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From Least-cost Plans to Implementable Electrification: A Regulatory–Financial Framework to Achieve Universal Access

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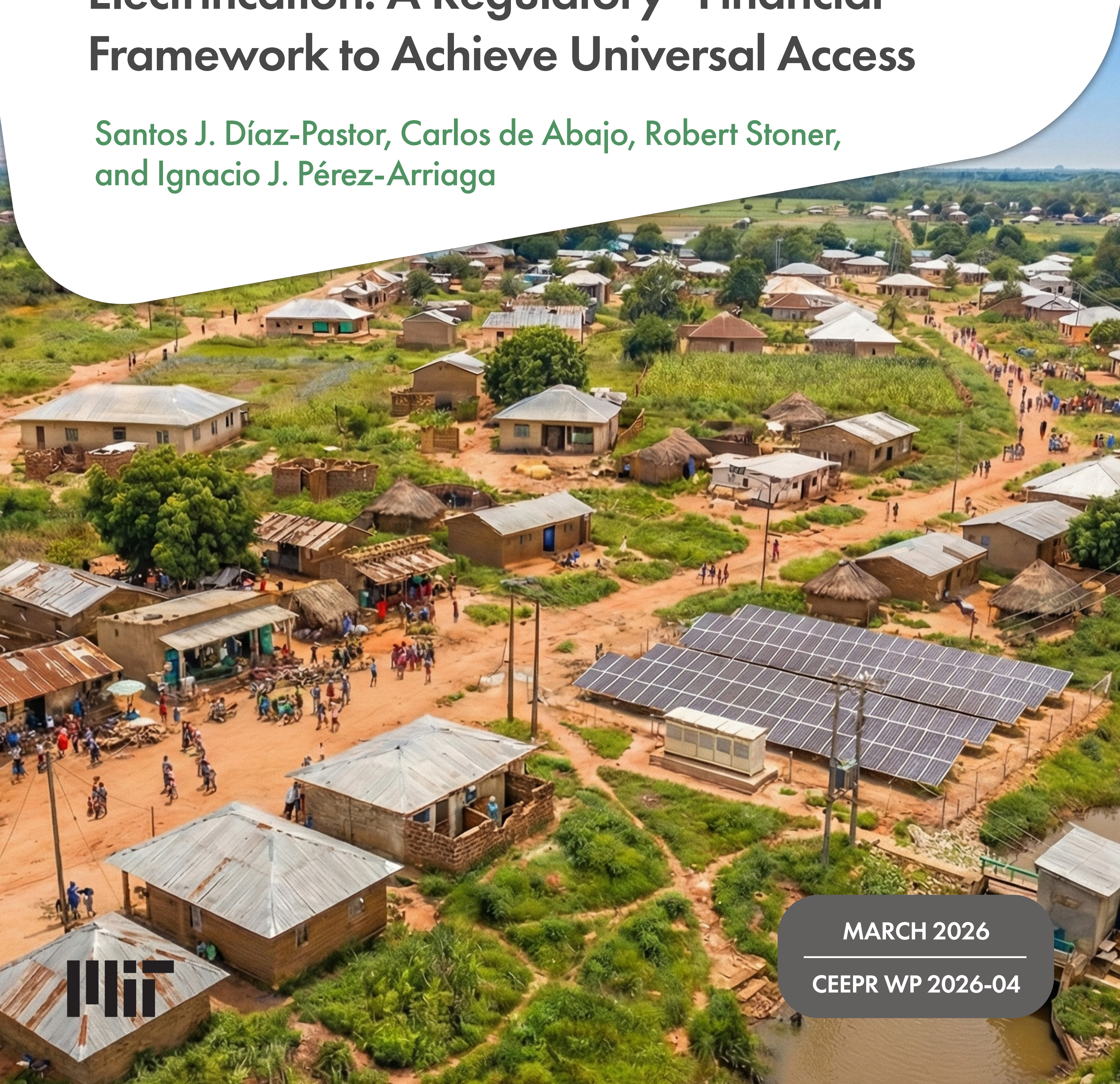

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From least-cost plans to implementable electrification: A regulatory–financial framework to achieve universal access

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Abstract

Achieving universal electricity access requires more than a technically rigorous least-cost electrification plan. In many low- and middle-income power sectors, affordability constraints and financially distressed distribution utilities prevent least-cost pathways from being implemented as initially designed. In addition, high perceived risk keeps the cost of capital as a severe limitation for expansion.

This paper develops an integrated regulatory–financial framework that links: (i) techno-economic least-cost planning across grid and off-grid options; (ii) implementable business models under cost-of-service regulation; and (iii) a financing architecture that coordinates public resources, concessional instruments, and commercial capital through a centralized platform that pools and ringfences flows and standardizes disbursement rules.

The cash-flow results separate two distinct implementation constraints. The first is the "viability gap", the shortfall between realized revenues and the regulated cost of service when affordability and weak retail performance prevent full cash recovery over the analysis horizon. The second is "financing needs", a timing mismatch between front-loaded expenditures and intertemporal cost recovery during rollout, which can bind even when long-run viability holds. The framework clarifies the corresponding policy levers: viability gaps require explicit, rule-based, and predictable compensation mechanisms, while financing needs require capital structures, tenors, and liquidity facilities aligned with the regulatory recovery schedule and a regulated return that covers financing costs and preserves equity value.

The approach provides a replicable methodology for regulators and policymakers to move from least-cost targets to implementable electrification programs with credible revenue adequacy and financeable cash-flow trajectories, grounded in a synthesis of implementation frictions documented across recent electrification programs and regulatory reforms.

Keywords: Universal Electricity Access; Infrastructure Investment; Public-Private Partnerships; Cross-Subsidization; Cost-of-service regulation

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1. Introduction and literature review

Universal electricity access remains an urgent global challenge. Despite broad consensus on its importance, current progress is far from sufficient. Projections indicate that under existing policies, 645 million people will still be without electricity by 2030, with more than 85% of them in Africa (IEA, 2025a; IEA et al., 2024). Achieving Sustainable Development Goal 7 (SDG 7) of the 2030 Agenda will require a sharp acceleration in connections. In Africa, this means reaching around 90 million people every year, which is three times the historical rate (IEA, 2022).

Reaching such a scale will demand a significant increase of the present capital inflows. Africa will need to mobilize around USD 25 billion annually between 2025 and 2030 to achieve electricity access targets, yet current commitments remain far below this level and have declined in real terms over the past decade (IEA, 2022).

Cost of capital constitutes a critical barrier. Risk premiums and interest rates on African power projects are commonly two to three times those prevailing in advanced economies, eroding project bankability and discouraging private participation (AfDB, 2025; IEA, 2023). As a consequence, private finance has concentrated on generation assets because these projects more often secure contracted revenues and explicit cost recovery, while network investment lags. Transmission and distribution—which underpin reliable service and rural expansion—continue to receive a disproportionately small share of total investment flows, exacerbating access deficits (BloombergNEF, 2024; RES4Africa Foundation, 2021).

Distribution companies (DISCOs) sit at the core of this problem. Political mandates to hold tariffs below cost recovery create quasi-fiscal deficits, weaken balance sheets, and limit the ability of utilities to expand service or serve as credible off-takers for new generation (Balabanyan, Ani et al., 2021; Klug et al., 2022; Kojima and Trimble, 2016). Financial distress at the retail end reverberates through the whole value chain, raising perceived risk and the cost of capital sector-wide (Vivien Foster and Anshul Rana, 2020).

Meanwhile, techno-economic electrification models have advanced rapidly, using geospatial optimization to map least-cost mixes of grid extension, mini-grids, and stand-alone systems. Yet these models typically assume uniform interest rates and ignore the financing and regulatory constraints documented above (Agutu et al., 2022; Aluko et al., 2025). This disconnect reflects a modelling shortcoming that can understate financing costs, particularly for off-grid infrastructure, and can leave masterplans technically coherent but financially infeasible.

This paper responds to those limitations. It proposes an integrated three-step framework that begins with a design of a least-cost electrification plan, then overlays cost-reflective regulatory and business models, and finally assembles a blended-finance architecture that consolidates public resources, concessional capital, commercial debt and tariff revenues. By aligning technical planning with bankable regulation and fiscally credible financing, the framework offers a pragmatic roadmap toward universal electricity access.

The remainder of the paper is structured as follows. Section 2 reviews contemporary regulatory and financial principles for universal access. Section 3 details the integrated methodology. Section 4 presents the cash-flow results implied by the framework and illustrates the resulting revenue requirements, gaps, and financing needs under cost-of-service regulation. Section 5 discusses policy and financial implications, and Section 6 concludes with recommendations for practitioners and decision-makers.

2. Lessons learned to achieve universal electrification

A substantial body of empirical and theoretical work now exists to explain barriers to universal electricity access, ranging from the techno-economic limitations of network expansion to the politics of tariff reform. Section 1 showed how these barriers materialize in practice as financially distressed distribution companies, high cost of capital and chronic underinvestment in networks.

Under these conditions, it is unrealistic to expect that a public utility or the public budget can finance universal access on its own. Most studies address one barrier at a time and therefore only partly explain why technically rigorous electrification plans often fail to move into implementation, as documented in the literature that diagnoses these mechanisms and their interactions (GCEEP, 2020; Pérez-Arriaga, 2024; Pérez-Arriaga et al., 2019).

To organize the discussion, the paper groups the prerequisites for lasting electrification into four mutually reinforcing pillars. Each corresponds to a distinct failure mode documented in the literature, and together they describe the conditions under which public and private actors can invest at scale along a shared electrification pathway.

2.1. Cost-effective planning: integrating grid, mini-grid, and stand-alone options

Universal access requires matching each locality to be electrified with the technology that meets demand at the lowest life-cycle cost. Rather than privileging grid expansion by default, electrification planning must consider terrain characterization, distance, population density and estimated demand, because these factors strongly affect cost structures.

Geospatial least-cost toolkits operationalize this insight (Ciller and Lumbreras, 2020). Application of the Reference Electrification Model (REM) in Asian and African pilots shows that automating technology selection at household scale can reduce total investment needs by about one-third compared with engineering judgement alone (Amatya et al., 2018; Ciller et al., 2019; Ellman, 2015). The World Bank's geospatial plan for Indonesia reached the same conclusion at national scale, showing that serving remote islands with renewables-based mini-grids while densifying the core grid reduces average connection costs by 30–50 percent and accelerates full coverage by several years (World Bank et al., 2013). Similar country applications of OnSSET in Ethiopia and Zambia confirm that least-cost mapping typically assigns stand-alone PV to more than half of unelectrified households, saving billions in public expenditure (Egli et al., 2023; Sahlberg et al., 2021). Most of these applications, however, optimize under simplified and largely uniform financing assumptions and therefore say little about who finances the investments, at what cost of capital, and how those costs are ultimately recovered (Agutu et al., 2022).

Notwithstanding the distortion resulting from oversimplified assumptions about the cost of capital, cost-effective planning stands as an independent non-negotiable principle. By lowering required investment, it reduces the total cost recovery need that must be covered through a combination of end user payments and explicit subsidies. It provides the technical and fiscal foundation for the remaining pillars: legal mandates for universal access, financially sustainable and scalable business models based on predictable revenues, and development-oriented delivery.

2.2. *Scalability: universal-access commitment for last-mile electrification*

Universal access requires a system-wide approach in which regulation, funding and planning converge to succeed. This principle moves beyond financing isolated projects. It embeds an enforceable duty to connect every household and channels finance through instruments that pay the total cost of providing service at scale. The aim is to make all connections financially viable, not only those in dense or affluent areas, although not necessarily identical nor equally costly. Otherwise, expansion stalls once commercially attractive segments are exhausted. Evidence from global power sector diagnostics supports this systems perspective and links durable progress to legal mandates, credible funding commitments and institutional capacity (Vivien Foster and Anshul Rana, 2020; World Bank, 2024).

A common strategy, often referred to as results-based financing (RBF), relies on cost-reflective tariffs and a share of subsidies linked to CAPEX deployment. It can connect many users quickly, but it does not guarantee last-mile delivery in high-cost areas. Private or commercial agents have no incentive to serve customers with weak demand in sparsely populated areas unless mandated to do so under an explicit service obligation, for example through a concession contract, and provided with a predictable mechanism to cover the resulting revenue shortfall. If the policy objective is to connect everyone, the financing architecture must render every connection viable on an investment life-cycle basis. This requires more complex institutional and financing arrangements that combine regulated obligations, cross-subsidies, access funds and performance-based incentives within a national roll-out plan (Pérez-Arriaga, 2023).

The operational expression of this political will is the universal service obligation (USO)—a legal duty imposed on utilities or concessionaires to connect all households in a defined territory. World Bank research shows that USOs, when paired with targeted subsidies, accelerate rural electrification without undermining financial viability (Estache et al., 2006; Estache, Antonio et al., 2004). Empirical work in developing-country utilities confirms that regions with legally enforced USOs achieve higher connection rates at comparable cost levels relative to regions operating under discretionary expansion policies (Leduchowicz-Municio et al., 2022).

Country experiences illustrate how a universal-access obligation unlocks economies of scale and attracts finance. Brazil's *Luz para Todos* program, launched in 2003, electrified more than 17 million rural residents by 2023, largely because federal law (Law 10.438 and Federal Decree 4.873) made electricity access a social right and required distribution companies to meet annual connection quotas, backed by a dedicated funding mechanism within the sectoral tariff account (Câmara dos Deputados, 2003; González-García et al., 2023; IEA, 2025b; Ministério de Minas e Energia, 2002).

China's "last-mile" campaign likewise reached full coverage by 2015 after the central government issued binding targets and channeled RMB 87 billion in cross-provincial transfers to provincial utilities (He, 2019). India's Saubhagya scheme, announced in 2017, leveraged a statutory obligation on state utilities to connect every willing household; by March 2022 the program had declared 100 % village electrification, with fewer than 10 000 households still unconnected (Arif, 2025; Ministry of Power, 2023; Ministry of Power et al., 2024). Rigorous evaluations note that these mandates not only boosted connection numbers but also reduced average connection costs by spreading fixed network expenses over a larger customer base (Oliveira et al., 2024).

Scalability therefore constitutes a related but independent principle. It requires a political commitment to full electrification and a comprehensive program design. Once the program is adopted and funded, and business models are in place, providers take on explicit coverage commitments, either through contracts or by mandate in publicly owned utilities. This turns electrification into a predictable multi-year program with clear accountability metrics.

2.3. *Sustainability: ensuring financial viability through cost-recovery and regulatory discipline*

Financial sustainability is achieved when electricity providers—whether utilities, mini-grid operators, or concessionaires—can maintain reliable service over time by recovering the full cost of delivering electricity (that includes a reasonable rate of return on the invested assets). Without financial viability, even technically optimal and politically backed plans risk collapse due to insolvency, underinvestment, or poor service quality.

A rich literature highlights the pervasive financial fragility of power sectors in low- and middle-income countries. Comparative diagnostics for more than a dozen systems show that chronic under-recovery of costs—through tariffs that are globally insufficient to recover total costs or weak collection, and technical and non-technical losses—systematically undermines the ability of utilities to invest and operate effectively (Huentele et al., 2020; Huenteler et al., 2017; Trimble et al., 2016). Cross-country studies in sub-Saharan Africa and other developing regions confirm that only a minority of utilities cover full-service costs and that persistent revenue shortfalls are a central reason for underinvestment and poor quality of service (Asantewaa et al., 2023; Eberhard and Shkaratan, 2012; Jamasb et al., 2017). These findings imply that trying to scale up access without first restoring financial balance tends to entrench an unstable utility sector.

The financial sustainability principle thus requires that regulators define cost-reflective revenue requirements and that tariff design, subsidy models and regulatory structures be deliberately oriented toward covering operational and capital costs over time. Because universal access must scale beyond commercially viable segments, sustainability typically requires some form of regulated remuneration and end user tariff setting, even if a limited share of connections can remain viable under purely commercial pricing. Evidence from both developed and developing power systems shows that regulatory schemes which recover these revenue requirements and link allowed revenues to clear performance targets support higher investment and efficiency in distribution networks (Joskow, 2024; NARUC and USAID, 2022). Recent integrated regulatory–financial frameworks go further by computing cost-reflective revenue requirements for entire national electrification plans and testing their implications for tariffs, subsidies and risk allocation; (Díaz-Pastor and Pérez-Arriaga, 2025) provide such an example for Uganda.

Operationalizing this principle also has direct implications for financing. In the benchmark case, regulators first quantify the cost of providing a guaranteed level of service and then translate it into a predictable revenue stream through a stable combination of end-user tariffs and explicit subsidies. Utilities and mini-grid operators can raise long term debt and equity against that revenue stream, because the regulatory commitment makes it credible to financiers. This benchmark fits mature systems. In many developing contexts, raising equity is more challenging and depends on country risk, regulatory credibility, business model attractiveness, and the expected shareholder return. Longer tenors and lower perceived risk reduce the weighted average cost of capital and therefore the financing component that feeds into tariffs. In those settings, balance-sheet stability reinforces this logic. The regulated asset base is typically stable or grows slowly, so short- or medium-tenor borrowing can be rolled over with limited tariff disruption.

In most low- and middle-income power systems, however, current practice departs sharply from this benchmark. Revenue requirements are rarely calculated explicitly or approved *ex ante*. Subsidies arrive late or in arrears, and governments rely on *ad hoc* transfers or short-term borrowing to keep utilities solvent. During rapid electrification, the investment profile is front-loaded, and debt service may overwhelm current revenues, so refinancing based on "financing as usual" is not credible. Providers therefore face high financing costs, short maturities and recurrent liquidity crises. These conditions raise effective costs, deter private participation and lock the sector into a high cost, low investment equilibrium. Credible commitments to cover cost reflective revenue requirements are thus not only a technical requirement of regulation but a precondition for mobilizing private capital at scale on affordable terms.

In sum, financial sustainability stands alone as a binding constraint in electrification strategy. An electrification plan without sustainable cost recovery leads to a cycle of service and failure: utilities default on maintenance, grid expansion stalls, and communities lose faith. This spirals into underperformance and drags down the broader electrification effort.

2.4. Development-focused planning: linking electricity access to productive uses and industrialization

Electrification is ultimately justified by the improvements it brings to people's lives. A development-focused principle therefore requires that new connections be coupled with measures that translate kilowatt-hours into higher incomes, better services, and stronger social outcomes. Without this coupling, demand often remains too low to sustain systems financially, and even well-designed access programs fail to generate the welfare gains they promise (Lemanski et al., 2025). Recent reviews and impact evaluations show that, in the absence of complementary interventions, the short- and medium-run effects of new connections on income, employment, and education can be modest or heterogeneous across contexts (Bonan et al., 2017; Bos et al., 2018; Lee et al., 2020). This evidence reinforces the need to treat electricity as a vehicle for development rather than as a stand-alone infrastructure asset.

A growing empirical and review literature shows that powering machinery, irrigation, refrigeration, and information and communication technologies can transform rural economies. This transformation can be achieved by increasing labor productivity, stabilizing agricultural output, and fostering enterprise growth. A recent systematic review of productive use in African agriculture finds that electric irrigation, agro-processing, and cold storage expand output and reduce post-harvest losses, while also increasing electricity demand and improving load factors for suppliers (Chris, 2023; Raji et al., 2024). Case studies of rural electrification and off-grid systems in East Africa similarly report higher profits for small firms and farms once electric equipment is adopted, although these gains materialize only when credit, market access, and technical support are in place (Bos et al., 2018; Grimm et al., 2017).

The broader socio-economic channels (time savings, access to information, and health) reinforce this development perspective. Studies document that electrification reduces time spent on fuel collection, increases evening study hours, and can support female labor participation once lighting and appliances are available (Bonan et al., 2017; Grogan and Sadanand, 2013). Substitution away from kerosene and traditional biomass can also lower indoor air pollution, particularly when electricity access is combined with a transition to clean cooking (Das et al., 2023). Taken together, this evidence establishes the development-focused principle as an independent requirement for sustainable electrification.

Transparency also matters. Publicly disclosed plans, targets, and subsidy rules strengthen accountability and reduce reversal risk across political cycles. The neglect of productive use, affordability, and community agency often accounts for why many apparently successful connection drives later face low consumption, revenue shortfalls, and social disappointment. Integrating this principle with cost-effective planning, a universal-access mandate, and financial viability completes the four-pillar framework of this paper and aligns electrification strategies with durable socio-economic progress.

These four requirements do not form an arbitrary checklist. They emerge from an implementation problem. A least-cost plan becomes an electrification program only when an implementing agent can (i) deliver the selected technology portfolio at scale, (ii) operate under a binding universal-access mandate, (iii) recover efficient costs through a transparent mix of tariffs and subsidies consistent with affordability, and (iv) stimulate demand and productive use so that revenues and welfare gains materialize over time. In fiscally constrained power sectors with financially distressed DISCOs, these conditions become mutually reinforcing. When one fails, the others lose traction.

3. Methodology: an integrated three-step framework for universal electrification

This section translates the four pillars previously discussed into a three-step operational framework that links planning, regulation, and finance. The architecture is conceived to address the objective of universal electrification within the confines of binding fiscal and financial constraints.

The framework is organized around three questions: (i) what must be built and what does it cost?; (ii) who should implement and operate the investments, and under which regulatory, business and contractual arrangements?; and (iii) how will the required investments be financed and their costs recovered over time?

This methodology is designed to be transferable across country contexts, with data and institutional parameters calibrated to local conditions. It has been refined through applications in Latin America and sub-Saharan Africa, where it has supported national electrification strategies and distribution sector reforms.

3.1. Step One: What must be done? – Crafting the techno-economic electrification plan

The initial step within this framework is the techno-economic analysis. These plans delineate the infrastructure to be constructed, its location and the timeframe for its completion, and produce the cost streams that will subsequently inform the regulatory and financial analysis.

The techno-economic plan relies on integrated least cost planning across on-grid and off-grid solutions. It uses georeferenced data and computer aided modelling to characterize demand, population distribution, and existing grid infrastructure. It then evaluates, for each locality, alternative electrification modes including grid extension, mini-grids, and stand-alone solar PV systems. It selects the option that minimizes life cycle costs, subject to policy constraints such as electrification targets or technology restrictions. A critical task at this stage is generating a detailed bill of quantities and a time profile of expenditures. The plan must define the capital expenditures and the explicit operating and maintenance needs over the planning horizon.

Step One delivers a system-wide electrification pathway. The scope is national or system-wide and targets universal electricity access within a specified timeframe, such as by 2030. Outputs include, for each year, the selected technology by area, the number of new connections, required network reinforcements and extensions, and associated capital and operating expenditures. Aggregated, these outputs provide a coherent investment and connection trajectory for the whole system.

Various tools and methodologies are available to provide valuable assistance in rural electrification projects. The appropriate model or combination of tools for a given project depends on its scope, ranging from pre-feasibility studies to detailed generation and network designs. As an example, Figure 1 shows the techno-economic results and least-cost plan to achieve 100% electrification in Rwanda using the Reference Electrification Model (Ciller et al., 2019).

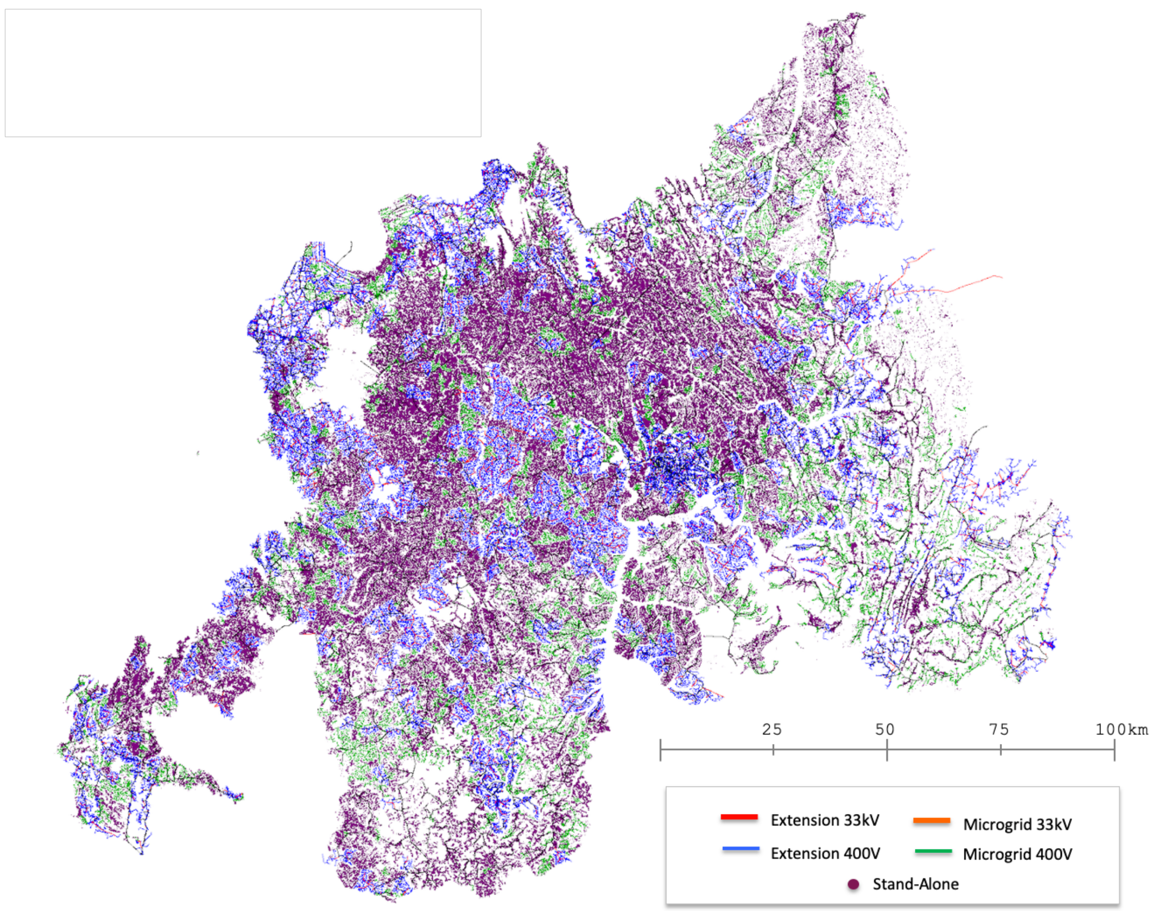

Figure 1. Results of the national techno-economic analysis to achieve 100% electrification in Rwanda by 2024 using REM. Source: Data from (MIT / IIT-Comillas Universal Energy Access Lab, 2019).

In the integrated framework proposed here, Step One, Step Two, and Step Three form an iterative process. Cost streams from the techno-economic plan inform the regulatory, institutional, and business model design in Step Two and the financial plan in Step Three. The resulting weighted average costs of capital for each technology can then be fed back into the techno economic analysis. The plan is adjusted until the three steps are mutually consistent. Where this iteration does not take place, electrification plans that look optimal on paper often prove unfinanceable within realistic fiscal envelopes and are set aside in implementation.

3.2. Step Two: Who should do it and how? – Regulation and business models

In the complex process of developing an electrification strategy, the second step is crucial as it determines the "who" and "how" of executing a well-designed techno-economic plan. Instead of adding engineering detail, Step Two translates the blueprint from Step One into mandates, contracts, and incentives for distribution companies and off grid providers. In a country with tight fiscal constraints that aims to combine universal access, financial sustainability, and private sector participation, the feasible design space is limited.

It is important to note that Step Two operationalizes two principles that were discussed in Sections 2.2 and 2.3. The first principle is scalability. Universal access requires a binding commitment to connect all households, not only those in low cost and high demand areas. Step Two therefore builds a universal service obligation through licenses, concessions, or equivalent instruments. It specifies service areas, access targets, quality standards, and enforcement mechanisms. The second principle is financial sustainability. Electrification must be consistent with affordability and fiscal constraints. Accordingly, Step Two stipulates a cost-of-service regime and a tariff and subsidy architecture that can recover efficient costs over time. It also specifies how cross-subsidies and external subsidies are executed in practice.

3.2.1. Tariffs subsidies and the cost-of-service regime

Regulators influence the financial sustainability of electrification mainly through the design of end-user tariffs. A common approach is a uniform tariff for a given class of consumers across a distribution area, regardless of urban or rural location. This roughly supports progressive rates and political acceptability. In this way, rural and low consumption customers pay the same rate as urban customers even though the cost of supply is higher for the former and their demand is lower. Tariff design may also rely on cross-subsidies from larger customers, typically industrial and commercial or urban consumers, toward poorer, rural, and low consumption households. Uniform tariffs therefore create a structural gap because revenues from high-cost, low-demand customers fall below their cost of supply under a uniform price.

In practice, a combination of tariff uniformity, cross-subsidies, and budget funded transfers is the rule rather than the exception in power sectors worldwide. They reconcile tariff uniformity, affordability, and sector solvency. They are a standard way to finance last mile electrification in many jurisdictions (Cuenca-Enrique et al., 2024; Eberhard et al., 2011; Maphosa and Mabuza, 2017; Trimble et al., 2016).

From a regulatory perspective, Step Two specifies the cost-of-service regime that governs service provision. The regulator sets an allowed revenue requirement for each regulated entity based on the cost streams defined in Step One. This includes efficient operating costs, depreciation, and a reasonable return on the regulated asset base. The allowed return is governed by the weighted average cost of capital. This parameter anchors bankability and investor participation.

In this framework, "cost reflective" refers to the allowed revenue requirement in aggregate, not to the end-user tariff (as it has been just explained "cost-reflective end-user tariffs" do not exist in practice, or at most they are very rare). The regulator recalculates the revenue requirement each year to track efficient costs and an allowed rate of return on investments. The implementation condition is that the regulated entity receives the allowed amount in cash within the year. Tariffs can contribute to that cash flow, but affordability constraints can prevent tariffs from reaching the cost reflective level. Step Two must then specify an explicit subsidy mechanism that pays the difference between revenues collected under affordable tariffs and the allowed revenue requirement.

The ultimate objective is to ensure that, on an annual basis, each company receives the stipulated revenue requirement. When rules are clear, they make each connection viable on a life cycle basis while keeping fiscal exposure visible to government and development partners.

3.2.2. Business models by electrification mode and the "utility-like" logic

To proceed with implementation, it is essential to select business models that have the capacity to implement the techno-economic plan on a large scale. In financially constrained environments characterized by weak utility balance sheets, there is a limited degree of financial flexibility. The viability of private participation is contingent upon the predictability of cash flows and the credibility of risk assessment and allocation. It is imperative that regulation and contracting be implemented to mitigate risk at the fundamental level prior to the implementation of financial de-risking instruments.

The fundamental implication is that as with the grid, off-grid provision often needs a "utility-like" structure. This means a regulated business model that is intended to be permanent, not a time bound project. It requires an allowed revenue model anchored in the efficient cost of service, with clear service standards and performance-based incentives. This logic applies to the main distribution grid, but also to mini-grids and stand-alone systems, where local willingness to pay often remains below full cost recovery.

For mini-grid developers, a limited number of projects have the potential to recover full costs through affordable local tariffs and anchor loads. Without a guaranteed subsidy mechanism, private capital is limited to unsustainable business models. These models include subsidies to the initial capital investment and a willing-buyer-willing-seller mechanism to set up tariffs. When more investment is needed, the tariffs must increase significantly, hitting affordability limits, and the mini-grid should be expected to collapse.

Under regulated remuneration and the guarantee of annual revenues, the regulatory authority calculates the efficient cost of providing, operating, and maintaining mini-grids, incorporating an allowed return. Regulated tariffs applied to end users will remain at affordable levels. The discrepancy is addressed through the implementation of a regulated subsidy program. In the context of competitive procurement, bidders offer the minimum subsidy required to supply electricity in a specified territory, while adhering to predetermined access and quality standards.

The same logic applies to stand-alone systems. Under an energy-as-a-service model, customers pay a fixed, affordable monthly fee but do not own the assets. At that fee level, revenues often do not cover the full cost of providing the service. Costs include purchasing systems, deploying them, replacing or repairing equipment, billing and collection, and maintaining customer service points, including access to appliances that enable basic productive uses. A subsidy must therefore complement tariff revenues. Competitive tendering can again determine the minimum required subsidy for a specified service standard.

Grid extension requires a different treatment, because an incumbent distribution company typically exists. In most cases, the distribution segment is financially distressed (Balabanyan, Ani et al., 2021). One option is a concession for the entire on-grid distribution business, including the existing grid and the future extensions specified in Step One. This option can be structured as a "full concession", where the concessionaire undertakes investments, operation, and maintenance, or as a model where major investments are publicly funded, and the operator is responsible for procurement, operation, maintenance, and minor investments. In francophone contexts, this latter model is often referred to as *affermage* or *délégation de service publique* (Hosier, Richard et al., 2017; Jacquot et al., 2020).

When a full distribution concession is not feasible in the short term, an alternative is to award separate concessions for specific grid extension projects. These concessions can later be transferred to the incumbent utility. Buy-out mechanisms can compensate concessionaires for the residual value of invested assets at transfer. A rural electrification agency or a publicly owned entity may also participate as an implementing agent where sufficient public or concessional funding exists.

Within the integrated framework proposed in this paper, concessions and other business models are therefore not treated as ad hoc responses to crises but as the standard vehicles through which cross-subsidies and explicit subsidies are operationalized. Their territorial scope, universal-access obligations, incentive schemes and financial relations with the rest of the power sector are defined consistently with the techno-economic plan and with the principles of scalability and financial sustainability. Under tight fiscal constraints, there are few alternatives to this type of utility-like, concession-based model if a country aims to combine universal access, private participation and long-term financial viability.

3.3. Step Three: How will it be financed? – The financial plan

With a robust techno economic plan in place and implementable business models defined, the electrification program reaches its major binding constraint. It must secure financing that matches the scale and timing of investments for the entire electrification process. Step Three designs the financing architecture that supports the implementation vehicles defined in Step Two. It specifies how capital and subsidies are mobilized, allocated, and disbursed over time. It also specifies how public resources, concessional finance, and commercial capital combine to reduce the sector blended cost of capital and to circumscribe long-term pressures on tariffs and sovereign budgets.

Both least cost planning and financial viability require the distribution sector to operate as an integrated system that combines grid extension, mini-grids, and stand-alone solutions in a coordinated way. Evidence from international experience shows that integrated strategies outperform fragmented ones in financial sustainability and in the efficiency of resource allocation (Ankel-Peters et al., 2025; Falchetta et al., 2022). Each pathway still needs a bankable business model, but all three should sit under one coherent architecture for financing, tariff design, and cross-subsidization. As previously discussed, integrated cross-subsidy frameworks have played a central role in balancing costs across heterogeneous consumer groups, which supports universal access objectives (CEER, 2020; Estache et al., 2006; Maphosa and Mabuza, 2017).

The key objective is internal consistency. It is imperative that the financial plan ensures sufficient cash flows on an annual basis to cover expenditures, including during the initial phase of intensive investment and low rural demand. Further, it is essential to ascertain whether the plan is capable of, not only meeting debt and equity obligations, but also of sustaining adequate financial ratios.

3.3.1. An integrated financial approach for long-term financial sustainability

The proposed financing strategy integrates market-based capital with targeted public support. The underlying objective is to leverage private financial resources in instances where revenue security exists. To that end, the strategic employment of subsidies is instrumental in addressing scenarios where social objectives or high unit costs jeopardize the full recovery of costs. This creates a layered financing stack that matches instruments to constraints. Capital markets support bankable cash flows. Public support addresses affordability and residual risk.

As noted previously, an accelerated rollout of the infrastructure creates two financing challenges that the plan must solve. First, the "viability gap" can arise when revenues collected under affordable tariffs remain below the cost of service. This gap must be covered through explicit subsidies or through clearly defined cross subsidy mechanisms. Predictability is central. If subsidy disbursement is discretionary or delayed, the program becomes not bankable because providers cannot rely on stable cash inflows. This depends on Step Two. It requires enforceable concessions or licenses, credible tariff setting rules and institutions, and payment security arrangements that make subsidy and cross subsidy transfers contractually reliable (Cornieti and Nicolas, 2023; Eberhard, 2007).

Second, the "financing needs" also arise from timing. Investment outlays occur upfront, while regulatory remuneration spreads recovery over asset lives. Newly connected rural customers also consume little electricity in early years. The program can therefore face near term liquidity constraints even with a credible long run revenue requirement. The financial plan must provide bridge financing and structure repayment schedules that match expected cash flow profiles over time. This is a working capital and demand ramp up problem. It calls for instruments such as grace periods, sculpted debt service, and liquidity facilities that are sized to early year cash deficits. Debt service should track the expected revenue trajectory, not the engineering life alone.

These two challenges determine the role of each financing instrument. Concessional finance is cheaper than commercial capital, but it is rarely sufficient to fund electrification at scale. Its primary role is to de-risk and crowd-in private capital, and to reduce the blended cost of capital so that tariffs and explicit subsidies remain feasible. Governments can access concessional loans through development finance institutions (DFIs). They can also mobilize grants, guarantees, and results-based subsidies. These instruments support early expansion when cash flows are weak and investment is front loaded.

Grants are most relevant when affordability constraints are structural and persistent, because they reduce the cost share that must be recovered from low demand customers and lower leverage during ramp up. Guarantees provide targeted credit enhancement that primarily expands debt capacity and can also improve tenor and pricing when they cover a binding priced risk.

Commercial debt then provides the bulk of debt volume for creditworthy operators, through corporate lending or project level structures, including syndicated facilities and participation by development finance institutions. These instruments require predictable revenues and enforceable contracts, so they depend on the regulatory and contractual choices established in Step Two. Lenders price residual risk through tenor, pricing, and covenants, and require security packages consistent with service obligations and tariff rules.

3.3.2. *A coordinated financing architecture for universal access*

An integrated financial plan needs a strong institutional focal point. Fragmented programs and parallel donor channels often create inconsistent subsidy rules and unstable disbursements. Fragmentation also raises transaction costs and can amplify policy and counterparty risk, which raises the cost of capital. Centralizing financial flows can therefore improve coordination, reduce volatility, and strengthen the allocation of scarce concessional resources (Briera and Lefèvre, 2024; Fay et al., 2021; Vikas et al., 2024).

This paper therefore proposes a centralized financial strategy that integrates funding across all three electrification modes and coordinates the actions of utilities, developers, investors, and the government. The approach targets universal access while remaining consistent with broader development objectives, including industrialization and productive use.

This needs a coordinating vehicle which this paper names "Finance-Co". Finance-Co is a government-affiliated financial intermediary dedicated to the distribution sector and universal access. It pools public resources and external support. It then channels funds to distribution companies and off grid developers under rules consistent with the regulatory framework.

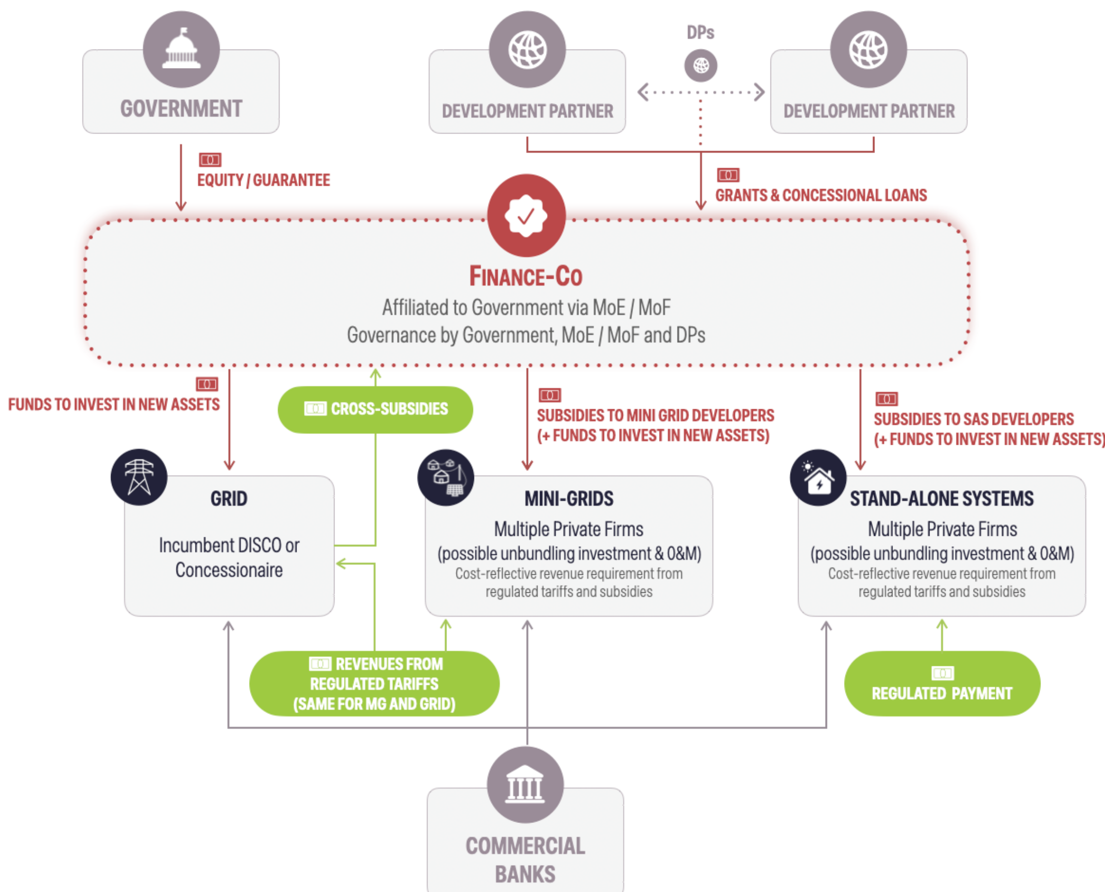

Figure 2. Stylized cash flow structure of an integrated financing vehicle for universal electrification, showing funding sources, subsidy channels, and implementing entities across grid extension, mini-grids, and stand-alone systems.

Figure 2 clarifies the economic flows that Finance-Co coordinates. Inflows include government backed equity and, where needed, government backed risk support such as guarantees. Development partners provide grants and concessional loans through the same vehicle. Finance-Co then allocates resources across grid, mini-grids, and stand-alone systems in a way that matches the plan's financing needs. For grid extension, it funds investments in new assets through the incumbent DISCO or a concessionaire. For mini-grids and stand-alone systems, it provides subsidies that close viability gaps. Where balance sheets remain constrained, these transfers can take the form of capital contributions that fund new assets. The figure explicitly recognizes private provision in these segments and the possibility of unbundling investment and operations. This feature matters because it allows the regulator to remunerate service delivery through regulated tariffs or regulated payments, while Finance-Co finances the capital component under concessional terms.

The outflows in Figure 2 also clarify the revenue backstop for each mode. Grid and mini-grid operators receive revenues from regulated tariffs. The figure assumes a common reference tariff when the regulatory framework requires comparable service quality across modes. Stand-alone providers receive a regulated payment. These revenue streams define the baseline cash flow for operations. Subsidies then close the residual viability gap when affordability constraints bind.

This architecture makes cross-subsidization explicit and auditable. Figure 2 shows a dedicated cross-subsidy channel that routes regulated tariff revenues into Finance-Co and reallocates them to fund off grid support, including mini-grids and stand-alone systems. This design enables redistribution across customer classes and geographies, while applying a consistent rule across grid and off grid provision. By routing transfers through Finance-Co, the framework creates a traceable allocation rule and reduces discretionary, ad hoc transfers.

Commercial finance remains part of the equilibrium. Figure 2 places commercial banks beneath all implementing channels. This reflects that commercial lending can participate alongside public and concessional flows when operators are creditworthy and contracts are enforceable. Finance-Co strengthens this channel by making public support more predictable and by using standard, transparent arrangements to protect lenders when the government chooses to provide credit support.

Finally, Finance-Co governance must balance national ownership with external oversight. The ministries of energy (MoE) and finance (MoF), or their equivalents, should represent the state. Development partners and other major stakeholders that provide capital and risk mitigation should participate in governance to align support with national priorities and to strengthen oversight of disbursement rules.

4. Results: Cash-flow dynamics under cost-of-service regulation

This section translates the integrated methodology developed in Section 3 into a cash-flow representation of implementation constraints under cost-of-service regulation. The objective is not to re-derive the techno-economic plan (Step One), nor to restate the regulatory and institutional design space (Step Two and Step Three), but to formalize the financial feasibility conditions that ultimately determine whether a universal electrification pathway can be executed at scale.

4.1. Notation and time indexing

Let t index years and let i index regulated entities. In the simplest case, i is the incumbent distribution company. In the integrated framework, i can also represent: (i) a distribution concessionaire (grid operation and grid extension in a defined territory), (ii) a mini-grid concessionaire, or (iii) a stand-alone service provider operating under a regulated energy-as-a-service model.

4.2. Annual realized revenues

Annual realized revenues are the cash revenues collected from end-users through regulated tariffs and charges. They are the only recurrent income of the electricity business. They depend on tariff levels, delivered energy, billing, losses, and collection performance.

A general representation for each entity i at time t is:

$$REV_{t,i} = \sum_{c \in C} (p_{t,i,c} \times E_{t,i,c} \times \eta_{t,i,c}) + R_{t,i}^{other} \tag{1}$$

Where:

- (c) indexes customer classes (for example residential, commercial, industrial).
- $(p_{t,i,c})$ is the regulated tariff or average regulated price for class (c).
- $(E_{t,i,c})$ is billed energy or an equivalent billing base for class (c).
- $(\eta_{t,i,c})$ is the collection rate.
- $(R_{t,i}^{other})$ captures other regulated income items, such as regulated connection charges, regulated service fees, or regulated transfers that are treated as revenue in accounts.

4.3. Annual regulated cost of providing the service as the revenue requirement

Under cost-of-service regulation, the regulator sets the revenue requirement that is intended to cover efficient costs and allow a reasonable return on invested capital. In a given year t, for each entity i, the cost of service is calculated using the following formula:

$$CoS_{t,i} = OPEX_{t,i} + DEP_{t,i} + (RAB_{t,i} \times WACC_{t,i}) \tag{2}$$

Where:

- $(OPEX_{t,i})$ is efficient operating expenditure allowed by the regulator.
- $(DEP_{t,i})$ is regulatory depreciation of the RAB.
- $(RAB_{t,i})$ is the regulated asset base.
- $(WACC_{t,i})$ is the Weighted Average Cost of Capital used to remunerate the RAB.

This representation is consistent with orthodox regulatory accounting principles, emphasizing that the allowed return is determined by the WACC. In essence, this parameter operates as the primary factor influencing the return on the RAB, consequently impacting the overall revenue requirement and the subsequent determination of tariffs (Gómez, 2013a, 2013b; Reneses et al., 2013).

4.4. Annual total expenditure as cash outflows

The revenue requirement is not a cash flow. It is a regulated accounting construct that defines the distribution of cost recovery over a period of time. On the other hand, the implementation of an electrification plan necessitates a cash-based perspective, as the DISCO and the other implementing entities are obligated to meet tangible cash obligations on an annual basis. These obligations encompass both investment outlays and financing payments. Consequently, the annual total expenditure is defined as the total cash outflow associated with the operation and financing of the business in year (t).

A practical decomposition is:

$$TOTEX_{t,i} = OPEX_{t,i} + CAPEX_{t,i} + \Delta NWC_{t,i} + TAX_{t,i} + DS_{t,i} + DIV_{t,i} \quad (3)$$

Where:

- $(OPEX_{t,i})$ includes actual administration, operation, and maintenance costs.
- $(CAPEX_{t,i})$ includes all growth and maintenance investments executed in that year.
- $(\Delta NWC_{t,i})$ captures net working capital variations.
- $(TAX_{t,i})$ captures income taxes and other cash taxes where applicable.
- $(DS_{t,i})$ captures debt service, including interest and principal repayments.
- $(DIV_{t,i})$ captures dividends paid to equity holders.

This definition preserves the key idea that the TOTEX includes real operating and capital expenditures plus the cash consequences of the financing structure.

4.5. Two gaps that bind implementation

The definitions above imply two distinct gaps. They have different economic meanings and require different policy and financial responses. Confusing them is a recurrent source of implementation failure.

4.5.1. The viability gap: when affordability prevents revenues from reaching cost of service

The first gap arises when tariffs are set below the cost of service. In that case, annual realized revenues fall short of the regulated revenue requirement:

$$VG_{t,i} = CoS_{t,i} - REV_{t,i} \quad (4)$$

Where $(VG_{t,i})$ is the viability gap.

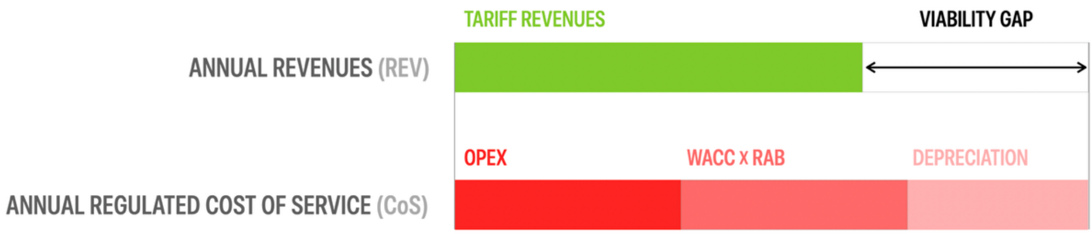

Figure 3. Regulated revenue requirement and tariff revenue adequacy.

Figure 3 plots this gap at year end. If tariffs remain below cost of service for prolonged periods without a credible compensation mechanism, the regulated business is structurally loss-making. In that case, private participation becomes unlikely and commercial debt becomes unavailable. Even concessional lenders will hesitate when cash-flow predictability is weak (Huentele et al., 2020; Walder and Kirkman, 1999).

The policy interpretation is direct: if a government chooses to keep tariffs below the regulated revenue requirement, the deficit becomes a public responsibility. The compensation instrument can take different forms (budget transfers, an access fund, a sector levy, or ring-fenced flows through an institution such as Finance-Co), but it must be transparent and enforceable. Otherwise, the viability gap increases risk, raises WACC, and augments the long-run costs faced by consumers and taxpayers.

4.5.2. The financing needs: when total cash expenditures exceed the cost of service in a given year

The second gap persists even in instances where the activity is considered viable from a regulatory standpoint. A DISCO may incur a cost of service compatible with a viable financial plan, yet it also faces a substantial cash deficit during the initial implementation phase. The annual financing needs of a given entity are defined as follows:

$$FN_{t,i} = TOTEX_{t,i} - CoS_{t,i} \tag{5}$$

Where $(FN_{t,i})$ is the financing needs of entity i in year t. Figure 4 highlights this gap by comparing annual regulated cost of service, $CoS_{t,i}$, with annual total expenditures, $TOTEX_{t,i}$. During the high-investment phase, capital expenditures rises sharply, working capital often rises, and debt service begins once debt is drawn. These cash items can push (TOTEX) above (CoS) even when (CoS) is properly defined and updated.

Figure 4. Regulated cost of service compared with annual total expenditure.

The core driver is the intertemporal structure of cost recovery. ($CoS_{t,i}$) remunerates investment through depreciation and the allowed return over the asset's economic life. It therefore converts a front-loaded cash outlay into a multi-year revenue requirement. It does not reimburse the full cash outlay in the year when the entity builds the asset. The resulting timing wedge is the "financing needs" gap. The entity must cover it through an appropriate mix of equity and debt, using instruments with tenors and repayment profiles consistent with rollout dynamics.

The economic interpretation differs from the viability gap. The financing needs gap is not, by itself, evidence of regulatory failure. It reflects timing. Investment is front loaded, while cost recovery is spread over asset lives. As a result, a program can fail because it lacks bridge finance even if subsidy policy is sound. A program can also fail because subsidies are uncertain or poorly executed even when capital is available.

Figure 5 illustrates the three annual decompositions of (REV), (CoS), and (TOTEX) within the same accounting period. The figure makes clear that electrification binds through two channels. First, revenue adequacy under affordability constraints determines whether (REV) can cover the (CoS) in the long run. The second is cash timing, which determines whether the entity can finance (TOTEX) during periods of intensive investment, when revenues lag behind expenditures.

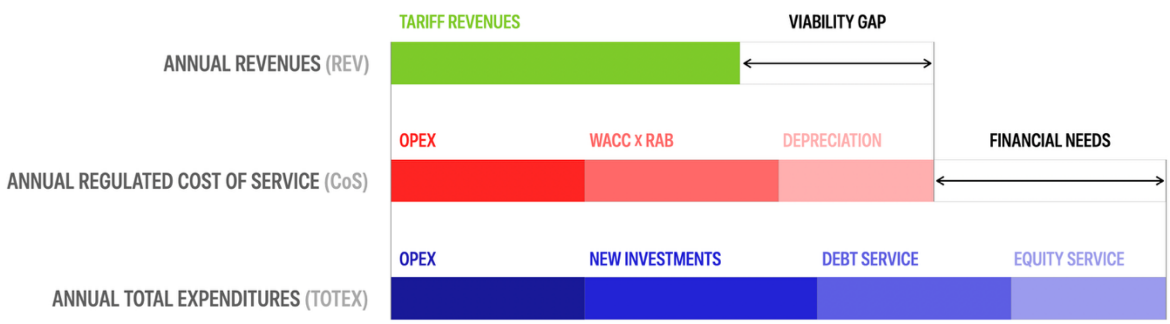

Figure 5. Mapping tariff revenues to regulated costs and total expenditure obligations.

4.5.3. Consolidated annual cash balance: sources and uses of funds

Figure 6 reframes the two gaps in a single sources-and-uses view. In any year t, the regulated entity must cover total cash expenditures through a combination of revenues, subsidies, and financing sources. A practical cash balance identity is:

$$REV_{t,i} + SUB_{t,i} + \Delta DEBT_{t,i} + \Delta EQUITY_{t,i} = TOTEX_{t,i} + \Delta CASH_{t,i} \qquad (6)$$

where ($SUB_{t,i}$) represents explicit subsidies/transfers paid to the entity, ($\Delta DEBT_{t,i}$) is net debt raised, ($\Delta EQUITY_{t,i}$) is net equity injected, and $\left(\Delta CASH_{t,i}\right)$ is the change in cash balances.

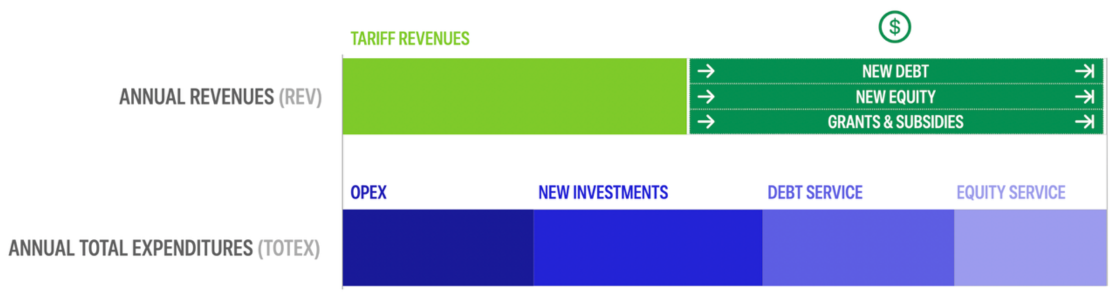

Figure 6. Tariff revenues and complementary financing sources to meet total expenditure.

This identity clarifies the operational meaning of the two gaps. If (REV) < (CoS), then (SUB) must compensate for the viability gap unless an explicit subsidy mechanism exists. If (TOTEX) > (CoS), then (DEBT) and (EQUITY) must cover financing needs, subject to constraints on leverage, tenor, and risk appetite.

Equation (6) also provides a rationale for why annual subsidy calculations are not sufficient. The government must ensure that required subsidies are predictable and disbursed on schedule. Where this is not credible, payment risk increases WACC and can dominate the business case, undermining implementability (DAC Working Party on Aid Effectiveness, 2011; Vivien Foster and Anshul Rana, 2020).

4.6. Long-horizon dynamics: the asynchrony between REV, CoS, and TOTEX

Figures 3 to 6 describe the annual cash-flow logic. Figure 7 extends the logic over a multi-year rollout (stylized over a 20-year horizon) and highlights a structural asynchrony: (TOTEX) typically peaks early due to front-loaded investment, (CoS) rises and remains elevated because the revenue requirement remunerates the accumulated asset base over asset lives, and (REV) lags because newly connected customers consume little electricity initially and because tariffs remain constrained by affordability.

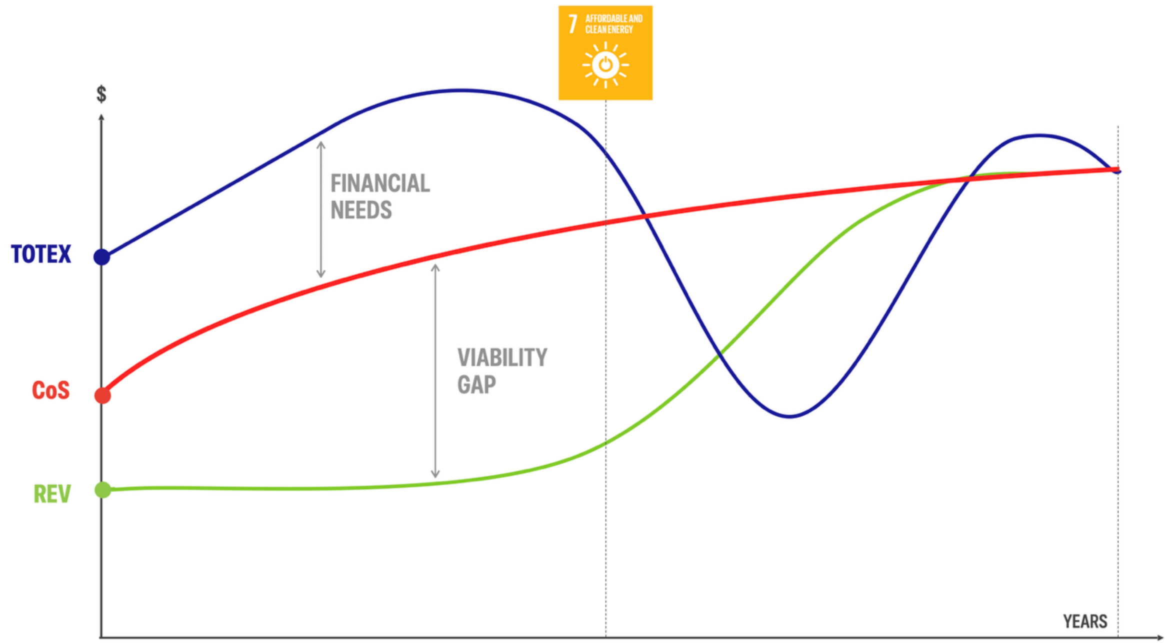

Figure 7. Evolution of revenues, regulated costs, and total expenditure over time.

The difference between the (CoS) curve and the (REV) curve corresponds to the viability gap defined in equation (4). The government must reduce this gap as early as feasible by increasing tariffs to the extent allowed by affordability and political acceptability and, in years when tariffs cannot reach the revenue requirement, by guaranteeing subsidies on an annual or multi-year basis.

The asynchrony between (TOTEX) and (CoS) emphasizes the importance of capital structure and financing instrument selection. Tenors and repayment profiles should align with the recovery horizon implied by the regulatory regime and asset lives. Longer tenors reduce annual debt service and reduce the annual tariff and subsidy pressure required to keep the program bankable.

A long-run feasibility condition can be stated in cumulative form. Over a sufficiently long horizon, cumulative sources of funds must cover cumulative uses of funds:

$$\sum_{t=1}^{T}(REV_{t,i} + SUB_{t,i}) + \sum_{t=1}^{T}(\Delta DEBT_{t,i} + \Delta EQUITY_{t,i}) \geq \sum_{t=1}^{T} TOTEX_{t,i}) \tag{7}$$

Equation (7) is therefore a cash-flow feasibility condition. It formalizes the fact that front-loaded (TOTEX) creates a temporary funding requirement that must be bridged by a combination of subsidies and external finance.

Investment recovery is instead a present value condition. Abstracting from terminal balance-sheet adjustments, long-run viability requires that the discounted remuneration stream covers the discounted cash cost of delivery at the relevant discount rate r :

$$\sum_{t=1}^{T} \frac{(REV_{t,i} + SUB_{t,i})}{(1+r)^t} \approx \sum_{t=1}^{T} \frac{TOTEX_{t,i}}{(1+r)^t} \tag{8}$$

Taken together, (7) and (8) separate two constraints that Figure 7 combines visually. The first is liquidity during rollout. The second is long-run cost recovery in present value terms. Debt and equity do not substitute for revenue adequacy. They smooth the timing mismatch between early cash needs and a slower build-up of (REV+SUB). When both constraints are satisfied, least-cost electrification plans become financially implementable over the rollout horizon.

5. Discussion and policy implications

The results above formalize a central implementation message: achieving universal electricity access under affordability limits requires distinguishing and addressing two separate constraints - revenue adequacy (closing the viability gap) and intertemporal liquidity and capital structure (covering the financing needs during rollout). Crucially, these constraints operate through different channels: the first concerns the credibility of recurring compensation for efficient costs under affordability parameters, while the second concerns the timing mismatch between front-loaded expenditures and intertemporal cost recovery.

Therefore, cost-of-service regulation becomes pivotal when electrification must accelerate while tariffs remain constrained by affordability and political economy. Unlike regulatory approaches that lock revenue trajectories for multi-year periods and only review them periodically, accelerated access requires a more responsive regime capable of frequent recalibration of the revenue requirement as execution deviates from baseline plans and financing conditions evolve. Regular reassessment reduces regulatory drift and strengthens predictability for investors, which is critical to mobilize longer-tenor capital for distribution and last-mile investments (Alexander, 2014). In this setting, the core implementation question is not whether tariffs can be raised to cost recovery in the short run, but whether the regulated revenue requirement can be secured annually through a transparent mix of tariffs and explicit subsidies.

This does not imply abandoning performance incentives. Rather, it implies recognizing that the primary implementability condition is that each implementing agent - whether on-grid or off-grid - can credibly expect to receive the regulated revenue requirement in cash (from tariffs plus explicit transfers) and can finance the front-loaded expenditures implied by the rollout.

In practice, however, affordability constraints and the commercial performance of the retail segment (losses, billing and collection) often prevent end-user payments from delivering the allowed revenue requirement in cash. When that occurs, the shortfall is not a residual accounting artifact: it is the binding constraint for bankability. Section 4 has characterized this shortfall as the “viability gap”, i.e., the difference between the regulated cost of service and realized revenues. If tariffs remain structurally below the revenue requirement, the resulting deficit cannot be ignored. It must be covered through a mechanism that is credible to both investors and lenders. Chronic under-recovery is a pervasive driver of utility financial distress and quasi-fiscal deficits in developing-country power sectors (Huentele et al., 2020). Three implications follow for policy design and for the financeability of network expansion and last-mile delivery.

First, make compensation explicit and rule-based. When governments choose affordability-driven tariffs, they are implicitly choosing to subsidize electricity service. Under a cost-of-service regime, this choice should be made explicit through a stable compensation instrument (for example, an access fund, a sector levy, a ring-fenced subsidy line, cross-subsidies or a standardized transfer mechanism embedded in regulation). Credible, rule-based compensation reduces discretion and payment delays, both of which increase risk premiums and WACC.

Second, convert implicit cross-subsidies into transparent and auditable flows where possible. Uniform tariffs often embed cross-subsidies from higher-consuming or higher-income segments toward low-income and rural customers. Uniform tariffs can support progressive rates and political acceptability, but they can also obscure the magnitude and beneficiaries of redistribution. Making cross-subsidies explicit – through transparent accounting and auditable transfers – can strengthen governance and reduce inconsistency across grid and off-grid modalities (CEER, 2020; Estache et al., 2006; Maphosa and Mabuza, 2017).

Third, treat subsidy predictability as a first-order bankability variable. Even when annual subsidy needs can be computed, governments often struggle to guarantee disbursements reliably through annual budget processes. In practice, subsidy payment risk can dominate the business case by raising perceived counterparty risk and, therefore, WACC. This predictability constraint is central to the political economy of access: it determines whether affordability objectives translate into durable service provision or into repeated arrears and investment stops (Pérez-Arriaga, 2024).

Closing (or explicitly funding) the viability gap is a necessary but not sufficient condition. A second constraint concerns the financing needs, which reflect the timing mismatch between front-loaded investment outlays and intertemporal cost recovery. They are not solved primarily by raising tariffs; they require financing structures consistent with rollout dynamics. Aligning debt tenor and amortization to the regulatory recovery horizon is therefore essential. When repayment profiles are too short relative to asset lives and to the speed of demand growth, debt service can generate severe early-year cash constraints even under a credible revenue requirement. Longer tenors, grace periods, and sculpted amortization profiles reduce annual cash pressure and improve implementability. In parallel, liquidity and working-capital finance must be treated as a program design variable rather than as an operator problem ex post. Expansion phases increase working capital needs (metering, billing systems, inventories) while rural consumption remains low initially. Liquidity and working capital facilities are therefore core implementation instruments during accelerated rollout.

These financing needs also clarify the complementary roles of concessional and commercial finance. Concessional instruments can lower the effective cost of capital and reduce the tariff and subsidy envelope required for feasibility. However, external concessional resources often face short commitment horizons relative to the persistence of affordability constraints (DAC Working Party on Aid Effectiveness, 2011; Gulrajani and Lundsgaarde, 2023). Results-Based Financing (RBF) can improve early liquidity and execution incentives within a defined program window (Vivid Economics and Savedoff, 2015), but it rarely substitutes for durable revenue adequacy when operating costs, replacement needs, and affordability-driven revenue shortfalls persist. Accordingly, the practical design challenge is not choosing between RBF and cost-of-service regulation but ensuring their consistency: short-horizon output payments can accelerate delivery while a stable revenue-adequacy mechanism sustains long-run operations and renewal.

The proposed integrated framework further implies that financial feasibility conditions are technology-neutral: the same revenue-adequacy and cash-timing constraints apply to grid extension, mini-grids, and stand-alone systems once they are operated as permanent service solutions. Accordingly, the key regulatory requirement is not a particular tariff design, but the existence of a coherent and credible mechanism that converts the regulated revenue requirement into timely cash receipts for each implementing agent—through a combination of user charges, explicit transfers, and/or auditable cross-subsidies consistent with affordability objectives. Without such a mechanism, private participation remains limited and service quality can deteriorate after initial rollout, independently of the chosen technology (Falchetta et al., 2022; Pérez-Arriaga, 2023; Pérez-Arriaga et al., 2019).

Competitive procurement and concessions can complement cost-of-service regulation. The framework supports tenders in which developers bid for the minimum subsidy required to deliver a defined service standard in a defined service territory. Competitive procurement reveals efficient subsidy needs, while cost-of-service logic anchors long-run viability and performance obligations. Empirical experience with distribution concessions and hybrid models suggests that well-specified obligations, credible remuneration, and clear risk allocation can improve utility performance and support access expansion (Hosier, Richard et al., 2017), such as the case of Umeme in Uganda (de Abajo, 2023; Díaz-Pastor and Pérez-Arriaga, 2025; Pérez-Arriaga et al., 2022; Twesigye, 2023). From an Energy Policy perspective, the key point is that procurement and contracting are not substitutes for regulation; they are allocation and enforcement mechanisms whose effectiveness depends on the credibility of the underlying revenue model and the predictability of the associated cash transfers.

This provides an economic rationale for the centralized financing platform (Finance-Co) proposed in Section 3.3. The platform's value proposition is financial and institutional: pooling and standardization reduce fragmentation and transaction costs; ring-fenced flows strengthen payment security and facilitate longer-tenor financing for regulated entities; and transparent accounting of subsidies and cross-subsidies improves governance and reconciliation between equity and sustainability objectives (Fay et al., 2021). International precedents support the feasibility of this institutional approach, even if mandates and legal forms differ across countries. In Bangladesh, IDCOL blended donor funding with domestic finance to scale distributed energy programs at scale (Cabraal, Anil et al., 2021). In Tanzania, the Rural Energy Fund combined donor and government oversight to finance rural access investments and to improve coordination across programs (Danielsson, L and Zhou, P, 2011; World Bank, 2023). In Spain, the Electricity Deficit Amortization Fund helped restore sector liquidity by centralizing financial management through a dedicated legal instrument (IEA, 2021; Morningstar DBRS, 2024). In the Philippines, PSALM and the universal charge mechanism helped stabilize financial flows associated with off grid electrification, with gains in administrative efficiency and financial transparency (CEDTyClea, 2025).

These precedents do not imply a one-size-fits-all institutional form. They support a robust functional proposition: when mandates, governance, and accountability are clear, centralizing financial management can reduce discretion and volatility in subsidy flows, improving bankability and lowering the effective cost of capital.

Finally, many national electrification strategies stop at least-cost planning and a high-level financing envelope. They rarely integrate OPEX trajectories, revenue requirements, or the balance-sheet constraints of implementers. This gap helps explain why technically robust masterplans remain unimplemented (Agutu et al., 2022). The integrated framework addresses this by forcing iteration between the least-cost pathway, the implementation model, and financing. In this setting, the cost of capital is endogenous and depends on business models, enforceability, and subsidy credibility.

If the implied financing is not feasible under fiscal and affordability constraints, the pathway must be revised in the model. This means adjusting standards, sequencing, or subsidies until planning, revenues, and cash flows align. Execution still depends on regulatory capacity, data quality, and governance safeguards in any pooled financing vehicle. Universal access therefore requires consistency across the full chain from pathways to revenue models to financeable cash flows, which frames the paper conclusions.

6. Conclusion

This paper presents an integrated three-step framework that aligns least-cost electrification planning with implementable regulation and annual cash-flow feasibility. The framework bridges a persistent gap between techno-economic roadmaps and the financing constraints faced by distribution utilities and off grid providers.

The results imply that electrification fails because of two distinct feasibility conditions. The first condition is cash revenue adequacy under affordability limits and weak retail performance. The second condition is early year liquidity stress when investment is front loaded and cost recovery arrives later. These two conditions require different instruments and different accountability. Revenue adequacy requires explicit and rules-based compensation that is settled predictably. This is where transparent subsidies and auditable cross-subsidization matter. Liquidity stress requires capital structures, financing tenors, and liquidity facilities aligned with the regulatory recovery horizon and with rollout dynamics.

Once stated this way, the same two feasibility conditions apply across delivery modalities. Grid extension, mini-grids, and stand-alone systems all depend on predictable cash recovery of efficient costs through a transparent mix of user payments and governed transfers. Competitive procurement and concession design can allocate responsibilities efficiently, but they cannot compensate for weak payment security or an incoherent revenue model.

The two-condition structure also clarifies why a centralized financing platform such as Finance-Co is pivotal. It can strengthen revenue adequacy by hardening settlement of subsidies and cross-subsidy transfers through standardized rules and ring-fenced flows. It can also address rollout liquidity by coordinating disbursements, reducing fragmentation, and improving the credibility of payment schedules. These functions reduce perceived risk and can lower the effective cost of capital when affordability support relies on annual budgets and short horizon concessional commitments.

The key implication is practical. Universal access becomes financeable when planning, regulation, and financing are designed as one system with enforceable obligations and credible settlement. In this paper, credible settlement means both revenue adequacy in cash and liquidity coverage during rollout. The framework provides an auditable architecture to convert electrification targets into implementable and financeable programs.

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