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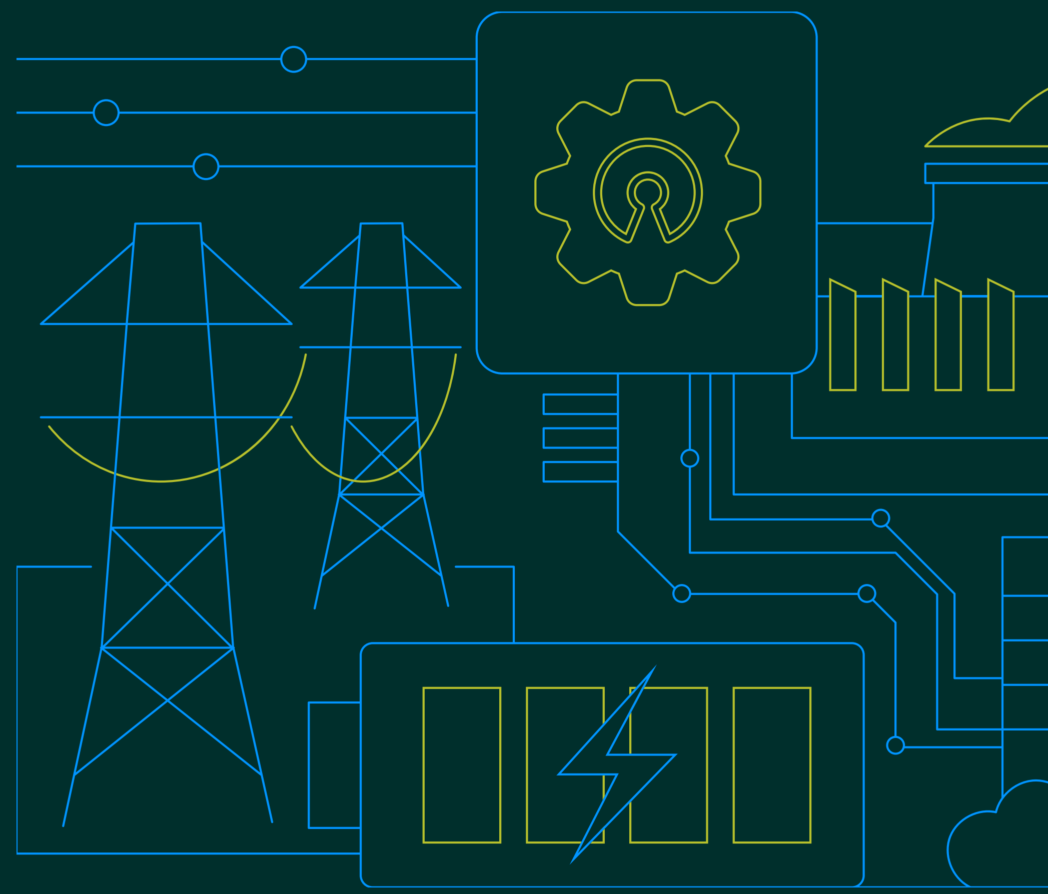
LF ENERGY

The Open Source Value Proposition for the Energy Sector

A Benefit-Cost Framework to Evaluate Open Source Solutions for Utility Grid Operators



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The Open Source Value Proposition for the Energy Sector

Quantify open source ROI. Increasing open source investment — from procurement to active development — yields a proven net value 2–5x higher than current operational costs.

Look beyond traditional TCO. Factor in compounding strategic and societal returns; standard TCO models severely underestimate long-term open source value.

Pool sector-wide R&D. Collaboratively produced open source tools distribute development costs and boost utility R&D efficiency.

Standardize core principles: Adopt comprehensive, modular, extensible, and interpretable design principles to streamline utility software evaluations.

Account for latent operational risks. Integrate reliability, compliance, supply chain, and cybersecurity risks into the analysis to account for true costs.

Incentivize code liberation. Release internal utility tools as open source projects to share maintenance burdens and foster industry-wide innovation.

Quantify full software lifecycles consistently. Pairwise scenario comparisons transform subjective procurement debates into an objective, evidence-based roadmap for utility operators.

Maximize your negotiating headroom. Maintaining a credible open source fallback option creates market competition and decreases costs across software and hardware purchases.

Phase out status quo inefficiencies. Despite initial ramp-up costs, open source yields superior long-term economics compared to legacy single-vendor models.

Leverage actionable impact metrics. Opt for intuitive metrics like the Efficiency Index (EI) and Benefit-Cost Index (BCI) to drive clear executive decisions.

Deploy mature solutions for rapid ROI. Adopting proven open source tools can deliver immediate operational benefits and shorter payback periods.

Direct public funding to shared infrastructure. Publicly funded open source solutions minimize redundant efforts and pass benefits to customers.

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Foreword

Put simply, the regulated utility or grid operator exists to benefit the ratepayer and the general public. That's the deal that was struck: a legal monopoly, granted in exchange for affordable, reliable, safe, and clean energy.

The question is how best to deliver on it. Building poles and wires is expensive and slow, so utilities increasingly look to digital solutions to increase infrastructure utilization, drive down costs, accelerate electrification, and reduce emissions. That shift is only accelerating now that utilities need AI-scale computing to power AI itself. Yet the utility approach to digitalization hasn't kept pace: rigid procurement, closed, isolated solutions, slow timelines, and high price tags.

Most of the tech world settled on open source as the default way to collaborate years ago. Utilities have been late to the party. In a free market, open source spreads as competition forces companies to collaborate on shared infrastructure and compete on what sits above it. Utilities don't face that competitive pressure. However, the same opportunity is there — shared development that reduces cost and speeds delivery, all of which can be passed to the ratepayer as lower prices and better service.

Over nearly a decade, LF Energy and its community have started to change the status quo. More utilities are strategically embracing open source, standing up open source program offices and releasing their own internal projects. As those investments grow, the entities making them need to uphold the original deal: show regulators and the public that this choice is prudent, that the benefits outweigh the costs.

The LF Energy Benefit-Cost Framework exists to make that case easier to build. For utilities new to open source, it's a way to borrow directly from the experience of those who've gone before them. For utilities further along, it's a tool for measuring progress and evolving strategy. By having a structured way to exchange experience and engage with regulatory partners, we'll be better able to deliver on that original mandate: affordable, reliable, safe, clean energy.

Alex Thornton,
LF Energy

Executive summary

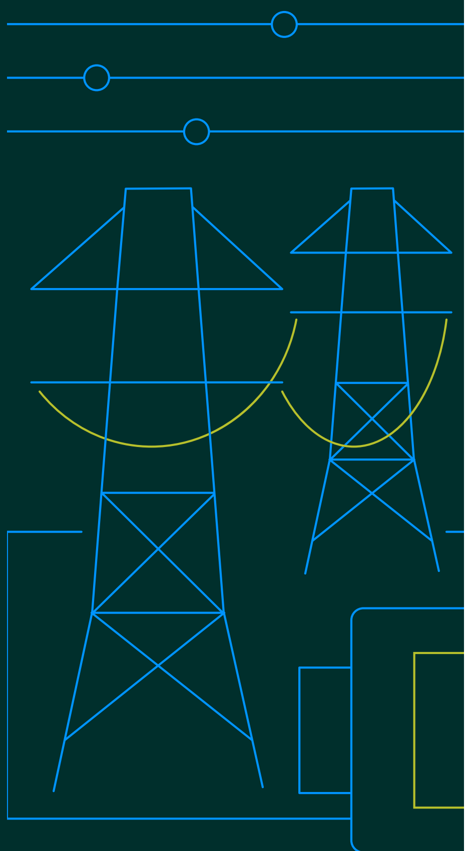
Grid operators are currently navigating high-stakes digital infrastructure choices amidst a period of rapid grid transformation. Increasing renewable penetration, expanding electrified large loads for AI data centers, supply chain uncertainty, and tightening requirements for reliability and cybersecurity are making software-defined operations an essential strategic resource for operators under pressure to manage long-run costs. When considering solutions, open source has many attractive properties that lower total cost of ownership: reduced licensing fees, increased flexibility, option value for customization, and access to best-in-class digital infrastructure collaboratively developed through open innovation. More broadly, open source creates a robust software supply chain, interoperable digital standards, and a shared knowledge base that helps millions of users achieve digital sovereignty.

But how can the relative benefit-to-cost of open source be methodically quantified? What is required is a practical, quantitative, and transparent methodology that shifts the discourse from subjective opinion to demonstrable evidence. Decision makers, regulators, and industry stakeholders need a comprehensive approach to compare a baseline software procurement strategy against alternatives across their full life-cycle. The net impact ought to encompass direct costs, risk exposure, strategic positioning, and broader public-value effects. Ultimately, the energy sector requires higher-quality data and a rigorous structure for interpreting those inputs.

This study introduces that solution: the LF Energy Open Source Benefit-Cost Framework. The Framework features pairwise scenario comparison, organizes value into four monetized components — total cost of ownership, risk, strategic value, and societal value — and distills the relative efficiency of each scenario using interpretable indices. This design empowers users to evaluate decisions consistently across individual projects and multi-year horizons while tailoring assumptions and weights to specific organizational priorities. The Framework aims to be flexible, extensible, and as comprehensive as possible.

The real-world case studies along with the detailed simulation example demonstrate that the Framework is more than theoretical; it captures value drivers that conventional analyses frequently overlook. Across a synthetic substation simulation and three case studies featuring distinct open source strategies, results indicate positive and growing returns from open source engagement when measured comprehensively. These analyses reveal that initial gains typically stem from reduced operating burdens and vendor interoperability, while substantial long-run value compounds through procurement leverage, community co-development, risk mitigation, and societal spillover benefits. These cases validate a variety of open source strategies for operators in the energy sector, ranging from simple adoption to releasing in-house solutions as open source to sustained investment in building open component ecosystems.

The overarching implication for the energy sector is significant. This framework provides the necessary data to place the total value of open source in context for decision makers. By translating fragmented technical, financial, and societal impacts into a structured evidence base, it facilitates more credible procurement choices, improves regulatory dialogue, and supports more strategic investment in digital infrastructure as a shared public good.



Introduction

An unprecedented shift in the global energy transition is underway, driven by both decarbonization of the power supply and expanded electrification of infrastructure. On the generation side, this shift is characterized by a rapid move toward renewable resources, which in turn presents grid operators with a new set of challenges.[1] Simultaneously, on the demand side, the grid must adapt to rising demand from high-capacity loads, most notably data centers and electric vehicle charging networks. New flexibilities are also emerging, enabling consumers and industrial players to dynamically adjust consumption patterns in response to grid signals and market incentives. Grid operators worldwide are therefore navigating major challenges in the energy sector. The rapid integration of renewable energy sources, distributed generation, and smart-grid technologies requires sophisticated software systems to manage increasingly complex operations.[2] As utilities face mounting pressure to modernize aging infrastructure while controlling total life-cycle costs, procurement policies and operational choices have become critical strategic decisions with far-reaching implications.

Open source software (OSS) is an incredibly valuable[3] and powerful class of public digital assets, but adoption in the energy sector is still evolving. The potential benefits of OSS use and contribution can be significant for grid operators, from lower total cost of ownership to reduced risk and greater speed or operational efficiency. Digitalization strategies should avoid overreliance on proprietary solutions, whose cumulative licensing fees, complex integration requirements, and vendor dependencies can become an increasingly heavy burden and exacerbate supply chain risk. On the other hand, operator-specific in-house solutions can duplicate effort, increase interoperability frictions between peers, and accumulate costly maintenance burdens over time.

A stronger alternative is collective action. Rather than each operator independently building or licensing equivalent tools, grid operators can pool resources into shared public digital infrastructure, avoiding monopoly overhead embedded in proprietary pricing and eliminating redundant R&D expenditure across

1 Renewable production incentives and feasibility are particularly sensitive to regulatory policy and volatile price signals.

2 Power systems are now increasingly software-defined: control, protection, and monitoring functions that were once handled by dedicated proprietary hardware appliances are now implemented in software running on general-purpose computing platforms. This shift dramatically expands both the flexibility and the complexity of grid operations.

3 Some estimates place the value of open source software to users at $8.8 trillion USD. Hoffmann, Manuel, Frank Nagle, and Yanuo Zhou. "The value of open source software." Harvard Business School Strategy Unit Working Paper 24-038 (2024).

the sector. The question is not merely whether open source is cheaper, but whether the energy sector is building digital infrastructure as a shared public good or repeatedly paying a private toll to access it. Regulators should also account for the broader societal benefits of adoption, including increased transparency and greater trust among downstream stakeholders, including consumers, local communities, and the broader economy. However, the lack of a systematic framework for evaluating these benefits against traditional proprietary solutions makes the case for OSS adoption harder to quantify. Decision makers need a comprehensive methodology that captures the full range of value OSS can offer grid operators.

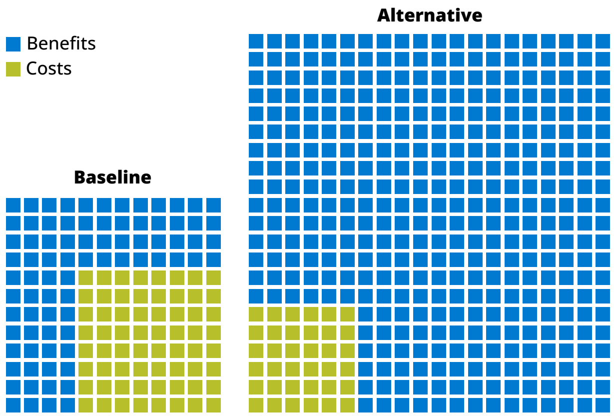
To address this need, we develop a quantitative framework to assess the total value proposition of OSS adoption from the perspective of grid operators. The LF Energy Benefit-Cost Framework compares a well-enumerated set of costs and benefits associated with OSS adoption against the benchmark of proprietary software procurement. Sources of value include total cost of ownership, risk factors, strategic value, and downstream benefits to a broader set of stakeholders, including consumers, local communities, and the regional economy.

In this report, we present the Framework, illustrate its application through a synthetic simulation, and use it to demonstrate the exceptional value generated by open source procurement in three real-world case studies. The case studies in particular place the tremendous value grid operators are already capturing by operationalizing increased OSS engagement through procurement and contribution.

The open source Benefit-Cost Framework for grid operators

FIGURE 1

Intuition of the LF Energy OSS Benefit-Cost Framework



We develop a novel framework to help illustrate the value proposition for using OSS in the energy sector. The objective is to characterize the relative benefits of choosing open source over proprietary software solutions from the perspective of an energy grid operator. The sources for these benefits and costs can become quite complex. We therefore add some structure to quantify the payoffs from this choice in monetary terms and make the comparison more tractable.

The Framework is designed to be used by grid operators, regulators, and other stakeholders to inform decision-making and policy development. The design goals are accuracy, usability, flexibility, and transparency. The Framework seeks to enumerate as many sources of benefit and cost as possible, suggest methods for quantifying them, and be easily adaptable to different contexts. Grid operators can scale the Framework to evaluate procurement or investment decisions over individual applications up to entire portfolios.

The Framework can be characterized by three key elements:

1. A comparison between a baseline scenario (e.g., proprietary software) and an alternative scenario (e.g., OSS).
2. A structured catalog of the benefits and costs associated with each scenario, organized into weighted categories and subcategories.
3. A single index that captures the relative efficiency of OSS adoption, which can be used to compare different scenarios and inform decision-making.

FRAMEWORK DESIGN PRINCIPLES

- **Comprehensive coverage:** The Framework aims to capture the different sources of costs and benefits associated with a grid operator's software procurement strategy as comprehensively as possible.
- **Modularity:** The Framework is flexible and extensible by allowing users to include or exclude channels that are not material in a specific context.
- **Configurable decision focus:** Weighted aggregation lets users and regulators emphasize priorities such as reliability, cybersecurity, and operating cost control.
- **Comparable values over time:** Future costs and benefits are discounted to present value to support consistent comparison across scenarios and years. Indices further support comparisons between different policy decisions.

Baseline and alternative scenarios

Our Framework centers on the comparison between two **scenarios**:

1. Baseline
2. Alternative

Each scenario represents a grid operator's policy choice for procurement, investment, and operations over a fixed operating horizon[4] and load commitment. To illustrate, a typical **baseline scenario** assumes the status quo of proprietary software procurement, while the **alternative scenario** involves adopting an open source solution, developing a custom solution in-house, or otherwise increasing investment in open source. For other operators, the baseline could be continued in-house development of a bespoke solution compared against the alternative scenario where the solution is released as an open source project. The scenarios will therefore contain different sets of benefits and costs. This pairwise comparison allows the decision maker to evaluate the relative net benefit of choosing the alternative scenario over the baseline scenario.

The policymaker must decide how to define the baseline and alternative policies. We keep these definitions general to accommodate different contexts, while suggesting useful defaults. Typically, the baseline is a scenario in which the grid operator adopts a proprietary procurement or "benchmark" solution, and the alternative is a scenario in which they adopt an open source solution. There can also be multiple alternative scenarios. For example, one alternative might be in-house development of a custom solution using open source components but keeping the solution private. Another alternative might be to release the in-house solution as open source. The policymaker can then compare both alternatives to the baseline through two pairwise comparisons.

The initial period is the point in time when the policymaker chooses between the baseline and alternative scenario paths; for example, when a software license is up for renewal, a new substation is being designed, or a digital transformation program is being scoped.

Scenario comparisons can be retrospective or forward-looking. Retrospective comparisons evaluate the relative efficiency of past procurement decisions, while forward-looking comparisons evaluate projections between two candidate policy paths. The Framework is flexible enough to accommodate both types.

4 This framework defaults to an industry-standard 20-year operating horizon but can be adapted to different planning horizons. A longer horizon is important for open source evaluations because strategic and societal benefits, such as procurement leverage and community-driven innovation, compound over time and would be significantly underestimated in a shorter window.

Measuring benefit and cost components

The key innovation of the Framework is its comprehensive and flexible enumeration of benefits and costs associated with each scenario. Benefits and costs are organized into categories, subcomponents, and line items, and are measured in monetary terms. The final measure of each category is a weighted sum of its subcomponents, as shown in Figure 2.

To keep estimates practical, each subcomponent can be disaggregated into line items. This gives users control over local detail and assumptions. For example, server procurement in different locations can be entered as separate line items within Total Cost of Ownership > CAPEX > Hardware. The user records the value of each line item for each scenario and period. The Framework then aggregates these values as a weighted sum to calculate the total benefit and cost for each scenario. Weights reflect the relative importance assigned to each component. Users can adjust them to emphasize organizational priorities such as cybersecurity resilience or cost control; under uniform weights, all components at a given level contribute equally.[5]

The next key challenge the Framework addresses is how to quantify each line item in monetary terms. Some line items are straightforward, such as the purchase price of a server or the cost of a software license. Others are more complex, such as the expected cost of an outage or the value of workforce development. The Framework provides guidance on how to estimate these values, including using historical data, industry benchmarks, and expert judgment. The following subsections define each of the four component categories in turn: Total Cost of Ownership, Risk, Strategic Value, and Societal Value.

FIGURE 2

LF Energy open source Benefit-Cost Framework components

CATEGORY	COMPONENT	SUBCOMPONENT
Cost	**Total Cost of Ownership**	**CAPEX** • Hardware Software • Applications • Integration • Multivendor qualifications • Civil work • Engineering & commissioning • Re-engineering & end-of-life
		OPEX • Operation & maintenance staffing • Upgrades • Preventative maintenance • Spare parts & standby • Support services
	Risk	• Service reliability • Regulatory compliance • Cybersecurity risk • Vendor dependence risk
Benefit	**Strategic Value**	• R&D efficiency • Procurement leverage • Operation efficiency • Maintenance
	Social Value	• Energy affordability • Workforce development • Regional economic development • Environmental impact

5 For example, Cost is the weighted sum of TCO and Risk, TCO is the weighted sum of CAPEX and OPEX, CAPEX is the weighted sum of its subcomponents, and each subcomponent is the weighted sum of its line items. A weight reflects the relative importance assigned to a component; uniform weights mean all components at a given level count equally. Under uniform weights, TCO and Risk each contribute 50% to the Cost component. Users can adjust weights to emphasize or de-emphasize specific components to reflect their organization's priorities.

Total cost of ownership (TCO)

The typical component considered in benefit-to-cost analyses is the total cost of ownership (TCO) for a given operating and procurement strategy. TCO is a well-established metric that captures the full life-cycle costs of a solution, including both capital expenditures (CAPEX), which are one-time upfront investments such as purchasing hardware, software licenses, or building infrastructure, and operational expenditures (OPEX), which are ongoing recurring costs such as staffing, maintenance, and support services. The Framework breaks down TCO into several subcomponents, including hardware, software, applications, integration, multivendor qualifications, civil work, engineering and commissioning, re-engineering and end-of-life, operation and maintenance staffing, upgrades, preventative maintenance, spare parts and standby, and support services. Each subcomponent is further broken down into line items that can be quantified in monetary terms. TCO items are the most tractable to estimate: most can be priced directly from accounting records, vendor quotes, or engineering specifications. The estimation question is simply which costs differ between the baseline and alternative scenarios and by how much: differences in the number of integrations required, staffing levels, or license fees translate directly into line-item values for each scenario.

Risk

While TCO captures direct, well-defined costs that can often be drawn from accounting records, risk is a more complex and nuanced component of the Framework. Risk captures potential costs associated with service reliability, regulatory compliance, cybersecurity, and vendor dependence. These risks can have significant financial implications for grid operators, and the Framework provides a structured approach to quantify them.

We quantify risk as **expected cost**, which is the product of the probability of an adverse event and the cost of that event. This approach is standard in decision analysis: it produces a single comparable number that reflects both how likely a bad outcome is and how severe it would be if it occurred, enabling consistent apples-to-apples comparisons across risk categories and scenarios.

- For **service reliability**, the financial magnitude of an outage is estimated as outage frequency × affected customers × unit revenue loss per customer, then multiplied by the probability of the adverse event to yield expected annual cost.
- **Regulatory compliance risk** combines recurring certification burden (audit preparation and remediation spend) with the expected cost of a non-compliance penalty, weighted by the likelihood of a compliance failure.
- **Cybersecurity risk** follows similar logic: the number of required security interventions (patch deployments, incident responses) multiplied by the cost per intervention and the annual likelihood of a security event.
- **Vendor dependence risk** captures both switching-cost exposure (migration and retraining costs if the operator needs to change vendors) and premium-pricing exposure from vendor interoperability, each scaled by the probability of the corresponding adverse event.

Strategic value

Moving beyond cost savings, grid operators can derive valuable strategic benefits from open source adoption. These benefits can include increased R&D efficiency by joining an innovation community, additional procurement leverage, operational efficiency, and reduced maintenance workloads. The Framework provides a structured approach to quantify these strategic benefits in monetary terms, allowing decision makers to capture the full value proposition of open source adoption.

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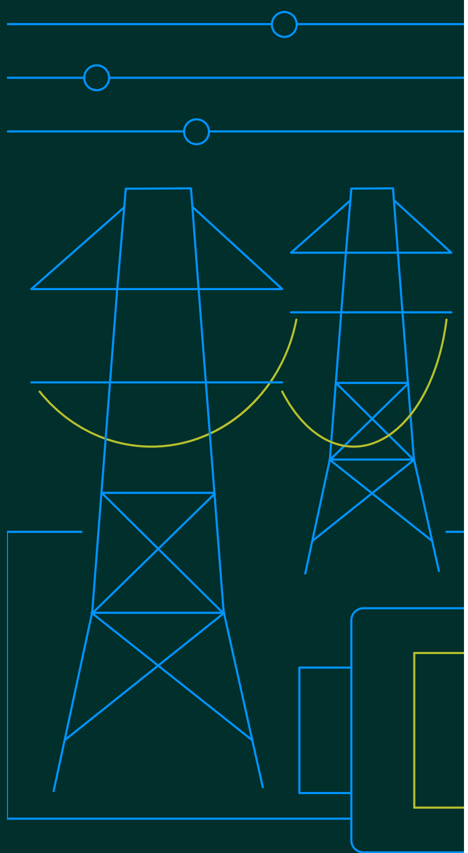
- **R&D efficiency** savings scale with the share of development effort that can be pooled with peers. The higher the collaboration share under the alternative, the greater the avoided duplication of R&D spend. More broadly, community innovation creates a knowledge base that transcends organizational boundaries. Ideas, features, and improvements are created and shared equally across operators.
- **Procurement leverage** is estimated from the negotiating headroom created by having a credible open source fallback, expressed as a percentage discount applied to the relevant procurement budget.
- **Operation efficiency** captures the reduction in integration and interoperability overhead: fewer custom point-to-point connections translate directly into lower CAPEX and reduced recurring maintenance costs.
- The **maintenance** subcomponent uses a time-to-value factor to reflect how quickly each scenario begins delivering its operational benefit stream; a faster deployment timeline means O&M savings arrive earlier, increasing their present value relative to a slower-deploying baseline.

Societal value

The strategic benefits described above accrue primarily to the grid operator itself. But grid operation is critical public infrastructure serving a broad set of downstream stakeholders, including electricity consumers, local businesses, communities, and regional economies. Therefore, open source adoption has the potential to generate non-trivial societal benefits across many facets, including energy affordability, workforce development, regional economic development, and environmental sustainability. This broader scope is intentional in the Framework design: benefits and costs are measured not only for the grid operator, but also for downstream stakeholders when those impacts are material and quantifiable. The Framework allows users to quantify these societal benefits in monetary terms, providing a more holistic view of the value proposition of open source adoption.

Each societal subcomponent follows a shared estimation structure: a population of affected stakeholders, an uptake or impact rate, and a unit value per person or unit of output:

- **Energy affordability** improves when the operator is able to lower delivery costs per kWh and pass these savings on to customers. Open source solutions that lower TCO and risk are a key strategy to achieve this incredible, far-reaching pass-through value.
- **Workforce development** is measured as training throughput × job-conversion rate × average annual wage, capturing the local income supported by OSS-enabled skill formation.
- **Regional economic development** combines redirected local procurement spend (the share of total CAPEX flowing to local or small suppliers rather than large incumbents), combined with avoided margin extraction from the competitive pressure that open standards introduce.
- **Environmental value** is derived through avoided emissions due to increased energy production and consumption from carbon-free sources. Open source adoption may encourage adaptations that align with regulatory incentives and lower the social cost of carbon as a whole.



Together, these four categories (Total Cost of Ownership, Risk, Strategic Value, and Societal Value) provide a comprehensive monetary basis for comparing the baseline and alternative scenarios. Once each component is estimated for both scenarios and across the planning horizon, the Framework aggregates them into a single present-value comparison per scenario. The remaining challenge is expressing this comparison as a single, actionable metric.

COMPONENT PRIORITIZATION

Since the Framework is comprehensive and modular, it's helpful to provide some guidance on which components grid operators should prioritize for their benefit-cost analysis. Users should approach data collection systematically, beginning with the most quantifiable metrics before moving to broader strategic impacts:

1. **Total Cost of Ownership (TCO):** Start here. TCO components draw directly from established accounting line items, providing a concrete baseline and supplying essential data for calculating the efficiency index.
2. **Risk Assessment:** Next, quantify risk reduction using an expected value approach — a well-defined method familiar to most utility financial and regulatory teams.
3. **Strategic Value:** Capture less direct operational and efficiency benefits next. Detailed implementation guidance and examples for modeling these harder-to-quantify impacts is available in the Framework project repository.
4. **Societal Value:** Evaluate downstream environmental and public benefits last, as these external factors often depend on specific regulatory mandates or regional policy priorities.

A progressive and learning-oriented approach to component measurement is highly recommended in practice. Even for TCO evaluation, all components might not be available from day one. Some might need to be approximated and progressively revised as more data becomes available.

See the Framework project repository for more details and examples for the valuation methodologies: https://github.com/lf-energy/lfe-oss-benefit-cost-framework

Using indices to summarize the open source value proposition

Benefit and cost accounting across the two scenarios is only half the challenge. Decision makers still need to distill this information into an actionable metric. The final aspect of the Framework is a single index that captures the relative efficiency of OSS adoption, enabling an intuitive pairwise comparison between policy options. We suggest two alternative indices to measure the relative efficiency of open source adoption.

Efficiency Index (EI)

We first consider the Efficiency Index (EI), which is defined as the ratio of the net benefits of the alternative scenario to the costs of the baseline scenario (Figure 3). The EI provides a measure of how much additional benefit is generated by adopting the alternative scenario relative to the costs incurred under the baseline scenario. Positive values (EI > 0) indicate that the alternative scenario is more efficient than the baseline scenario, while negative values (EI < 0) indicate that the baseline scenario is more efficient.

FIGURE 3

Efficiency Index (EI) Formula

$$\text{Efficiency Index} = \frac{\text{Increased benefits under alternative} + \text{Reduced costs under alternative}}{\text{Baseline Costs}}$$

For example, if EI = 1.5, then switching to an open source procurement policy generates new *net* benefits that are 150% of the current proprietary operational cost: for every €1 of baseline costs, the alternative scenario generates €1.50 in additional net benefits. This implies that the alternative policy is relatively more efficient than the baseline (in terms of net value) and the operator would be wise to pursue it. If EI = 0, the increased benefits and reduced costs are €0 under the alternative. Therefore there is no efficiency gain by switching to the alternative policy and, from a pure efficiency perspective, the operator is indifferent between the two choices. If EI < 0, then the baseline is actually more efficient than the alternative — either less costly or more beneficial.

Benefit-cost Index (BCI)

An alternative index is the Benefit-Cost Index (BCI). We define the BCI as a ratio-of-ratios between the benefit-to-cost ratio under the alternative scenario and the benefit-to-cost ratio under the baseline scenario (Figure 4).

FIGURE 4

Benefit-Cost Index (BCI) formula

$$\text{Benefit-Cost Index} = \frac{\text{Benefit-to-cost ratio under alternative}}{\text{Benefit-to-cost ratio under baseline}}$$

Since benefits may well exceed costs in both the baseline and alternative scenarios, the BCI gives a relative sense of how the alternative performs compared with the baseline: The BCI measures how much benefit is generated for each unit of cost incurred under the alternative scenario. Values greater than 1 indicate that the alternative scenario generates more benefits than costs, while values less than 1 indicate that it generates more costs than benefits.

For example, if BCI = 1.5, then switching to open source improves the benefit-to-cost ratio by 50% over the baseline life-cycle ratio for the digital infrastructure. If BCI < 1, then switching to open source is inefficient for the given project or solution: the operator would be better off under the baseline scenario.

The EI and BCI measure efficiency from different vantage points. The EI is most useful for external or regulatory comparisons because it expresses the alternative's net gain as a share of existing baseline expenditure, making it easy to communicate relative value to oversight bodies. The BCI is better suited to internal business cases because it shows whether the alternative's own benefits outpace its own costs, without requiring the baseline as a reference.

Framework in action

In this section, we illustrate how the Framework can be applied in practice. To build intuition, we first apply the Framework to a synthetic scenario for our primary use case: a grid operator adopting an OSS solution. The example attempts to accurately reflect the real-world costs and benefits for a grid operator adopting a SEAPATH-based solution for a single substation.

We next demonstrate the application of the Framework in a series of case studies based on real-world grid operator scenarios. We explore three scenarios that span the spectrum of OSS adoption, collaboration strategy, and investment decisions. The first case study focuses on a grid operator comparing the adoption of an industry grade, production-ready OSS solution to a proprietary solution baseline. The second case study focuses on a grid operator that has developed an in-house solution and is considering donating it to the open source community. Finally, we outline a third case in which the grid operator invests in costly development of an open source library before putting it into production and releasing it to the public.

Together, these examples span the full range of open source procurement decisions a grid operator might face, progressing from controlled assumptions toward real-world data and from inward adoption toward outward contribution. They illustrate not only the scale of value created by open source but also the specific sources that generate it, providing validation of both the Benefit-Cost Framework and open source strategy itself.

Synthetic example

We begin with a simulated scenario to demonstrate a detailed approach on how the Benefit-Cost Framework helps enumerate and quantify the net value creation for a grid operator sourcing OSS instead of proprietary solutions. We considered the adoption of OSS across a set of grid operators and evaluated the potential benefits and costs associated with this adoption. While the simulation draws on real-world cost estimates, risk probabilities, and strategic value grounded in industry expertise, it is fictional and should not be treated as representing actual results.

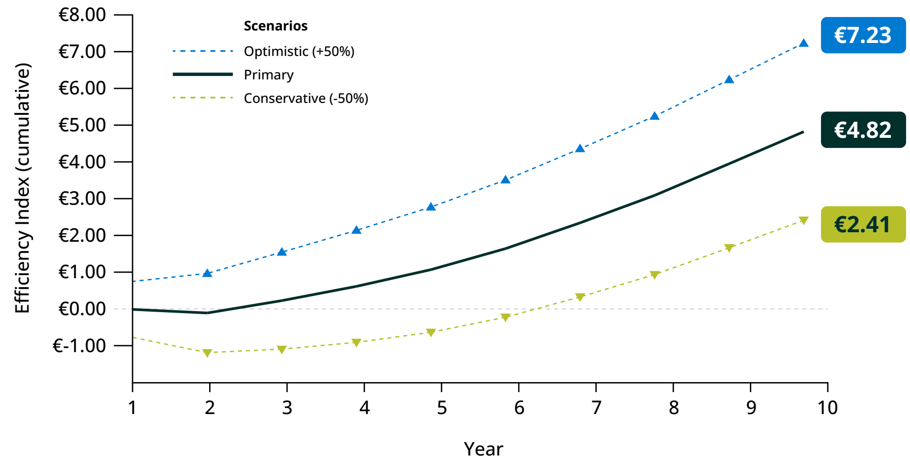
In particular, the simulation around a grid operator is considering the LF Energy **SEAPATH**, an open source virtualization platform for digital substations developed by LF Energy that provides a host for real-time protection, automation, control, and monitoring functions (capabilities traditionally handled by expensive proprietary hardware appliances), instead of a proprietary solution. The example assumes a single-substation operator, a 10-year operating horizon, and uses substation-level estimates for costs and benefits.

In Figure 5, we plot the evolution of the Efficiency Index (EI) over the 10-year operating horizon. In addition to the primary scenario, we also plot optimistic and conservative scenarios, which represent the cases where net benefits are 50% greater or less than the primary scenario. The EI is positive from the first period and rises steadily across all three scenarios, reflecting the compounding nature of strategic and societal benefits as they grow faster than baseline costs. This implies that when properly accounting for all sources of increased benefits and reduced costs, grid operators under this example enjoy immediate return on investment from switching to the OSS alternative. The widening gap between the optimistic and conservative bands in later periods highlights sensitivity to benefit realization, particularly for procurement leverage and environmental impacts. By the end of the operating horizon, the operator has generated €4.90 in new net value for every €1 they would spend in baseline operating costs.

FIGURE 5

Simulated value proposition of open source procurement (SEAPATH)

Source: simulation values drawn from co-author research and experience.



The sources of value under the open source alternative are a mix of private strategic benefits enjoyed by the operator and societal gains distributed across a wider range of stakeholders. In terms of strategic value created for the grid operator, procurement leverage, meaning the ability to use a credible open source fallback to negotiate better terms with hardware and software vendors, is the single largest benefit driver. Important sources of external value created include workforce development and environmental benefits which scale over time. Meaningful cost savings also accrue from reduced hardware procurement, lower cybersecurity risk, and reduced operation and maintenance staffing. These gains are partly offset by new upfront costs: specification redesign, application software, and server infrastructure required for the SEAPATH deployment.

The simulation illustrates that the value proposition for open source substation virtualization is robust across a wide range of assumptions. The key insight is that the most important sources of value are not simply lower procurement costs but strategic and societal benefits that compound over time. Decision makers who evaluate open source adoption purely on a TCO basis are likely to significantly underestimate its total value.

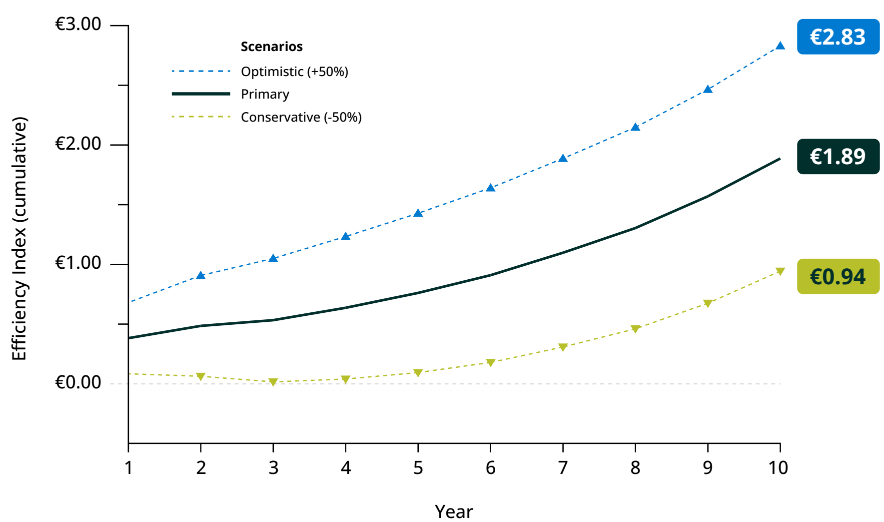
Case study: Simple switch to open source procurement

Applying the Benefit-Cost Framework to real-world scenarios can more credibly illustrate the value proposition of increasing open source engagement for grid operators. In this case study, we use data from a grid operator that has adopted OpenSTEF, an OSS solution for short-term energy load forecasting. At the time of adoption, OpenSTEF had established a level of industry-grade quality and required only modest integration costs to bring into production. Adopters of mature open source solutions are immediate beneficiaries and can realize positive value within months without costly initial investment or a lengthy payback period. We can compare the operator's own estimates of costs and benefits for the proprietary solution baseline against the open source alternative. The case study illustrates how the Framework can be used to evaluate the relative efficiency of open source software adoption in a real-world context, with results shown in Figure 6.

FIGURE 6

Case study: Value created by adopting an open source solution (OpenSTEF)

Source: internal estimates provided by the case study partner



The EI shows positive immediate value creation from the first period and rises steadily throughout the 10-year horizon. Adopters of mature open source solutions reap the benefits of community investment and avoid costly payback periods. Value growth accelerates in later periods as community-driven strategic benefits compound. The gap between scenarios widens substantially over time, underscoring the sensitivity of long-run returns to benefit realization assumptions. In this case, the operator realizes €1.89 in new net value for every €1 of baseline expenditures.[6]

The primary driver is the elimination of the proprietary vendor operation and support contract, replaced by a lower-cost open source alternative, delivering an immediate OPEX saving. Strategic benefits then build progressively: testing and validation efficiency improves as community tooling matures, knowledge exchange with the broader open source community reduces dependence on expensive consulting, and access to open source talent strengthens hiring and retention. Procurement leverage emerges

6 Framework users have discretion over which components to include in their analysis. The scale of net benefits is somewhat smaller in the case studies compared with the synthetic example, which was designed to be as comprehensive as possible. In this sense, the case studies presented can be viewed as conservative estimates.

in later periods as the operator establishes a credible fallback position. The main drag is the cost of new outsourced support operations introduced under the alternative scenario.

The adoption case demonstrates a pattern that is likely to generalize: the initial payoff comes from increased vendor interoperability and reducing direct operating costs, while longer-term value accumulates through community engagement and strategic positioning. The investment case strengthens as the operator actively participates in the open source ecosystem and captures the associated co-development and knowledge-exchange value.

Case study: Converting internal solutions to open source projects

Not every grid operator can find a suitable off-the-shelf solution, whether proprietary or open source. Many have instead built their own in-house systems, often investing substantial resources over years of iterative development. For these operators, a distinct question arises: Once that internal tool exists, is there value in releasing it to the broader open source community?

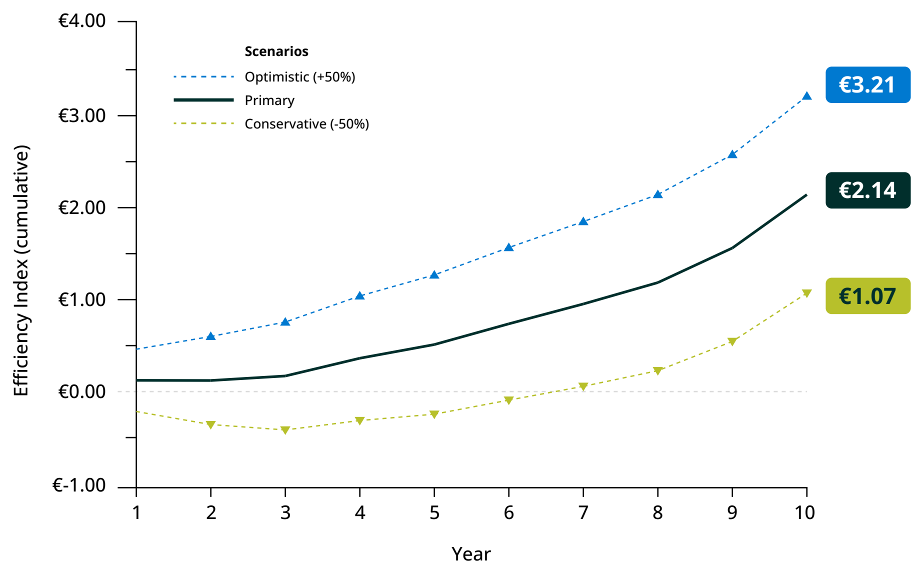
We consider the case of a grid operator that has developed an in-house solution to manage its operations. In this case, the solution in question is the OpenSTEF project. The original developer has invested significant resources into developing this solution, and it has become a critical part of its operations. However, the grid operator recognizes opportunities to reduce costs, accelerate innovation, and create value for peers facing similar challenges, and it decides to contribute the solution to the open source community. Compared with the previous case of OpenSTEF adoption, this operator is choosing between the baseline of keeping OpenSTEF an internal solution against the alternative in which they release OpenSTEF as an open source project.

Figure 7 traces the resulting EI trajectory over a 10-year operating horizon after which the operator decides to release OpenSTEF as open source.

FIGURE 7

Case study: Value created by releasing an internal solution as open source (OpenSTEF)

Source: internal estimates provided by the case study partner



Unlike the adoption case, the EI starts near zero and remains modest for the first half of the horizon before accelerating sharply in later periods.[7] By making OpenSTEF an open source project, the grid operator realizes €2.14 in new value for each €1 in baseline costs by the end of the 10 year operating horizon. Keeping the maintenance of DIY solutions in-house is clearly inefficient in comparison. The J-curve pattern reflects the lag between upfront community-building investments and the compounding of strategic and societal benefits. Even under conservative assumptions, the EI breaks even before the end of the operating horizon; under primary and optimistic scenarios it rises substantially, confirming that the decision to convert an in-house solution into a proper open source project pays off when strategic and societal value is accounted for.

Value creation is shared between the operator making their project open source and the wider community. For the operator, reduced service reliability risk, arising from distributed maintenance responsibility across a wider contributor community, is a primary driver of reduced cost burden as the burden of development is distributed more evenly with the community. Additionally, the operator gains strategic benefits from knowledge exchange, co-development, hiring and retention, and growing procurement leverage also contribute meaningfully in later periods. The primary transition costs are community engagement overhead (documentation, co-development events) and open source preparation activities, which are modest relative to the aggregate strategic and societal gains. An extremely important source of societal value in this case is energy affordability pass-through onto customers: By enabling broader community adoption, open sourcing the solution allows other grid operators to deploy it at lower cost, generating societal benefits through improved energy access and lower consumer prices that dwarf the individual operator's own TCO savings.

The open sourcing case makes clear that value creation is an important mixture between private benefits and strategic value for the creator and newly created societal value. Both are positive and strategically aligned but only considering the impact on operating costs understates the true impact of creating digital public goods. When strategic value and broader societal impacts are properly included the case for releasing internal solutions as open source projects becomes quite strong. Compared with keeping the solution in-house, the downside risk for the original developer is relatively small in comparison with the potential for ecosystem-wide benefits, but the benefits arrive with a lag, underscoring the importance of a sustained, multi-year commitment to community building rather than a one-time code contribution.

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7 Note that the decision point in this case comes at the moment when the operator is deciding whether or not to release their solution as an open source project. Therefore the initial investment period, which would be identical under both the baseline and alternative, is not considered in this case.

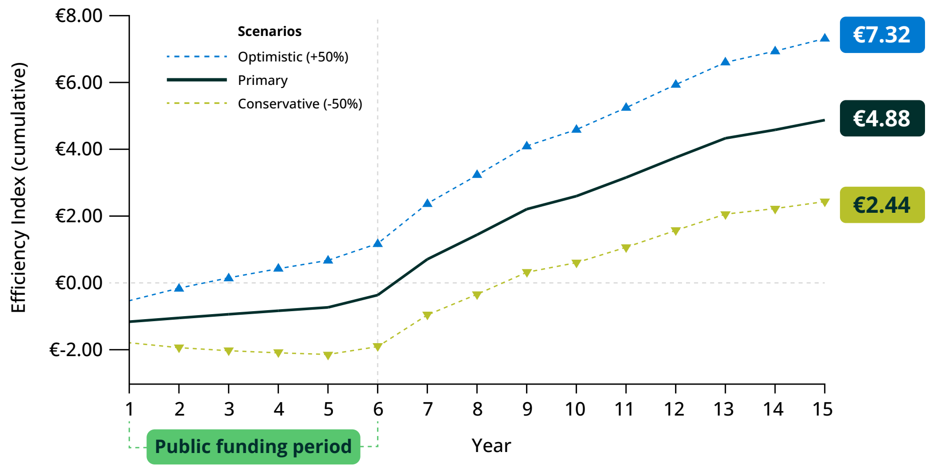
Case study: Investing in open source

A final case demonstrates that investing resources to develop open source solutions is not only worthwhile, but reveals the status quo of proprietary procurement is actually quite inefficient by comparison. In this case, the operator identified a gap in grid simulation functionality. They began working on this functionality internally and eventually released the project as PowSyBl, a modular and scalable library designed for grid modelling, visualization, and simulation. A key feature of PowSyBl is that it is equally well suited for simple and complex use cases, making it a general solution suitable for other operators beyond the project creator.

FIGURE 8

Case study: Investing in open source (PowSyBl)

Source: internal estimates provided by the case study partner



The grid operator committed to an initial investment period during which they were supported by EU funding.[8] This incubation period allowed the operator to invest in the quality of the solution to the point that it was both ready to use in production and release as an open source project.

The return on investment for PowSyBl is substantial. We plot the cumulative EI over a 15 period operating horizon in Figure 8.

The return trajectory for PowSyBl clearly shows a period of loss during the initial development period. At this point, the regulator and even the grid operator themselves might naturally be questioning whether developing the open source solution is worth the investment. The evidence shows that it clearly was. Not only did the investment yield a positive return, the scale of net benefits created by PowSyBl were €4.88 for every €1 in expenditures they would have spent had they continued with proprietary procurement. Not only was the investment in open source a success, it was nearly 5x as efficient compared with the proprietary baseline.

In this case, the operator identified two key sources of value. First, the investment in PowSyBl created a tremendous level of reuse value across many different use cases within the operator. They could now apply and scale this solution to many different operations at lower additional cost. Second, the investment in

8 Despite the fact that the initial PowSyBl development funding did not come from the operator’s budget, we still account for this investment by classifying it as CAPEX.

PowSyBl as an open source project creates spillover benefits for peer operators, who no longer need to make duplicate investments or re-invent the wheel. The same level of internal productivity gains enjoyed by the originator of the open source solution can be realized by a number of external peers with minimal investment.

Investing in open source solutions is clearly a dominant strategy from the perspective of the operator, the regulator, and society at large. This case demonstrates the critical role that public support can have on the power generation ecosystem. By having the patience and vision to invest in open source solutions like PowSyBl — a high quality, modular approach to operational functionality — public funding generated an incredible source of value that would have been unattainable under the proprietary business-as-usual approach.

Conclusion

Making the case for open source adoption in the energy sector can be challenging, especially when factors like risk, strategic value, and societal benefits are difficult to quantify. The Benefit-Cost Framework provides a structured approach to evaluate the relative efficiency of OSS adoption, enabling grid operators to make informed decisions about procurement, investment, and operations. By quantifying the benefits and costs associated with open source adoption, the Framework helps decision makers understand the full value proposition of OSS and make more informed choices about how to manage their digital infrastructure.

The synthetic example and operator case studies presented here share a consistent finding: Open source adoption generates positive and growing returns when evaluated comprehensively. The simulation demonstrates that procurement leverage and societal benefits compound over time, meaning that evaluations based on total cost of ownership alone will significantly underestimate total value. The real-world adoption case study confirms this pattern, showing immediate OPEX savings followed by accumulating strategic gains as the operator deepens community engagement. The open-sourcing case study reveals a distinct J-curve dynamic of modest early returns followed by accelerating strategic and societal value, underscoring the fact that releasing in-house solutions as open source is mutually advantageous for creator and community alike. The investment case shows that open source wins in the long run and that the public sector has an important role in fostering long run efficiency through supporting open digital infrastructure.

This analysis helps form **action items** and **policy recommendations** for the key stakeholders in the energy sector:

- **Grid operators:** Open source can make operations run lean and efficient, improve flexibility and scalability, and reduce costly risks. These benefits are not theoretical: we have established a growing body of evidence that open source is 2-5x more efficient in the long run. Choose open source solutions when possible, prefer collaborative development over in-house maintenance, and opt for modularity & scalability to maximize the community uptake multiplier.
- **Regulators:** A growing threat landscape in cybersecurity, economic & geopolitical uncertainty, and environmental change present new challenges for the future of the energy sector. Open source is not only cost efficient, it's a path to innovation, digital sovereignty, reliability, and stability for utility infrastructure. Supporting open source software development has spillover benefits to many constituents and has an incredible payoff over longer operating horizons.

As the energy sector navigates an accelerating transition, integrating more renewable generation, accommodating new electrification loads, and modernizing aging infrastructure, the software systems underpinning grid operations will become an increasingly critical and consequential resource. The Framework presented here offers a practical foundation for treating digital infrastructure as a shared public asset rather than a series of isolated procurement decisions. Grid operators, regulators, and policymakers can apply the Framework to specific decisions using the accompanying worksheet, using informative metrics like the Efficiency or Benefit-Cost Indices, and in doing so build a shared evidence base for open source investment across the sector.

This work marks a beginning, not an endpoint. The Framework presented here is a first step toward a shared, evidence-based language for evaluating open source investment in the energy sector — not a finished or final instrument. We intend to keep refining it in partnership with grid operators across the industry, applying it to a wider range of contexts, technologies, and procurement decisions, and incorporating what we learn along the way. We welcome operators, regulators, and industry partners to join us in that effort.

Resources

- LF Energy Benefit-Cost **Framework open source repository**
- **LF Energy**
- “Releasing Internal Code into a New Open Source Project: A Guide for Stakeholders” Ibrahim Haddad, Ph.D, Executive Director, LF AI & Data and Pytorch Foundation. DOI: 10.70828/HVJQ3486. **https://www.linuxfoundation.org/research/releasing-internal-code**
- “Strengthening Europe’s Tech Sovereignty” **https://digital-strategy.ec.europa.eu/en/policies/eu-tech-sovereignty**

About the authors

Sam Boysel is a Data Scientist at the Linux Foundation. In this role, he contributes to a variety of empirical initiatives to uncover new insights into open source communities. His work often leverages microeconomic theory to analyze behaviors, incentives, and community dynamics across open source ecosystems. Before joining the Linux Foundation, he was a postdoctoral researcher with the Laboratory for Innovation Science at Harvard. He holds a B.A., M.S., and Ph.D. in Economics.

Mital Kanabar is founder and president of PowerProfs Inc, Canada. With 20+ years of industry experience serving the power & energy domain, Mital holds 25+ international patent applications, and has published 50+ journal/magazine/conference articles. As a Professional Engineer in Ontario and Vice-chair of IEEE PES PSRC Relaying Communication, he is committed to advancing the energy industry.

In his professional career at GE Vernova and L&T, he led customer-centric innovations for software-defined grid automation, digital electric power substations, and AI applications for electrification and decarbonization — accelerating the energy transition we all need.

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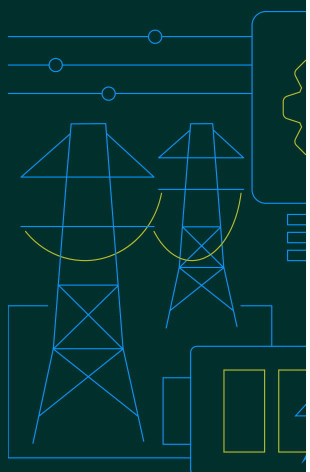

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