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Sustainable Rural Electrification Project Management: An Analysis of Three Case Studies

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Abstract: Universal access to energy is a global challenge for sustainable development that requires granting last-mile access to energy services to rural and isolated communities. However, achieving access is not sufficient: it must be done affordably, reliably and with an adequate quality. Universal access to energy goes beyond the mere selection of a technical solution or infrastructure; it demands being able to design management models for projects aiming to guarantee that households may access energy services in a sustainable way. This study analyzes the main elements (i.e., governance, technological and business models) of management models in universal access to energy projects and their impact on the different dimensions of sustainability (i.e., social, environmental, and economic). The study then presents three case studies of rural electrification projects having different configurations of the management model, with special focus on the differences in the business model, and it analyzes their outcomes from a sustainability perspective. The analysis of the three case studies suggests that the choice of the business model is key to ensuring sustainability, with fee-for-service models giving the best results. The analysis also highlights the importance of collaboration and involvement of the communities in projects engaging multiple agents with different roles.



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Keywords: management model; rural electrification; sustainability; governance; technology; business model

1. Introduction

Universal access to energy is essential to foster and guarantee the progress of less-favored and isolated rural communities [1]. Energy poverty has become a world problem and a threat to the environment, public health, safety, and the world economy [2]. According to the United Nations, the 17 Sustainable Development Goals (SDGs) cannot be achieved without sustainable energy, which is why high priority was given to affordable and non-polluting energy in SDG 7 [3].

The world population with access to energy has increased from 83 percent in 2010 to 90.2 percent in 2021. However, and despite the overall improvement in access to energy in the last years, rural areas in developing countries still show access levels that are far from the objectives declared in the 2030 Agenda [4]. In these cases, the main challenge still remains to address the “last mile” problem; that is, to reach to the most vulnerable and isolated communities: 759 million people do not have access to energy yet, of which most of them live in rural areas, representing a total of 85 percent of the global deficit in access to energy services [5].

The SDG 7 states that universal access to energy must be achieved by using renewable energies, improving the efficiency of energy systems, increasing international collaboration, extending the infrastructure and developing technologies [3]. Therefore, guaranteeing access to energy and energy services is not enough: it is imperative to provide reliable and affordable energy of sufficient quality [6]. Additionally, it is necessary to increase the production and delivery of energy services in a way that is compatible with the SDGs, a

reason why the design of such provision must be made under the principles of universality, diversity and sustainability [3,7].

The origin of the “last mile” challenge is that it makes it very expensive, often prohibitive and not affordable, to provide remote rural communities with energy because the demand for energy from these communities is relatively low. Therefore, energy providers (ESCOs) discard those investments due to the impossibility to make them profitable without increasing their tariffs or having them subsidized by the state; instead, they focus on urban areas, densely populated and with higher average income population [8]. However, for universal access to energy to happen, it is necessary not only to provide access to energy, but also that the energy services are accessible: even when households may access a network or purchase individual energy generation systems, access rates may remain low due to the high initial costs, interconnection fees, wiring, and electric appliances. Hence, universal access to energy requires the development of business models that make access affordable, be it by means of subsidies or payment methods that are compatible with the economy of the households. Long-term sustainability of universal access to energy must also consider the local context and the different agents involved; for this reason, the underlying business models must be tailored to the characteristics of the population and be flexible enough to be consistent with local needs. Therefore, there is no single business model in universal access to energy, but rather different possibilities and characteristics that may be particular to each project. The big challenge is then being able to provide tailored solutions that do not slow down the projects aiming to achieve universal access to energy [5].

Because of the abovementioned barriers, project managers not only need to focus on using high-quality technology that may address local needs but must also ensure that the project’s business model is consistent with cultural values, awareness, and the agents involved in the planning and execution of the project [9]. In other words, a correct management of the project will ensure its sustainability through the provision of a reliable, high-quality and affordable access to energy in rural areas [10].

To further clarify what constitutes a correct management in sustainable rural electrification projects, the main objective of this study is the elaboration of a comprehensive management model to analyze how different configurations of the model may affect sustainability. This is one of the main contributions of this study, as existing literature on rural electrification rarely adopts a managerial view of the projects. The analysis involves the examination of three different studies of real projects of rural electrification led by private entities. The remainder of the study is structured as follows. Section 2 lays out the possible configurations of the management model, with three different components (i.e., governance model, technological model, and business model), after observation of previous academic research on rural electrification projects. Furthermore, it links the impact of the different components of the management model with the three pillars of sustainability (social, environmental, and economic). Section 3 analyzes in further detail three study cases of rural electrification carried out by a private entity. Section 4 summarizes and discusses the main findings of the research. Finally, Section 5 presents the conclusions and limitations of the study.

2. Conceptual Framework

2.1. Management Modeling of Rural Electrification Projects

The configuration of a management model for rural electrification projects is complex and multifaceted. Real cases of rural electrification projects cover primarily the technological elements, project funding and the roles of the different agents involved [11], even though the terminology varies from one case to another [12]. From a wider perspective, the configuration of the management model requires the consideration of aspects relative to ownership, operation and maintenance, selection of technologies, viability and feasibility, funding, or stakeholders’ roles, among others [11–14]. This study synthesizes these elements in three fundamental components: governance model, technological model, and business model (Figure 1). While governance may often be equated to the broader

idea of project management, in rural electrification projects its scope extends to ownership of the initiative or project, the operation of energy provision and the relationships between actors/stakeholders [13,14]. A similar clarification is required in the case of the business model; while some may limit this component to the funding of the project, the business model covers more aspects, such as system acquisition, maintenance, or payment methods [12].

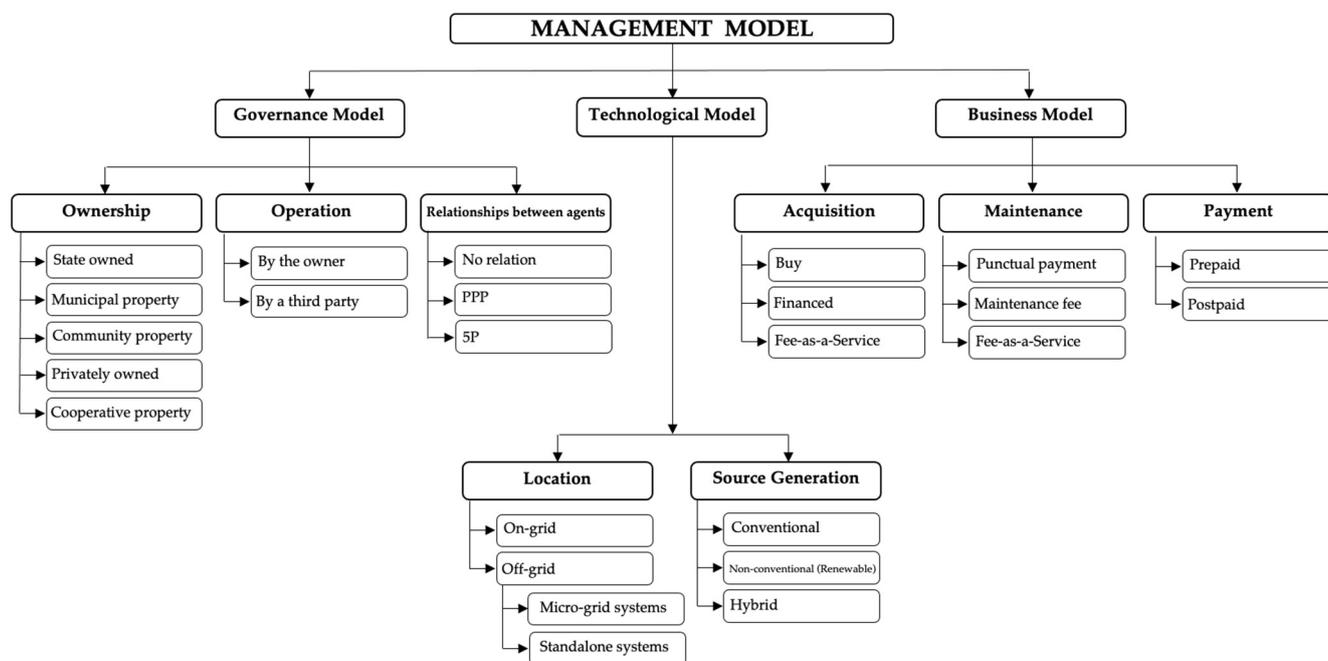


Figure 1. Management model for rural electrification projects.

2.1.1. Governance Model

Based on classifications of governance models of rural electrification projects found in prior research, we can highlight three main elements: ownership of the project, operation of the service and the relationships between agents [13,15,16]. Regarding ownership, the projects may be *state owned*, *privately owned*, *municipal property*, *community property*, and *cooperative property* [15]. *State ownership* refers to projects planned by the state and generally managed by existing electric companies [17]; in contrast, *privately owned* projects are those in which the systems and/or network that grant access to energy belong to the end users or a private company [18–20]. Ownership falls in *municipality* or local authority, or in the *community*, when the energy systems or network have been donated by an entity (public or private) but the control and management of the electric service has been transferred to the local authorities or to the community, respectively [21]. A final option is that of *cooperative* ownership of the project, in which a group of individuals oversees, implements and collectively owns the energy provision service to satisfy their energy access needs [22].

Regardless of ownership, the owner of the project is not necessarily responsible for the operation and maintenance of the service; from the perspective of operation and economic management of the service, there are two different options: either the service is operated *by the owner* or *by a third party* [13,23]. When projects are privately owned and operated by the owner, owners are responsible for the operation of the service, even though they may delegate preventive maintenance to end users and corrective maintenance to expert staff [24]; in *state-owned* projects, operation and preventive and corrective maintenance are generally subcontracted to electric companies; in the case of *municipal* or *community* ownership, citizens generally oversee operation and maintenance; finally, when service operation is overseen by a *third party*, the responsibility for operation and maintenance of the service is transferred to an entity that works autonomously from the owner; the staff of

the third party has (or receives) the training and qualification to perform preventive and corrective maintenance, and the entity receives economic payments from periodic (weekly, monthly, yearly) service fees [25,26].

The third element of the governance model involves the relationships between the agents participating in the project. Because of the need to mobilize resources to broaden the coverage of the energy service, there are several actors involved in the energy service provision in rural electrification projects in remote areas [11]. From the review of prior experiences, three different forms of participation may be found: non-existent (the owner of the project executes it autonomously and independently), *public–private partnerships (PPPs)*, and *pro-poor public–private partnerships (5P)* [27]. A PPP consists of agreements between the public and private sector, where resources from both are combined to provide the service; in a PPP, the public sector lays out the regulatory framework and protects the end users' rights, while the private participants contribute to the project with resources, knowledge and effective operation. The rise of initiatives oriented to improve universal access to basic services in developing countries has led to the emergence of a new type of relationship (5P), where not only states and private companies collaborate, but also incorporate other agents to the project, such as microfinancing institutions, banks or credit unions, universities and nonprofit, not-for-profit, and non-government organizations (NGOs) [17,21,27]. The main objective of 5P is the provision of services to poor communities, often ignored in PPP due to business risks. In 5P, poor people are not only users but also project partners; private companies may develop corporate social responsibility initiatives, public bodies may fulfill their obligation to provide universal access to basic services, and the communities may collaborate in broadening such access.

2.1.2. Technological Model

Rural electrification projects may rely on different technologies, depending on how dispersed are the potential users or their proximity to an existing electric network [28]. When the citizens and the communities live in areas that are close to an existing grid, and the orography is not a problem, *on-grid* systems (i.e., extending the existing network) comes up as an optimal solution [29]. On-grid systems provide enough electric power to connect several lighting devices, such as lamps, and other electric appliances [30]. In these cases, existing electric companies take on the initial infrastructure investment and operate the service, including the maintenance of the different systems [31]. When expanding the grid is not possible due to the fact of long distances between the users and the existing network, *off-grid* solutions are necessary; off-grid systems are independent systems, able to self-generate and store energy [32,33]. Among off-grid systems, there are different options depending on the dispersion of users. If the dispersion is low, *microgrids* generate energy at a local level and supply electricity to a reduced number of users, who are interconnected through a shared distributed system [19,34,35]; when the dispersion is high, *standalone systems* (e.g., *solar home-systems*) are the best solution, especially considering that the cost of grid connection increases with distance from grid [18,36–38].

Energy generation technologies vary depending on the chosen system. Based on the source of energy, they can be categorized as *conventional*, *non-conventional (renewable)*, and *hybrid*. Conventional technologies use fossil fuel [38,39], whereas non-conventional technologies refer to those that use exclusively renewable energy sources [17,21,38,40,41] and hybrid technologies combine both [20,28,38,42]. As the availability of renewable sources of energy may be variable, non-conventional technologies make it necessary to use energy storage systems, such as batteries; hybrid systems generally try to avoid the use of batteries by incorporating diesel generators and reducing the capacity of storage systems [43].

2.1.3. Business Model

Ensuring that the business model of service provision is successful entails the collaboration of different agents (e.g., the state, donors, NGOs, or private companies) [44], and different alternatives can be offered to beneficiaries [45]. For instance, ownership of the energy generation system may fall on the end user (customer) or in the owner of the project (if state or privately owned). When customers own the system, they may have made a pay-up-front purchase or have their purchase financed in different payment installments using microcredits [46]. They are also responsible for the maintenance of the system, bearing the costs associated with maintenance and repairs; to avoid exceptional high expenses, another option is to make periodic payments (a maintenance fee), regardless of whether the systems needs repairing or not [45].

If the customer does not own the system, an *energy-as-a-service* (EaaS) model may be used. EaaS involves that the customer makes a periodic payment for energy provision that includes maintenance and substitution of the system when it reaches end-of-life or end-of-service-life [18,47]. EaaS improves the affordability of energy access because the energy provider maintains ownership of the system and has a duty to keep it operational [45]. Additionally, in EaaS there are two possible payment methods: *prepaid* and *postpaid* [48]; the former allows customers to pay only for the energy used, avoiding expenses when they do not have the money to make the payment (they would not have access to energy in the meanwhile), whereas the latter allows consumers to have access to energy even when they cannot make the payment occasionally (settling the debt in later installments) [49].

Finally, financing of all payments related to access to energy in rural electrification projects generally are subsidized either by the state or other public entities, or by private companies that bear a fraction of the cost of the equipment or the periodic fees; the subsidy may be equal for all customers or proportional to their income.

2.2. Rural Electrification Management Models and Sustainability

Achieving sustainability in rural electrification projects is one of the main challenges for developing countries [50,51]. The use of technologies that are tailored to rural areas widens access to energy [7], but selecting the right technology might not be enough, as it is necessary to consider all aspects related to sustainability throughout all the phases of the project, both at a technical and management level [52,53]. For example, choosing the right business model, achieving effective knowledge and technology transfer and including the beneficiaries in the decision making process facilitate the sustainability of the project [18,54,55].

Sustainable development refers to meeting “the needs and aspirations of the present generation without destroying the resources needed for future generations to meet their needs” [55]. A common view of sustainability is that of the three pillars, which differentiates between social, environmental, and economic sustainability [56]. Social sustainability refers to the ability of social identities, relationships, and values to continue in the future [57], which requires that social cohesion is sustained and that individual needs are met [58]. Environmental sustainability represents the ability to improve human well-being, while protecting the sources of raw materials and guaranteeing the integrity of ecosystems [59]. Economic sustainability refers to the ability of a project to sustain a given level of economic production indefinitely [60,61]. To better guide the decisions of rural electrification projects, the following subsections analyze the effect of the different possible configurations of the management model presented in Section 2.1 in each of the pillars of sustainability, by taking different frameworks defined to assess sustainability, either with a project management approach [62,63] or a rural electrification view [64–67].

2.2.1. Social Sustainability

The social dimension focuses on the improvement in the quality of life of the population, and it is associated with the fulfilment of their basic needs and their active participation in society. It is essential that the beneficiaries are involved in the development of the project, from its design to its implementation, so that the projects are adapted to the particular characteristics of the area and it is easier for the communities to appropriate the technology, thus ensuring their awareness and actual use of the solution [54,68].

From the management model, all three components (i.e., governance, technology, and business models) have a direct effect on different aspects related to social sustainability found in prior literature: funding, energy equity, availability of services, availability of support, profile of operation staff, degree of local participation, project duration, and default rate, or affordability.

Funding helps assess whether the beneficiaries can take care of the periodic expenses associated with access to energy, whether they should own the systems or whether the cost of the service is subsidized to facilitate affordable access to the least favored [68]. These decisions are affected by the governance model, through leadership and relationships between actors, and by the business model, when establishing the modality of acquisition.

Energy equity refers to the requirement that the project must focus on poorest communities and with higher barriers in access to energy, regardless of their social condition or the dispersion of such communities [63], which is highly related to the governance model, depending on the involvement of the community in decision making, and to the technology model, in system selection.

The service also must meet a minimum level of service offer and reliability, in what constitutes the availability of services. Such level varies depending on the characteristics of the community and must be analyzed as part of the project planning, considering the specific needs of each potential user. Availability of services may be assessed based on duration of energy shortages or blackouts as well as users' perceptions [64,69,70], and it is highly associated with the technological model. Additionally, beneficiaries may be provided with the necessary resources to repair the systems or replace them if they are beyond repair; in other words, they need to have available support, which must be both accessible and affordable to users [20,69]. Availability of support is therefore associated with the governance model, by defining who is responsible for service operation, and the business model, by the defined maintenance fees.

Regarding the profile of operating staff, the project must include personnel that has the required skills to operate and maintain the project, so that effective knowledge and technology transfer to the beneficiaries is possible [64]. Additionally, the project should include and empower women in such operation and maintenance tasks [68]. These aspects are affected by the governance model, depending on how community participation is incorporated into the project, which also affects the number of local population involved in the design and operation of the project [62,69].

Choices in ownership (i.e., governance model) and service modeling (i.e., business model) have an effect on the duration of the project. Rural electrification projects require an adoption and adaptation period among end users, as well as additional maturing time that facilitates analysis and fine tuning, which is why short and fast implementation projects with no subsequent monitoring should be avoided [68].

Finally, it must be possible to assess whether access to energy is really affordable for the beneficiaries or, on the contrary, it is necessary to revise the business model to change system acquisition or service provision to prevent abandonment by the users, measured as default rate [20,68,69].

2.2.2. Environmental Sustainability

Environmental sustainability considers the different aspects that impact natural resources and local ecosystems of the areas where the project will be implemented [6]. Decisions in the technology component of the management model are the ones with the most direct effect on environmental sustainability, which may be assessed through CO₂ emissions, impact on the ecosystem, replacement of other polluting sources or compatibility with future grid services.

CO₂ emissions facilitate quantitative comparison and selection of the most appropriate technology to achieve lower levels of pollution. It is necessary that the project management considers which is the right choice among the possible energy sources and systems [61]. Ecosystem impact is based on a qualitative and quantitative analysis of how respectful with the environment is the service infrastructure of the project, both at visual and acoustic levels. At the initiation phase of the project, the decision of the technology must consider and analyze the characteristics of the area and the population, as well as the dispersion of the community [62,64]. When developing rural electrification projects, current use of energy sources must be considered, so that the system to be introduced provides the highest reduction in the use of conventional sources and maximizes the use of non-polluting natural resources in the area [68]. Finally, the solution must guarantee the compatibility of the service with future developments and avoid the generation of technological waste due to obsolescence or abandonment of the system [68]; that is, the technology should be flexible and adaptable.

2.2.3. Economic Sustainability

The top priority of the project in the economic sustainability dimension of a rural electrification project should be to have the ability to autonomously bear the costs associated with the provision of the service in the future. Achieving economic sustainability requires that the costs of the electric service are high enough to maintain the systems operational in the long term but also low enough to guarantee affordability. Decisions of the business model directly affect economic sustainability and, in general, different business models are piloted, helping fine-tune the model until an optimal balance is achieved [5]. As seen in Section 2.1.3, decisions in the business model include system ownership and acquisition, maintenance mode, and payment methods. In developing countries, system acquisition is often prohibitive to the residents in rural areas. Therefore, ensuring economic sustainability involves the adoption of non-conventional business models where the end users only assume a percentage of the total cost.

Broadly, economic sustainability may be assessed by observing the profitability of the project, operation and maintenance costs, and capital and installation costs [68]. That is, the project must (1) be profitable enough to facilitate scaling up, which is why the business model must consider all the associated costs when fees and prices are set-up; (2) observe the economic resources necessary to ensure continuance of the project (higher economic resources entail higher fees and costs for beneficiaries); (3) consider the initial investment to deploy the technical system for energy provision (higher investment in more difficult implementations).

Table 1 shows a summary of the potential impact of decisions in the configuration of the business model on the three pillars of sustainability. The following section analyzes the effect of different decisions in the configuration of the management model in the sustainability of three real projects of rural electrification.

Table 1. Impact of decisions in the management model on sustainability in rural electrification projects.

Dimension	Model Component		
	Governance Model	Technological Model	Business Model
Environmental	CO ₂ emissions		X
	Impact on the ecosystem		X
	Replacement of other polluting sources		X
	Compatibility with future grid service		X
Social	Funding	X	X
	Subsidies	X	X
	Energy equity	X	X
	Availability		X
	Maintenance availability	X	X
	Profile of operators	X	
	Project duration	X	X
	Degree of local ownership	X	
Economic	Default rate		X
	Profitability		X
	Operating and maintenance costs	X	X
	Capital and installation costs		X

3. Case Studies

3.1. Overview and Previous Considerations

This section showcases the analysis of three rural electrification projects in remote areas of Peru and Mexico. The three projects were led and developed by acciona.org, the corporate foundation of ACCIONA. Acciona.org's projects are based on four fundamental principles: (1) the projects are aligned with the main activity of the corporation with impact on human development (energy, water, and sanitation), which helps take advantage of the knowledge, expertise, and developed networks on these areas in developing regions while also empowering local employees; (2) prioritization of projects in areas that are less attended by other institutions, primarily impoverished rural and remote areas, where service provision is not planned; (3) the main objective of the projects must be the design of solutions that are sustainable in the long term. To do so, affiliate non-for-profit organizations are established; the affiliate organizations act as service providers, which facilitate the creation of long-term relationships with the beneficiaries; (4) collaboration with other local, national, and international organizations, including public, private and academic institutions, as well as other civil society organizations and local communities.

The three projects share some characteristics in their configuration of the management model. The governance model is based on private ownership of the projects, initiated by acciona.org and executed by their national affiliates, in this case acciona.org Perú and acciona.org México. The relationship model is 5P, with different collaborating actors at all levels. An advantage of the 5P configuration is that it guarantees the support of larger public and private entities to promote the project while bringing closer the potential beneficiaries by means of existing communication channels that facilitate adaptation of the project (e.g., local population, banks and credit unions, NGOs) as well as innovation through collaboration with academic and research institutions. 5P models also help overcome a big limitation of purely private ownership with no relations, where the design and the decisions in the other elements of the management model are mostly driven by the risk

and low profitability of this kind of projects, which hinders the involvement of the local communities, the understanding of their needs and adaptation of the projects [48,71].

Except for slight differences, the three case studies include similar configurations of their management models in the governance (privately owned, 5P) and technology components (non-conventional, off-grid standalone systems; the technology of the three projects is based on solar home systems due to the dispersion of the communities and long distances to the electric network). Thus, even though the main implications of this configuration on the sustainability of the project will be analyzed, the main focus of the analysis will be the impact of the decisions related to the configuration of the business model on the sustainability of the projects. The following subsections introduce the setting of the three projects and analyze their management model according to the components presented in Section 2.

3.2. Case Study 1: Luz en Casa Cajamarca

Peru had a poverty rate of 30.1 percent in 2020. Access to electricity now extends to 98.35 percent of the country, but this figure drops to 92.45 percent in rural areas [71]. The department of Cajamarca, with 1.5 million inhabitants, has the lowest electrification rate in the country due to the wide dispersion of households in rural communities, which account for 70 percent of the population [72]. The “Luz en Casa Cajamarca” project (Table 2) was developed by the Spanish acciona.org foundation and the Peruvian civil association acciona.org Peru—the affiliate of the acciona.org foundation in Peru. The main objective of the project was to improve access to energy in the region of Cajamarca.

Table 2. “Luz en Casa Cajamarca”: Project overview.

Project Title	<i>Luz en Casa Cajamarca</i>
Beneficiaries	Residents in Cajamarca, Peru
Project Period	2009–2021
Institutions	acciona.org foundation acciona.org Peru Banco Interamericano para el Desarrollo (BID)

3.2.1. Governance Model

“Luz en Casa Cajamarca” is a privately owned project led by acciona.org. In this project, members of the community are selected to work for acciona.org as freelance technical staff, and they oversee installation, set-up, and corrective maintenance of the systems, and provide support in shortage and reconnection tasks.

Local management of the project is performed by acciona.org, which assumes the project’s operational tasks. Acciona.org is supported by a network of volunteers who provide occasional collaboration and by the Committees of Photovoltaic Electrification (CEFs). CEFs are a key agent in the operation of the project, acting as intermediaries between acciona.org and end users, helping in system inspection tasks and preventive maintenance, and collecting, transporting, and depositing the periodic fees associated with the service.

The relationship model can be labeled as 5P, including the collaboration of the acciona.org Foundation as promoter, funding body, coordinator, and supervisor; acciona.org as promoter and long-term operating agent; Ministerio de Energía y Minas (MEM) and Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN) as regulators; Banco Interamericano para el Desarrollo (BID) as co-financer; Universidad Politécnica de Madrid (UPM) as academic and technical advisor; municipalities as partners and communities; CEFs as users and representatives.

3.2.2. Technological Model

Electricity was generated by second-generation solar home systems (SHS), standalone portable equipment that use renewable energies and allow to reach homes that fall out

of the grid extension plans. SHS are solar photovoltaic generators rated between 11 and 100 Wp (Watt-peak) and have a storage battery [73]. Second-generation SHS are equipment specifically designed to optimize solar energy use, with higher capacity and efficiency than first-generation systems but lower required power. A novelty of these systems is that they feature a DC-DC voltage adapter for radio to allow radio connection of different voltages below DC 12 V and a socket to charge mobile phones [74]. Therefore, the service provided by the SHS in the project allows up to four hours of light using spotlights and the charge and use of entertainment and communication equipment, such as mobile devices.

3.2.3. Business Model

The business model was based on EaaS, where a monthly fee is charged for service provision. In this model, the users did not buy the systems: the systems were owned by acciona.org, which also oversaw maintenance and replacement in case of system failure or end-of-service-life. The decision to implement EaaS was made upon a cost analysis that showed that it was the only option that could support sustainable operation and maintenance costs, even assuming that the complete initial investment would not be recovered. To ensure affordable tariffs, it was necessary to negotiate with the Peruvian government to design a policy and regulatory framework for regulated tariffs in rural electrification with off-grid photovoltaic systems, and to incorporate the tariff into the national cross-subsidy system. The system established that 80 percent of the fee was paid by the state, and end users paid the remaining 20 percent of the fee. These amounts were set after consideration of the average household expenditure of 16.4 soles in access to energy (kerosene, candles, batteries) prior to the start of the project and the calculation of operation costs of the project to ensure sustainability. Prior to the coming into effect of the framework, the service fee was 15 soles per month, whereas after the implementation of the project, the fee was reduced to 10 soles per month, which was paid periodically once the service was provided (i.e., a postpaid system). Figure 2 shows a summary of the management model of the “Luz en Casa Cajamarca” project.

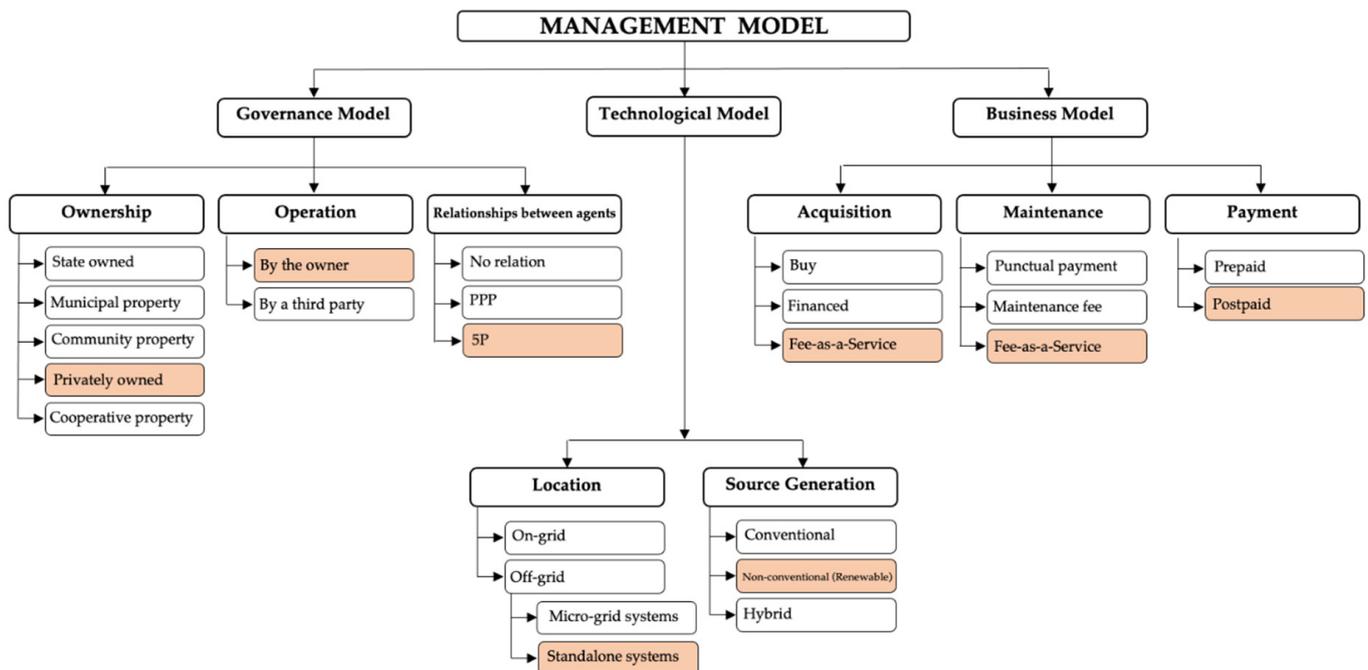


Figure 2. Configuration of the management model of the “Luz en Casa Cajamarca” project.

3.2.4. Main Results and Impact on Sustainability

“Luz en Casa Cajamarca” provides energy to 3910 households spread through 188 different communities after 12 years. With the project, acciona.org set in motion a social model that is close to the community and the users, who are not only beneficiaries of the service but can also take part in the operation and management of the project. The data from quantitative questionnaire-based satisfaction surveys of all users showed high rates of acceptance of the project among beneficiaries; additionally, the model ensured affordable access to energy, as default rates dropped from 3.03% to 0.19%. Awareness and sensitivity activities in the communities have increased credibility and seem to validate the management model. Users highlight time availability as one of the main advantages of the system, as they now have study and cooking time at night.

The project contributed to prevent the emission of 1544 tons of CO₂ per year and the generation of 1.65 tons of battery waste, with a minimal environmental impact due to the use of SHS that do not require the deployment of any additional infrastructure. Energy savings for households was estimated to be 656,880 soles per year (approximately EUR 163,000 per year).

The project made energy fees affordable for users with a balance between revenue and costs that ensures the economic viability and continuity of the project. The technology also helped reduce initial costs associated with infrastructure deployment: standalone SHS cost 2000 soles, compared to a cost of 70,000 soles for grid extension in these areas.

From a sustainability perspective, we observed two main shortcomings of the project. The first of them was related to corrective maintenance and operation, both at economic and human levels; because of the isolated and remote location of households, it is very difficult to supply repair parts, as well as to effectively repair faulty systems and collect service fees. The second shortcoming had to do with the low availability of qualified technical staff; even though the project put emphasis on the identification of users with communication and social mobilization skills to increase awareness and reach all potential beneficiaries, it is still necessary to identify residents with the minimum required technical skills.

3.3. Case Study 2: Luz en Casa Oaxaca

In 2010, 3 million people (2.6 percent of the population) did not have access to energy in Mexico yet. In Oaxaca, this percentage rose to 5.3 percent due to the remote and isolated location of the households [75]. The “Luz en Casa Oaxaca” program (Table 3) was ideated by the acciona.org foundation and the local acciona.org México, analogously to “Luz en Casa Cajamarca”. The main objective of the project was to improve access to energy in the state of Oaxaca. The project is now included in the broader EncASa Oaxaca program, which seeks to provide integral and universal access to different basic services: electricity, drinking water, sanitation, and clean cooking.

Table 3. “Luz en Casa Oaxaca”: Project overview.

Project Title	<i>Luz en Casa Oaxaca</i>
Beneficiaries	Residents in Oaxaca, México
Project Period	2012–2021
Institutions	acciona.org foundation acciona.org Mexico Gobierno del Estado de Oaxaca Agencia Española de Cooperación Internacional para el Desarrollo (AECID) Agencia Mexicana de Cooperación Internacional para el Desarrollo (AMEXCID)

3.3.1. Governance Model

Same as “Luz en Casa Cajamarca”, this project was privately owned by the acciona.org Foundation and acciona.org Mexico. Acciona.org Mexico is formed by a team of local technical staff from the country, which facilitates the communication with the communities (indigenous habitants represent 35 percent of the population in Oaxaca and the region is the most linguistic diverse in the country, with more than seven languages and dialects spoken, such as Mixteco, Zapoteco, and Chinanteco). Acciona.org México is in charge of local management and operation of the project.

The relationship model was 5P, with the collaboration of the acciona.org foundation as promoter, funding body, coordinator and supervisor; acciona.org México as promoter and responsible of the project in the long term; Gobierno del Estado de Oaxaca, Agencia Española de Cooperación Internacional para el Desarrollo (AECID), and Agencia Mexicana de Cooperación Internacional para el Desarrollo (AMEXCID) as co-financers and intermediaries. The international organization KIVA participated as micro-financers, local municipalities acted as partners, and the communities and CEFs participated as end users and representatives.

3.3.2. Technological Model

The project consisted of the deployment of third-generation SHS, or pico photovoltaic systems. An additional benefit of third-generation systems when compared to second-generation SHS (such as those used in “Luz en Casa Cajamarca”) is that they are more compact, lighter, easier to install and use (plug and play), and that they have integrated LED lights that allow for more efficient use of energy, in turn extending the duration of the batteries [74]. Third-generation SHS also use lithium batteries (instead of lead batteries), further reducing the weight of the system which, in turn, facilitates transportation to the communities [76].

3.3.3. Business Model

In “Luz en Casa Oaxaca”, the end users acquired and owned the systems due to the impossibility of implementing EaaS models when the project started due to regulatory constraints. In this user-ownership model, end users paid for half of the cost of the system and the other half was subsidized by the project’s funding bodies. Additionally, if a user could not afford the payment up front, different installments could be made by participating in a micro-credit program directed by KIVA (this program was only active in 2014). As end users owned the systems, they were responsible for maintenance, which entails additional costs beyond the warranty period of the systems.

The model requires higher availability of maintenance than EaaS because the end users have to be able to reach acciona.org’s technical staff for diagnostic and repairing tasks. This decision also has an impact on the governance model, by delegating operational tasks in each area to local entrepreneurs who, from the so-called Centros Luz en Casa (CLCs), provide support and receive fee payments; they also establish franchises to sell appliances that are compatible with the SHS in order to extend the functionalities of the systems beyond lighting. CLCs are usually already existing local businesses located in reference sites that dedicate part of their space and time to support “Luz en Casa Oaxaca” users. Local entrepreneurs receive training to provide effective corrective maintenance and keep constant communication with the project’s management bodies for fee and stock management; in return, they receive a commission fee for each repaired system or sold item. Currently, the project has five CLCs and four Centros EncASa (the latter offer support for sanitation, cooking and drinking water services, in addition to SHS systems and compatible appliances).

Figure 3 summarizes the management model of the “Luz en Casa Oaxaca” project.

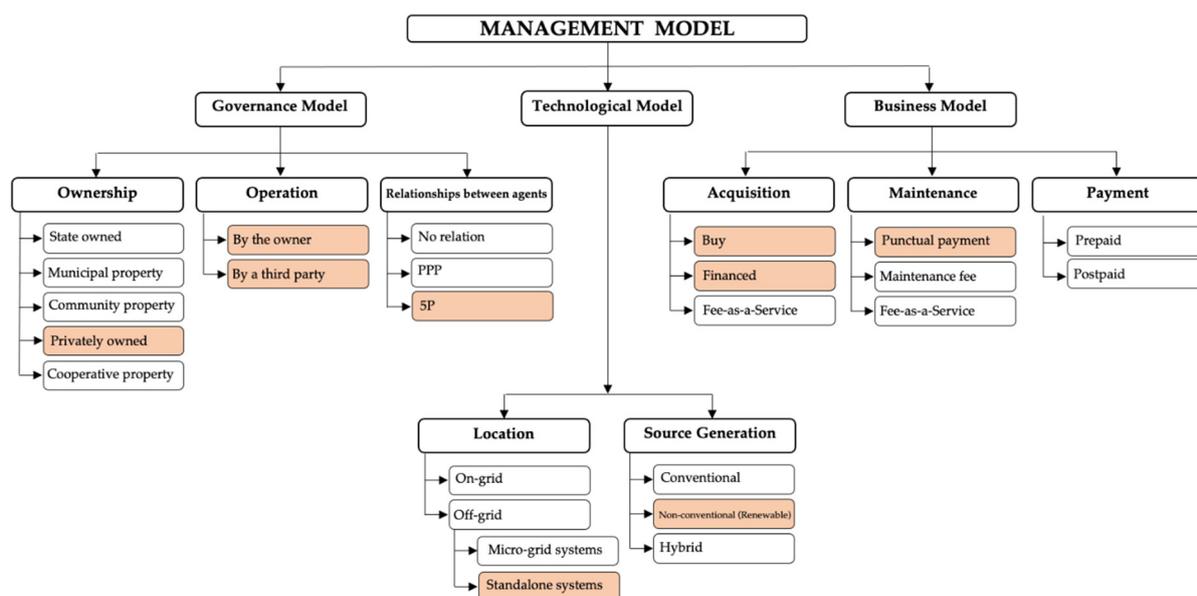


Figure 3. Configuration of the management model of the “Luz en Casa Oaxaca” project.

3.3.4. Main Results and Impact on Sustainability

The project, including Luz en Casa Oaxaca and EncASa Oaxaca, provided energy access to 8525 households in 628 communities after 9 years. Acciona.org subsidized the systems through a partnership involving several public and private entities, ensuring affordability for the most needed and improving universal access. The multi-agent configuration, supported by the CEFs and CLCs, provided higher availability of repairing staff than the “Luz en Casa Cajamarca” project through the identification and training of personnel with technical skills, in addition to awareness and social sensibilization skills. Three out of the nine local entrepreneurs were women who have become referents in the communities they provide support to, advancing towards gender equality. The partnership with public agents helped not only subsidize the systems but also improve and facilitate communication with the communities and a previous identification of the communities that would benefit from the project.

The SHS helped prevent the emission of 1075 tons of CO₂ per year and 12.42 tons of uncontrolled battery waste, with low impact on the environment. Household energy savings were estimated at 18.75 M pesos per year (approximately EUR 758,200 per year).

The subsidization program reduced cost acquisition in half, facilitating affordability, and the SHS reduced initial and deployment costs.

We observed two elements that could be improved from a sustainability perspective. First, maintenance costs may be high for end users. Because of the business model, costs associated with maintenance and repairing are not included in the price and, therefore, must be bore by the users, increasing costs in the case of system failure. Consequently, repair rates were low and, in some cases, the systems were abandoned when they stopped working because users could not afford the cost associated with repairing or replacing the system. Second, subsidization of system acquisition makes it necessary to increase awareness and sensibilization, as having the system subsidized increases the perception of higher costs if replacements are needed, which in turn may increase system abandonment rates. However, the alternative is to use conventional sources of energy, which are more harmful for both end users and the environment.

3.4. Case Study 3: Luz en Casa Amazonía (Napo)

In the Amazon rainforest area, only 82.7 percent of the population has access to electric energy [71], which means that about one in five people do not have access to energy. The “Luz en Casa Amazonía” Project (Table 4), designed by the acciona.org foundation and

acciona.org Perú, aimed to improve access to electric energy of indigenous communities in the Peruvian Amazon rainforest.

Table 4. “Luz en Casa Amazonía”: Project overview.

Project Title	<i>Luz en Casa Amazonía</i>
Beneficiaries	Residents in the Peruvian Napo, Ucayali and Amazonas River basins
Project Period	2016–2021
Institutions	acciona.org Foundation acciona.org Peru Agencia Española de Cooperación Internacional para el Desarrollo (AECID) Fondo Nacional de Desarrollo Científico, Tecnológico y de Innovación Tecnológica (FONDECYT)

3.4.1. Governance Model

Analogously to the previous two projects, “Luz en Casa Amazonía” was privately owned by the acciona.org foundation and acciona.org Peru. Acciona.org Peru is supported by CEFs and has CLCs for local management and operational tasks, including fee collection and payment, repairs, and sales.

The relationships are 5P, with the collaboration of the acciona.org foundation as promoter, funding body, coordinator, and supervisor; acciona.org Peru as promoter and long-term operator; Ministerio de Energía y Minas (MEM) and Organismo Superior de la Inversión en Energía Minera (OSINERGMIN) as regulators and policymakers; the Peruvian Government, Agencia Española de Cooperación Internacional para el Desarrollo (AECID), and Fondo Nacional de Desarrollo Científico, Tecnológico y de Innovación Tecnológica (FONDECYT) as co-financers; Universidad Politécnica de Madrid (UPM), Fundación de Ingenieros del ICAI para el Desarrollo (FICAID), and the Instituto de Investigación Tecnológica (IIT) as academic and technical advisors and partners; municipalities as partners; communities, CLCs (four), and CEFs as users, representatives, and micro-franchises.

3.4.2. Technological Model

The technology applied for service provision was based on third-generation SHS (same as in “Luz en Casa Oaxaca”), but using the pay-as-you-go (PAYG) functionality of the system to simplify the payment process. According to the World Bank, PAYG is one of the most effective solutions to provide decentralized access to energy in remote communities of developing countries [77]. PAYG systems, which were not used in the previous two projects, allow for a prepaid system of energy provision in which the end user pays a fee for a code that unblocks the SHS for a period of time. Once that period expires, the user must complete another payment and a new unblocking code is generated, or else the SHS will be blocked. Therefore, PAYG systems facilitate remote management of off-grid systems, reducing default rates and the risk associated with the initial investment [78].

3.4.3. Business Model

As in the “Luz en Casa Cajamarca”, the energy was provided as EaaS. The business model improves the affordability of the technology: users can also benefit from cross subsidies and the tariff is regulated; therefore, end users only pay 20 percent of the total costs (approximately 9 soles per month). The main difference with the “Luz en Casa Cajamarca” project was that PAYG systems give more freedom to end users, which can accommodate their consumption to their disposable income.

Figure 4 summarizes the management model of the “Luz en Casa Amazonía” project.

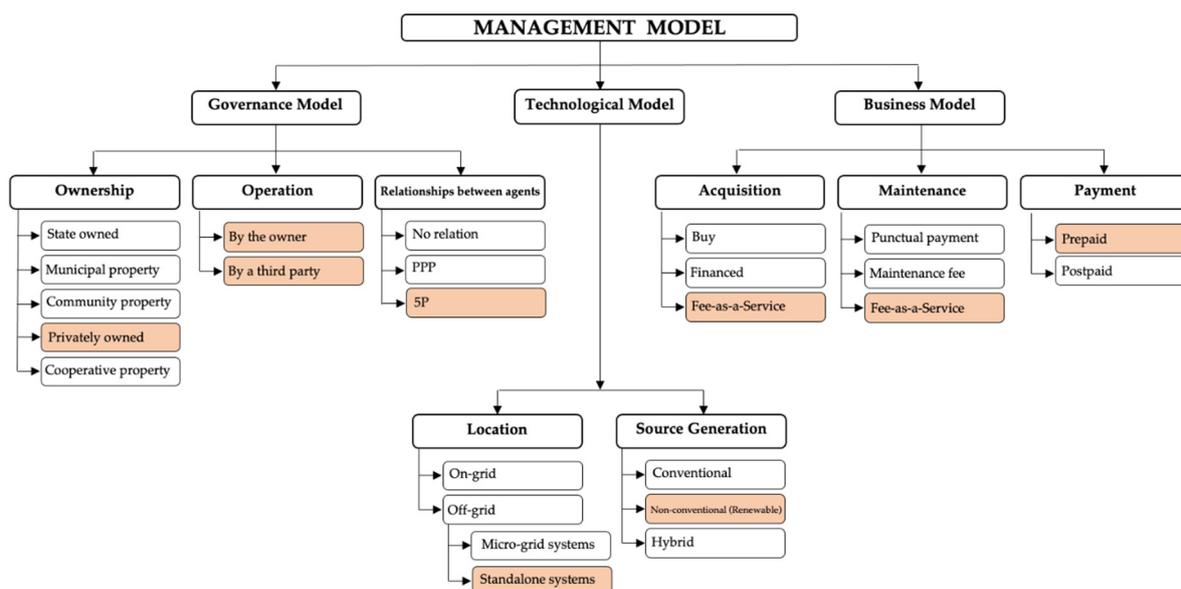


Figure 4. Configuration of the management model of the “Luz en Casa Amazonía” project.

3.4.4. Main Results and Impact on Sustainability

The project provided access to energy to 1518 households in 58 communities after 5 years. From a social sustainability perspective, acciona.org spread out a clean electrification solution for remote rural indigenous communities that minimizes the use of fossil fuel. According to satisfaction surveys collected by the project promoter with replies to a quantitative questionnaire of all participants in the pilot project, all the beneficiaries (100 percent) reported the highest level of satisfaction with the use of the SHS, and the majority of them (98 percent) were also satisfied with their energy savings. The multi-agent model and the incorporation of the CEFs and CLCs make service management and operation viable, as the households are only accessible by the river, and the weather conditions (temperature and rain) are extreme, which further complicates distribution and support.

The implementation of PAYG systems also has a positive impact in operation and management because prepaid installments help reduce default rates (which are close to zero) and delays in fee payments (a reduction of 83 percent, from 68 to 11 days). CLCs have made 80 percent of system repairs (including a 13.2 percent rise in the last year), thus reducing trip cost and time of local entrepreneurs and facilitating maintenance.

With a minimal environmental impact, the project has helped reduce 158 tons of CO₂ emissions per year and prevented 13 tons of uncontrolled battery waste. The estimated energy savings for all households was 216,133 soles per year (approximately EUR 53,365 per year). The EaaS model also favors environmental sustainability because acciona.org was responsible for the management of faulty systems, which were collected and sent to the provider of the SHS for adequate recycling of each component.

Fees have been made affordable, and the balance between revenue and costs ensures the continuity and economic sustainability of the project.

Despite the good results of the project, we observed a missed opportunity, because EaaS with prepaid modes may enable the use of information and communication technologies to improve fee collection and management, as well as the delivery of activation codes to users.

4. Discussion

Upon the analysis of the three case studies of rural electrification project, we can assess the impact of different configurations of the management model in the sustainability of the projects.

4.1. Social Sustainability

First, we observed a strong influence of the governance model in the social sustainability of the project, with better results in the projects where the number of agents involved in the operation of the project was higher. From the three projects under analysis, it is recommended to incorporate actors that (a) facilitate awareness and social sensibilization, (b) facilitate knowledge and technology transfer, and (c) know the local culture and customs [11,71]. For example, the incorporation of the CLCs in the latter two projects was so successful that CLCs have been added to the “Luz en Casa Cajamarca” project, which now has 12 active CLCs. The inclusion of entrepreneur profiles and CEFs in the projects improves the availability of maintenance, allows for training of local users, increases the participation of women in technical tasks and, in the end, facilitates the continuity of the project by generating a socially sustainable model.

The business model also has an effect on the social sustainability of the project. From the analysis of the three case studies, EaaS seems to offer better results in improving affordability, which is one of the main challenges in universal access to energy [43]. Besides, EaaS guarantees maintenance and replacement of faulty systems which, in turn, contributes to continued use and (again) to universal access because repairs do not entail additional cost for end users [77].

Funding and subsidization are also key for social sustainability. Both are heavily dependent on the agents involved in the project (states, regulators, and policymakers) and the resulting business model [79,80]. For example, only after the negotiations of acciona.org in Peru it was possible to create a regulated EaaS tariff for photovoltaic systems, which in turn made it possible to subsidize the fee and improve affordability of the systems.

4.2. Environmental Sustainability

In all three cases the results were similar, a result consistent with the use of the same technological model in the three projects (standalone systems using non-conventional or renewable sources). The positive results confirm previous literature, which identifies this kind of systems as the most adequate choice in rural electrification projects because they can reach remote and disperse communities, have high reliability and provide a more stable access to energy that does not depend on conventional grids nor requires complex infrastructure [55,81,82].

However, the use of systems that have a limited service life (mainly because of the batteries) requires the establishment of protocols to facilitate recycling of the different elements of the SHS, which otherwise would generate toxic waste and damage to the ecosystems [43]. Current trends in rural electrification assess whether it is possible to use fewer batteries to reduce the waste generated by SHS [82] by using independent micro-grids that rely on hybrid sources (e.g., solar and diesel) and require much lower battery capacity [69]. For instance, the acciona.org foundation is currently piloting a project in Copal Urco (Peru) to validate the sustainability of the technological model with hybrid sources (using diesel only as a backup source of energy generation).

4.3. Economic Sustainability

Economic sustainability is affected by the three main components of the model, as every aspect had a direct impact on the total costs and profitability of the project. First, the use of standalone systems has lower initial and infrastructure deployment costs, which favors economic sustainability [82]. Second, multi-agent governance models also have a positive effect on the economic sustainability of the projects; for instance, when the project incorporates the CLCs, maintenance costs are reduced due to the fact of less frequent trips and higher repair rates [79]. Third, projects operated as EaaS achieve a balance between revenue and costs that facilitates economic sustainability [81], even though profitability is only possible when a regulated tariff and subsidy are in place. This seems to suggest that fee-for-service models (both for system acquisition and maintenance) offer better results regarding economic sustainability.

5. Conclusions

The first part of this study showed a great variety of possible configurations of the management model in rural electrification projects. From a review of the literature, we elaborated a model that showed the different elements of the management model with three main components: governance, technological and business models. The governance model included all aspects relative to the actors involved in the project: owners/promoters or operators and their relationship with other agents, such as financiers, regulators, academic institutions, and the communities and users that gain access to energy. The technological model considers choices in the technology based on the location of the communities, their dispersion, proximity to an existing grid, and available sources of energy generation. The business model includes how the systems are acquired and owned, maintenance costs, and the type of contract for service provision.

Our review highlights the concerns of rural electrification project promoters about achieving sustainability and affordability of the service to provide effective universal access while considering the diversity of each context that requires flexible and adaptable solutions. It is very complex to make decisions about the management model that improve the three dimensions of sustainability (social, environmental, and economic) because, most often, economic sustainability (namely, the profitability of the project) becomes the most relevant variable. It is not rare to observe decisions that improve the profitability but at the expense of affordability for end users.

Our analysis of the configurations of the management model of rural electrification projects identified 16 elements and their impact on the dimensions of sustainability. From the analysis, we observed that the environmental sustainability was mostly dependent on the technological model, but the business model had the higher impact on the social and economic sustainability of the project. The analysis of the three case studies under the lens of the management model and its impact on the sustainability of the project facilitated the identification of the strengths, weaknesses and areas of improvement of each project.

The main finding of the study is the key role of the business model and the collaboration between the agents involved in the sustainability of the projects. The choice of the business model is critical, and the analysis showed that fee-for-service models seem more adequate to ensure sustainability of the project. Socially, it allows for affordability of the systems to users in extreme poverty, by combining the fees with subsidies. Economically, in combination with an adequate regulatory framework and subsidization, it facilitates profitability and reduces operation and maintenance costs notably.

Collaboration between agents is essential to achieve sustainability. The analysis of the case studies suggests that variety of roles is important and that the communities and end users must have an active role in the project. In this sense, 5P and involvement of the communities in operational tasks seem to highly favor social sustainability.

The study is not exempt from limitations. Most notably, the three case studies had very similar configurations of the governance and technological models. While this choice allowed us to better understand the effect of the different configurations of the business model on the sustainability of rural electrification projects, a wider selection of case studies with different configurations of the governance and technological model are necessary to better understand the impact of each element of the management model on the different dimensions of sustainability.

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