THE LINUX FOUNDATION | Research

The Open Source Opportunity for Microgrids

Five Ways to Drive Innovation and Overcome Market Barriers for Energy Resilience

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Jessica Groopman
with Jeff Lindstrom
Intentional Futures

Foreword by
Chris Xie and Yue Chen
Futurewei

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Challenges and opportunities for the open source microgrid industry

OSS has the potential to **democratize, standardize, and better integrate** microgrids, but the open source microgrids market is still nascent.

Open source models increase access to microgrids by lowering financial barriers to entry and sharing best practices, designs, and tools.

Open source accelerates microgrid design and time-to-market, enabling better modularity, efficiencies, and open data sharing.

By driving consensus on standards and fostering transparent collaboration, **open source can improve interoperability and standardization of microgrids.**

Different components of **open source business models,** such as software, support services, training, customization, and modularity, enable innovation and optimization of microgrids.

Open source enables market innovation toward energy resilience at scale via open source–enabled business models, security, talent pipelines, and cost reductions.

Collaborative and consistent policymaking is needed to revamp energy regulation that is outdated, fragmented, and favorable to centralized grid infrastructure.

Resistance from industry incumbents must be met with **onramps to open source programs and education to address security concerns.**

Data sharing, education, and goal alignment will support energy incumbents as they face economic hurdles and uncertainty in the adoption of microgrids.

The diverse group of stakeholders—from utilities to governments to communities—need **a central hub to collaborate, engage, and build the microgrid landscape.**

Data standardization, application modularity, demonstration of cost benefits, and market coordination will support greater microgrids interoperability.

Resistance to technical adoption and talent gaps can be diminished through a focus on **education, community access, and skills development.**

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Foreword

The summer of 2022 ranked among the most severe heatwaves across three continents—Europe, America, and Asia—indicating an unmistakable trend of global warming. The following winter brought an equally unprecedented deluge of rain and snow to Northern California, a region unaccustomed to such extremes in weather. These extreme climatic conditions strained the existing power infrastructure beyond its limits, necessitating power usage limitations and even triggering power outages. According to Gallup's 2022 research, the high-temperature days are projected to significantly decrease life evaluations by an estimated 17% by 2030, given the current climate projections.

The climate crisis, however, presents us with an opportunity to rethink our energy systems. There is an urgent need to pivot towards greener, more resilient, and self-sustained energy systems. Not only would this mitigate the impacts of climate change, but it would also enable the infrastructure to effectively handle the power load fluctuations triggered by extreme weather conditions.

This research report does a comprehensive analysis of the micro-grid market and reveals certain gaps and challenges. However, with increased government funding, policy support, and incentives for sustainable energy solutions such as open source based micro-grids, the landscape is ripe for innovative approaches.

The open source microgrid holds immense potential benefits but also presents its own set of challenges and opportunities. A clear, strategic pathway that addresses these issues will set us on course towards achieving genuine energy sustainability, freedom, and security. It is time to seize the opportunity at hand and work towards a future resilient to climate change and powered by clean, reliable energy.

We wish to thank authors Jessica Groopman and Jeff Lindstrom from Intentional Futures for their tireless hard work on this research report. We would also like to express our sincere gratitude to Hilary Carter from Linux Foundation Research who shares our vision and demonstrates synergy from start to finish. Also, we thank the many domain experts and collaborators who contributed to this report. We hope that this research report will provide value in your pursuit of energy freedom.

Yue Chen, Head of Technology Strategy, *Futurewei*
Chris Xie, Head of Open Source Strategy, *Futurewei*

Introduction

Compounding economic, environmental, and societal disruptions in recent years have heightened demands for energy resiliency. Microgrids, which are small-scale, local energy systems that connect and operate independently from traditional utility grids, are emerging as versatile and powerful solutions. Several factors will help scale microgrids; this analysis explores the role of the open source ecosystem.

The global microgrids market is growing at a 17.6% compound annual growth rate (CAGR) according to Guidehouse Insights, bolstered by adoption across commercial, industrial, military, institutional, and remote implementations.[1] Broad investment trends around decarbonization, rural electrification, and national security, plus growing reliance on digital, wireless, and cloud technologies—and related network cybersecurity threats—are driving demand for upgrades and new installations of microgrids. That said, supply chain disruptions, resistance from incumbents, interoperability challenges, and fragmented standards and regulations have hampered market acceleration in recent years.

While the "open source microgrid" marketplace is nascent today, open source represents enormous potential to accelerate microgrid innovation more rapidly by overcoming these barriers. This research analyzes the current state of microgrid market challenges and drivers as well as examples from the open source microgrids landscape and open innovation in other industries. We identify five ways the open source ecosystem can catalyze microgrid market adoption:

1. **EXPANDS ACCESS TO MICROGRIDS,** democratizing both energy access in emerging markets and microgrids resources and education for all
2. **ACCELERATES MICROGRID DESIGNS AND TIME-TO-MARKET,** by enabling modularity, efficiencies, and open data sharing
3. **IMPROVES INTEROPERABILITY** and standards adoption, by fostering ecosystem collaboration, consensus, transparency, and compatibility across the stack
4. **ENABLES MICROGRID BUSINESS MODELS,** via software, support and consulting services, training and certification, customization and integration, collaborative partnerships, and advancing modularity
5. **ENABLES MARKET INNOVATION TOWARD ENERGY RESILIENCE AT SCALE,** via open source–enabled business models, security, and cost reductions

This report offers actionable insights and recommendations for key stakeholders to get involved. Near-term, open source can help catalyze energy access in developing economies. Over time, open source benefits the entire microgrids market, across a broad ecosystem of stakeholders, from utilities and financiers to industry, policymakers, developers, and communities. In an era in which climate change requires us to scale distributed renewable energy resources as rapidly as possible, open source tooling and programs can help level the playing field.

Defining microgrids and open source

A MICROGRID is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the larger grid. A microgrid can connect to and disconnect from the grid to enable it to operate in either grid-connected or island mode. Microgrids are one of several adjacent technology designs to improve energy resiliency and can overlap with others, such as virtual power plants (VPPs) or distributed energy resource management systems (DERMS).

OPEN SOURCE refers to software for which the source code is available under an open license. Not only can the software be used for free, but users with the necessary technical skills can inspect the source code, modify it, and run their own versions of the code, helping to fix bugs, develop new features, etc. Some large open source software projects have thousands of volunteer contributors. The Open Definition was heavily based on the earlier Open Source Definition, which sets out the conditions under which software can be considered open source.[2]

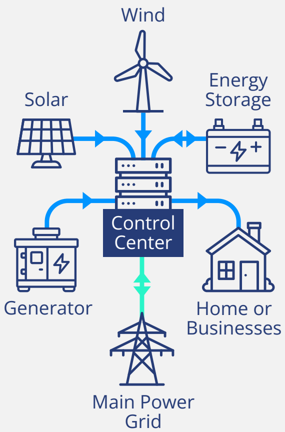


IMAGE SOURCE: WISCONSIN STATE JOURNAL RESEARCH

FIGURE 1

UTILIZING A MICROGRID

Microgrids are self-contained energy systems that can be connected to the larger grid or function as an "island."

STORAGE A battery or system of batteries where excess power can be stored; critical when using intermittent DERs such as solar power.

LOAD Anything that consumes the power produced by the microgrid, such as a house.

CONTROLLER Responsible for handling the complex union of the microgrid's DERs and storage with the larger grid.

NANOGRID
Nanogrids are a type of local energy-self-sufficiency-system typically with "islanding functionality," similar to microgrids with three distinct differentiating characteristics:

1. Smaller in size, nanogrid deployment is (typically) faster, easier, and more modular than microgrids.
2. More localized to the customer and individual buildings, nanogrids also lean more toward direct current configurations and can offer increased customization opportunities for users.
3. Compatibility and connection to other nanogrids, micro-grids, and the utility grid catalyzes aggregated resources that can contribute to the creation of VPPs.

DISTRIBUTED ENERGY RESOURCE
Distributed energy resources (DERs) are small, modular energy generation, storage, and demand response technologies that provide electric capacity or energy or load reductions where you need them. Typically producing less than 10 megawatts (MW) of power, DER systems can usually be sized to meet particular needs and are installed onsite. DER systems may be connected to the local electric power grid or isolated in stand-alone applications. DER technologies include wind turbines, photovoltaics (PV), fuel cells, microturbines, reciprocating engines, batteries, flywheels, HVAC systems, hot water heaters, and electric vehicles.

DISTRIBUTED ENERGY RESOURCE MANAGEMENT SYSTEM
A software-based solution to monitor, control, and dispatch grid-connected and behind-the-meter DERs across customer, grid, or market applications in real time. These assets may be utility or third-party or customer-owned and directly or indirectly controlled by the utility. Driven by the need for active power optimization at the electricity distribution level, a DERMS can address voltage sags and surges on specific utility distribution feeders.

VIRTUAL POWER PLANT
A system that relies upon software and a smart grid to remotely and automatically dispatch and optimize DERs via an aggregation and optimization platform, often linking retail to wholesale markets. Driven by market signals and pricing, a VPP can address system-wide frequency variations.

The state of the microgrids market

Microgrid market drivers

Microgrids are on the rise. The global market exceeded $11.6 billion in 2022 and is estimated to reach more than $50 billion by 2030, with a CAGR of 17.6%, according to Guidehouse Insights.[3] Although microgrids have been around for decades, today's market is increasingly powered with a range of renewable energy sources rather than traditional diesel-powered networks. The microgrid market is expanding in capacity and applications and across regions.[4]

But tapping into a wider range of energy sources isn't the only catalyst; the recent interest and investment is accelerating thanks to several converging trends.

FIGURE 2

CLEAN ENERGY MICROGRID CAPACITY BY REGION

World markets: 2022–2031 (Guidehouse)

SOURCE: GUIDEHOUSE INSIGHTS

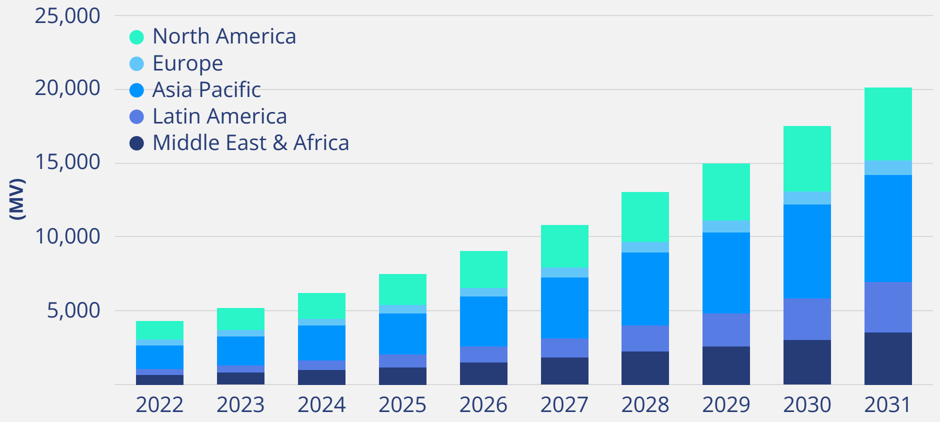
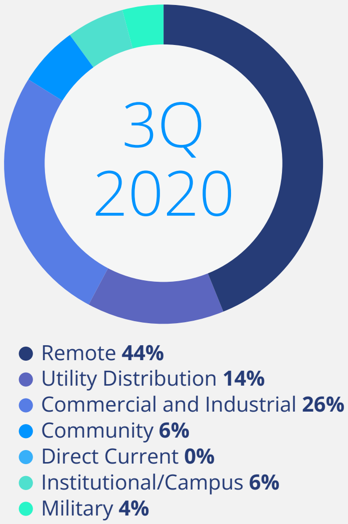
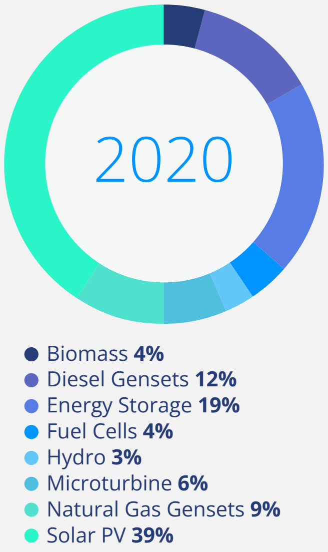


FIGURE 3

MAJOR MICROGRID MARKETS



SELECTED MICROGRID CAPACITY BY TECHNOLOGY



SOURCE: GUIDEHOUSE INSIGHTS

TABLE 1

MICROGRID MARKET DRIVERS

2. GROWING INTEREST ACROSS STAKEHOLDERS
Increased pressure from the investor community to decarbonize meets rising demands for greater energy resiliency, sovereignty, and risk mitigation across diverse parties, from governments and militaries to businesses, cities, consumers, and more. Microgrids represent a flexible and scalable solution.

1. RESILIENCY, ENVIRONMENTAL, & SOCIAL DEMANDS
Extreme weather events, aging grid infrastructure, and risks of power outages are driving interest and adoption of microgrids to improve energy reliability; market growth is compounded by widespread climate mitigation and adaptation investments and "net zero" strategies across private and public sectors.

3. NEW REGULATION & POLICY INCENTIVES
New and varied climate legislation is emerging that is favorable to microgrids and adjacent domains, such as electric vehicles and construction. Though fragmented, favorable public and private sector policies can be found worldwide, across both industrialized and developing nations.

4. ECONOMIC INCENTIVES & NEW BUSINESS MODELS
Rising fuel costs and declining renewable energy costs converge to boost microgrids adoption. Meanwhile, technological advances are enabling innovative vendors and large utilities to connect digitization and distributed energy to unlock novel ways of monetizing energy infrastructure and services.

RESILIENCY, ENVIRONMENTAL, AND SOCIAL DEMANDS: MICROGRIDS ARE A RELIABLE ENERGY SOURCE AMIDST UNCERTAIN TIMES.

There are many reasons why our access to reliable energy is under threat. In the face of aging grid infrastructure, growing energy demands, increased cybersecurity threats, political uncertainties, and increasing frequency of extreme weather events (most likely linked to climate change), microgrids represent a viable alternative to traditional, highly centralized grids. Last year alone, the United States faced 22 extreme weather- and climate-related disaster events, with losses exceeding $1 billion each—a cumulative price tag of nearly $100 billion.[5]

"For the grid to be reliable and resilient during the increasing threats of extreme heat, flooding, fires, winds, and storms, we need distributed systems with local control that enable neighborhoods to take full advantage of investments in distributed clean energy. Traditional systems that rely on moving power over long distances from centralized generation will not be sufficient to handle the changes in climate we're experiencing today."

- MARISSA HUMMON,
CHIEF TECHNOLOGY OFFICER, UTILIDATA

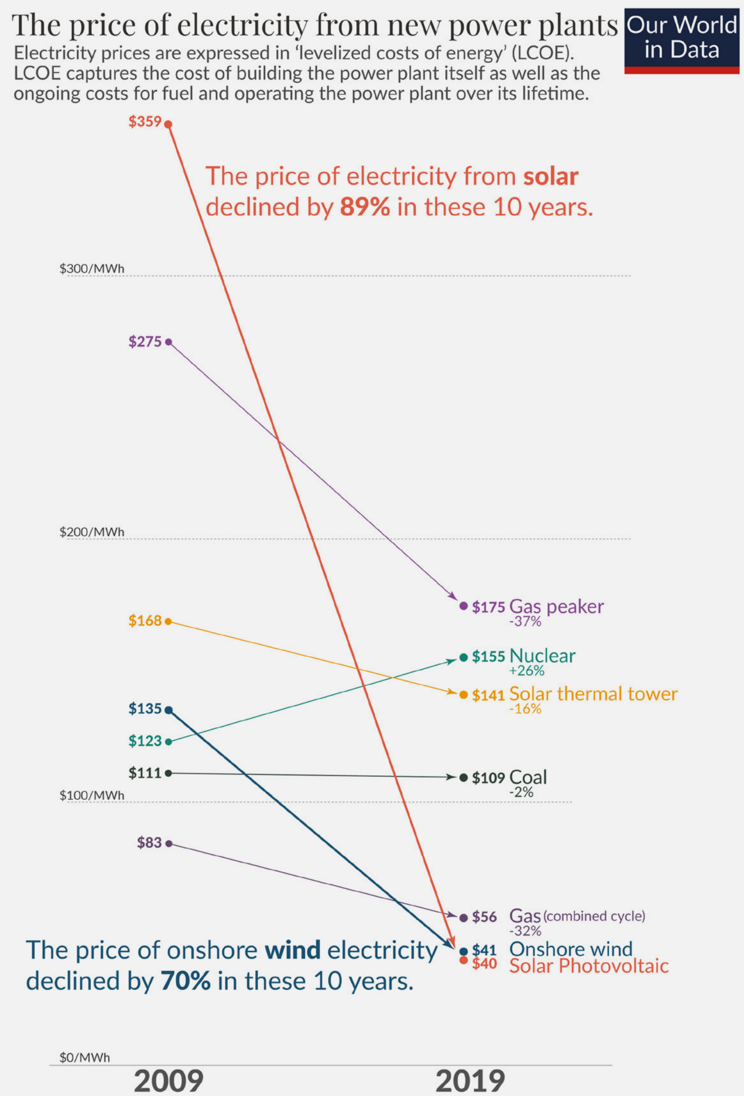
These challenges are no longer isolated to certain geographic regions. People (and governments) the world over desire greater energy sovereignty and reliability. Culturally, there is a growing desire for energy sovereignty, including an emphasis on localized economies and peer-to-peer infrastructure inspired by mobile networks. At the institutional level, resiliency concerns are among the top national security threats. In fact, several governments, such as the U.S., China, India, and Australia, are already including microgrids among their climate and national security investments.[6]

Such demands for resilience are part of broader environmental and social investment trends supporting both climate mitigation and adaptation strategies. While many existing microgrids have relied on diesel—among the dirtiest of fossil fuels—today's microgrids are utilizing higher and higher levels of renewable energy sources, such as solar, wind, hydrogen, or bio-powered generators. Transitioning to renewable energy is critical to reducing emissions and driving decarbonization strategies among industrialized economies.

Microgrids offer a pathway from fossil fuels toward renewables and rural electrification in developing regions, such as Africa, India, and Southeast Asia. Microgrids are also considered critical tools to help reduce poverty and bridge economic inequalities by connecting more people to reliable energy and Internet infrastructure.[7] Five years after microgrids were installed in Kenya's Sidonge village, residents reported a 180% increase in school attendance by girls.[8]

FIGURE 4

THE PRICE OF ELECTRICITY FROM NEW POWER PLANTS



SOURCE: OURWORLDINDATA.ORG

ECONOMIC INCENTIVES AND NEW BUSINESS MODELS: MICROGRIDS CAN REDUCE COSTS AND UNLOCK NEW REVENUE STREAMS. Dramatic shifts in energy costs have benefited the microgrids market directly, both by enabling a greater share of renewables into microgrids energy sources and by improving the economics of microgrids deployments. In 2009, the cost of building a solar plant was 223% more than that of a new power plant that burns fossil fuels.[9] In the last decade, the growing adoption of solar and wind has reduced the cost of electricity generated by renewables by some 90%, effectively reversing the calculus: *Renewables are now cheaper than coal.* With more and more installations, the costs of renewable energy resources will continue to decline. In recent years, rising fuel costs, increasing carbon pricing initiatives, and growing tax and regulatory incentives have made renewables even more competitive.[10]

Experimentation and technological progress over the last few decades are also unlocking new business cases for microgrids. This has larger utilities entering the game: A recent study found that while only 13% of utilities, manufacturers, and network operators claimed to be fully active in the microgrid sector, some 28% were "actively engaged," and a further 39% were at "an early stage of exploring microgrids as an opportunity."[11] Emerging business models run a wide gamut and are essential for broader microgrid adoption, given the return on investment (ROI) expectations of large grid operators. Our research found the following business model trends driving microgrid monetization:

1. **ADVANCES IN DIGITAL CONTROLS ENABLE ENERGY-AS-A-SERVICE (EAAS) MODELS,** in which software, remote sensing, analytics, and other technologies enable providers to offer "pay-as-you-go" cloud-based service models for energy with remote monitoring and optimization. EaaS is also now used in the U.S. for institutional, commercial, and industrial microgrid applications. In these models, public/private entities design, build, own, operate, and maintain microgrids, while customers take on little to no risk and don't have to put up any upfront capital.
2. **LARGE UTILITIES PARTNER WITH LOCAL COMMUNITIES,** in which infrastructure and energy management becomes two separate businesses. Communities benefit from local (greener) infrastructure and greater efficiencies and reliability, while grid operators manage loads and infrastructure to ensure flexibility and stability while increasing the share of renewables on the distribution grid.
3. **RETROACTIVE INSTALLS,** in which companies offer a differentiated product/service to form a microgrid out of existing equipment or update an existing fossil backup power system with integration of new renewables.
4. **SYSTEMS INTEGRATION AND MANAGEMENT,** in which vendors or other third parties help configure and implement a full or modular microgrid and/or charge fees for service and maintenance.
5. **PROSUMER AND PEER-TO-PEER MODELS,** in which local energy nodes (residential, vehicle, or commercial) could generate more sustainable power via microgrids and sell excess energy to other members of the community or the utility, reducing costs for all.

While nascent, these models are creating new tailwinds for microgrid adoption. Meanwhile, several adjacent trends, from standard pricing mechanisms to blockchain tokenization to regulations, could further influence economic incentives for microgrids.

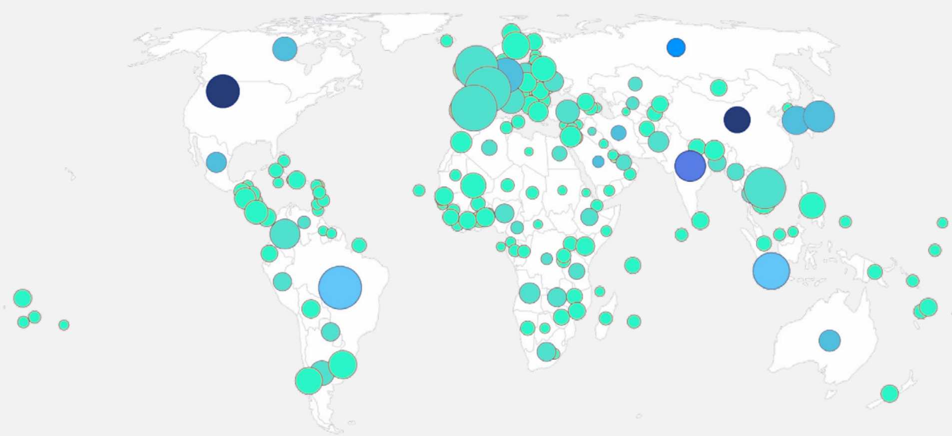
NEW REGULATION AND POLICY INCENTIVES: MICROGRIDS AND DERS APPEAR IN EMERGING LEGISLATION. Around the world, a growing number of climate policies, such as those around carbon reduction, electrification, and energy resiliency, are favorable for microgrids. Key countries are passing important legal precedents.[13]

In the United States, the recent Inflation Reduction Act earmarks some $370 billion dedicated to the energy transition, including production and investment tax credits, which help lower investment costs and incentivize the use of DERs. Other U.S. policies, such as the Federal Energy Regulatory Commission Order 2222, help aggregated DERs to compete on the same footing as traditional power plants and other grid resources in wholesale markets by enabling asset-based demand response (i.e., participation of an onsite energy source into the grid). A range of policies promoting microgrids exist at the state level as well: Lawmakers in 18 different states proposed or enacted 112 bills between 2015 and 2020, according to the Smart Electric Power Alliance and EnerKnol.[14]

FIGURE 5

CLIMATE CHANGE LAWS OF THE WORLD

SOURCED FROM CLIMATE-LAWS.ORG AND MADE AVAILABLE UNDER THE CREATIVE COMMONS CC BY-NC LICENCE.



Number of Climate Laws and Policies

1 15 44 72

The **size** of the circle represents the number of climate laws and policies. The larger the circle, the higher the number of climate laws and policies.

Country Greenhouse Gas Emissions Data (CAIT 2016) (MtCO2e)

<169 >5,833

The **colour** of the circle represents carbon dioxide emissions from the use of fossil fuel and the manufacture of cement, land-use change, and forestry (MtCO2e). The darker the circle, the higher the emissions.

PARTNERSHIPS BETWEEN LARGE UTILITIES AND LOCAL COMMUNITIES FORGE NEW BUSINESS MODELS

E.ON (one of Europe's largest energy suppliers), RWTH Aachen University, and the town of Simris, Sweden, demonstrate how cooperation between the private sector, local government, and engaged citizens can generate value for all. Working with stakeholders to test and implement a local microgrid, the project connected local solar panels, wind turbines, battery energy storage, smart energy management, and connected users, resulting in a significant decrease in electricity consumption as well as carbon emissions. The system's built-in peer-to-peer energy exchanges and automation helped to balance and optimize the grid. "Prosumers" were compensated for the resources they shared with neighbors *and back into the grid.* The collaboration was part of the E.U.'s Interflex Project, designed to "investigate the use of local flexibilities to relieve distribution grid constraints."[12]

"From fleet electrification to expanding the tax credit horizon for EVs, solar, wind, and storage, the Inflation Reduction Act mentions "microgrids" over 10 times!"

- JANA GERBER, NORTH AMERICA MICROGRID PRESIDENT, SCHNEIDER ELECTRIC

GROWING INTEREST ACROSS STAKEHOLDERS: MICROGRIDS ARE ENABLING BROADER MARKET OPPORTUNITIES.

From cities to companies, communities to consumers, demand is widening for microgrids. Electrification expands the landscape of demand for electric power. Electrified cars, buses, trucks, trains, scooters, buildings, EV charging stations, and countless other forms of infrastructure don't just require reliable electricity; they can contribute energy back into the larger grid as well. Thus, municipalities around the world are evaluating microgrids as part of their smart city initiatives to create critical infrastructure for the future.

"As the grid continues to reveal its frailty, companies realize the costs of being without power (and benefits of having something onsite or local). For example, many grocery stores are obligated to throw everything away if the power is out for more than three hours. That's a pretty short window."

- CAMERON BROOKS, EXECUTIVE DIRECTOR, THINK MICROGRID

Beyond cities, any company can benefit from a microgrid's long-term cost savings and energy security—particularly those with large offices or campuses, or data centers that could lose large sums of money with a power outage. Microgrids can also help companies reduce reliance on fossil-fuel resources, such as backup diesel generators. New building and electricity distribution technologies are driving the market from the industrial side, enabling large manufacturing sites to themselves serve as microgrids. In addition to the resiliency benefits outlined above, industrials—already under intense pressure to decarbonize—are increasingly realizing the potential for microgrids to further boost efficiencies and returns, from supporting EV fleet charging infrastructure to providing grid services. Farmers, schools, retailers, hospitals, automotive, and technology companies are following suit.[15]

PART OF THE UNITED STATES' BIPARTISAN INFRASTRUCTURE LAW CREATES A $10.5 BILLION GRID RESILIENCE AND INNOVATION PARTNERSHIPS PROGRAM to accelerate the deployment of transformative projects that will help to ensure the reliability of the power sector's infrastructure. This funding is likely to benefit microgrid adoption as an implementation option to enhance grid flexibility and improve the power system's resilience against growing threats of extreme weather and climate change.

Microgrids are also trending smaller and more hyper-local, which is beneficial for smaller companies as well as communities and households. A Bloomberg NEF study reports that the average microgrid size was 7.7–7.9 MW prior to 2018 and is now around 1.7–1.9 MW.[16] Couple this shift with growing political and cultural demands among people for more energy autonomy, environmental concerns, and localized sovereignty, and microgrids may play an important role in "prosumer" models, where households or small communities both use and sell renewable energy and storage. A report from the Netherlands found that microgrid technologies could make a local "techno-economy" 90% self-sufficient through decentralized energy sharing at the local level between multiple households.[17]

"Microgrids are becoming the platform for both energy access and energy transition for emerging markets. They are helping hundreds of countries delink the grid from fossil fuels and obtain electricity with a high degree of reliability and sovereignty."

- MANOJ SINHA, CHIEF EXECUTIVE OFFICER, HUSK POWER

Microgrid market barriers

Despite the many tailwinds in driving this market, microgrids also face significant challenges preventing widespread adoption. Our research surfaced the following barriers hindering microgrid market growth.

1. **INCUMBENTS CONTINUE TO RESIST WIDESPREAD MICROGRID DEPLOYMENT.** Legacy power structures are often resistant to change and slow to implement it at scale. The microgrid space faces barriers from existing utility providers and some industry and government stakeholders.

   Some "advanced" economies with older infrastructure, such as the U.S., are slow (or have little incentive) to break through cultural barriers to innovate or pivot from entrenched business models. Utilities' reticence to new grid models or advancing software capabilities—particularly built with open source—is often framed around cybersecurity or heightened risk. Though dynamics vary by region. Europe, known for its embrace of decarbonization, has focused less on microgrids and much more on large-scale renewable infrastructure (e.g., wind) and trading between countries (via VPPs). While some large utilities have embraced microgrids, particularly in Australia, few have invested in integration with traditional infrastructure or VPPs, never mind full transformations.

   > "Is it a lack of awareness or a cover for maintaining the status quo?" posed one industry veteran. "When it comes time for transition, utilities are often averse. They don't want to evolve and adapt to the market; they want to control change based on their own needs. The ability for large utilities to control microgrids will be an important factor in adoption."

   Some point to demand-side obstacles too, such as the intensive procurement rules around vendors, or common "buyer criteria" that vendors must have deployed in their region or use case context. This demand for proven brands or implementations could represent an even greater challenge to open source microgrid deployments.

   In some countries, governments are slow to embrace microgrids due to vested interests in the oil & gas sector. Similar to resistance against renewables by the coal industry, diesel-based economies and supply chain participants in certain parts of the world see little financial gain in transitioning to microgrids focused on renewable energy resources. In other countries, government corruption hampers progress. For example, microgrid vendors interviewed cited examples of government officials in certain countries who refused to sign off on projects until they were accommodated for personal gain.

2. **FRAGMENTED STANDARDS AND LOW INTEROPERABILITY IMPAIR MICROGRID MARKET INNOVATION.** As in many other technology markets, common standards and the ability for adopters to easily plug into various manufacturers' components, and exchange information between them, is a crucial catalyst for efficient deployment and democratized access. Microgrids suffer from fragmentation in several areas:

   - Lacking standards in both component hardware and system architecture (e.g., batteries, digital relays) as well as component technologies (e.g., switchgear, solar inverters), which stifles modularity and commercially available "building blocks"
   - Lacking standards in the "middleware" controls layer (e.g., software, APIs, technical regulation of power flows) to help abstract away from diverse configurations and enable commercialization, such as in the form of new apps or marketplaces
   - Lacking a standard mechanism (e.g., price) for demand/supply control to enable easier exchange across local/distributed/wholesale markets

These issues result in low interoperability between microgrids with large utilities (and their proprietary control regimes), undermining energy resilience opportunities and new business model innovation.

The huge range of variables involved in microgrid deployments—location, use case, time, devices, power sources, and more—simultaneously explain why configurations (particularly software) trend toward high customization and showcase the underlying need for more standardization.

"Interconnectability is key. It will speed up the entire microgrids industry when things fit together faster–common protocols for data, for communications, for devices. Take the automotive industry as an analogy: Hundreds of components go into a car from around the world. It must all fit together to drive off as a car, seamless and invisible to the customer."

- STEPHEN PHILLIPS, CHIEF EXECUTIVE OFFICER, OPTIMAL POWER SOLUTION

"The Internet works because we have a core set of technology standards people adhere to because that's what makes it function. This doesn't exist for microgrids yet. Today, almost all microgrids are custom-designed and hand-built, more like a medieval craft than a commodity product. Electrical tech, from solar panels to plugs to batteries, is still inferior in having anything modular for plug-and-play operation."

- BRUCE NORDMAN, RESEARCHER, LAWRENCE BERKELEY NATIONAL LABS

3. **EXISTING POLICIES AND REGULATORY REGIMES HAVE YET TO ADAPT, HAMPERING MICROGRID BUSINESS MODEL INNOVATION.** While a handful of policies (outlined above) have recently emerged as more supportive of microgrids, most existing energy policies lack guidance or incentive that favor microgrids. The broader state of energy regulation remains highly favorable to centralized grid infrastructure and inadequate for driving microgrid deployment.

   The challenge lies in changing existing regulatory regimes to incentivize utilities toward localized energy resilience better. For instance, in the U.S., regulated utilities earn money through investing in infrastructure and charging energy users on their bills—not through market mechanisms such as efficiency, equity, or innovation. Thus, per the current policy, utilities typically earn nothing when a customer installs a microgrid. Indeed, it reduces operating revenue in many cases. Another related challenge lies in permitting, including friction and delays in obtaining permits from local authorities to deploy microgrids.

   In some regions, the challenge is less about changing an existing policy and more about defining a new policy for utilities' business model continuity. For example, regulators must consider how "prosumer" microgrids would exchange revenues with grid operators to ensure they are compensated for infrastructure maintenance.

"It's not just about resolving the wording of existing regulations, but more structural. For example, money to maintain distribution systems comes from charging energy users on their bills proportional to energy consumption. Historically, this money is intended to compensate for the use and maintenance of the grid, so what is the role of regulation to ensure revenue and uptime in new models?"

- FERDINANDA PONCI, PROFESSOR, INSTITUTE FOR AUTOMATION OF COMPLEX POWER SYSTEM, RHINE-WESTPHALIA TECHNICAL UNIVERSITY OF AACHEN

Compounding these challenges are policymakers' general lack of understanding of microgrids, the glacial pace of legislative change, and the reluctance of incumbents to commit to or collaborate on anything more than proposals and roadmaps.[18]

"Neither governments nor utilities can stop microgrids. Still, they can certainly slow progress, limit discussions, and shape policy."

- CAMERON BROOKS, EXECUTIVE DIRECTOR, THINK MICROGRID

4. **MICROGRIDS' LEARNING CURVE REMAINS A BARRIER TO ADOPTION ACROSS STAKEHOLDERS.** The wide range of applications, technologies, jargon, and expertise involved to understand microgrid deployment presents significant roadblocks to market maturity. Policymakers and municipal leaders may conflate one type of microgrid (a military application) with other types (such as a neighborhood) and their distinct value propositions. Grid operators and vendors struggle with the high level of customization and piecemeal solutions for different use cases, not to mention finding the talent with the necessary skills and expertise to design and manage microgrids. Customers and citizens are often unaware of the benefits or requirements of microgrids or how they differ from solar panels and the existing grid. Finally, we are all subject to the learning required to navigate new technology and its promises and perils.

"People still struggle to understand microgrids; even the term is too technical for some. We find that calling it a locally sustainable and renewable power plant often resonates more with customers."

- VIPUL GORE, PRESIDENT & CHIEF EXECUTIVE OFFICER, GRIDSCAPE SOLUTIONS

5. **MACROECONOMIC TRENDS, SUCH AS INFLATION AND SUPPLY CHAIN DISRUPTIONS, HAVE ALSO HIT THE MICROGRID MARKET.** Though more recent than the above challenges, increasing prices, energy costs, and compounding supply chain bottlenecks have challenged microgrid build-outs worldwide. As microgrid infrastructure involves key components, such as semiconductors, batteries, and solar panels, supply chain delays translate into longer lead time to design, higher competitive pressures, and ultimately fewer installations.

Readers may note that certain trends represent drivers and barriers to microgrid adoption. Like many emerging technologies, different regions are driving market narratives differently. The Russia–Ukraine war compounds the demand to get Europe off Russian oil and diversify more rapidly into renewables. Yet, Europe's emphasis on large-scale renewable energy initiatives has mostly overlooked microgrids. Europeans often equate microgrids with remote applications, such as those in Africa or Southeast Asia. Microgrid use case variability and interest across stakeholders is widening in Australia and North America, whereas Japan's early microgrid adoption is shifting more toward VPPs.

Some countries, such as China and Germany, are subsidizing electrified infrastructure (and Internet) in developing nations, which drives cost models down for adopters. In contrast to extending large, centralized grids, microgrids can more cost-effectively deliver power to rural regions, which benefits economic development for lower-income residents via affordable, increasingly renewable, self-sufficient access to energy and the Internet. Despite India's existing grid, many NGOs are investing in energy access there to reduce frequent outages and extend access.

Policy tailwinds are picking up in the U.S., despite its slow uptake of electrification. Countries such as India had microgrids for years before relevant regulation came about, whereas others, including Nigeria, adopted similar policies more rapidly. As they say, the future is fragmented.

> "In this era of climate crises, we're not seeing as much growth as we could. It's a matter of deploying the capital. We saw some $150 billion in subsidies deployed to pay for natural gas amidst the Russia-Ukraine conflict. Imagine if we invested that $150 billion in microgrids: We would have decades of energy supply!"

- MANOJ, CHIEF EXECUTIVE OFFICER, HUSK POWER

Open source for microgrid development

Founded on the principles of openness, collaboration, transparency, and community-oriented development, the open source technology ecosystem has a long history of driving accessibility, interoperability, and innovation. The open source ecosystem represents enormous potential to accelerate microgrid innovation rapidly. The wide range of microgrid applications and their distributed and localized nature render deployments idiosyncratic and often highly customized. This complexity and the need for multiple systems to talk to one another have sparked the immense need for interoperability and standards.

To evaluate the current landscape of open source microgrids and its core value propositions and gaps, we interviewed 17 microgrid leaders from across the market—utilities, vendors large and small, microgrid designers, and research and policy experts working in various parts of the world. We also analyzed open source activities across the microgrids space and canvassed other industries to identify pathways and recommendations to accelerate open source microgrids adoption.

> "We need to accelerate the adoption of microgrids for many reasons, but to accelerate all the supply and demand trends already happening, open source could be the missing ingredient to take it all to the next level."

- PETER ASMUS, ADJUNCT FACULTY, SENIOR ADVISOR, MICROGRID STRATEGY & THOUGHT LEADERSHIP, ALASKA CENTER FOR ENERGY AND POWER

The open source microgrids landscape today

While the microgrid market is growing internationally, the "open source microgrid" marketplace remains nascent. Most in the industry are not aware of open source offerings, and there is generally low penetration of open source technologies across suppliers and adopters of microgrids today. We identified more than 20 open source microgrids projects around the world, as well as four standards that microgrids developers can access and use today. The framework on the following page offers a sample landscape view of open source microgrid activities across six categories:

OPEN SOURCE MICROGRIDS LANDSCAPE

STANDARDS

OpenFMB Duke Energy, Siemens, & others	Sunspec Modbus Sunspec	IEEE 2030.5 IEEE	Open ADR Berkeley Lab, Ford, NEEA, PGFA, Southern California Edison

MODELING & SIMULATION TOOLS

GridLAB-D Pacific Northwest National Laboratory	OpenDSS Electric Power Research Institute	Open Modelica Microgrid Gym Paderborn University	tkRule-Based Optimized Service Restoration E.ON Energy Research Center, RWTH Aachen University
VILLAS Framework E.ON Energy Research Center, RWTH Aachen University	Pymgrid: PYthon MicroGRID Total Energies	Open Microgrids System Simulator GridApps-D	Open Power System Data Neon Energy

SOFTWARE & PLATFORMS

CoSiF IEEE	OpenPayGo EnAccess, Solaris	Hyphae LF Energy	Open Source Microgrid (OSM) University of Texas
Open Energy Microgrid Controller National Renewable Energy Laboratory	Open Energy Playground RISE Interactive	Grid eXchange Fabric (GXF) LF Energy	

COMPONENTS & HARDWARE

Open Microgrid University of California Berkeley	Autonomous Power Interchange System Sony Computer Science Lab	Microgrid-in-a-Box Idaho National Laboratory

EDUCATION

Micro-Grid Academy Alliance for Rural Electrification
James E Rogers Energy Access Project Duke University

FOUNDATIONS

EnAccess
Linux Foundation

*NOTE THAT THIS LANDSCAPE OFFERS A SAMPLE OF OPEN SOURCE MICROGRIDS PROJECTS AND SUPPORTING ENTITIES AND IS NOT A COMPREHENSIVE LIST. WE INVITE THE COMMUNITY TO HELP CO-CREATE THIS ON GITHUB AND REFERENCE LF ENERGY'S INTERACTIVE LANDSCAPE.

- **OPEN SOURCE MICROGRID EDUCATION AND TRAINING:** There are several open source educational resources and training programs available for learning about microgrid technology and development.
- **OPEN SOURCE MICROGRID STANDARDS:** There are several open source standards available for microgrids, including the OpenADR and OpenFMB standards. These standards enable interoperability between different microgrid systems and components, ensuring that they can communicate and work together seamlessly.
- **OPEN SOURCE MICROGRID MODELING AND SIMULATION TOOLS:** There are several open source tools available for modeling and simulating microgrid systems, such as GridLAB-D and OpenDSS. These tools enable designers and developers to evaluate the performance of microgrid systems and optimize their design and operation.
- **OPEN SOURCE MICROGRID SOFTWARE AND PLATFORMS:** There are several open source platforms available for the development and management of microgrids. These platforms provide a framework for integrating various microgrid components, including energy storage systems, renewable energy sources, and load management systems.
- **OPEN SOURCE MICROGRID COMPONENTS/HARDWARE:** There are some open source components available for use in microgrid systems, such as inverters, controllers, and sensors. These components can be used to build customized microgrid systems that meet the specific needs of different communities and settings.

Overall, the landscape of open source microgrid technology is diverse and growing rapidly. As the demand for sustainable and reliable energy solutions continues to grow, we can expect to see continued innovation and development in this area.

LF ENERGY
Hyphae

CASE EXAMPLE:
HYPHAE: OPEN SOURCE MICROGRID CONTROLLER PROJECT

The Hyphae Project was developed in a partnership between Sony and LF Energy, motivated by the desire to develop open source microgrids that large-scale energy providers could connect to and learn from. Hyphae is an automated controller software that automatically distributes locally produced renewable energy over a direct current (DC) grid to interconnect with alternative current (AC) grids.

Hyphae aims to buoy energy availability, stability, and independence by developing solutions for DC microgrids that translate to AC microgrids. Industry expert Antonello Monti notes:

> "DC microgrids are the future of the industry, as they are more efficient. Most microgrids are still currently AC, however, if we have proof of concept in DC that can translate to AC, we will have more AC adoption and broader interoperability—which drives scalability."

Currently, Hyphae is supporting bus terminals at RWTH Aachen University as well as a handful of other businesses and universities throughout Germany. In the future, Hyphae seeks to ease the connections between energy producers and consumers using microgrids by offering Hyphae as a microservice integrated into existing energy infrastructures.

Hyphae is managed in part by the Hyphae Technical Steering Committee and welcomes partnerships with hardware providers to ensure the system is truly interoperable.

Evaluating open source value propositions for microgrids

The opportunities and value propositions open source presents for microgrids address several market barriers described earlier in this report. We asked those interviewed to identify the key benefits of open source for microgrids as well as what barriers and gaps would need to be overcome. We also analyzed where opportunities lie across the microgrids "technology stack." Our analysis found that value propositions exist for the open source to support broad industry collaboration, standardization, and innovation across several layers, as outlined in Table 2 on the right.

TABLE 2

OPEN SOURCE OPPORTUNITY ACROSS THE MICROGRIDS STACK

<table>
<tr><th rowspan="2">VALUE LAYER</th><th>EXPANDS ACCESSIBILITY
to microgrid adoption</th><th>ACCELERATED DESIGN
sharing and composability</th><th>IMPROVES INTEROPERABILITY
and standards adoption</th><th>MARKET INNOVATION
energy resilience at scale</th></tr>
<tr><td>Energy Access/ Economic Development
Democratized Access to Resources, Education</td><td>Efficiency
Modularity
Open Data</td><td>Consensus
Compatibility Across the Stack
Transparency
Flexibility</td><td>Time to Market
Cost Reductions & Business Models
Security Improvements
Talent Pipelines</td></tr>
<tr><th rowspan="2">COLLABORATION LAYER</th><td colspan="4">COORDINATION AND COALITIONS ACROSS STAKEHOLDERS:
Education • Design & framework sharing • Best practice sharing • Stakeholder consortia
Policy design • Joint projects and development</td></tr>
<tr><td colspan="4">STANDARDS: Set of rules or procedures for transmitting data or connecting nodes in a microgrid system, such as protocols, technical standards, mechanisms for energy flow
SAMPLE PROTOCOLS: Demand response protocols, data communications, communications with utilities, pricing management</td></tr>
<tr><th rowspan="3">MICROGRID TECHNOLOGY LAYERS</th><td colspan="4">DATA MODELING & SIMULATION: Data flowing across and about microgrid systems, used to train software and machine learning programs, and model and simulate microgrid systems
SAMPLE DATA: Consumption data, load data, weather data, pricing data, power source data</td></tr>
<tr><td colspan="4">SOFTWARE & PLATFORMS: Comprise some ~20% of microgrid configurations, such as energy management systems, control systems, APIs, algorithms
SAMPLE USE CASES: Weather prediction, energy forecasting, demand management, system balancing, load control, DER aggregation, simulation models, optimization recommendations</td></tr>
<tr><td colspan="4">COMPONENTS & HARDWARE: Some 75% of microgrid configurations consist of hardware
WIDGETS: Switchgear, controllers, relays, inverters, remote terminal unit, smart meters, fault recorders, other IoT devices
POWER SOURCES: Solar panels, batteries, generators, storage</td></tr>
</table>

Value proposition 1: Open source improves accessibility to microgrid adoption

The lower the financial barriers to participation, the more people can benefit. A distinguishing feature of today's open source software versus proprietary software is that a more diverse community of users often adopts open source software. The more accessible the product, the more diverse the users—developers, designers, prosumers, and industrial users alike—whose inputs tend to reflect a wider range of needs and use cases.

> "OS accelerates everything in digitization. Whether large or small, it's a way to break barriers and democratize new ways of building, applying, and monetizing"
>
> - ANTONELLO MONTI, PROFESSOR & INSTITUTE DIRECTOR, RHINE-WESTPHALIA TECHNICAL UNIVERSITY OF AACHEN

ACCESS TO ENERGY AND ECONOMIC DEVELOPMENT IN EMERGING MARKETS

Emerging markets are a key beneficiary of open sourcing microgrid technologies and building blocks. In parts of Latin and South America, East and West Africa, and Southeast Asia—where some 14% of the world's population remains without power[19]—microgrids represent access to reliable electricity that is more resilient during extreme weather events and not beholden to foreign exporters.

> "Many communities just cannot afford a $2 million controller."
>
> - VIVEK BHANDARI, CTO, POWERLEDGER

> "Often, there is not a lot of money in the system to support poor communities. Open source could enable us to have a community version of a platform available, and the investment is reduced significantly. Vendors' roles shift toward services: Custom deployments, cloud operations, and maintenance."
>
> - MICHAEL GOLDBACH, CPO, NEW SUN ROAD

Open sourcing microgrids can also accelerate access in terms of speed to deployment in emerging markets. Leaders we spoke with pointed out that traditional vendors and more developed markets are often very slow to act—between clearances, permits, or other bureaucracy—and open sourcing microgrid building blocks can help smaller vendors and emerging markets move more rapidly. Moreover, microgrids represent a scalable vehicle for emerging markets to drive economic development while transitioning away from fossil fuels.

> "Traditional large players are going to be looking for the multi-million-dollar microgrids projects, so they aren't being hostile to local $10,000 projects. With open source, everyone has access to learn about the technology; it's not a competition."
>
> - VIVEK BHANDARI, CTO, POWERLEDGER

ACCESS TO RESOURCES, EDUCATION, AND BENEFITS OF MICROGRIDS

Democratizing access via open source sharing of best practices, designs, tools, and value models can accelerate understanding and expertise across multiple stakeholders. Like all new and disruptive technology systems, microgrids face resistance and doubt from energy incumbents and generally are not widely understood by most. A microgrid knowledge curve exists across stakeholders, utilities, prosumers, developers, policy makers, business adopters, and more. Many of them struggle to understand:

- Value propositions of microgrids, such as cost efficiencies, investment returns, security, and resilience.
- Differences between hardware components, software, networks (e.g., owning solar panels vs. being connected to a microgrid)
- Differences between the multitudes of different kinds of microgrids (piecemealed solutions and customization, skills needed)
- Policy limitations, the timing for new development, and mechanisms for change

ENACCESS

ENACCESS MAKES OPEN SOURCE DER PROJECTS MORE ACCESSIBLE

EnAccess is a Holland-based energy access foundation founded in 2017 whose mission is to support, curate, and promote global energy access by directly supporting energy system builders and energy users alike. Focused primarily on renewable mini-grid energy management solutions, EnAccess funds hardware and software "building block" projects, offering grants for high-risk, high-reward research, and hosts a library of free, ready-to-implement open source hardware, software, and business models. They work to integrate as many of the open source projects in the space as possible, such as:

- Micropowermanager
- Prospect.energy
- OpenPaygoMetrics

EnAccess has partnered with companies such as FirstElectric and NPOs such as the Access to Energy Institute to build a variety of interoperable DER components, including smart meters and battery management systems. Amid the sea of proprietary components and dominant legacy players, EnAccess is a rare example of an active ecosystem where engagement from DER innovators, developers, and users manifests in tangible, accessible, open source DER tooling.[20]

Value proposition 2: Open source accelerates microgrid design

Among experts we interviewed, the most commonly cited benefit of open source for microgrids is *speed*—to understanding, design, implementation, and ultimately, better results for all. Microgrid deployments suffer from delays and cost uncertainties due to high customization and low collaboration. Without shared standards, developers must navigate a massive array of equipment, protocols, algorithms, energy and data storage, and connection types to determine the right solution for each customer's application.

ACCELERATING EFFICIENCIES AND COST BENEFITS

Sharing of open source tools and best practices allows developers to more rapidly advance in designing microgrids by building on top of one another rather than reinventing the wheel with every implementation. Accelerating design also has cascading benefits on costs and efficiencies for developers and consumers.

> "If open source gave developers a simpler way to develop microgrids, it would amount to less time spent in the design phase, greater capacity for more projects, and therefore more money per project for builders. For example, if developers had an open source protocol for a converter to put into their code that offered a standard for connecting from a utility to a microgrid, it would help avoid the mix and match of projects that otherwise contributes to delays and costs. Reduced time and ease of implementation could also reduce overall costs, so end users benefit too."
>
> - JORGE ELIZONDO, PRESIDENT, HEILA TECHNOLOGIES

ACCELERATING MODULAR DESIGNS

"Building blocks" help abstract away the complexity of diverse/custom configurations. To help address the high customization and reduce deployment time and costs, hundreds of companies worldwide are working to transform microgrids into modular products. This approach involves commoditized components or bundled offerings that can be connected together. Such an approach would include:

- Pre-configured key hardware components
- The ability to customize operations through software (often in the cloud)
- Streamlined deployment procedures that reduce the need for onsite engineering during installation

The modular market share is estimated to grow to 22.9%, representing the majority of microgrids deployed by project number, by 2029, according to Guidehouse.[21] Open source can accelerate the microgrids modularity trend even more, expanding the range and accessibility of what is modularized, accelerating design time for module development, enabling best practice sharing and collaboration, and extending modularity from what is predominantly hardware-/component-based today to software or applications tomorrow.

ACCELERATING OPEN SOURCE DATA

Sharing system data and data on what works and does not work can also accelerate microgrid design and adoption. Experts we interviewed pointed to the value of more open data for:

- Project viability and best practice development
- Optimizing hybrid systems (which switch across different power sources)
- Deriving visibility into economics and financial benefits of system performance

- Supporting planners, developers, banks, and others that want to support projects
- Having a standard method for presenting and accessing microgrids data across jurisdictions

Making microgrid performance data available to investors could help them more rapidly understand the efficiency gains, resiliency improvements, and overall financial benefits of microgrids (relative to traditional or no infrastructure).

> "Microgrid development is not just a technical engineering endeavor, it is a financial engineering issue. Making data available open source for the investment community would be a great way to make financing decisions, coordination, and actionability easier."

- STEPHEN PHILLIPS, CEO, OPTIMAL POWER SOLUTIONS

Policymakers evaluating microgrids could also benefit from open data and resource sharing.

> "Money flows in once regulation is in place because it provides stability. This is as true in India as in the U.S. We have seen that once a policy is in place in one region, others draw on it for policy precedent."

- MANOJ SINHA, CEO, UTILIDATA

GRIDLAB-D IS AN OPEN SOURCE SIMULATION TOOL FOR MODELING AND ANALYZING MICROGRIDS.
It can simulate the behavior of different energy resources and the power flow within a microgrid. Developed with funding from the Pacific Northwest National Laboratory and the U.S. DOE Office of Electricity, GridLAB-D couples power flow calculations with distribution automation models, budding energy use, appliance demand, and market models in order to estimate the benefits and impacts of smart grid technology.[22] GridLAB-D is one of several open source microgrid simulation tools that help developers more rapidly evaluate designs and implementation decisions.

LF ENERGY IS SUPPORTING SEVERAL OPEN SOURCE ENERGY PROJECTS THAT HELP DEVELOPERS ACCELERATE DESIGN AND DEPLOYMENT.
In addition to Hyphae, outlined above, it supports Grid eXchange Fabric, an open source software platform that enables hardware monitoring and provides several "out-of-the-box" functions that provide high security, scalability, and availability and a generic design with no vendor lock-in.[23]

Value proposition 3: Open source can improve microgrid interoperability and standardization

There is an immense need for a common system architecture in the microgrids space. Fragmented standards, the lack of interoperability between devices from different manufacturers, and the inability to integrate or exchange data, APIs, or supply/demand mechanisms hamper microgrid adoption and innovation. Not only does this create additional challenges to remote devices working together efficiently and reliably, but it also creates additional barriers to "plug-and-play," value-added functions, new business models, and adoption by utilities, such as exchanging with microgrids to better leverage underutilized assets or developing interoperability across applications.

Just as common plugs and outlets allow for manufacturers to innovate on top of electrical wiring, or the adoption of Hypertext Transfer Protocol Secure allows secure communications over the Internet regardless of jurisdiction, universal standards are a critical enabler for network adoption and network effects.

OPEN SOURCE CAN HELP DRIVE CONSENSUS AROUND STANDARDS, WHICH ENABLES INTEROPERABILITY between different microgrid systems and components, ensuring they can communicate and work together seamlessly. Even larger firms, such as Schneider Electric, are trying to standardize the sizing of microgrids to cut down on customized engineering costs. Multiple parties can come together around open source protocols to test, improve, and agree on their shared adoption. Two examples of this, enabled through LF Energy, are the Carbon Data Specification and EVrest, which are open source data and software focused on standardizing data requirements for tracking carbon emissions and abstracting across multiple standards in the electric vehicle space.[24]

OPENFMB: A UTILITIES-DRIVEN OPEN SOURCE STANDARD FOR INTEGRATING DISTRIBUTED ENERGY RESOURCES IN MICROGRIDS

Duke Energy brought together a coalition across 25 utilities, vendors, research labs, and government agencies in order to lead the development and commercialization of a field device interoperability framework, known as the Open Field Message Bus (OpenFMB).

OpenFMB is a reference architecture and framework for integrating distributed energy resources in a microgrid. It allows nodes—meters, relays, inverters, cap bank controllers, etc.—to manage distributed resources that communicate via common semantics and federate data locally for control and reporting. It also enables legacy equipment to be retrofitted for new capabilities and features and extended life.

The standard was ratified in 2016 by the North American Energy Standards Board, a leading energy industry Standards Development Organization accredited by the American National Standards Institute (ANSI). All can use the standard, though membership is required to participate in its User Group. There are several OpenFMB working groups that help support and govern the OpenFMB ecosystem's open source technology artifacts (use cases, data models, demos, etc.) available on various public repositories to help facilitate awareness, education, implementation, testing, and certification of OpenFMB. Today, Duke and several organizations in the User Group are testing microgrids use cases and sharing learnings across members.[25]

OPEN SOURCE CAN DRIVE COMPATIBILITY ACROSS THE MICROGRIDS STACK. Although the landscape of open source microgrid projects is relatively nascent, projects are emerging across software platforms, components and hardware, simulators, and more. This signals potential for greater consensus, shared uptake, standardization, and interoperability across multiple parts of microgrid technology and distributed energy networks. Open interfaces and open source reference implementations enable interoperability between solutions, whether in-house or vendor-built, so that all are able to leverage best-of-breed options in the ecosystem. Better interoperability of microgrids would enable customers to adjust their microgrids in a modular, streamlined, and efficient way.

Technology maturity is one determinant of where open source could support interoperability sooner than later. Certain more mature elements of microgrid configurations have been around for decades, such as solar PV panels or relays. Thus, their commoditization and relatively lower vendor resistance may facilitate open sourcing such technologies.

Vipul Gore, CEO of Gridscape Solutions, came to the microgrids industry from the telecom space and shares a parallel anecdote:

“Early in the telecom networking industry, we had netcards, and finding a driver for all the cards was very hard. Now they are open source. It took thousands and thousands of devices to become available on the Internet to get to that point. As energy networks evolve, certain elements of microgrids that get more commoditized, like solar PV systems, batteries, transformers, or switch gears, will become more generic, and control software operating these elements could certainly become open source more easily in years to come.”

On the other hand, more emerging microgrid technologies, such as intelligent software systems and analytics for energy optimization—and the novel use of big data and AI generally—are viewed as the differentiator between control schemes and therefore will likely face open source resistance to remain proprietary in the near-term.

TRANSPARENCY OF CODE CAN HELP ENABLE BETTER HARDWARE–SOFTWARE COMPATIBILITY. Open source projects allow for greater scrutiny and verification of code, which, in addition to security and reliability benefits, allows developers to more easily and flexibly design for compatibility so disparate hardware and software can talk to each other.

“If we want to open source microgrid software and hardware, it has to be coupled and compatible with industry-standard solutions.”

- VIVEK BHANDARI, CTO, POWERLEDGER

If open sourcing certain software remains incompatible with key standards or hardware, that could further diminish functionality or add fragmentation or complexity to an already complex design configuration process.

"There are examples of RTU hardware that enable developers to write custom programs into it. We could imagine open source algorithms for microgrids, which could be used as inputs or outputs to this hardware."

- VIVEK BHANDARI, CTO, POWERLEDGER

MODULARITY HELPS ENABLE INTEROPERABILITY. As outlined above, open source can help accelerate the current trend toward modularity of microgrids.

"The key to accelerating microgrid designs with open source is that when others want to build on top of what is available open source, they can enhance functions further."

- VIVEK BHANDARI, CTO, POWERLEDGER

Standards and interoperability are an important enabler for creating this flexibility, so that solutions can be easily and efficiently customized, retrofitted, and built upon to meet the specific needs of microgrid projects.

"Open source could help bring interoperability to a higher level. One area it could really make a difference is helping define a missing middle layer, akin to an API. We need a middle layer that can perform as a component that is more standardized, so I can buy from any vendor, but when I link it into the system it doesn't make a difference."

- ANTONELLO MONTI, INSTITUTE DIRECTOR, RWTH AACHEN

THE INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC) is an international standards organization that publishes international standards for electrotechnology. The IEC also cooperates closely with the International Organization for Standardization (ISO) and the International Telecommunication Union (ITU). In addition, it works with several major standards development organizations, including the IEEE. Leaders we spoke with pointed out that some movement toward standards is happening in microgrids. However, it is geographically dependent: Many in North America are adopting IEEE standards while European developers are looking to the IEC.

Value proposition 4: Open source enables microgrid business models

Open source microgrid business models, like other open source technology business models, can focus on providing accessible software tools, platforms, and frameworks for designing, simulating, managing, and optimizing microgrids. By leveraging open source principles, these business models aim to encourage collaboration, innovation, and the wider adoption of microgrids for distributed energy generation.

TABLE 3

KEY COMPONENTS OF OPEN SOURCE MICROGRID BUSINESS MODELS

OPEN SOURCE SOFTWARE AND TOOLS
These businesses develop and maintain open source software tools that enable the design, simulation, and management of microgrids. By making the source code freely available, they encourage developers and researchers to collaborate, contribute, and adapt the tools to meet specific needs and requirements.

SUPPORT AND CONSULTING SERVICES
In addition to providing open source tools, these businesses often offer support and consulting services to help clients design, implement, and optimize microgrid projects. These services can generate revenue while fostering the adoption of open source solutions in the energy sector.

TRAINING AND CERTIFICATION
Open source microgrid businesses may also offer training and certification programs to educate users on how to effectively use and implement their software tools. This not only helps to increase the user base but also generates revenue for the business.

CUSTOMIZATION AND INTEGRATION
Businesses can provide customization and integration services to adapt their open source tools to specific customer requirements or integrate them with other software platforms and systems. This allows clients to achieve tailor-made solutions while benefiting from the flexibility and cost advantages of open source software.

COLLABORATIVE PARTNERSHIPS
Open source microgrid businesses can form partnerships with other organizations, such as research institutions, utilities, and technology providers, to drive innovation and develop new solutions that address the unique challenges of microgrid implementation and operation.

While it is rare to find microgrid companies employing a purely open source business model today, some organizations incorporate open source elements into their broader offerings. These companies develop open source tools or leverage open source platforms to enhance microgrid solutions and services. Note that the following examples are not purely open source microgrid companies, but they incorporate open source principles in their offerings.

Several leaders we interviewed pointed to **the potential for open source to expand microgrid modularity to enable business models.** This could include hardware building blocks and pre-configured software functions akin to algorithms or APIs, such as a forecasting module, a battery optimization algorithm, an inverter design, or an operating system for a resource-constrained device. A marketplace of modules could emerge, incentivizing builders to improve upon one another; to develop apps and interoperability across the marketplace.

Building blocks could also enable business model flexibility, given that open source software can be easily customized to meet the specific needs of microgrid projects without the constraints of proprietary software.

> "The adoption of an open source toolkit does not eliminate the need for a third-party provider—customers can't manage everything!"

- FERDINANDA PONCI, LF ENERGY MEMBER AND RESEARCHER, INSTITUTE FOR AUTOMATION OF COMPLEX POWER SYSTEM, RWTH AACHEN

OPENREMOTE

OpenRemote is an open source IoT platform that offers energy management and microgrid solutions. Their platform enables users to manage energy generation, storage, and consumption in microgrids and distributed energy systems. OpenRemote offers a community version of their platform and provides support, customization, and consulting services.[26]

OPENER (OPEN SOURCE ETHERNET/IP™ STACK)

OpENer is an open source implementation of the EtherNet/IP™ protocol that enables microgrid controllers and devices to communicate. While OpENer is not exclusively focused on microgrids, its open source solution can be utilized in microgrid communication systems. Companies that implement microgrids can use this open source platform to enable device communication within their projects.[27]

Value proposition 5: Open source can foster microgrid market innovation

Can energy adopt open source to accelerate innovation as other sectors have done in recent years? This research analyzed programs and precedents from other industries that could be applied to the microgrids market. Examples from non-energy industries that could be applied to open source microgrids are woven throughout this section.

Once dominated by proprietary technologies, the telecommunications and IT industries have embraced open source in recent decades to transition off legacy technologies more rapidly and created foundational protocol and software layers across a wide range of innovations, from mobile to 5G networks to AI and more. Today, open source is a critical part of these sectors' enterprise innovation strategies.

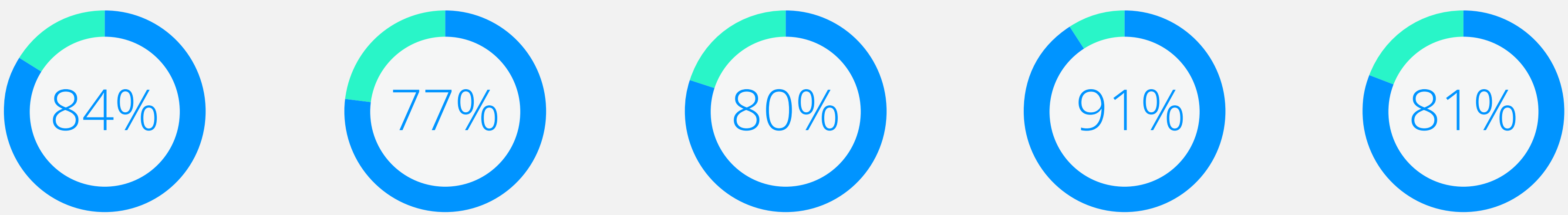
While the energy industry has, to date, been relatively slower to innovate and more resistant to emerging technologies than IT or telecommunications, there is enormous potential to apply open source program designs in the microgrids industry to help overcome common barriers by improving:

1. Innovation speed/time-to-market
2. Business model viability
3. Cost reductions
4. Security improvement
5. Developer and talent pipelines

FIGURE 6

ADVANTAGES OF ENTERPRISE OPEN SOURE

Over 75% of telecommunications & IT leaders view enterprise open source as advantageous to innovation, flexibility, adoption, and security, according to Red Hat's 2022 Executive Survey[38]



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1. INNOVATION SPEED AND TIME-TO-MARKET

Large telecommunications and IT companies have embraced open source technologies and approaches to move faster into the future. While collaborations across dozens of other market constituents may seem less efficient than going alone, new products and services that lack standards, interoperability, or marketplace viability risk sunk investments and poor customer experiences. Partnerships between open source groups and standards bodies have also helped accelerate time-to-market.

Open source can support microgrid network effects

Just as technology leaders came together to create an open source operating system for mobile, energy stakeholders could collaborate on networks and platforms to enable next-generation energy applications and business models far more rapidly than going alone.

> "The big catalyst we need is to figure out the network effects for microgrids. Open source could help microgrids stakeholders figure out a business model so that as more people join, perhaps through a pricing scenario, it becomes more valuable for others to join."
>
> - KEN DULANE, DIRECTOR OF INDUSTRY AND INNOVATION, FREEDM SYSTEMS CENTER, NORTH CAROLINA STATE UNIVERSITY

A new infrastructure for distributed network economics is emerging, as innovations in telecom and IT (from IoT to smart cities, autonomous vehicles to "Industry 4.0") converge with energy through electrification. This further underscores the need for open collaboration because *interconnectivity unlocks new market potential.*

A MARKET BREAKTHROUGH DEVELOPED VIA OPEN SOURCE

The Android operating system, now used by billions of people. To spur innovation, Google created the Open Handset Alliance, a consortium of 84 firms across mobile handset makers, application developers, mobile network operators, and chip makers to co-develop the Android Open Source Project, an open source mobile phone platform based on the Linux kernel. Instead of Google launching its own mobile device, the group open sourced a fully integrated mobile "software stack" consisting of an operating system, middleware, a user-friendly interface, and applications. Android remains free and is utilized broadly by Samsung, Xiaomi, Amazon, LG, and others, saving them millions of dollars in development costs.

2. BUSINESS MODELS

The open source movement in tech has brought about several business models that could be applied to the microgrid ecosystem. The classic freemium-premium model is one such option, where certain elements (such as a database, software code, or core technology) are available to anyone. The vendor monetizes services via software or service-level agreements on top. A big value-add of this model is the ecosystem of users and developer talent created around open source. Just as open source has enabled IT and telecom vendors to maintain competitive differentiation in software controls, the opportunity is also ripe for microgrids.

Service providers charge a fee for custom implementations, cloud operations, maintenance, security, etc. Interestingly, the "building blocks" model can be developed by open source coalitions, such as LF Energy, or it could be contributed by a company that continues to monetize it with unique value-adds.

OPEN SOURCE BUSINESS MODELS

Distributed database platform **MongoDB** offers a freemium-premium approach, offering a community server and free download of their database and atlas, with limited processing power and storage. Users can upgrade to their paid services to access their "Database-as-a-Service" managed offering or premium Enterprise Advanced, which provides enterprise management capabilities, advanced security features, GUI, analytics integrations, authentication, and technical support.

Using open source to onramp users and developers into a broader ecosystem is also **Google's approach with several AI products**, including its TensorFlow machine learning platform, its Material Design framework, and its Go programming language. All three are completely open source; anyone could run them on another cloud provider, such as Microsoft Azure. However, they sit in the Google ecosystem, bringing a significant share of users, talent, and customers into that ecosystem, where they also use paid services from Google Cloud.

IBM-owned **Red Hat**, whose 2021 revenues topped $17 billion, provides open source software platforms, middleware, applications, and management products to enterprises and governments. The company makes money through storage, support, training, and consulting services. Currently, it offers enterprise open source solutions in hybrid cloud architectures, cloud native deployments, and management and automation software specific for large utilities, which can include the incorporation of microgrids.[28]

THE ZEPHYR REAL-TIME OPERATING SYSTEM (RTOS) was developed by a company called Eonic Systems, later acquired by Wind River Systems. In 2015, Wind River made the RTOS kernel open source and royalty-free but continued providing it to its clients, charging them for cloud services.[29] Zephyr's "bundle" includes all components needed to develop resource-constrained and embedded or microcontroller-based applications, such as:

- A small kernel
- A flexible configuration and build system
- A set of protocol stacks
- A virtual file system interface with several flash file systems for non-volatile storage
- Management and device firmware update mechanisms

3. COST REDUCTIONS

Open source software is typically free to use, which can significantly reduce research and development costs compared with proprietary solutions. Transitioning to open source platforms has helped telecom companies reduce vendor lock-in and competitive constraints of legacy infrastructure by enabling companies to govern and orchestrate their own differentiated/more flexible services for customers and cut down on licensing and maintenance fees paid to vendors. Open source also serves as an alternative or complement to in-house teams, saving companies and customers money while driving market development. As such, open source has helped shift cost models from Capital Expenditure to Operational Expenditure by reducing infrastructure maintenance costs and investment risks.

Open source can support cost savings across the entire micro-grids ecosystem. Utilities and operators, vendors, integrators, educators, and more can reduce costs of research, development, simulation, proof-of-concept testing, and more, as exemplified in the Linux Foundation Networking (LFN) example below.

LFN IS AN INDUSTRY COALITION TO ACCELERATE OPEN SOURCE BUILDING BLOCKS, PLATFORMS, AND COLLABORATION FOR ADVANCING NETWORK INFRASTRUCTURE. The program serves as a “center of gravity” for over 100 members across service providers, cloud providers, enterprises, vendors, and system integrators. Members actively participate in software development, collaborating on projects, interoperability, deployments, and security, contributing their own in-house code to the foundation, and releasing it as open source. The program stewards a growing open source networking technology stack, including nine projects.

One project, OpenDaylight, is a modular open platform for customizing and automating networks of any size and scale. Alongside other open source communities, it contributed significantly to the development of technologies core to 5G, including the development of Software Defined Networks and Network Function Virtualization.

WAYS TO PARTICIPATE

- Attend project meetings
- Attend developer events
- Join approved projects
- Propose a project
- Write documentation
- Contribute use cases
- Analyze requirements
- Define tests/processes
- Review and submit code patches
- Build upstream relationships
- Contribute upstream code
- Start or join an OSN User Group
- Provide feedback through EUAG
- Host and staff a community lab
- Answer questions
- Give a talk/training
- Create a demo
- Evangelize LFN and its projects

From market-ready building blocks to speedier time-to-market via collaborative deployments, leaders estimate over $9 billion worth of software innovation has been created since the LFN foundation launched in 2018.

4. IMPROVED SECURITY

Because in-house security teams can be limited in size, suffer from strained capacities, and be biased, open source contributions have been adopted and trusted across the IT industry. A 2022 Red Hat survey of telecom IT leaders found that 87% believe enterprise open source is as secure as or more secure than proprietary software, with 80% stating that "open source 'plays a key role in organizations' security strategy.'"[30] The nature of open source technologies, which are supported by a community, means the world's open source developers are vetting the code, pre-empting risks with patches, which significantly increases security resilience—and can save significant costs.

"The paradox is that open source is often more secure than non–open source," says Antonello Monti, Institute Director, RWTH Aachen, who researches complex power systems. Monti supervises two projects with LF Energy and points out that open source industry groups often have even greater governance and security. There is a common misperception in the energy space that open source solutions are less secure, which several leaders we spoke with pointed out the need to address:

> "We will have to overcome the skepticism of technology built on open source. We try to explain to big incumbents with this mindset that most of cloud computing today is built on Linux! There are plenty of examples of mission-critical applications running on open source."
>
> - MICHAEL GOLDBACH, CPO, NEW SUN ROAD

While security concerns may be misplaced, uptime considerations can depend more on application than open versus proprietary. For example, microgrid applications such as hospitals and militaries cannot risk disaster in the event of downtime or breach, compared with the distributed grid or remote community applications, where a 98% uptime may suffice.

5. DEVELOPERS AND TALENT

Enabling more people to access code, algorithms, API libraries, software, development kits, or other components builds the foundation for a developer ecosystem, wherein researchers and builders explore, learn, use, contribute to, and often help improve these tools. Companies such as IBM, Microsoft, Verizon, and Ericsson court developers young and old with the understanding that they will drive their own innovation, develop apps within their build environments, improve security, and feed their own long-term talent pipelines. Lowering barriers to entry also has several second-order effects, such as increasing the diversity of people and application contexts, extending tooling into new markets, and further bridging the digital divide.

Open source can help draw developer talent into the microgrids space. Open source participation represents an opportunity for energy companies to better engage developers and pipelines of talent. Across the open source microgrids projects we identified, more than 50% are contributed by universities and research institutions. Open source projects for microgrid simulators, software, hardware, and standards aren't just resources for designing microgrids, but for engaging with the contributor communities that maintain them. Other programs include the Energy Access Project from Duke University, which is a dedicated open source forum for engaging students with stakeholders around the development of new, disruptive tools and models that break down barriers to improved energy access worldwide.

Challenges and gaps to open source microgrids deployment

Democratizing access to microgrids via open source is unlikely to spur widespread microgrid deployment on its own. Many challenges facing the market require dedicated education, programs, policies, and financing in order to bridge the gaps.

Challenge	NEEDS
REGULATORY BARRIERS Outdated, fragmented policies, or lack of policies altogether; many policies remain favorable to centralized grid infrastructure	• Policymaker participation • Broader awareness • Collaborative policy design • Greater consistency across jurisdictions
COLLABORATION NEEDED Across a diverse group of stakeholders in the energy ecosystem: Utilities, microgrid developers, public sector, governments, commercial institutions, communities, and more	• A central hub for open source microgrids engagement and learning • Comprehensive landscape of open source microgrids resources • Clear roles and activities for microgrids ecosystem stakeholders
INDUSTRY INCUMBENT RESISTANCE Slow pace of change among utilities, vested interests in fossil fuel-based economies, and concerns around security and safety	• Onramps to open source programs • Address security and safety concerns • Support to overcome resistance (e.g., utility interconnection requirements)
LOW INTEROPERABILITY Between devices, inability to integrate or exchange data, APIs, or supply/demand mechanisms, and fragmented standards hamper adoption, innovation	• Consensus amid standards fragmentation • Standard way of presenting/accessing data across projects and jurisdictions • Coordination with relevant markets (EVs, facility-based charging) • Application-specific modularity • Demonstration of cost benefits
ECONOMIC HURDLES Energy incumbents struggle to understand business model implications; macroeconomic uncertainty increases risk aversion	• Data sharing of microgrids economics • Education on value propositions and ROI • Alignment with decarbonization goals
DIGITAL BARRIERS AND TALENT GAPS Stakeholders struggle with change, whether due to cultural resistance, digital divide, fear, or lack of microgrids engineering skills	• Broad education about microgrids • Access to open source communities • Accessible microgrids skills development in engineering, physics, bioregional knowledge

The diverse range of microgrid applications and design configurations also presents a challenge to open source. From remote (off-grid) to neighborhoods, from stationary and mobile military installations to institutional campuses, to business and industrial applications, open source is no silver bullet for the massive array of technological and commercial deployment considerations.

A common refrain in the microgrids market underscores this challenge. **"If you've seen one microgrid... you've only seen one microgrid, not them all!"** Jorge Elizondo, founder of Heila, Kohler's modular platform that embraces open source for microgrid deployment, says:

"There's a trap about creating new standards. Many people want to come up with the standard that will solve all issues, but that just contributes to the problem, as there is one more standard that everybody else needs to work with!"

While everyone agrees on the need for standards, some question the capacity of open source to support microgrid standardization at the scale and speed required. The biggest risk of any standard, whether developed through open source or not, is simply furthering the proliferation and fragmentation of standards. Elizondo explains:

"Say you have 100 standards, then you say, 'let's create a new standard to cover them all.' Well, now you have 101 standards!"

Others point to timing, arguing that a common system architecture is a prerequisite to aligning around the standardization of communications, equipment, or any other component.

"The real problem space is lack of consensus on universal architecture or foundational systems, and people wanting to move slowly into the future while we need to make big changes quickly. Open source could be very helpful for microgrids, but it doesn't solve these core challenges."

- BRUCE NORDMAN, RESEARCHER, LAWRENCE BERKELEY NATIONAL LABS

In addition, open sourcing full architectural blueprints has faced resistance due to the risk posed by electricity, safety standards, and utility interconnection requirements.[31]

Recommended pathways forward for the microgrids ecosystem

Democratizing microgrids through open source lies at the heart of the imperative to improve energy resilience and transition to renewables. It is estimated that 75% of our planetary carbon emissions can be mitigated through the electrification of energy and transportation.[32] To accelerate the role of open source in achieving this once-in-a-generation transformation requires unprecedented collaboration, shared commitment, and governance across stakeholders in the energy ecosystem.

Open source leadership must start with "end to end" in mind, not over-indexing on any single protocol or component but helping enable a broader vision of "plug and play" or "converting anything to anything" through its program strategy.[33]

How can you contribute to open source microgrids?

Democratizing microgrids through open source requires identifying the key stakeholders in the microgrids market and helping unite them around common challenges, tools, building blocks, and value propositions. Below we surface key roles these constituents can play.

Roles and recommended steps

MICROGRID DEVELOPERS

Microgrid developers are those focused on how to design and sell microgrids, such as technology vendors, technical installers, or building/construction groups. Several providers in **adjacent sectors** (such as solar, storage, batteries, and EVs) are also important collaborators for standards adherence, application specialization, advocacy, and adoption. Microgrids developers can help:

- **Reference and contribute microgrids projects within the open source energy project landscape** across each stage of microgrids deployment, from best practices analysis and simulations to design and deployment.
- **Contribute to open source data sharing,** to provide other stakeholders greater transparency into microgrids performance, adoption trends, and finance models.
- **Design for modular microgrids with open source building blocks** to accelerate microgrid deployments and reduce time and costs of customization.

UTILITIES AND ENTERPRISES

Large energy suppliers and grid operators have immense influence in grid technology design and implementation, resource allocation, policy and developer relations, and global reach. Different utility models—investor-owned, municipally owned, or rural electric cooperatives—also have nuanced differences in regulation and priorities that could impact regional microgrid growth. In addition, diverse **commercial, institutional, and industrial adopters** of microgrid solutions have economic and shared interests in deploying microgrids using open source. Industry resources can help:

- **Align energy resilience objectives and funding** with open source strategy (e.g., paid time allocation for open source contribution) as well as related infrastructure, talent, and outreach efforts.

- **Contribute code, open source software, and microgrids building blocks** to develop open source microgrids software, functions, and components in order to accelerate time-to-deployment, interoperability, and broader industry innovation.
- **Join open source energy coalitions,** such as the LF Energy program, and/or open microgrids alliances to accelerate microgrid technology innovation, interoperability, standards agreement, and decarbonization efforts and to engage in collaborative pilots, business model development, and joint ventures.

OPEN SOURCE COMMUNITIES AND FOUNDATIONS

Open source communities, such as the Linux Foundation and GitHub, play a crucial role in stewarding open source technologies, expanding accessibility, and legitimizing open source in commercial, government, and development environments. As they have done in other industries, open source groups can accelerate microgrids innovation in many ways:

- **Cultivate coalitions dedicated to open source microgrids.** LF Energy's relationships with large utilities can help drive collaboration, consensus, and movement toward more distributed and open energy infrastructure. Open source microgrids coalitions could also go beyond typical membership schemes of large utilities and vendors to include customers, industry groups, governments, policymakers, citizens, prosumers, cooperatives, cities, non-profits, multi-laterals, investors, and more.
- **Support and influence microgrids standards alignment via related open source programs** across key programs, such as LF Energy, Networking, Edge, Automotive (and equivalents). For example, agreement on 5–10 grid coordination mechanisms, *"or even to experiment with these five or 10"* as one interviewee suggested[34], could catalyze standardization across the market far more rapidly than without such a program.
- **Facilitate open source access to microgrids *learning.*** Open source communities must go beyond code contribution. Given the high specificity and diversity of microgrid application contexts, create forums, repositories, and activities that drive knowledge-sharing: Analysis of past projects, learnings across technologies, implementation decisions, simulations vs. real-world, governance, financing models, roadmaps, stakeholder collaborations, policies, customer adoption, best practice sharing, training, conferences, hackathons, and community support.

GOVERNMENT AND PUBLIC SECTOR

Governments include national/federal, regional/state, local/municipal; also military and government institutions as microgrid adopters. **Regulators, policymakers, and agencies,** including executive agencies such as Departments or Ministries of Energy, are responsible for the regulatory design, oversight, and potential subsidization of grid resilience and decarbonization mandates. In addition, **public utility commissions** are often in charge of utility rate cases and programs with the greatest impact on interconnection and approval of specific microgrid projects. These public sector stakeholders can help:

- **Participate in open source programs** to interface with other stakeholders, define funding and safety priorities, contribute regulatory perspectives or digital public goods, aggregate public data, and bolster program access across the public sector.
- **Drive broader awareness and accessibility to microgrids** via open source program resources and campaigns.
- **Leverage open source to design policy updates that favor microgrids and distributed energy** by learning from precedents, driving standards alignment, and assessing governance needs.

“The current lack of clarity around how to build only distracts from understanding the benefits of microgrids. It becomes too overwhelming. OSS can help center learning and collaboration and ease the process for everyone.”

- FERDINANDA PONCI, LF ENERGY MEMBER AND RESEARCHER, INSTITUTE FOR AUTOMATION OF COMPLEX POWER SYSTEM, RWTH AACHEN

While microgrid best practices have been published by MIT,[35] Pacific Gas & Electric,[36] the World Bank,[37] and others, the open source ecosystem offers both precedent for industry collaboration and wide reach among technology builders—both key for commercial adoption.

HUSK POWER SYSTEMS PUBLISHES A ROADMAP FOR MICROGRID DEPLOYMENT IN EMERGING MARKETS, SPURS INDUSTRY INNOVATION.

Husk Power Systems has led microgrid deployments in rural Asia and Africa, pioneering implementations and industry advancements. The company recently released the first-ever industry roadmap for developers, which outlines a framework for scalability, metrics, and commercial viability for the solar microgrid industry in emerging markets. The roadmap received input from over a dozen stakeholders, including development banks, private sector trade groups, academics, think tanks, and multilateral agencies. The roadmap translates the barriers to sustainability and scale into clear industry performance indicators, with a timeline that establishes a path to success. Ultimately, it lays a foundation for uniting the ecosystem around a set of common goals, detailing what actions are required by 2030 for the industry to scale and be bankable, focusing on cost, demand, quality of service, and rate of deployment.

Manoj Sinha, Husk’s founder and CEO, hails from the semiconductor industry, where he found inspiration for the roadmap as a way of overcoming barriers.

“Some 100 years ago, governments helped scale national power grids with subsidies, but this is not the case with microgrids. They won’t radically scale until we combine forces to bring it all together. Yes, it’s a risky bet to publish a roadmap that may divulge your own secret sauce, but we have to do that for the industry to grow. Years ago, when I worked in semiconductors, Intel published a semiconductor roadmap. These roadmaps don’t just help other companies; they help the entire industry pie grow more. This knowledge-sharing is essential to making the sector scale quickly.”

Conclusion

Microgrids are an essential tool to improve energy resilience and advance decarbonization. While several forces are driving increased adoption, the microgrids market faces a range of challenges that the open source ecosystem is well poised to address.

- **IMPROVING ACCESS TO MICROGRIDS RESOURCES** lowers barriers to energy access, expertise, and understanding across all stakeholders
- **ACCELERATING MICROGRIDS DESIGN** and time-to-market helps overcome economic and policy hurdles through open data sharing, improved cost efficiencies, and modularity
- **IMPROVING INTEROPERABILITY** and standards adoption, by fostering ecosystem collaboration, consensus, transparency, and compatibility across the stack
- **ENABLING MICROGRID BUSINESS MODELS,** via software, support and consulting services, training and certification, customization and integration, collaborative partnerships, and advancing modularity
- **ENABLING MARKET INNOVATION TOWARD ENERGY RESILIENCE AT SCALE,** supporting the energy sector to adopt proven open source–enabled business models, security benefits, and cost reductions demonstrated in the IT and telecom industries

Near-term, open source can help catalyze energy access in developing economies by extending accessibility, enabling modularity, and lowering implementation costs. Over time, open source tooling, methods, and collaboration programs stand to benefit the entire microgrids market across a broad ecosystem of microgrid stakeholders.

While adoption and participation of open source microgrids tooling is in the early days, our analysis of the open source microgrids landscape identifies more than 20 projects underway and four standards available for deployments today. Stakeholders across the ecosystem can immediately get involved by participating in available programs and activities, addressing outstanding gaps and challenges, and co-creating shared resources to accelerate microgrids learning, development, and governance.

Open source energy infrastructure is a rapidly growing field that has the potential to revolutionize the way we generate, distribute, and consume electricity. Open source microgrids can benefit everyone, from the largest utilities and governments to remote communities and individual residents as well as the planet itself.

Additional research questions to explore

- Why is there not an obvious leading open source solution for energy, in comparison with other open source solutions in other industry sectors, such as cloud and ICT?
- How can developers best enable the landscape of open source microgrids projects available today?
- What is required to develop an industry-wide open source energy innovation solution akin to OpenRAN for 5G/6G or OpenEV for cars?
- What are the potential open source disruptive solutions needed for the renewable energy sector to achieve decarbonization (e.g., energy storage at micro/nano levels; data and energy interoperability)?
- How can developers accelerate open source versions of commercial energy storage products, such as Tesla Powerwall?
- How can the open source ecosystem address regulatory challenges within and across jurisdictions?
- How can existing open source programs in other industries support open source adoption in energy?

Methodology

This research was conducted between October 2022 and March 2023 as a joint effort between the Linux Foundation, Futurewei, Intentional Futures (iF), and Peter Asmus. iF conducted a mixture of primary research interviews, secondary research, and a canvass of open source microgrids projects and activities. IF conducted 17 interviews with microgrid leaders from across the market—utilities, vendors large and small, microgrid designers, and research and policy experts working in various parts of the world. The analysis also included an evaluation of other industries to identify pathways and recommendations to accelerate open source microgrids adoption. In addition, IF conducted extensive secondary research evaluating microgrids market research reports, investment trends, vendors, and relevant articles across microgrids publications.

Appendix: List of Interview Participants

ANTONELLO MONTI Professor & Institute Director, Rhine-Westphalia Technical University of Aachen; Technical Advisory Committee Chair, LF Energy

BRUCE NORDMAN Researcher, Lawrence Berkeley National Labs

CAMERON BROOKS Executive Director, Think Microgrid

CHRIS VILLARREAL President, Plugged In Strategies

FERDINANDA PONCI Professor, Institute for Automation of Complex Power System Rhine-Westphalia Technical University of Aachen

JANA GERBER North America Microgrid President, Schneider Electric

JORGE ELIZONDO President, Heila Technologies

MANOJ SINHA Chief Executive Officer, Husk Power

MARISSA HUMMON Chief Technology Officer, Utilidata; Board Member, Grid Forward; Governing Board Member, LF Energy

MICHAEL GOLDBACH Chief Product Officer, New Sun Road

MICHAEL CLARK Chief Executive Officer, Encorp

SRDJAN LUKIC Deputy Director, FREEDM Microgrid

STEFAN ZELANZY Managing Director, Access to Energy Institute

STEPHEN PHILLIPS Chief Executive Officer, Optimal Power Solutions

VIPUL GORE President & Chief Executive Officer, Gridscape Solutions

VIVEK BHANDARI Chief Technology Officer, Powerledger

About the Authors

JESSICA GROOPMAN is an industry analyst and the Director of Digital Strategy and Innovation at Intentional Futures. She leads research on human and societal impacts of emerging technologies, specializing in AI, blockchain, IoT, renewables, and more. Her recent research covers sustainability and climate tech, Web3, and digital inclusion and DEI. Based in the San Francisco Bay Area, Jessica works with organizations internationally, supporting strategic advisory, digital transformation, and research across several industry verticals. She is a regular keynote speaker and media contributor, advises start-ups, has served as a contributing member of the International IoT Council and the IEEE's IoT Group, and was named among Onalytica's 100 Most Influential IoT Thought Leaders. Prior, Groopman led research practices at Kaleido Insights, Tractica, Harbor Research, Altimeter Group, and more, having authored over 40 reports and contributed to several books.

JEFFRY LINDSTROM is a Senior Strategist on Intentional Futures' Digital Strategy and Innovation team, where he consults on technology's applications, implications, and possibilities. Jeffry's background in marketing and non-profit management blends with human-centered design and design thinking methodologies to shape an empathetic, stakeholder-centered approach to research and strategy development. Jeffry has studied at the University of Washington, the Pratt Institute, IDEO, and Parsons New School, and his hobbies include interior design, portrait photography, and tennis.

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