *working group*s (WGs) and *special interest groups* (SIGs).
- Third, what can we learn from the OSS community in terms of stewarding public goods that leaders of other sustainable development initiatives might apply to their work? In addressing this question, we explored the tools, structures, and guidance available to all projects across the Linux Foundation.

Methodology

We went through (1) the project website and the git repository of each project listed on the LF projects page (https://www.linuxfoundation.org/projects), (2) all projects and subprojects loaded in the LFX Insights database (https://insights-v2.lfx.linuxfoundation.org/projects), and (3) new projects on a list of initiatives to be onboarded. We crosschecked these against the available landscapes (https://landscapes.dev). Simultaneously, we invited the LF community to list and describe in a shared Google sheet their projects that served each goal.[8] Finally, we conducted keyword searches of the LF website for terms core to the SDGs to discover projects that didn't appear on the projects page or in the LFX Insights database (https://www.linuxfoundation.org). We coded each project according to the text on these pages through 2 May 2023 and then updated projects and project data through 18 August 2023.

In late April 2023, we initiated a series of interviews of experts in digital public goods and the executive directors of those LF projects supporting multiple SDGs, to explore our research questions in detail and from a practical perspective. In late May, we published a preliminary data analysis on the *LF Blog* and pointed to the new home page of the LF Sustainability initiative, and we invited the community to participate.[9] Finally, we invited all interviewees to review and edit the document online, especially the excerpts of their interviews. This version represents all these sources and contributions.

FIGURE 1

LIST OF THE SUSTAINABLE DEVELOPMENT GOALS

Used courtesy of the United Nations, under UN Guidelines, Aug. 2019, https://www.un.org/sustainabledevelopment/wp-content/uploads/2019/01/SDG_Guidelines_AUG_2019_Final.pdf.

Why the Sustainable Development Goals?

There are different ways to measure and map the sustainability of human activity on planet Earth. In 2015, the United Nations published its "2030 Agenda for Sustainable Development" with a sense of great urgency around seventeen specific goals.[10] These SDGs built on the eight Millennium Development Goals as well as UN Global Compact's measures of corporate governance in terms of the environment, human rights, labor, and anti-corruption.

For our analysis, we selected the SDGs (Figure 1) not just because they are well known, formalized, and globally promoted, as are their indicators of achievement, but also because they bring dimensionality to sustainability beyond humanity's impact on climate, giving shape and texture to the range of challenges that earthlings face. Moreover, the digital solutions hosted by the Linux Foundation are global collaboratives.

In 2016, the UN Global Compact took care to map its "Ten Principles of Responsible Investment" to the seventeen SDGs, so that participants (Figure 2) across automotive, financial services, healthcare, retail, consumer goods, and technology—including Hitachi, Intel, NEC, and Qualcomm in hardware and equipment, Fujitsu, Microsoft, and VMware in software and computer services, and Ericsson and Huawei in telecommunications—could see how their enterprise goals in environmental stewardship, social responsibility, and corporate governance (ESGs) contributed to the SDGs.[11]

As it turns out, almost all SDGs contained some component of environment, social, and corporate governance (Figure 3). Those more familiar with other measures of sustainability in the private sector will find that the SDGs translate nicely.

Where ESG goals are perennial, for organizations to meet through their ongoing operations year after year, SDGs are time bound and

FIGURE 2

ACTIVE PARTICIPANTS IN UN GLOBAL IMPACT

Source of data: UNGC Participants Search, as of 13 July 2023, https://unglobalcompact.org/what-is-gc/participants/search

targeted at global crises, for multi-stakeholder networks like the Linux Foundation to help meet through their collective ingenuity. By meeting their ESG goals, businesses make sustainable development possible.

"LF Sustainability is a really important initiative for the Linux Foundation. The SDGs provide a really beautiful, clear framework of what our goals are," said Gabriele "Gab" Columbro, executive director of Fintech Open Source Foundation (FINOS) and general manager of Linux Foundation Europe. "It may be even more important for Linux Foundation Europe, because of Europe's focus on impact projects—and how the public sector has seen open source as a way of creating a human-centered Internet and a digital future for Europeans, with the SDGs in mind."[12]

FIGURE 3

HOW SDGs MAP TO ESG MEASURES

Data from https://d306pr3pise04h.cloudfront.net/docs/about_the_gc%2FWhite_Paper_Principles_SDGs.pdf

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Digital Public Goods

In 2020, the Secretary-General of the United Nations presented a "Road Map for Digital Cooperation," which described the role of "digital public goods … in unlocking the full potential of digital technologies and data to attain the [SDGs]." The road map discussed the need to steward these technologies to minimize not just the deliberate assaults on democratic societies such as state censorship, mass surveillance, and cyberattacks on critical infrastructure but also the unintended violations of human rights through, say, algorithmic bias and the unauthorized collection and unsafe storage of *personally identifiable information* (PII) that disproportionately harm vulnerable persons and marginalized groups.[13] The Digital Public Goods Alliance formed to accelerate this process, by describing five categories of digital assets that could support sustainable development:

- **Open standards:** Standards and specifications accelerate global innovation and collaboration. They lower the barriers to entry, preclude vendor lock-in, and lubricate workflows and global supply chains, with greater tracking and traceability of assets and process automation in support of, for example, Goals 2, 3, 10, 11, and 17.
- **Open source software:** Developers of programs that run on computer systems or networks can choose to distribute their source code under licenses that make the code available at cost or without any payment from users, that users may modify and redistribute without further permission in support of any SDG, starting with Goal 9. Developers may specify other conditions to the use and sharing of their code.
- **Open content:** All these open assets require documentation. New users need guidance, whether they want to contribute to asset development or participate in working groups exploring new directions. Those projects that engage and train prospective users help to educate and include more people in the process (e.g., Goals 4, 5, 8, and 10).
- **Open artificial intelligence (AI) models:** As we have seen with ChatGPT, AI tools have gone mainstream. Yet, training such tools like large language models can burn considerable time and energy.[14] Sharing well trained and tested AI models openly cannot only minimize waste in energy and human resources but also advance the fight against poverty (Goal 1), contribute to quality education (Goal 4), help to manage cities more efficiently (Goal 11), fuel economic growth (Goal 8), and increase our understanding of Earth's systems and its ecosystems on land and in water (Goals 13, 14, and 15).[15]
- **Open data:** Data is the new oil. Like oil, those who capture it must first refine it so that others can find it useful.[16] Once refined, with special care to protect and secure PII, open data can accelerate innovation, collaboration, and coordination of efforts. The benefits of open data are increased transparency, greater user engagement, exploration of new markets or other data products, and greater efficiencies. These benefits support initiatives related to oversight and accountability (e.g., Goals 11 and 16), responsible production and consumption (e.g., Goals 2, 6, 7, 12, 14, and 15), and disaster prevention (e.g., Goal 13).
- **Open hardware:** Using those categories, we analyzed all the projects under the Linux Foundation (Figure 4).[17] We've added a sixth type of asset, open hardware, to reflect the need for design specifications licensed in such a way that users can study and learn from them, customize them to local conditions, and create their own objects as through 3D printing, whether those objects are drones, robots, machines, medical equipment, or replacement parts (e.g., Goals 10 and 12).

FIGURE 4

THE LINUX FOUNDATION HOUSES ALL TYPES OF OPEN DIGITAL ASSETS

Source: Data compiled from individual project websites and git repositories, as of 18 Aug. 2023.

Arpit Joshipura, senior vice president and general manager of LF Networking, LF Edge, and LF Energy, underscored one of the most important benefits of these assets: reduced waste in people's time, attention, and creativity and in public and private resources. "If we look at the fundamental premise of OSS, it is [a high percentage] of any stack or any industry. It is that percent that is *common*, that is *shared*, and that is *nondifferentiated*," he said. "The value the Linux Foundation provides is bringing competitors, ecosystem partners, and end users together to create this layer of software *once*."[18] It's not anti-competitive; it's a "*pre*competitive platform that supports cooperation and leveraged development."[19] The LF approach minimizes duplication and fragmentation of effort, which is the essence of open source's contribution to responsible production (Goal 12). "We are preventing rework that costs resources—people resources, time resources, hardware resources, and eventually energy resources," Joshipura said.

In this section, we review why each type of digital asset is essential and point to the benefits of open source versus closed (i.e., proprietary) licensing of intellectual property (IP) rights, similar to other shared global resources such as climate and oceans.[20]

Open Standards and Specifications

The Linux Foundation is legendary for its stewardship of the Linux kernel. So why are we starting with standards and specifications rather than OSS? Because open standards are vital to the global adoption of digital public goods and their integration with other systems. Yet, if implementing them requires proprietary technology, then the costs of licensing may outweigh the benefits of open source implementation.[21]

Jory Burson, vice president of standards at the Linux Foundation, wants digital innovators to pause and think differently about their licensing decisions: "Most project founders think in terms of software and go with what they're familiar with, like Apache-2.0. I'm asking them to step back, think about *all* the assets they'll be developing, and choose the right licenses. [Open asset licenses like] Apache or MIT might not cover everything they want to create."[22]

Licenses and other legal information (Goal 16) are critical to the practical value of open standards and all other digital public goods over time. To Burson, the standards development process is a community's means of reaching agreement. Indeed, all projects under the LF purview start with legal agreements, among them the *contributor license agreement* (CLA) and one or more open asset license. Tools such as LFX's EasyCLA and the CLA Bot, used by FINOS, expedite the process of securing agreements from contributors and any audit of those CLAs, so that there are no licensing surprises for implementers.[23]

In her role, Burson encourages project leaders to consider what they might want to standardize from the get-go. Projects can have different types of intellectual property like vocabularies, data formats, processes, and design patterns that fall within scope, that a commercial venture might copyright or patent.[24] In addition to increasing developer participation and interoperability, standards also increase the predictability of performance with other technologies, services, or products.[25] For projects seeking a high

degree of collaboration from developers and implementers, she recommends the *community specification license* (CSL), which covers code and noncode contributions, gives contributors greater clarity of their rights, and doesn't require a legal entity to leverage.[26] In contrast, she pointed to traditional open standards projects like those under the Joint Development Foundation (JDF), formed to streamline and accelerate the process of creating industry or market standards under a *limited liability company* (LLC) structure.[27] In 2020, the *joint technical committee* (JTC) of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) approved the JDF as an official submitter of *publicly available specifications* (PAS), the ISO/IEC's nomenclature for open standard. Since then, JDF has offered projects the tools (e.g., check-the-box templates) and a channel for developing and proposing technical specs to the JTC for potential approval and global recognition.

Burson said that, in its role as a submitter, JDF has successfully shepherded four specifications through the ISO-JTC1 PAS process:

- The OpenChain spec for open source license compliance (ISO/IEC 5230:2020 ed.1 - id.81039);
- The SPDX standard data format for "communicating software bill of material (SBOM) information, including components, licenses, copyrights, security references" and metadata associated with software packages (ISO/IEC 5962:2021 ed.1 - id.81870);[28]
- OpenChain's security assurance specification (DIS 18974); and
- The Green Software Foundation's software carbon intensity spec (DIS 21031).[29]

Burson described the CSL development, review, and approval process as a hybrid of (1) the WC3 process, which is more horizontal, involving working group members and a technical community focused on "quality and fairness in technical decisions," and (2) the process for open hardware standards, which is more vertical, requiring outside experts in the domain to review security, accessibility, potential threats, and unintended harms.[30] The CSL provides enough structure to address all the mission critical elements—not just licenses and specs but scope, governance, code of conduct, release planning, and roles—so that the community can move fast without breaking things it doesn't mean to break. According to Burson, over two hundred standards projects are underway within the LF community.[31]

A SAMPLE OF OTHER OPEN STANDARDS PROJECTS

- The Coalition for Content Provenance and Authenticity (C2PA) combats the ubiquity of fake news and other misleading information online by developing open standards for certifying the source and provenance of media content.[32] A project of the JDF, C2PA gives consumers and publishers tools for understanding whether different types of media are authentic and their sources, genuine, whether it's coverage of climate science, election results, healthcare, or labor practices.
- GraphQL has created a specification describing its query language and grammar, the type and introspection systems used for querying, the execution and validation engines, and, crucially, the algorithms behind them. No black boxes. The spec gives users firm footing and a framework for its tools, client libraries, and service implementations.[33]
- Open19 has developed one specification for servers and another at a system level, both fully describing the configuration of the Open19 platform and the hardware components of its infrastructure, namely Open19 cages, bolt switch, external power shelf, and cables.[34]
- ONNX (Open Neural Network Exchange) is an open standard for machine learning (ML) interoperability under LF AI and Data.

Choosing the right license is half the battle. Making the license easy to find and easy to understand is the other half. Individuals

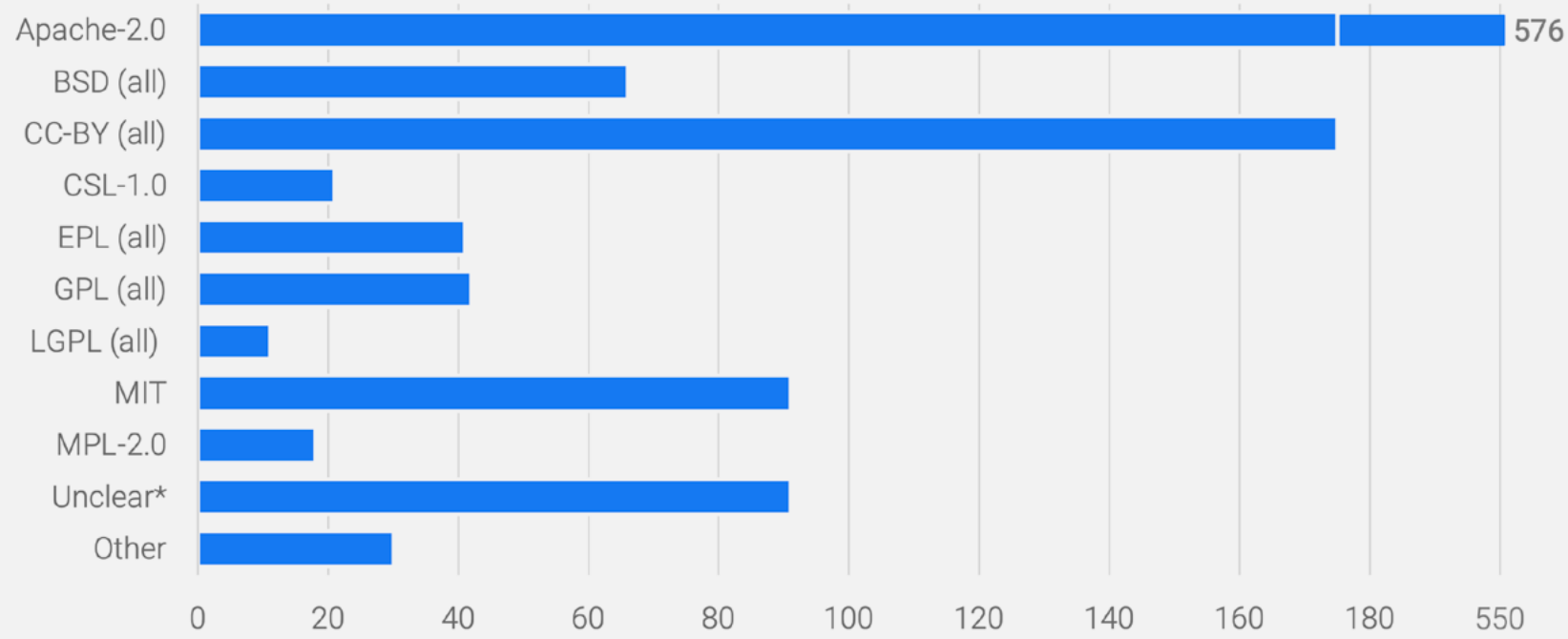
and organizations are reluctant to use any asset with unclear or undiscoverable terms of use. In our analysis, we looked for the licenses applied to each digital asset (Figure 5). Most were obvious or easy to find, but roughly 10 percent were not clearly stated or not discoverable to people unfamiliar with the website or repository, and many projects did not explicitly license content and code separately. The more difficult a license is to find, the higher the barrier to using the digital asset. That reduces a project's potential to advance equality and equal access (Goal 10).

Open Source Software

By releasing the Linux kernel as free and open software, Linus Torvalds introduced what the Internet Society described as "perhaps the single largest collaborative project in the planet's history," in its induction of Torvalds into the Internet Hall of Fame.[35] Recently valued at $6 billion, the Linux operating system is core to global digital infrastructure (Goal 9): it runs 90 percent of the public cloud workload and 62 percent of all embedded operating

FIGURE 5

MOST COMMON LICENSES WITH THE LINUX FOUNDATION



Source: Data compiled from individual project websites and git repositories, as of 18 Aug. 2023.

systems.[36] Fortune Business Insights projected Linux's market to grow from $18.34 billion this year to $66.28 billion by 2030—that's a compound annual growth rate of 20.1 percent.[37] A former Unix systems engineer called Linux "a shapeshifter that can conform to the needs of any given engineering environment, and it's incredibly stable because of the army of contributors that fortify weak points in the software."[38] It is the epitome of OSS as a digital public good.

But, where saving energy is critical (Goal 7), particularly where innovators are using batteries and solar power, Linux may consume too much energy. "Zephyr got started because the Linux kernel was not smaller than three megabytes," said Kate Stewart, vice president of dependable embedded systems at the Linux Foundation. "For responsive things like sensors and actuators that care about power footprint, we needed a better solution. Zephyr was the solution."[39] Stewart described Zephyr as a *real-time operating system* (RTOS) designed to support security best practices and be safety certifiable.

Stewart said that contributors to the Zephyr project are building out small, scalable RTOSes optimized for resource-constrained networks of devices. Such networks will help users to spin up an Internet of Things (IoT) across multiple architectures, reduce their costs, and accelerate the launch of new products and services. "Zephyr is the fastest growing RTOS project in the last two decades," said Michael Dolan, senior vice president and general manager of projects at the Linux Foundation.[40] Members of the Zephyr community are already imagining billions of connected embedded devices—simple connected sensors, light emitting diode wearables, modems, and small wireless gateways—that work to improve health and create decent jobs and equal opportunities on one hand, and support diverse business models and markets on the other, with monitoring tools to strengthen institutions.[41] That's the power of OSS.

Open Content

"When it comes to sustainability, our view is that technology has a significant role to play," said Clyde Seepersad, senior vice president and general manager, LF Training and Certification. He holds a master's in development economics and sees the challenge through that lens: "What is structurally missing in a sustainability and developing economy context is technical talent. If you're going to move as expeditiously as possible, then having homegrown talent within the local organization really helps."[42]

Nurturing talent requires open content. The Linux Foundation has been creating and publishing multiple forms of content to support community members wherever they are in their open source journey. This includes not just online courses but tutorials, webinars, events, and project communication channels to familiarize newcomers with the community and distribute veteran know-how widely (Figure 6).[43]

From 2016 through August 2023, LF Events organized and promoted 495 events around the world, including many virtual sessions during the pandemic, with another 46 and counting through April 2024.[44] Community members have opportunities to participate in, speak at, and sponsor these gatherings, essential to recognizing progress and looking to the future. On YouTube, the public has access to over 1,000 videos of featured LF conference sessions and keynotes, interviews, and leaders in open source, with roughly 800 of them from 2022 and 2023.[45] If membership in the LF community is an experienced good, then there's plenty of content for the public to experience.

Open AI Models

Artificial intelligence needs no adjective to characterize its prominence in the global zeitgeist. During the cold war, it moved from the pages of fiction to the halls of science, where mathematicians, sociologists, and cognitive scientists worked to program and study the performance of AI models—models that simulated human

FIGURE 6

TYPES OF FREE CONTENT ON OFFER

Many projects and programs create and publish open content of some kind. Here we highlight the free educational materials available to visitors on the Linux Foundation site. The courses are available in English on the LF website and worldwide on edX's platform, where 80 percent of its learners live outside North America. Courses are also available in Japanese and Chinese on those respective LF sites.

Measured by number of items available on Linux Foundation, LF Events, LF Training and Certification, and LF YouTube websites, as of 18 Aug. 2023. edX data from "2022 Impact Report: 10 Years, 10 Mantras," edX LLC, 1 Feb. 2022, https://impact.edx.org/2022.

analytical and decision-making processes—and used data sets to train them.[46] But the machines were big, the data sets were small, and neither were readily accessible. Today with the availability of cloud computing and software services, anyone can scrape together some data and experiment with open source AI.

Ibrahim Haddad, executive director of LF AI and Data and the PyTorch Foundation, emphasized the significant advantages that open source offers the AI community, particularly in terms of transparency of development. When asked about the implications of the recent open letter, "Pause Giant AI Experiments," he suggested that developers address concerns and foster trust by making their models accessible under open source licenses,

lowering the bar to enter this complex domain while raising the barrier of innovation.[47]

According to Haddad, "releasing models and their associated elements and training data under an open source license and utilizing them as shared resources can pave the way for various business models to derive value from them." Stressing the importance of openness, he believes that adopting an open approach is the key to resolving many of the challenges associated with AI.

As another example, Sumer Johal of the AgStack Foundation pointed to AgStack's field carbon model project: its community is bringing transparency, discoverability, and governance to the wide gap in the measurement, reporting, and verification for the carbon footprint on agriculture fields—at scale. "People have been going at these models for a decade in the private sector. But any one private actor wants to keep the model proprietary. By nature of the carbon market, these models must be transparent, because buyers want to know what they're buying." They want to understand the technologies and the methodologies in use. They want assurance that no single entity has the power to revoke all the assets they're using.

OTHER IRREVOCABLE AI ASSETS UNDER THE LINUX FOUNDATION

- PyTorch is a fully featured framework for building deep learning models commonly used in applications like image recognition and language processing.
- MLflow is an open source platform for the ML life cycle.
- The federated AI technology enabler (FATE) project represents the first industrial-grade federated learning open source framework for enterprise and institutional collaboration on data while protecting data security and privacy; it supports federated learning architectures and secure computation of any ML algorithms.
- KServe is a standard model inference platform on Kubernetes, built for highly scalable use cases.
- Kedro is a Python framework for creating reproducible, maintainable, and modular data science code.
- Horovod is a distributed training framework for TensorFlow, Keras, PyTorch, and Apache MXNet.
- Adversarial Robustness Toolbox contains tools for developers and researchers to evaluate, defend, certify, and verify ML models and applications against such adversarial threats as evasion, extraction, inference, and poisoning.
- Flyte is a Kubernetes-native workflow automation platform for complex, mission-critical data and ML processes at scale.

Open Data

Open data is data that is free to use, reuse, or redistribute subject to measures that preserve the data's provenance and openness. The World Bank elaborated on two dimensions of data openness—the legal and the technical—meaning that the data owners or custodians have the legal right to publish the data into the public domain or with minimal usage restrictions, and the technical means of publishing them in electronic formats that are open and machine readable, so that anyone can access and work with them using readily available tools.[48] Ibrahim Haddad of LF AI and Data underscored transparency in provenance and methods—not just the where but the how. "Data gathering is a very delicate exercise to be done in an open, ethical, and unbiased way," he said.

Given the risks in collecting, using, and holding PII, the United Nations recommended appropriate PII protections throughout the life cycles of data sets, processing PII in ways that are (a) justified and lawful, (b) bound by purpose, (c) limited in scope necessary to fulfill that purpose, (d) performed for accuracy and currency, (e) secure and confidential according to data classifications, (f) limited in time to the purpose, (g) transparent to the individual data

subject and open to that individual's request for access, changes, deletion, and limits on processing, including the application of AI/ML, and (h) protected if transferred to other parties.[49]

For a range of sustainability goals, creating a means of analyzing and using data from a combination of public, private, and commercial sources is essential. An asset critical to the success of the Linux Foundation's OS-Climate (OS-C) project is the data commons with a data mesh, with Red Hat leading development. By treating data as code, this data management platform provides data comparability, accuracy, and trustworthiness for data from public, private, and commercial sources, such as International Energy Agency's energy transition scenarios, corporate disclosures, and asset-level data (e.g., factories, mines, and power plants).[50] Its architecture enables federated data sourcing to preserve data ownership and integrity, even in the production of derived datasets. With the platform, private sector actors can disclose competitively sensitive information in a highly secure environment where they control which entities can access each data point.

Examples of the open data products available in the OS-C data commons are the Carbon Footprint Datasets for Sovereign Bonds, derived from a range of data sources such as the Partnership for Carbon Accounting Financials, consistent with the second version of the global greenhouse gas (GHG) accounting and reporting standard for the financial industry.[51] These datasets are essential for asset owners and asset managers—such as those in the UN convened Net Zero Asset Owner Alliance (NZAOA, an OS-C member) and the Net Zero Asset Managers initiative—to achieve the transition to net zero investment portfolios.[52]

OTHER PROJECTS CREATING OPEN DATA ASSETS

- AgStack's asset registry is a global, inclusive, neutral, and company-agnostic public field boundary dataset that hosts unique IDs for agriculture fields anywhere on the globe. From deforestation tracking for food (per the new European Union Deforestation Regulation), to food traceability and safety, these "geoids" provide a unique and universal ID to a field boundary.[53] Future versions of the asset registry will continuously update with data on boundaries from satellites and crop field registrations. Scientists will use this dataset to train ML models to ascertain more field boundaries.
- FINOS members work with its DataHub, a synthetic data library, as well as its security reference data.
- Node.js Security Project Working Group is overseeing datasets of vulnerability disclosures, which will be publicly available and openly licensed; Node.js Core Security Group will encourage security best practices.[54]
- openIDL is an open blockchain network for collecting and sharing statistical data in an efficient, secure, and permissioned-based way for the insurance industry. The solution helps to streamline regulatory reporting, yields new insights for insurers, and enhances timeliness, accuracy, and value for regulators.
- Overture Maps Foundation's open base map data supports an entity reference system.

Open Hardware Designs

At its essence, *open hardware* means access to the free and open code of the hardware designs, according to Joshua Pearce, the Thompson chair in innovation at Western University's Ivey Business School and faculty of engineering. It includes "mechanical drawings, schematics, bill of materials, printed circuit board layouts, and firmware," plus the software that drives it and the instructions for assembling it, all released under free and open terms.[55] Pearce's expertise spans open hardware, solar photovoltaic technology, distributed recycling and additive manufacturing, and policy and economics. "How things have changed in the last twenty years is massive," he said. He pointed to two enabling inventions: the Arduino microcontroller, which is "an open source microcontroller that comes with an OSS stack and gives you all

kinds of control" over running devices like motors or cameras and collecting data through sensors; and the RepRap 3D printer, "a 3D printer that can print its own parts running off an Arduino software stack."[56] By Pearce's estimate, the development of this class of digital public goods is roughly fifteen years behind that of OSS.[57] "We don't have an open source version of every piece of hardware just yet, whereas in software, we've at least one, if not many alternatives."[58] Several projects hosted under the Linux Foundation are looking to change that.

LF OPEN HARDWARE INITIATIVES UNDERWAY

- CHIPS Alliance delivers common hardware for interfaces, processors, and systems.
- KiCad, a full featured electronic development application, provides the best possible electronics design tool for commercial and community users and fosters the adoption of open hardware designs. Its OSS suite covers electronic circuit schematics, printed circuit boards (PCBs), and associated part descriptions and supports both standalone and integrated design workflows in which developers design a schematic and corresponding PCB together.
- Open19 Foundation fosters a community around data center open hardware—brick cage, power shelf, server bricks, and data cable—that drops in standard 19-inch racks with cable-free installation and maintenance.
- RISC-V is an abstract model of a computer microprocessor, represented by an open *instruction set architecture* (ISA) designed according to *reduced instruction set computer* (RISC) principles.[59] It describes the behavior of this hardware.[60] The Roman five represents the fifth generation of this model. With its modular technical approach and open ISA, anyone can build with it.[61]
- OpenPOWER Foundation stewards the open source POWER ISA, a RISC ISA across software, hardware, and systems. Its members are working on advanced microprocessors, servers, networking, storage and GPU-acceleration technology. They want to deliver more choice, control, and flexibility to developers of the next generation (next-gen) of cloud, edge, and high performance computing data centers.
- Open Prosthetics provides a forum for collaboration among users, designers, and funders in the field of prosthetics and coping with missing body parts. It is an open design effort, dedicated to public domain prosthetics.

Aligning Profits and the Planet

Sumer Johal, executive director of the AgStack Foundation, sees "a real opportunity for multiple projects at the Linux Foundation to work together, to address the climate sustainability challenges collaboratively." He thinks the Linux ecosystem is waking up to this opportunity, "but we're not waking up to it fast enough because most people don't know that we have all these [assets] working together or that can work together." He underscored, "We have a lot of 'lego blocks' at the Linux Foundation, and we can work to assemble these into private and public sector solutions for addressing the SDGs."[62] Johal reiterated Joshipura's statement, that this is not a feel-good exercise—rather, this is the value of LF membership, of participating in project governance. "What we do in SDGs as a *precompetitive* set of projects all working for the greater good of humanity cannot and should not be perceived as a giveaway but as a launching pad for the private sector," he said.

Business managers want to understand the potential risks, rewards, and trade-offs where, in the use of digital public goods, *leverage* is the ratio between assets borrowed and assets owned. In a shared leverage model, for example, a company uses open source asset libraries—standards, code bases, data, AI models, content, and hardware designs—to multiply the features and functionalities that it offers in its own digital assets. In a study of over 8,000 different library versions of open source Maven-based Java, researchers found that libraries with fewer than 100,000 lines of code "have disproportionately more leverage on free and open

source software dependencies in comparison to large libraries."[63] They showed that, when the financial returns from borrowing these assets exceed the costs of integrating them, this leverage amplifies profits: "Leveraged libraries add only a four percent delay in the time interval between library releases while providing four times more code than their own." However, if the stewards of an open source asset do not continually test for and tend to the asset's security (and, in some cases, regulatory compliance) as FINOS does, then this leverage can also amplify financial risks: "Libraries with such leverage [representing three-fourths of the libraries in their sample] also have 1.6 higher odds of being vulnerable in comparison to the libraries with lower leverage."[64]

Using these open source assets, companies can make profits by saving the planet, benefiting from common standards, interoperability, improved security, and faster time- and cost-to-market, especially when addressing the needs of the Global South. Johal was clear: "Profits and planet are aligned in the work we're doing. We must be unapologetic about the intent of making tons of money by solving the climate crisis through the lens of the SDGs."[65]

Projects for the Goals

As noted, the Linux Foundation hosts over 850 open source projects, with 777,000 developers contributing code and 17,000 organizations supporting this development. Each project supports an important goal in its community. Choosing a handful of these projects to spotlight in this section was no easy task, and the omission of any project is no reflection of its value in sustainable development. Rather, this selection reflects the breadth and depth of the Linux Foundation's contributions.

Goal 1: No Poverty

The first goal is to "end poverty in all its forms everywhere."[66] One approach is to register the land assets of smallholder farmers, whose livelihoods are the most exposed to climate risk, so that they can access financing against their land equity.[67] The AgStack Foundation stewards a public dataset of crop field boundaries created and continuously updated with data on boundaries from satellites and field registrations, but those registrations don't include ownership data. When landowners register an asset—typically a polygon but the code can handle any geospatial geometry—they receive a geoID, a unique 256-byte/16-character alphanumeric identifier. Polygon representation of land helps to describe and record land uses, transitions, and their relationships.[68] AgStack's goal is to build out a set of services that such asset registration will unlock as the AgStack ecosystem grows, such as crop insurance based on geotagged photographs.[69] It plans to use this global, inclusive, neutral, and company-agnostic dataset for training ML models to ascertain more property boundaries.[70]

Another approach is a more inclusive financial network. That was the goal of the Bakong project sponsored by the National Bank of Cambodia, the country's central bank. Cambodia is on the UN list of least developed countries, with 67 percent of adults without bank accounts in 2021, according to the World Bank.[71] The National Bank wanted to modernize its retail payments system so that it not only reached the country's unbanked population but also promoted its national currency, the riel (KHR), and reduced the costs of regulatory compliance for nonbank payment service providers.[72] The bank chose the Hyperledger Iroha blockchain framework with account-based permissioning according to roles.[73] It worked with Hyperledger Foundation member Soramitsu, a veteran blockchain developer and a major contributor to the Hyperledger Iroha codebase.

Security was paramount. They enlisted Deloitte to audit the code, KPMG to audit the business model, and the British cybersecurity firm Nettitude to conduct an in-depth security review, an assurance test, and comprehensive penetration testing. Bakong passed all these reviews and went into production testing, with pilots in 2019.[74] Any Cambodian citizen could open a Bakong account, regardless of holding a retail bank account, and that was a plus for women. The pilots were successful: transactions took fewer than five seconds, network throughput exceeded 2,000 transactions per second, and fees for interbank transfers were much lower.[75]

In 2020, the National Bank of Cambodia and Soramitsu officially launched the Bakong system, effectively pioneering a quasi central bank digital currency in the process. By November 2021, the central bank reported that the Bakong app had 270,000 users; and it worked with local banks to expand the acceptance of Bakong so that nearly 7.9 million people had access to it directly or indirectly through its banking partners' apps.[76]

In January 2022, Bakong received a 2021 Nikkei Superior Products and Services Award for its achievements. At the Inclusive Fintech Forum in Kigali, Rwanda, in June 2023, the Cambodian delegation showcased how "Bakong has transformed the way Cambodians transact and engage with financial services, promoting financial inclusion and empowerment [and] fostering an environment conducive to innovation and economic growth."[77] The chief card and e-payment officer of ABA Bank, which joined the Bakong project in August 2020, maintained that Bakong had increased financial inclusion "by providing an easy, convenient, and safe foundation for transactions and payments within Cambodia and abroad."[78]

Goal 2: Zero Hunger

The second goal is "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture."[79] The AgStack community has accepted the challenge. Its members are building out accessible, reusable digital infrastructure tailored to sustainable agriculture. With the open data (such as the field boundary dataset), AI modeling, and software applications, the AgStack team believes that any farmer can make data-driven decisions and manage such resources as water, fertilizer, and field workers more effectively.

Sumer Johal, executive director of the AgStack Foundation, has grand ambitions. "Half the world's population, half the world's labor force, works in agriculture. Surely executives everywhere in any tech company are thinking, 'How can we provide digital products for half the labor force of the world?'" he speculated. "To do that, they need open datasets, curated and maintained in open forums, that AI—especially these large language models or LLMs—can learn from, but are specific to agriculture. Those don't exist today." AgStack is looking to build the community that will create and host them.

For starters, farmers need weather forecasts to give them a heads up on increasingly volatile weather. AgStack is setting up a weather server to tailor hourly forecasts to any latitude and longitude (lat-lon), so that farmers can anticipate and respond to changing weather in crop management.[80] The AgStack team expects faster response times to improve yields and incomes. In partnership with institutions like CGIAR (formerly Consultative Group on International Agricultural Research), the team is also setting up an asset-enabled messaging framework for sharing insights on farms, pests, diseases, and markets. It will autogenerate syndicated data for ML/AI applications in agriculture. The goal is to put the know-how of other farmers and experts at farmers' fingertips, especially in the Global South, helping them to reduce poverty, waste, and the overall amortization of carbon footprint of the food produced.[81]

AgStack's most ambitious project—the field carbon model—originated in the stars. Johal explained, "About a dozen years ago, NASA started the *soil moisture active passive* (SMAP) project."[82]

Using a host of datasets, the Jet Propulsion Laboratory and a bunch of scientists created a nine-kilometer grid model for the entire planet's soil carbon flux. He described it as a complex climate model: "It's not open to the average person. It's permissive, meaning that it's known in the scientific community, but it doesn't exist in a repository that people can inspect, comment on, and evolve. It's also not specific to a particular agriculture field."[83] He said that AgStack was taking it and modifying it for agriculture within the scientific community. He brought on two major scientific veterans, John Kimble from NASA and Jerry Hatfield from the US Department of Agriculture (Ret.), who spent more than three decades working on such models.[84] They are leading the technical steering committee to create a scientifically open model that anybody can inspect and evolve over time. Johal said that, if AgStack relied on the traditional scientific process, routing the model through a peer reviewed journal, then it would take a decade for scientists to review. In code, peers can review in minutes, not years, he said. By representing all these models in code, Johal plans to turn scientists into software developers.[85]

Another application of data to achieve zero hunger is the Sustainable Africa Initiative, cofounded by OS-Climate, the Climate Risk Research Foundation, and Generation Humanity, in partnership with Sustainable Solutions for Green Growth and Green Energy Mission Africa, both based in Nigeria.[86] Initially, software engineering and data science students at several Nigerian universities will train to build out the OS-C physical risk and resilience tool for analyzing maize and rice, two staples in Nigeria's food supply.[87] The broader hope is that the analysis of climate data and agricultural data will help stakeholders to identify climate-related risks to specific crops in hundreds of locations and then clarify which investments to make and other actions to take—such as irrigating or using different seed strains—for agricultural adaptation and resilience. By helping to ensure food security, they will contribute to economic and social stability, since Nigeria depends on large food imports to feed its people; and its main source of revenue, oil exports, will decline as the world shifts to clean energy. The Sustainable Africa Initiative intends to extend its efforts into Kenya and other African countries, in partnership with the Tony Elumelu Foundation as well as with bilateral and multilateral economic development agencies.[88]

Finally, two Call for Code projects also serve the smallholder farmers anywhere in the world. The first is the recommendation engine Open Harvest, which suggests task timelines for each crop; its verification engine uses drones and ML models to confirm these recommendations so that farmers can manage crops and fields, make profits, and earn blockchain-based reputation tokens for financial institutions.[89] The second is OpenTempus, which generates long-term (annual) weather forecasts for temperature and rainfall to help smallholder farmers make better decisions about what to plant and when.[90]

Goal 3: Good Health and Well Being

The third goal is to "ensure healthy lives and promote well-being for all at all ages."[91] That's among the goals of LF Public Health, which builds, promotes, and sustains OSS to improve global health innovation.[92] For example, its Cardea project puts an easily verifiable, trustworthy, unalterable proof of health tests or vaccinations in patients' hands so that they can share them in a privacy-preserving way. Its MedCreds app allows medical authorities to issue test and vaccination results directly in the form of verifiable credentials to individuals in a digital wallet. Wallet holders can request peer-to-peer credentials from others using the MedCreds system, developed by ProofMarket.io. Its RareCamp project is building out a platform to develop treatments for monogenic rare diseases.

During the pandemic, LF Public Health spun up several solutions in response. One was COVIDCreds, a COVID credentials initiative focused on interoperable use of open standard-based privacy-preserving credentials and other related technologies for public health purposes. Another was COVID Green, an open

source COVID-19 Google Apple exposure notification (GAEN) app for contact tracing. A third was COVID Shield, an open source exposure notification solution with privacy as its top priority and exposure notification technology by Apple and Google. Last was the Herald project, which constructed an original open source cross-platform proximity detection solution according to epidemiology requirements for controlling COVID-19. It incorporated Bluetooth low energy (BLE) tech to help calculate accurate and frequent distance measurements between phones running iOS 9.3+ and Android 5.0+, including devices that didn't support BLE advertising.

Multiple projects emerged from IBM's Call for Code initiative. One set helps to organize alternative digital infrastructure during emergencies. One such project is ClusterDuck Protocol, open source firmware. That's a specific type of software programmed into a read-only memory that supplies the low-level control for a device's specific hardware, usually wireless IoT devices. The ClusterDuck team used it to create customizable sensor and communications networks. If communication infrastructure fails during, for example, a natural disaster, this technology restores communications for saving lives or finding food, water, and shelter.[93] Civilians can send short messages to report on their status, and governments can reach out to the public.

Related to that is DroneAid, through which those affected by disasters can use visual symbols (adapted from a subset of the icons created by the UN Office for the Coordination of Humanitarian Affairs) to express their needs via drones.[94] Then the drones scout for first responders to respond to those in need. Developers used a symbol language to train the visual recognition model, which analyzes video from a drone to detect and count specific images, plots those locations on a map, and initiates a response.

Finally, Zephyr RTOS supports a range of products, from the Oticon hearing aid and CuteCircuit's SoundShirt for multisensory media experiences to Wearable Technologies' Mahi personal safety response system for elder care and the wearable barcode scanner ProGlove that protects people from repetitive stress injuries at work.[95]

Goal 4: Quality Education

The fourth goal is to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all."[96] With the global reach of LF free courses and other open content, learners can access practical training, pursue certifications, and put their new skills and knowledge to work within the LF ecosystem—in support of gender parity (Goal 5), decent work (Goal 8), and reduced inequalities (Goal 10).[97] "Technology has reached a place where it is a continually moving ecosystem," said Seepersad. "And so our strategic goal is to ensure that there's a high quality, affordable, globally available on-ramp to these technologies as they come to market."[98] Seepersad's team is so close to the customer, that it can turn a need into a course pretty quickly.

Education serves another key role in the LF constellation: removing constraints to growth. "Let's talk about the constraints on growth in your user base? And how best do we address them?" Sometimes, the constraint is publicity. No one knows about the new digital asset. "We might do a free course and try to raise visibility. Or people know about it, but they haven't had a chance to develop the skills, in which case, we might do an entry level set of technical trainings," said Seepersad. Managers have also come to him for help on hiring: "'All these folks are claiming to have these skills on LinkedIn. But when I interview them, it's all smoke and mirrors.' We might say, 'Let's do a certification exam where we can validate that the individual has the skills.' It comes down to training in the service of the greater goals of the project. Right now, we're working with the Green Software Foundation on a free training course, and it has a lot of success. That's a really new concept. Last I checked, at least 30,000 people had enrolled."

Seepersad summarized: "The key for us is working closely with projects to figure out at what point the software itself is stable enough—meaning that there aren't major feature changes—that

we can afford to create a training program that's valid for six to twelve months. Within that, we bake in routine updates."[99]

LF ORGANIZATIONS SEEKING TO HELP WHOEVER WANTS TO LEARN

- In its COBOL programming course, OMP offers introductory-level educational COBOL materials with modern tooling.
- LF AI and Data has data practices courseware for education as well as such as OpenDS4All, which accelerates the creation of data science curricula at academic institutions.
- LF Asia LLC produces events for open source technologies and open source projects around the world for education and networking.
- Under LF Networking, ONAP University offers training courses for users, developers, and any other interested parties of member and nonmember companies alike.
- OMP hosts Mainframe Open Education, a convenient, easy-to-use platform where experts share up-to-date materials and foster collaboration with the broader community. Its Mainframe Modernization Working Group has created a common definition and framework around modernization of mainframe space and produces educational material to promote these to a wider audience for better alignment.
- R User Group Support (RUGS) Program facilitates the person-to-person exchange of knowledge in small group settings on a global scale.

FIGURE 7

LF TRAINING BY GEOGRAPHY

With the global reach of LF free courses and other open content, learners can access practical training, pursue certifications, and put their new skills and knowledge to work within the LF ecosystem—in support of gender parity (Goal 5), decent work (Goal 8), and reduced inequalities (Goal 10). Here, the darker the color indicates a greater number of trainees in LF courses in the region.

Source: LF Insights, https://insights-v2.lfx.linuxfoundation.org/global/training-and-certification-analytics/training, as of 16 Aug. 2023.

Goal 5: Gender Equality

The fifth goal is to "achieve gender equality and empower all women and girls."[100] For the most part, that's the ethos of open source. "Anybody with a good idea could be part of the conversation," said Seepersad of LF Training and Certification. "People know you by your handle; they don't know your gender expression, your ethnicity, or your religion, not even where you're from. A level of camaraderie jumps over a lot of the social aspects that might otherwise get in the way of discussions and unlocks potential."[101] But it doesn't happen in a vacuum. The LF approach to governance starts with a code of conduct: as part of their onboarding to the LF constellation, new project communities and working groups must discuss, identify, and codify acceptable and unacceptable speech and behavior as well as specify the consequences of breaking this code.

Equally important is community enforcement, a "rule of code." And so project leadership requires more than technical acumen. For example, LF Events has an explicit code of conduct for all virtual and in-person events. It covers expected behavior including health and safety requirements, unacceptable behavior with examples such as harassment or sexualization, and the consequences of failing to comply, such as immediate removal without a refund and imposing a temporary or permanent ban on participating in future LF events. The code also provides guidance for witnesses and subjects of such behavior, and mechanisms for expressing pre-event concerns regarding another individual who might attend. Finally, LF Events trains its conference staff to respond to any such incidents and support victims by providing them with an escort, contacting venue security or local law enforcement, briefing key event staff, and otherwise helping those to feel safe during the event.

The Linux Foundation also maintains a travel fund for those who could not otherwise attend a conference integral to their growth in the open source communities where they contribute.[102] Ten of its project organizations also run mentorship programs, with 372 mentees participating since 2019.[103] In mid-May 2023, the Linux Foundation held its annual Open Source Summit North America in Vancouver, Canada, where a third of conference speakers identified as female or nonbinary.[104]

"*Representation matters*," said Robin Bender Ginn, executive director of OpenJS Foundation. "The more we feature women, the more women show up. I attended Grace Hopper [the conference] last year for the Linux Foundation. We had hoped to get seventy-five women to attend a hackathon. We had *three hundred* sign up in the first 24 hours."[105] Because OpenJS Foundation stewards a lot of legacy, older technologies that are still widely implemented—JavaScript is not the shiny new asset—Ginn is cultivating a conduit of new and diverse people to work on it. "When I started, we had zero women on our board of directors and technical oversight committee," she said. "When I was hired, I committed to a 35 to 50 percent goal. It was really frustrating at first, but now we're at 45 percent." She credited the board and TOC members themselves. "With our board, I'd do quiet behind-the-scenes nudging. If someone was going to nominate, or maybe two people from one company were thinking about running for a board seat (because those are elected), I would quietly nudge, 'Hey, maybe you could nominate her? Or support her running?'"[106]

As with all things cultural, the Linux Foundation focuses on progress, not perfection. In a 2021 LF survey of *diversity, equity, and inclusion* (DEI), 82 percent of respondents felt welcome in the open source community, 55 percent believed that project leaders valued their opinions, and 37 percent saw clear processes in place for them to become leaders as well of open source projects.[107] But 36 percent of respondents had experienced stereotyping of some sort because of perceived demographics, 30 percent doubted whether project leaders would enforce codes of conduct (evidenced by unaddressed use of racist jokes, sexual imagery, and other unwelcoming language), and 22 percent didn't see equal opportunities to participate in decision making for people with

diverse backgrounds. The survey authors wrote, "Women, nonbinary, LGBTQ+, and people with disabilities were twice as likely to have experienced threats of violence in the context of an open source project, and transgender respondents were three times as likely."[108]

LF project and community leaders took this feedback seriously. They outlined tactics for "inclusion by design," such as outreach and attention to workflows, DEI sponsorships and funding, hospitality focused on onboarding and mentoring, DEI training across roles within scenarios and real-world examples, alignment with local issues and local nonprofits where the underrepresented reside, and applied measurements to understand what's working and what's not.[109]

DEI INITIATIVES UNDERWAY TO NURTURE THE CULTURE AND RECOGNIZE POSITIVE GROWTH

- AI Fairness 360 is an extensible toolkit for identifying, examining, reporting, and mitigating bias in ML models throughout the AI application life cycle.
- ASWF's Diversity and Inclusion Working Group encourages diversity and inclusion across the OSS ecosystem for visual effects (VFX) and animation.
- The Diversity and Inclusion Badging Initiative of CHAOSS applies DEI metrics to pinpoint issues that make open source events and projects safe spaces for everyone. CHAOSS is adding tools to support DEI in its Augur toolset for ontologically consistent data science and analytics, with traceable data provenance.
- The DEI-A (diversity, equity, inclusion, and accessibility) Working Group of the R Consortium seeks ways to encourage and support DEI-A in the R Community; and its R-Ladies look to achieve proportionate representation by encouraging, inspiring, and empowering people of genders currently underrepresented in the R Community.
- The Diversity Equity and Inclusion Special Interest Group of FINOS strives to improve diversity demonstrably through increased participation of underrepresented people on the board, among FINOS team members, and across the FINOS community.
- Inclusive Naming Initiative (INI) Fund helps projects and companies make consistent, responsible choices to remove harmful language from their code, content, and communications, spanning repositories, use cases, events, curriculum development, and tooling like code scanning. *Fast Company* recognized INI with an honorable mention among its 2021 World Changing Ideas Awards.[110]
- OpenJS Foundation's ICU message format for JavaScript supports i18n plurals and gender capable messages and can lead to better translations.
- Open Hardware Diversity Alliance of RISC-V International seeks to unite the community in offering programs, networking opportunities, and learning forums for the professional advancement of women and underrepresented individuals in open hardware.
- OMP's Open Mainframe Mentorship program helps the next gen of contributors to develop skills for a long career in open mainframe technology.
- The Shubhra Kar Linux Foundation Training (LiFT) scholarship program aims to increase diversity in open source technology by providing access to training courses and certification exams for deserving individuals at no cost. The 2022 recipients used open source technology in digital identity (Hyperledger Foundation), cybersecurity of women and youth, applications of the principle of least privilege, social justice, feminist hackerspace (marialab), GirlScript Summer of Code bootcamps, and family planning.
- The Software Developer Diversity and Inclusion Project identifies, evaluates, and promotes best practices from

research and industry to increase diversity and inclusion in software engineering. It has three initial working groups in neurodiversity, DEI-A best practices, and a talent pipeline for diverse individuals.

Goal 6: Clean Water and Sanitation

The sixth goal is to "ensure availability and sustainable management of water and sanitation for all."[111] LF projects here help to increase access to safe and affordable drinking water for all, reduce waste, and increase recycling and safe reuse, complementing efforts of farmers to end hunger.

The agricultural production of fruits, vegetables, and other plants into juices, concentrates, and sugar normally generates three trillion liters of H_2O that goes to waste annually. Botanical Water Technologies (BWT) figured out how to "filter and purify" it into potable water. Its patented invention not only helps these food producers to reduce their waste but also contributes to the water supply. BWT bottles and sells a portion of it under its Aqua Botanical brand to the climate conscious (retail), and its business customers can reuse or donate the recovered water (wholesale).

In such reclamation projects, provenance matters. Daniela Barbosa, executive director of the Hyperledger Foundation, pointed to BWT's choice of the Fujitsu track and trust service, built with Hyperledger Fabric distributed ledger technology, to mark every step in BWT's processes—from collecting, filtering, and refining to selling, buying, delivery, and use.[112] Fujitsu's service delivers granular and real time data on production down to the weighbridges and pumps, meaning that BWT can certify its water at the purification unit level before trading it on the Botanical Water Exchange (BWX).[113]

BWX supports three types of transactions for recovered water: (1) sales of actual water, where companies buy water for resale in retail beverage markets, (2) sales of "water credits," modeled after carbon credits, where companies offset the huge volume of water they use in manufacturing processes or cooling systems, and (3) bulk donations of water.[114] Through BWX, BWT donates one percent of every commercial transaction to the BW Foundation, to fund projects that deliver clean drinking water to people in need.[115]

BWX went online in the second quarter of 2022. Currently every "water harvesting unit" can harvest ~460,000 liters or ~122,000 gallons a day. BWT has onboarded key partners. As they onboard more of the 100 large international enterprises that have expressed interest in joining, BWT and Fujitsu are building out the network, with goals of full deployment and delivery of clean drinking water to 100 million of the world's most vulnerable population by 2025. To address fraud and inefficiencies in other markets critical to the food supply (Goal 2), Fujitsu's platform also supports a rice exchange (RiceX) and a fertilizer exchange (FertX).[116]

Hyperledger Foundation has devoted staff time to help Fujitsu raise awareness of this vital blockchain-based solution, as an example of a differentiated for-profit application built atop a jointly developed precompetitive layer of open source technology.

Another project hosted by the Linux Foundation is Liquid Prep, an end-to-end solution for farmers interested in analyzing and optimizing the water they use for their crops.[117] After interviewing farmers in the Hassan district of Karnataka, India, a team from IBM developed a mobile application with a more visual interface.[118] The app read data from soil moisture sensors on a stick and fed it to the IBM cloud, where an IBM service combined it with weather data and data about the specific crops planted, and prepared watering guidance for farmers.[119] During droughts, farmers have much better information for managing their water use strategically.

In transportation, those who take long train rides may appreciate the wastewater pump monitor with sensors to detect temperature, moisture, and pressure of waste tanks in train toilets. Running Zephyr RTOS, the system gives train staff a heads up on

potential clogs or other problems before the tanks overflow into train cars.[120] With accurate data on tank status, railway operators can optimize maintenance processes, reduce maintenance costs, and improve the passenger and crew experience.[121]

Goal 7: Clean Energy

The seventh goal is to "ensure access to affordable, reliable, sustainable, and modern energy for all."[122] Arpit Joshipura, general manager of LF Networking, LF Edge, and LF Energy, sees how these three domains fit together in achieving that goal: the global transition to green energy requires collaborative, open, and neutral solutions to decarbonization, with business intelligence at the application layer, built on a central supporting layer of data and services, atop an infrastructure layer of edge computing and distributed intelligence. He reiterated his theorem, "Nondifferentiated development should always be done once, in a collaborative manner," and its postulate, "Companies always end up overestimating the differentiation that they bring."

In sum, the energy sector's challenge is a digital one, including innovating at the edge: to cloudify and virtualize networks on open hardware, leverage IoT to manage transportation and real estate assets, and deploy AI to optimize network load.[123] "My LF Energy and LF Edge projects focus on manufacturing, oil and gas, retail, next-gen grid generation and distribution and so forth, where we're doing predictive analysis of scarce resources so that we don't burn what we don't need to burn," he said. His LF Networking projects focus on the connectivity layer—"all of 5G, all the telecommunications infrastructure where we burn most of the energy on the radio access networks and towers"—where he works with partners like the Next Generation Mobile Networks (NGMN) Alliance on green networks.[124]

In LF Energy, Joshipura has organized the projects under his purview into a high-security stack of applications, supporting services, and infrastructure. The following four LF Energy projects have entered the early adoption phase, meaning that industry players are considering them for deployment.

Operator Fabric

Let's Coordinate is a popular implementation of Operator Fabric in Europe where the European Union put certain regulations in place for the *transmission system operators* (TSOs) and *distribution system operators* (DSOs) to coordinate and communicate about certain events in their transmission pipelines.[125] The energy companies are now coordinating across borders using Let's Coordinate. It's basically a fabric for operators to communicate.[126] Such implementations have potential to help TSOs, DSOs, and *regional security centers* (RSC) to integrate more *distributed energy resources* (DERs) into the grid, increasing the availability of renewable energy in the whole system.

PowSyBl

Clearly, power grids are becoming more complex and more interconnected. Operators must preserve their grid's reliability and security while evolving it, integrating intermittent renewable energy. Another LF Energy project, PowSyBl, can help. It's an open source set of power system blocks in Java and Python, appropriate for grid security analysis, dynamic power flow simulations, visualizations, and data exchanges. These blocks work via such formats as European Network of TSOs for Electricity's common information model for grids model exchange spec and the Union for the Coordination of Transmission of Electricity data exchange format.[127] With PowSyBl's modular approach, developers can extend and customize its features.[128]

SOGNO

A third application addresses the need for a massive infusion of renewable energy resources, normally at the distribution level (i.e., medium and low voltage). DSOs want advanced intelligence and automation solutions, and LF Energy's SOGNO (short for service-based open-source grid automation platform for network

operation) fits the bill. Developed by RWTH Aachen University with support in excess of €20 million from the European Union's Horizon 2020 research program, SOGNO can estimate state, predict load, and control voltage.[129] It features a plug-and-play, cloud-native, microservice-based architecture for distribution grid automation. The project PLATONE demonstrated SOGNO's capabilities in Italy, Greece, and Germany.[130] Operators can take a modular approach to building out the next generation of data-driven monitoring and control systems, steadily evolving with the growing requirements for business intelligence. That's what Areti, the grid operator of the city of Rome, decided to do. It has officially adopted the SOGNO platform for its next-gen distribution management system and will deploy it in the biggest city-level grid in Europe.[131]

Grid eXchange Fabric (GXF)

A central supporting solution at the data and services layer is GXF, a software platform for monitoring and controlling hardware and smart devices in the public space. With several generic functions ready to use, such as smart metering and distribution automation, GXF gives industrial users scalability, high availability, high security, a generic design, and no vendor lock-in. For example, DSO Alliander leverages GXF as the backend of its smart meter front end, which uses different Dutch protocols to communicate with 3.4 million smart meters.[132]

Outside LF Energy, "Zephyr also has a very effective power consumption story," said Stewart, VP of LF's dependable embedded systems. "If you're consuming only the power you need for the functions you need, then you conserve. As a result, you start to see Zephyr in microgrid transformers, wind turbines, and monitoring lightning attractors on those high-tower electric pylons.[133] If the lightning attractors deteriorate, that could be a problem." For instance, the Institute for Development of Advanced Applied Systems (IRNAS), one of the Zephyr members, worked with the Slovenian firm Izoelektro to bolt Zephyr onto its pylons and send open telemetry data about the risks of the monitors. The device's battery has to last for ten years on that.[134]

Goal 8: Decent Work

The eight goal is to "promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all."[135] Around the world, tech skills are in demand, with the fast growing need for assembly specialists and application engineers, and the greatest need for software engineers, project managers, and DevOps engineers who can work remotely.[136] "One of the structural factors holding back the more broader adoption and utilization of these technologies is access to technical talent," said Seepersad of LF Training and Certification. "What we can do is make entry level talent training available. We generally do that for free, and then have cost effective mechanisms for getting people up to professional competence in these technologies. It's not just affordable, but also high quality and globally available."[137]

This training "supports sustainability indirectly by increasing the overall standard of living within a country," Seepersad explained. "If we train more technical talent in developing countries, so that they can increase the [gross domestic product] per capita income, then that not only unlocks more resources for use, but also moves folks away from subsistence." For example, the FinOps Foundation has dedicated itself to "advancing people who practice the discipline of cloud financial management through best practices, education, and standards."[138] Similarly, the Internet Security Research (ISR) of the ISR Group reduces "financial, technological, and educational barriers to secure and private communication over the Internet."[139] People who aren't in a daily battle for food and water have greater mental bandwidth to think about sustainability.

Goal 9: Innovation, Infrastructure, and Industry

The ninth goal is to "build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation."[140] The portfolio of digital inventions under the Linux Foundation's umbrella can help catalyze sustainable solutions across the other SDGs from A to Z—namely, from the aforementioned AgStack to Zephyr.

Zephyr supports systems such as electrical grid monitoring with on-device machine learning. Stewart explained how the latter supported the transition to renewable energy and helped improve the efficiency and dependability of electricity grids. More efficient grids make for lower carbon emissions (Goal 13).[141] "On various smart devices, if you see a device that has suddenly gone from a day battery life to a week battery life, then its manufacturer has likely switched to using Zephyr underneath the covers," she said.[142] It is the breadth of implementations that makes Zephyr integral to digital innovation and infrastructure across industries where the Linux kernel is too big to fit.

Another important example is the Cloud Native Computing Foundation (CNCF). Mike Dolan, senior VP and GM of projects at the Linux Foundation, described this simultaneous epiphany of LF members, that the world was swiftly shifting to a cloud computing model. People were telling him, "'If we're going to get there, then we need to teach people how to do it, because it's different.' We were talking about changing fundamental development patterns, going from traditional application development" where developers wrote code to an organization's infrastructure but could never move it, "to something that runs on a service in a cloud, where developers have no access to the underlying primitives and must rely on server side implementations," he said. "That's a very different mindset, how you write code for that. It was more existential than anybody's one platform. Now it seems obvious. Ten years ago, it didn't."[143]

The Linux Foundation hired people with expertise like Chris Aniszczyk, who understood exactly where cloud computing was going, because he was part of architecting that engineering work at Twitter. Even the big tech behemoths like Google and Microsoft realized that they had to do cloud computing in open source, because nobody's one software model was going to dominate. The promise of portability was essential: "Customers would see right through any vendor lock-in play," Dolan said.

For years, end users had designed their software around virtual machines and elements of heavy infrastructure, not around the coming containerization of computing.[144] That's where Kubernetes came in.[145] It was a project within Google, for managing containerized applications across multiple hosts. The community forming around CNCF had a clearer glimpse of the future: "This is much bigger than Kubernetes. This is cloud native," they realized. "How do we enable cloud native computing as a development model?"[146] It needed a logging platform, telemetry, testing frameworks, networking, and parts of the stack that didn't exist yet. So they formed the CNCF and started reaching out to the community.[147] Figure 8 shows the total number of technical contributors to CNCF across commits, pull requests/changesets, issues, and documentation aggregated over the last ten years.

Let's not forget the workhorses of the digital age—not just the Linux kernel but JavaScript, underpinning 98 percent of the world's websites.[148] "Year after year, JavaScript ranks as the number one programming language in surveys such as GitHub and RedMonk," the OpenJS Foundation team wrote in its grant proposal to the Sovereign Tech Fund. "Every student studying computer science from an early age is learning JavaScript because of its ubiquity in the World Wide Web."[149] But it's not just for the frontend of a website. "You need JavaScript for AI, for cloud native. You need JavaScript for gaming, for the metaverse," said Ginn of the OpenJS Foundation. "Everyone's working on the next big thing. Well, they still can't do their next big thing without JavaScript."[150]

FIGURE 8

CONTRIBUTORS TO CNCF PROJECTS

Source of image: https://insights-v2.lfx.linuxfoundation.org/cncf/technical-contributors/contributor-strength, as of 15 July 2023.

Here's the challenge: such projects, tools, and utilities are critical building blocks of the digital economy, yet very small teams maintain them. "Sustaining a stable and secure open source project puts pressure on project developers," Ginn said. The teams under the most pressure are stewarding the most popular and widely used technologies in commerce and business. But these aren't always the trendy projects that attract new developers, particularly those working in infrastructure support and security. Ginn views it as a recruiting opportunity. "We're a peace-loving JavaScript," she likes to say.[151] The JavaScript community is a welcoming place for underrepresented groups to hone their technical, collaborative, and leadership skills.[152]

Goal 10: Reduced Inequalities

The tenth goal is to "reduce inequality within and among countries."[153] Open source is the great leveler. For tech start-ups as well as small and medium enterprises (SMEs) in developing economies, all LF open assets serve as table stakes for playing in digital markets. In Latin America and the Caribbean (LAC), Inter-American Development Bank (IDB) Lab partnered with the LAC Network Information Centre, which administers the region's Internet number system, and the Latin American Cooperation of Advanced Networks of academic institutions, to give more users and entrepreneurs access to safe peer-to-peer transaction technologies. They recognized the power of public blockchains to level socioeconomic playing fields while increasing personal protections for consumers, job seekers, workers, and their families. IDB

Lab experimented with different networks for different projects before it selected what would become Hyperledger Besu, an Ethereum client designed to be enterprise friendly for both public- and private-permissioned network use cases. With Hyperledger Besu, LACChain could build a public-permissioned network that synthesized the requirements of dozens of industries and hundreds of companies relevant to IDB Lab's goals.[154] But, where users pay gas fees on Ethereum, the corporates pay those fees on LACChain.[155] Hyperledger Foundation devoted staff time to raise LACChain's public visibility through webinars and case studies.[156]

Using Hyperledger Besu, IDB Lab implemented a chain with neutral and robust governance, developed tools for economic sustainability, and introduced a non-profit orchestration entity. Initially, more than 115 entities joined, with 205 nodes deployed, over 40 inclusion projects launched, and 17 countries engaged. Developers built interoperable sidechains and Layer 2 networks so that LACChain could scale with demand. The hope is that, now that IDB Lab has wound down its involvement, LACChain will endure under LACNet. Nodes are already operating in the United States and Europe.

LF INITIATIVES STRIVING THE REDUCE INEQUALITIES WITHIN AND AMONG NATIONS

- LF Europe provides a neutral, trusted hub to develop, manage, and scale open technology projects globally.
- Node-RED, a project of the OpenJS Foundation, supports low-code programming for event-driven applications, especially in areas with unreliable sources of energy and telecommunications networks and uneven application of the rule of law.
- Open Voice Network delivers voice assistance to billions of people who own smart devices but worry about surveillance.
- StackStorm supports positive action through event-driven automation for auto-remediation, incident responses, troubleshooting, deployments, and more for DevOps and site reliability engineering.
- TakeTwo, a Call for Code project, reduces racial bias in digital content, whether overt or subtle, in text across articles, headlines, web pages, blogs, and code.

Goal 11: Sustainable Cities

The eleventh goal is to "make cities and human settlements inclusive, safe, resilient, and sustainable."[157] Nearly 60 percent of the world's population lives in cities today, and the United Nations projects the figure to reach 70 percent by 2050.[158] Cities also generate over 70 percent of global CO_2 emissions, and so they are great places to start decarbonizing.[159]

LF Energy's EVerest can help with transportation; it's an open source modular framework and firmware for electric vehicle (EV) charging. EVerest manages communications around energy among different parties: the vehicle, local energy generators and batteries (Modbus, Sunspec), adjacent chargers, the grid (including specific grid constraints), cloud backend for payments, and the user interface. Thus far, several companies have adopted it: HeyCharge (US/Germany) for putting its offline charging methods on every charger; ChargeByte (Germany) for its smart charger controllers; Texas Instruments (US) and PHYTEC (US/Germany) for their reference designs for chargers; and Mahle (Germany) and iLumen (Belgium) for launching EVerest-based alternating current (AC) chargers.[160] Companies can use its edge and distributed intelligence for infrastructure management (acquisition and control).

The Civil Infrastructure Platform team is developing a base layer of industrial-grade core OSS components, tools, and methods to create Linux-based embedded systems that meet the safety, reliability, and other requirements of modern municipal infrastructure including electric power generation, energy distribution, management of oil and gas, water, and wastewater, and provisioning healthcare, communications, and transportation services.[161]

In the construction industry, the ISAC (intelligent supervision assistant for construction) app collects data on home construction

quality assurance. Created by developers in Nepal and Colombia for the organization Build Change, the IASC app emerged from IBM's Call for Code.[162] The team used IBM Watson visual recognition with a classification and object detection model to train AI on images of construction elements. Users take photos of house renovations or construction sites, select "quality assurance check," and upload their photos of the site. The app combines ML and image processing to generate feedback on specific construction elements (i.e., rebar and masonry) and flag instances of noncompliance.[163] The app extends *post-disaster rapid response retrofit* (PD3R) technology to help builders, local officials, and homeowners spotcheck the quality of newly built or retrofitted homes.

Another Call for Code project is an open source low-cost, IoT-based *earthquake early warning* (EEW) toolkit called OpenEEW. It uses low-cost, high-quality seismometers to monitor ground motion and, if it detects signs of an earthquake, it issues alerts to help people seek safety in time. People who own a seismometer can link their instruments to a dashboard of seismic data. OpenEEW welcomes volunteers to install sensors, start networks in areas known for earthquakes, and contribute to the technology.

Zephyr also powers an ad hoc smart waste monitoring system, where each waste container monitors and regularly reports on its own contents to a waste disposal service. The service comes to remove the waste only when necessary. With a network of such containers all reporting on their contents, a waste disposal service or department of municipal sanitation can plan the most efficient collection routes and schedules, saving energy and preventing garbage can spillovers that attract rodents, raccoons, and other disease-carrying animals in cities like New York.[164]

LF PROJECTS FOR SUSTAINABLE CITIES

- Automotive Grade Linux unites automakers, suppliers, and technology companies in accelerating the development and adoption of a fully open software stack for the connected car.
- Dronecode, a project of the Dronecode Foundation, hosts open source and open standard projects critical to the drone industry; it helps the industry overcome software and hardware barriers to accelerate drone adoption of critical applications in energy, utilities, construction, and other sectors by uniting the industry around a neutral, open source platform.
- Fair Change, a Call for Code project, captures incidents and sends data to police officers, including a map for search and visualization of incident clusters, aimed at avoiding escalation.
- Grid Capacity Map, an LF Energy project, gives customers and stakeholders public information about grid capacity and grid connection cost in different locations; it helps manage customer and stakeholders expectations on grid connections to deliver a better connection experience with fewer surprises for both grid owner (DSO/TSO), grid customers, and other stakeholders.
- Home Edge, an LF Edge project, provides edge orchestration for home edge devices for smart home use cases.
- Kepler.GL, a project of the OpenJS Foundation, expedites geospatial data analysis to visualize geotemporal trends in a city or region over time.
- Legit-Info, a Call for Code app, helps residents understand how local laws (city, county, and state) shape their jobs, job opportunities, the environment, and their safety.
- OpenYurt, a project under the CNCF, extends the cloud native ecosystem to edge computing and IoT scenarios; it helps manage large scale edge computing workloads in different architectures in typical edge computing scenarios such as the IoT, logistics, transportation, retail, manufacturing, and so forth.

Goal 12: Responsible Production and Consumption

The twelfth goal is to "ensure sustainable consumption and production patterns."[165] According to Joshua Pearce of Western University, work in this area is well underway in large sustainable technology sharing sites such as *Appropedia*.[166] Moreover, open source solutions—like Green Software Foundation's Carbon Aware software development kit that helps users find the most energy efficient time and place to run their applications, or like Circulor's Hyperledger Fabric-based system for tracking the rare mineral tantalum to prevent any unethically sourced minerals out of the global supply chain—highlight open source's impact on Goal 12.

Additive manufacturing minimizes supply chain costs because producers can print almost any three-dimensional object as needed, wherever a 3D printer resides, rather than burn fuel to transport it from factory to warehouse to point of use. "What we've shown is that you can exchange the designs and then fabricate them yourself for the cost of materials and a little bit of electricity," said Joshua M. Pearce, professor of information technology and innovation at Western University. "A ton of my work has shown that we can beat foreign child slave labor *on cost* for plastic distributed production of parts, by using waste plastic that we can source locally."[167] According to antiquated economic theory, that shouldn't be possible, he said. "Big companies with almost zero labor cost should annihilate someone making products at home. But the 3D printers allow anyone to make custom parts to amazing specifications for little more than the cost of electricity. If we use a solar powered 3D printer built from free designs, then the marginal cost for the next thing goes to basically zero.[168] If we use recycled plastic filament made from an open source recyclebot, then it's two cents a kilogram.[169] Big companies can never compete with that, because they have to manufacture it, package it, ship it, advertise it, and do everything else, whereas I just make the thing I want—and so can you."[170]

That said, these 3D innovators sometimes struggle with incompatible file formats: the destination printer can't read the file. To address the interoperability challenge in industrial workflows, the 3MF Consortium developed an open specification for the format of 3D manufacturing print files so that designers could send their 3D models to any printer or system that accommodates that format.[171] To expand its ecosystem, the 3MF Consortium also developed a compatibility matrix of the additive manufacturing hardware and service bureaus that support the 3MF specification and its "extensions such as beam lattice, material, slice, and other functionality."[172]

Fragmentation is another form of waste. Under Kate Stewart's stewardship, the Zephyr project has been consolidating much of the RTOS ecosystem that had been very fragmented. The result has been tremendous growth in adoption, largely because Zephyr tapped into a collective challenge to support an RTOS that can provide security and safety for resource-constrained devices. "They were all singular projects, each meant for a single type of device. Then people threw the code for one device away, and started on the next device," said Mike Dolan, senior VP and GM of projects at the Linux Foundation. The rising concerns around cybersecurity led developers to evaluate what they were doing, and they concluded that theirs was one of the more insecure ways to develop code. "Nobody was ever improving the security of any of these devices," said Dolan. "Some of the RTOSes were so obscure, that you couldn't reuse them, you couldn't maintain them, and sometimes you didn't even have the rights to them; you were getting a binary blob from some vendor, and in many cases you didn't even know who that was."[173] Through Zephyr, the ecosystem now has a code base that, as of this writing, runs over 500 types of boards.[174]

Dolan likened the waste in the RTOS ecosystem to that of the movie industry. "From movie to movie, innovators would literally build up the entire software stack for the VFX for a movie, throw it all the way, and start on the next project because of how the

industry funded and staffed movies," he said, "You didn't have the same staff. You didn't have the same infrastructure, the same people around for the next movie. It was a whole new crew."[175] The Academy Software Foundation has adopted open standards for VFX plug-ins, content management systems used in media production, and the exchange of rich material and look-development content across applications and renderers to end the cycle of waste.

Goal 13: Climate Action

The thirteenth goal is to "take urgent action to combat climate change and its impacts."[176] The Linux Foundation's OS-C project has targeted this goal squarely with an ambition equal to the task. Truman Semans, chief executive officer of OS-Climate, walked through the OS-C team's approach. First, it recast the problem in terms of investors and financiers: investment and banking portfolios are presently overexposed to climate risks and underexposed to climate solutions. Then it asked asset owners such as pension funds, asset managers, and banks what they needed to flip that equation. The answer was data and analytical tools to help measure risk and resilience, realign the portfolios, and model the transition of the economy toward sustainability.

The OS-C team limited itself to three action items: create a data commons supported by a data mesh, build these analytical tools, and form a community of organizations and individuals who wanted to help contribute to and use these assets. The data commons and the tools are "the precompetitive components" of the OS-C solution, said Semans, and the team is building those out as quickly as it can. Here is an overview of the components.

Sector Alignment Tool

Allianz took the lead on this one to help investors construct a climate-aligned portfolio and select appropriate securities. Allianz and the other members of NZAOA have committed to transitioning its investment portfolios to net-zero GHG emissions by 2050.[177] NZAOA's intermediate targets are cutting CO_2 by 22–32 percent by 2025, and 40–60 percent by 2030.[178]

"Investment managers can assess how well a company is aligning with net zero goals and Paris Agreement goals.[179] They can take that alignment into account in their buy-sell-hold decisions for a company's equities and fixed income, and in their engagement with companies' executive teams to encourage accelerated transition toward net zero," Semans said. "That tool is going through rounds of testing and refinement, and we're building out sectors on energy and steel. We'll eventually add a sector on chemicals and others."[180] Since NZAOA has in aggregate more than $10 trillion in assets under management, facilitating its transition with this tool will have a profound impact on global financial markets.

Physical Risk and Resilience Tool

"BNP Paribas is taking the lead on this tool, using it internally today for analyzing risks in its multimillion asset portfolios, and working toward incorporating code into tools for loan origination, credit analysis, and so on," Semans said. "The precompetitive layers of the code of our project are sufficiently developed that a commercial or other proprietary user could take the code today, elaborate on it, bring in additional commercial datasets, and achieve very high impact uses for both corporate and financial firms."[181]

He emphasized that lenders and investors could already localize current OS-C tools and data to generate insights on risks and, ideally, work toward identifying and generating new finance products and opportunities. Semans even expects users in the research community and public good space to combine this tool with the data mesh to assess, for example, "agricultural risk around rice and maize in Nigeria that will ultimately increase the food security of hundreds of millions of people."[182]

Transition Analysis Modeling Platform

Airbus originally developed and contributed this tool to OS-Climate, and CapGemini has taken the lead on developing it further. "It's really exciting," in Semans' view, because "CapGemini is going to be using this in commercial advisory with large industrials." Core to this platform is the WITNESS tool (for "world environmental impact and economics scenarios"), a complex *system of systems* (SOS) approach to transition simulations, where parties collaborate openly to assess their energy transition paths at a macro level.[183] In his view, "WITNESS and SOS trades are the nucleus of the fulfillment of our long term vision, where we can knit together a range of different models and analytic tools for high quality policymaking and high quality integration of climate factors into the strategy and investment decisions of financial sector institutions and real economy corporations."[184]

Data Commons and Data Mesh

The architecture, developed by Red Hat, features a federated data governance model and data infrastructure as a platform, where owners of both open and proprietary data can safely and securely pool their respective data assets without jeopardizing their ownership. On the supply side, the platform ingests data from diverse sources (e.g., databases, data lakes, files, big data clusters); on the demand side, it transforms data to suit consumers' business intelligence tools, applications, and so forth.

In the OS-C view, there will never be a single data source for all decision-relevant climate data: decision makers often must analyze data points from multiple sources to reach the confidence level they require for strategy, investment, and policy decisions. OS-Climate addresses this need with its world class data mesh, which enables federated data gathering from multiple existing data sources.[185] Via the OS-C data exchange, the data mesh will allow users to search, aggregate, and federate these multiple data sources and pipe the data into open analytics.

OS-C needs Python developers and data scientists with domain expertise who can develop the math that the Python developers will then implement, if the data scientists aren't top shelf developers as well. Semans would also like individual contributors for release engineering and DevOps. "Our goal is to find people who have a passion for the SDGs and climate solutions and really want to work on those kinds of projects, within the Linux Foundation's community of 640,000 contributors globally," he said. "We're looking for people who, if they don't have experience in the financial sector or in the new sectors like energy, are willing to invest the time to train up, get onboarded, and begin adding value to these projects."[186]

The payoff will be accelerated reallocation of financing and investment away from projects and companies that are lagging in the transition to climate sustainability, into securities and loans that support projects and companies furnishing solutions across multiple SDGs.

Goal 14: Life Below Water

The fourteenth goal is to "conserve and sustainably use the oceans, seas, and marine resources for sustainable development."[187] In a recent paper, the World Wide Fund for Nature (WWF) stated, "We need connected platforms of platforms—we need a data commons where we can unite data and, crucially, share and iterate methodologies, models, and code."[188] The WWF pointed to the OS-C data mesh as a leading example of such "a composition of components that make it easier to share and distribute data at scale, and a collection of processes and practices … ultimately to make climate data easier to find, easy to access, easy to understand, and easy to compare."[189] The WWF plans to launch a Geospatial ESG Consortium, which OS-Climate will join, to "improve biodiversity insight at the scale required."[190]

With further development supported by agencies such as National Oceanic and Atmospheric Administration (NOAA), the OS-C data

mesh combined with its analytics and AI could address needs for protecting biodiversity in both marine and terrestrial ecosystems. For example, it could help identify specific types of climate-related risk in specific biodiversity hotspots, thus clarifying where project investments are most needed to restore and protect ocean and coastal ecosystems. We anticipate investments in products and services built on open source AI and data that optimize the use of assets. We also expect marine biologists and scientists involved in any census or in-depth study of marine life to consider the kinds of tagging methods supported by Zephyr and described in the next section—especially for multiyear tracking.[191]

Goal 15: Life on Land

The fifteenth goal is to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss."[192] Truman Semans has already cited OS-Climate's potential contributions to biodiversity and geospatial ESG data solutions above.[193]

Robin Ginn of the OpenJS Foundation pointed to OpenJS projects supporting the conservation efforts in large trans-frontier conservation areas defined in the Southern African Development Community Protocol on Wildlife Conservation and Law Enforcement (1999) in southern Africa through the work of the Peace Parks Foundation, using JavaScript technologies to fight poachers and save rhinos.[194]

Zephyr use cases feature *automatic identification systems* (AIS) transponders. Kate Stewart of Zephyr pointed to Zephyr's tagging and tracking projects, such as Lildog and Lilcat that help pet owners locate and care for their pets and Anicare ear tags for livestock that help monitor herds and file claims against loss.[195] Among those initiatives helping conservationists is Smart Park's OpenCollar.[196] Two of its projects incorporate trackers pioneered by IRNAS (with Zephyr running on Nordic Semiconductor devices) that are embedded in the collars of elephants and implanted in the horns of rhinoceri.[197] In a recent talk, Luka Mustafa, founder and CEO of IRNAS, described how the trackers help conservationists to coordinate their efforts on the ground, so that they can catch poachers red-handed and take legal action against them, using the data associated with detached horns as evidence in court.[198] He said that these actions help to improve the chances of survival for more animals. IRNAS is adding features such as machine learning to detect, for example, when a poacher is attempting to saw the horn off an animal or when the motion pattern of the tracking device matches that of a four-wheeled vehicle, not of a hefty four-legged animal.[199]

Goal 16: Peace, Justice, and Security

The sixteenth goal is to "promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels."[200] That is the aspiration of many a project community under the Linux Foundation umbrella, evidenced in part by the codes of conduct written, the SIGs and WGs formed, and the mechanisms for conflict resolution such as the Linux kernel's code of conflict, which "provides guidelines for discourse in the kernel community and outlines a path for mediation if someone feels abused or threatened."[201]

Security

Digital supply chain security is tantamount. As technology tasseographer Don Tapscott has said, "There are two types of servers—those that have been hacked, and those that will be hacked."[202] By 2025, cyber attackers will have hit the global software supply chains of 45 percent of organizations worldwide, according to Gartner.[203] That's three times more than in 2021, a year spent unraveling one of the most sophisticated hacks ever of software vendor logistics.[204] Projects across the LF ecosystem have security as their mandate, such as the Open Source Security Foundation (OpenSSF).

Ginn of the OpenJS Foundation said that OpenJS projects Node.js and jQuery had $300,000 and $350,000 respectively from the OpenSSF's Alpha-Omega project to bolster Node.js security and remediate vulnerabilities and to conduct a risk audit of jQuery system-wide and modernize more of its infrastructure.[205] Ginn said governments were also recognizing the importance of open source security. Her case in point: the Sovereign Tech Fund, funded by the German Federal Ministry for Economic Affairs and Climate Action, invested ~$902,000 in the JavaScript ecosystem to strengthen its infrastructure, security, and maintenance. It was "the largest one-time government support investment ever to a Linux Foundation project."[206]

Stewart, VP of dependable embedded systems, stressed the importance of security in all the projects under her purview. Many of the Zephyr use cases have safety as well as security considerations. "When I moved to VP, I insisted that *dependability* be in my title," she said. She was using the formal definition of *dependability*, spanning safety and security as well as maintainability, reliability, and availability. She noted that, until recently, open source projects tended to focus on features and fast development iteration. "We needed to change how we approached software. As the open source components have features that are used in safety critical systems, we need to help product makers do the right level of analysis to understand whether an open source component and its features are safe to use for a specific application."[207]

For those who host their open source projects with the Linux Foundation, the LFX platform provides security tooling for automated scanning to pinpoint potential vulnerabilities and recommend fixes, screening for noninclusive language, managing permissions, mapping and prioritizing code dependencies, and flagging incompatible licenses, regardless of a project's source control systems.[208] There are no fees.

Regulatory Compliance

In addition to security is regulatory compliance. FINOS is a vertical specific to financial services as a highly regulated industry, said Columbro. FINOS' open source readiness group prepares banks to navigate the regulatory aspects of open source. "The issues we face are maybe 60–70 percent similar to all corporations," such as "How do you structure an open source program office to be effective and efficient in its knowledge and management of licenses?" and "How do you train your set of developers into the culture of participating in an open source project?" His readiness group addresses those concerns head on: "Open sourcing the code doesn't mean open sourcing the data. It doesn't mean potentially sharing private information."[209]

Columbro then moved to the "30–40 percent of issues that are very specific to the banking system," namely, "financial regulation, antitrust, and electronic records management." He explained that, "in more highly regulated industries, organizations need to evidence specific requirements to their own compliance departments and, therefore, to the regulators." He argued that, "one way or another, financial services have to interact with each other to go about their business. They're trading, they're exchanging money. There's already a degree of technological interaction. Without it, there's no market. No business." Savvy open source innovators in his vertical look for "common requirements across multiple organizations, that are generally big ticket items on the bottom line for everyone, so that we can mutualize costs and standardize grading" without jeopardizing anyone's "differentiating crown jewels."[210]

PROJECTS THAT HELP TO SECURE CRITICAL PUBLIC/INDUSTRY INFRASTRUCTURE

- Project Alvarium aims at constructing a framework and software development kit for trust fabrics that deliver data from devices to applications with measurable confidence.
- LF Edge's Fledge platform for the industrial IoT acts as an edge gateway between sensor devices and cloud storage systems.
- LF Energy's FledgePower helps network operators to monitor and interact with substation equipment as they onboard a bunch of different things (e.g., renewable energies, devices at the edge, and electric vehicles) without opening up attack vectors.

PROJECTS THAT PROTECT HUMAN RIGHTS

- For private information, the Confidential Computing Consortium strives to secure data in use and accelerate the adoption of confidential computing where individuals and organizations can collaborate openly in privacy-preserving ways.
- Five-Fifths Voter, a Call for Code project, helps minorities to devise optimal voting strategies and limit voter suppression so that they can exercise their right to vote.
- Open Sentencing helps expose bias in the judicial system and prepares public defenders to address racial disparities head on.
- TakeTwo flags racial bias in digital content, whether overt or subtle, in text across articles, headlines, web pages, blogs, and code so that content creators can revise before publishing.
- Truth Loop helps members of a community to make sense of the policies, regulations, and legislation that will affect them the most. Through the Truth Loop app, they can share short video testimonials of how policies have affected them or how proposed policies could harm the community.[211]

Goal 17: Partnerships for the Goals

The seventeenth goal is to "strengthen the means of implementation and revitalize global partnerships for sustainable development."[212] The Linux Foundation is a portfolio of such partnerships (Figure 9). These address the core challenge of duplication of efforts in sandboxes or incubation, which could lead to a competition for resources and a fragmentation of solutions in the absence of standards and market mechanisms.

By organizing projects and programs in common domains such as networking, AI and data, energy, edge computing, and blockchain technologies under their own umbrellas, the Linux Foundation helps to cross-pollinate ideas, curate conversations among project teams, and steward those that community deems most promising, ultimately freeing up talent and funding.

Scaling is another challenge that partners can help to tackle. For example, LF Training and Certification calls on local collaborators. "As an organization, we're only 300 people. If we're going to get leverage and scale, we have to do it through partnerships on the ground," said Seepersad of LF Training and Certification. "In Zambia and Kenya, we created scholarship funds where we provided the content for free in partnership with local organizations." His team also partnered with the government of Trinidad and Tobago, where he grew up. There the government invested in "a talent training initiative to reach underserved communities and offer non degree programs that on ramp people into technology careers." Linux donated its curriculum, which the government will fold into larger initiatives. In Ukraine, Linux formed a translation partnership "focused on upskilling and retraining people as they were coming out of military service."[213]

Neutrality is key. Sumer Johal of AgStack made the case for the Linux Foundation's hosting the mission-critical pieces of technology needed to achieve the SDGs: "We are creating technology widgets. These widgets must be transparent." The need for transparency points "to what only a neutral or open source organization

FIGURE 9

THE LARGEST PORTFOLIOS OF PROJECTS HOSTED BY THE LINUX FOUNDATION

Source: Data compiled from program and foundation websites and git repositories, as of 18 Aug. 2023.

can build," Johal said. "It's not so much that it's open source; it's more that the organization building it must be neutral. It cannot be an open source arm of a private sector company or have bias toward any vendor." Equally important, it must be willing, able, and ready to work in an open and collaborative way. Many nonprofits and nongovernmental organizations aren't even chartered to operate that way. Johal argued that creating such an organization was "uniquely possible at the Linux Foundation because of the scale at which we can operate."[214] The next section explains why.

Human Infrastructure for Sustainable Development

"Most open source projects started as technical collaborations on the Internet," said LF's Michael Dolan.[215] "There was no funding, no charter, no governance of these projects. A few people decided to put their code out there" and invited others to contribute. Such was the case with the Linux source code, which its creator Linus Torvalds shared via a digital network, once he'd developed the kernel of an operating system.[216] Dolan continued, "Maybe there was a license that identified the IP terms," such as the GNU general public license that Torvalds used. Maybe there wasn't.

Dolan described the social, political, and economic structures that formed organically around the Linux kernel, like a planet around a star, with collisions of ideas that have coalesced into a substantial body of work, cultivated over decades by a vibrant community of practitioners—some 38,000 of them today.[217] "It's a unique open source project in terms of its impact longevity and innovation cycle," he said. This section reviews what has been described as the *human infrastructure* essential to such large scale, geographically distributed, virtually organized, and longitudinally sustained collaborations.[218]

Legal Structure

"When we first started branching out beyond Linux, we would set up a new legal entity for each project, usually a corporation in Delaware," said Dolan. In the United States, they filed for §501(c)(6), §501(c)(3), or §501(c)(4) status. They dealt with the Internal Revenue Service (IRS) for eighteen months to get approval. It was laborious. For each new entity, the team set up new bank accounts, a new structure around managing the funds, a new audit engagement, a new legal engagement, and all the supplier forms. Even though the same people were administering the new entity, they still had to sign off on LF members' supplier policies, anti-bribery statements, privacy policies, and other supplier terms and conditions for each new entity. "Sometimes, we had to push back and say, 'Hey, we're a nonprofit. We're not allowed to do what you're asking us to do.' That was a lot of work. We did a few of them that way and learned quickly that it wasn't working well, not at our speed and scale."[219]

Developers had no patience for it. So, the team decided to put new projects under the Linux Foundation because they had IRS approval and all the supplier setup forms and agreements in place. They started slotting all these projects under the LF entity. They set up templates for governance that had a charter, the scope of the project, and the IP terms of the core assets that companies wanted to see, like antitrust policy statements and privacy policies.

"We could move very quickly. Then we started growing faster than we even anticipated," Dolan recalled. The Linux Foundation looked for other ways to optimize for scale and risk mitigation and adopted the Series LLC model to provide a project community with an entity for asset ownership and individualized project governance. A Series LLC typically consists of an "parent" LLC with one or more series set up under the parent. As such, each series is a separate entity within the Series LLC.[220]

"The model worked very well for us because we could literally script out and create entities with little to no overhead," said Dolan. "Now we don't have to file anything new when we create a new project entity—or a set of project entities. But they give us legal insulation around the intellectual property and potential risks from any one of the projects."[221]

Funding

When the Linux Foundation started hosting other projects beyond the kernel, the project communities wanted to start with that nucleus of open collaboration where people could get together

under a neutral home and define their IP structure and how they were going to make decisions. "The key to governance was, we got them to write down their technical community governance—generally in some form of open 'do-ocracy,' where the people doing the work made the decisions," said Dolan. "There's no incremental cost if we let people work on something together." The Linux Foundation calls a basic open source collaboration a *community project,* where the community is self-governing. Community projects are very lightweight in terms of resources, and community participants generally maintain them day to day. "The Linux Foundation gives them a home to collaborate, a place that is validated, that their legal team has approved, their business people have approved, and that their engineers can start creating in a very rapid cycle," said Dolan.[222]

Some project communities also want to pool resources from companies that support their communities, or a community may want to support multiple projects. Any community project can add a funding model under the LF "foundation-as-a-service" model. Communities may want funding to pay for:

- Security audits
- A neutral release engineer or documentation writer to assist the maintainers
- Bug bounties
- Cloud build services
- Marketing programs to promote their project
- Mentorships
- Sponsoring community members' event-related travel so that they can meet up and collaborate in person.[223]

The LF fundraising model has increased efficiencies as the operation scales; and, with thousands of members and sponsors of its projects, the Linux Foundation has relationships with many of the world's leading innovators. That network makes it easier to facilitate future projects with future sponsors of those projects.

The Linux Foundation, a §501(c)(6) nonprofit under the US tax code, has also optimized its entities to support funding for various business or charitable purposes. LF Charities is a charitable nonprofit organization under §501(c)(3) of the US tax code. Certain organizations have funds for charitable purposes such as the advancement of education or science. Those funds generally go to support programs within LF Charities. LF Europe, a nonprofit under Belgian law, helps companies that want to provide supporting funds to a European entity. The LF family of entities can help supporters of its communities to direct their resources quickly and efficiently to the project communities. Linux also put funds in place to benefit multiple projects in the same sphere, like cloud native computing or edge computing.

Open Governance

Ibrahim Haddad of LF AI and Data sees the LF governance structure as a real benefit. "One of the reasons an organization wants to bring a project to the Linux Foundation is to signal that the organization is no longer controlling the project," he said.[224] Organizations do this to attract more developers to the community, increase adoption of the technology, and grow the project's ecosystem and its importance, relative to similar competing projects. As part of that transition, the organization transfers project assets like trademarks and GitHub accounts to the Linux Foundation. An open, fair, and neutral governance model for the project dispels concerns that the project's founding company or former owner has power to discriminate against any other company or individual in the future.[225] Haddad added, "More than 90 percent of the hosted projects follow the same governance model. In some cases, projects have existing governance that passed the openness and fairness tests. In such cases, we document the governance model."

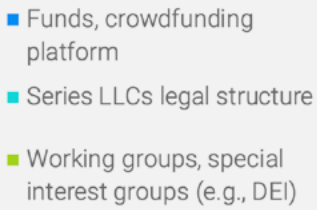
"The communities that maintain code projects have built out project life cycles," said Daniela Barbosa of the Hyperledger Foundation.[226] "As projects go from labs [or sandboxes] to

FIGURE 4

THE LINUX FOUNDATION HOUSES ALL TYPES OF OPEN DIGITAL ASSETS

The Linux Foundation puts the structures in place for open source communities to succeed.

Source: Data compiled from individual project websites and git repositories, as of 18 Aug. 2023.



incubated to graduated, the community maintainers do quarterly reports to a *technical oversight committee* (TOC). In those reports, they need to highlight what's going well and where they need help, and they discuss their long-term road maps. The quarterly report helps staff and the TOC to identify where and how they can be helpful." As people move their projects through the life cycle, they get more services. "We want to make sure the project maintainers get what they need to succeed."

Barbosa views the maintainers of the code projects as "the kings and queens of their own projects. If they want to move from incubated to graduated, or if they decide that they're done and want to go into a dormant stage, then we have a process for that," said Barbosa.[227] Robin Ginn said that, at the OpenJS Foundation, "Our strategy is to celebrate the original founders and the role that technology played. Then we move the code into an archive status, we communicate a lot with end users, and we set expectations on security fixes."[228]

Outlining the process clearly and then following it are important, so that the staff or the TOC can confirm a project's or a community's health. "If we don't do that, then a new person is going to join and have a terrible experience—like, posting a question to a forum where there's no one to answer it," said Barbosa. "We spend a lot of time and effort making sure that new members have a path to succeed."[229] The same goes for new companies that want to use the code and for special interest groups. "We want to make sure that, when new people come into these volunteer organizations, chairs are there to welcome them, and SIG charters are in place," she said, to clarify mission, goals, membership, governance, processes, meetings, and disbandment. Without those, there's no structure for producing results for the community (Figure 10).

A Substrate for Action

The combination of legal, funding, and governance structures is effective. "That's where we've thrived," said Dolan. "When we put projects together, we've threaded the needle in such a way that companies understand why we get it, academic research communities understand their role, governments can see a public-plus-private benefit, and other nonprofits appreciate the multistakeholder convening function."

What the Linux Foundation does is very different from the typical statement of work that procurement officers at governments and nongovernmental organizations commonly put out to vendors for bids on sustainable development projects. Some vendor wins. The vendor develops a solution and has natural incentives to maximize its profit from that project. Suddenly, that vendor becomes the

only party that can effectively implement or support its solution anywhere in the world. The bid winner takes all. "That the vendor becomes the sole developer who understands the code base and benefits by excluding others that is an antipattern of open source," said Dolan. Many times, open source foundations are excluded from supporting sustainability projects because sponsoring organizations just can't break away from their bidding approach to hiring or giving out grants. "If you want to do something productive in open source, then you can't do it that way," Dolan said.[230]

Sumer Johal of AgStack sees a different challenge. "We must unleash the public and private sectors' capacity to collaborate, and the only way is through open source," he said. "If it's managed and governed collectively and properly, then we should see a flood of new sponsorships from both public and private sectors, with people who want to unleash their organization's products and services to solve the global climate crisis by leveraging open source. If we're not seeing that—and we're not, yet—then companies aren't seeing our work and rubbing their hands together with visions of making tons of money; and the public sector isn't seeing us as an accelerator of economic progress."[231] What might help? Distinguishing the shared, undifferentiated, and precompetitive stack more sharply from the proprietary, unique, and competitive offerings that members could develop and offer their customers, citizens, and stakeholders, he said. "We must be unapologetic about the intent of making tons of money [in the private sector] by catalyzing new economic growth [in the public sector]—especially in the Global South—by solving the climate crisis."[232]

Columbro, executive director of FINOS, echoed Johal's sentiment, that "open source is a means to an end. Open source projects must be able to demonstrate whether they are moving the needle on those goals." For the projects under his stewardship, Columbro focuses on the business problems of banks and financial institutions: "Ultimately, the top metric in a vertical foundation like FINOS is the business value these open source solutions deliver, the tangible business problems that open source solves for these organizations." In solving these problems at FINOS, however, "we have made diversity, equity, and inclusion part of everything we do" through, for example, FINOS' cross-cutting DEI special interest group. "We can be an engine of enablement for members so that they don't have to start from scratch," he said.[233]

Perhaps the biggest takeaway is not simply that the Linux Foundation manages such a massive and diverse portfolio of digital public goods and contributes to so many SDGs but that it provides the human infrastructure—the legal structures, various sources of funding, mechanisms for cultivating communities of practice, a tested model of governance, and tools for measuring the health and effectiveness of all the above—that makes sustainable development possible.

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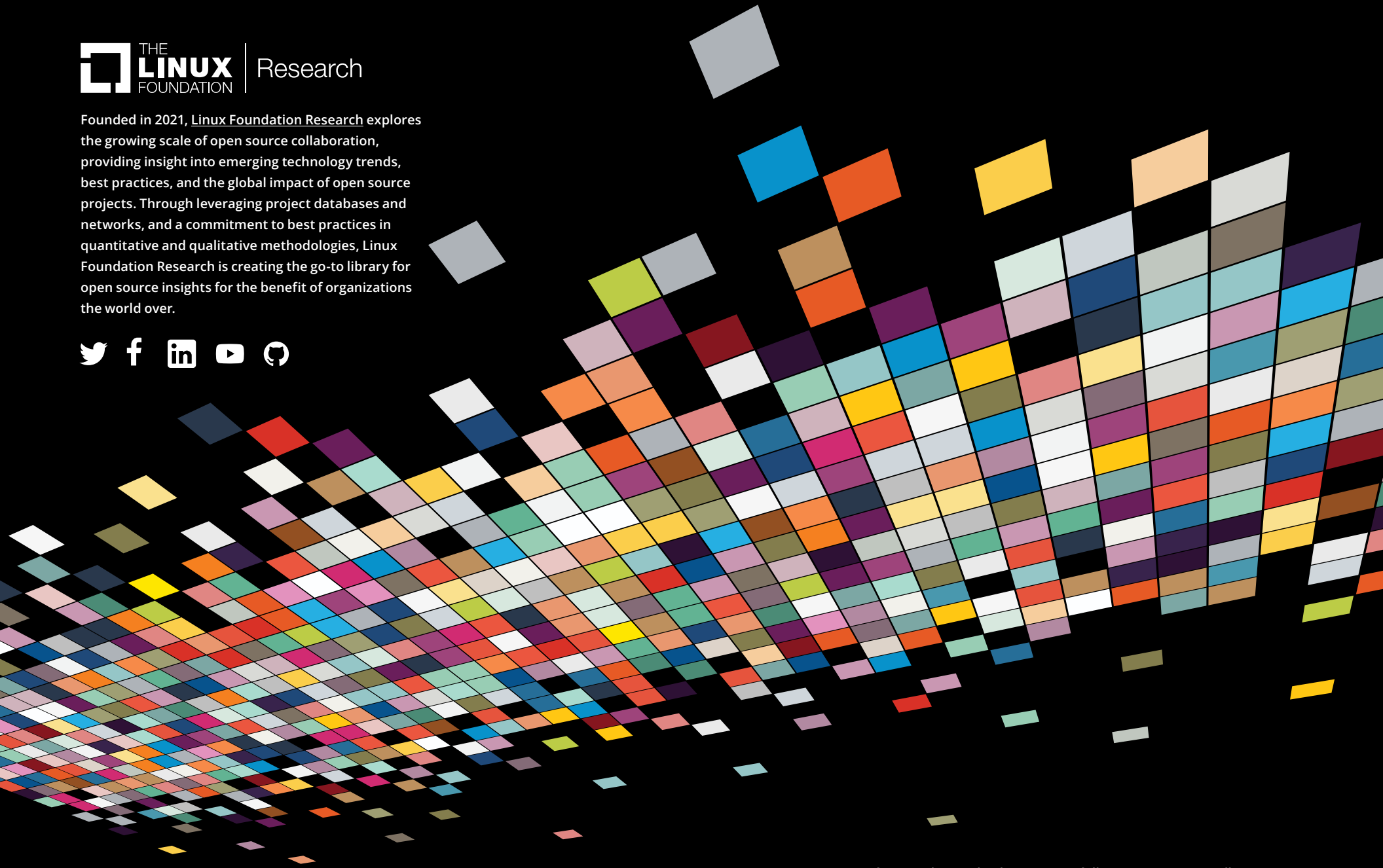

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