Sustainability of Renewable Energy Projects in the Amazonian Region

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Chapter 7
Sustainability of Renewable Energy Projects in the Amazonian Region

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Introduction

The Amazon region is shared by nine South American countries (Brazil, Peru, Bolivia, Colombia, Ecuador, Guyana, Venezuela, French Guyana, and Suriname). It covers an area of approximately 6,000,000 km^2. The Amazon region is a fragile ecosystem with high biodiversity, and it has a major contribution in mitigating climate change. That is why the region has received the title of "lungs of the planet." Historically, the Amazon region has been inhabited by a great diversity of aboriginal people who have managed to live in harmony with the forest for centuries. However, because of the colonization of the late nineteenth and early twentieth centuries, which has accelerated in recent years with timber extraction, oil, mining, agriculture, livestock, and tourism, the region has been losing steadily native forest, emerging urban centers, and increasing the nonindigenous population. Urbanization in various parts of the region is pressing to provide basic services to the population such as drinking water, sewerage, and electricity.

In the case of Ecuador, there are six Amazonian provinces, Orellana, Pastaza, Napo, Sucumbíos, Morona Santiago, and Zamora Chinchipe, representing an area of 120,000 km^2 (48% of the country size). According to the results of the 2010 Census of Population and Housing, there is an estimated total population of

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750,000 in the Ecuadorian Amazonian region, which represents 5% of the country total population (INEC 2010). Ten different ethnic groups constitute the rural population in this region (CODENPE 2012). Services coverage at provincial level reaches 55.6% of drinking water and 41.4% of sewerage, well below the national average, which is 72% and 53.6%, respectively (INEC 2010).

In year 2012, the electricity coverage in Ecuador was 96.9% at national level and reached 89.8% of rural population mainly through investment on grid extension (ARCONEL 2013). The government fund program FERUM (Fund for Rural and Urban-Marginal Electrification) financed this investment. Nevertheless, this approach has left behind the most isolated and disadvantage rural communities where a grid extension is unfeasible due to their limited access, grade of dispersion, and low demand. Most of this population is scattered along the Ecuadorian Amazon region. For instance, the electricity coverage in this region reached 88.6% in 2012 (ARCONEL 2013), but if this indicator is disaggregated into urban and rural, the rural electricity coverage was just 72%, almost 18 points below the national average.

Since year 2000, some efforts to solve this problem focused on installing photovoltaic solar home systems (SHS) on Amazonian households, through government and international donor's initiatives (Vasconez 2010). After their implementation, however, there has not been a systematic evaluation making it difficult to know the current technical situation of approximately 3000 systems as well as their real impact on local conditions. This lack of information and the abandonment of many of these projects have hindered the scaling up of decentralized rural electrification (DRE) initiatives in Ecuador where the electric grid is unfeasible.

In 2008, a new constitution took effect establishing the "good living" condition as the main objective for the country. Rural electrification was a national priority in order to contribute to improve the living conditions of rural population. The good living or "sumak kawsay," its translation from the Quechua language, is a indigenous view of the world that focuses on the human being and seeks to meet the needs in order to get a good quality of life. This view proposes to live in peace and harmony with nature and looks for the indefinite prolongation of cultures (SENPLADES 2013). It is clear that the good living has important similarities to the accepted concept of sustainable development as defined by the World Commission on Environment and Development – WCED in 1987.

In both paradigms, good living and sustainable development, energy access has been recognized as an important goal. In that sense, the use of renewable energy in isolated and fragile ecosystem like the Ecuadorian Amazon region is a feasible solution that contributes on improving people's life and reducing negative impacts on the environment.

In 2010, one of the several public electric distribution companies EERCS C.A., known as Centrosur, started the project "Yantsa Ii Etsari" (that translates as "light from our sun" in Shuar language) to electrify, with SHS, 3000 isolated indigenous households (Shuar and Achuar) scattered along the province Morona Santiago in the southern part of the Ecuadorian Amazonian region. After 6 years of continuous operation, 3266 SHS have been installed, covering almost 100% of identified

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isolated indigenous population. Centrosur operates and maintains the SHS, which demands important human, economic, and technological resources.

This chapter aims to analyze sustainability challenges and prospects for renewable energy projects for electricity service provision in the Amazon region context using the Yantsa Ii Etsari project as a case study. This experience could be relevant for other decision-makers or researchers interested in sustainable energy development in isolated and fragile regions such as the Amazon. The chapter reviews the research projects implemented by Centrosur and academia in order to enhance sustainability of the Yantsa Ii Etsari project in areas like "mobility," "operations and maintenance," "environmental impact assessment," and "policies and procedures." Finally, a discussion on the way forward for sustainability assessment protocols for renewable energy projects is presented.

The Yantsa Ii Etsari Project

Based on literature review of field reports and unstructured interviews to key administrative and technical staff, Jara-Alvear and Urdiales (2014) developed a qualitative analysis of the project Yantsa Ii Etsari from formulation to implementation (Fig. 7.1). The trigger that raised the political will of the Ministry of Electricity and Renewable Energy (MEER) to invest on the project was a human rabies epidemic – spread by bats that affected the study area in 2008. It was believed that electricity access (lighting) will improve local conditions among households, which has also proved a reduction on vector diseases (Mendes et al. 2009). Once national funds were released, 120 isolated communities were selected in an agreement between Centrosur, the National Council of Electricity (CONELEC) (nowdays ARCONEL), and the indigenous organization (FISCH). It was a top-down approach, where the final users participated during the project socialization stage, through workshops, and later on in the installation process.

The electricity needed in a typical indigenous family of the study area was estimated in 322 watts-hour per day (Wh/day), which is supplied by a standardized SHS (Table 7.1). It might appear potential productive uses of electricity for homeowners or communal services that would require more energy. However, one of the advantages of solar photovoltaic systems is their modularity so that additional energy needs can be met with more panels and batteries in the same installation. The standardization facilitated the bidding process and logistics to accomplish the project aims (Jara-Alvear and Urdiales 2014).

Between 2010 and 2015, about 20 local or regional contractors did the transportation and installation of 3266 SHS in almost 200 communities (Table 7.2). This aspect enhanced local professional capabilities. Based on commissioning reports, the average cost of an SHS was $16 per peak watt (Wp) where transportation and installation costs have an important 41.6% share (Jara-Alvear and Urdiales 2014). Table 7.3 shows the average costs of the SHS installation. Once the installation was finished, Centrosur and the household head sign a service contract, where the user

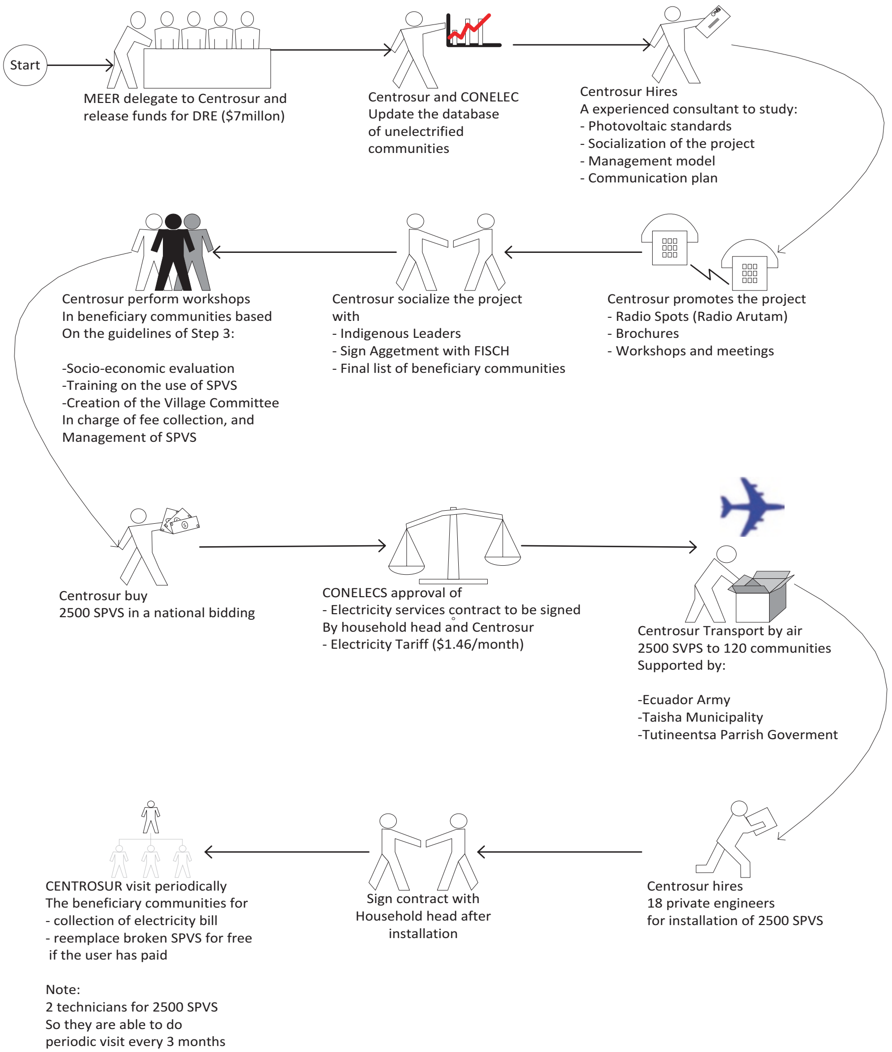

Fig. 7.1 Flowchart of Yantsa Ii Etsari project. Source: Jara-alvear and Urdiales (2014)

has to pay a fixed fee of US$1.46/month and the utility will provide maintenance and continuous services. The utility has to work in coordination with a community electrification committee that provides routine minor maintenance services. Although the fee does not cover the investment, it does raise awareness of aboriginal people on the duty to pay for services. Therefore, the electric utility uses resources from its budget to subsidize transportation, spare parts, and other costs in order to guarantee the financial sustainability of the project.

Table 7.1 Characteristics of SHS

Description	Value
Solar photovoltaic panels	150 Wp
Battery	150 Ah
Solar regulator	20 A
Inverter (12 V/120 V)	300 W
Average solar radiation	4 kWh/m^2/day
Expected production of SHS	400 Wh/day
Load (lights, radio, TV/DVD, battery charger)	322 Wh/day

Source: Jara-Alvear and Urdiales (2014)

Table 7.2 Number of SHS installed by the project

Year	Number of communities	Number of SHS
2011	15	290
2012	108	2063
2013	7	109
2014	34	432
2015	32	372
Total	196	3266

Source: Urdiales (2015)

Table 7.3 Average costs of SHS installation

Description	Cost	Observation
Equipment	$1400	Complete SHS
Transport	$600	Variable cost: Air freights, fuel. Not included community labor
Labor	$400	Variable cost: Labor of installation, workshops and informative campaign
Total	$2400	

Source: Jara-Alvear and Urdiales (2014)

Sustainability Overview of Yantsa Ii Etsari

After the Brundtland report was released in 1987, sustainability has gained attention in academia, industry, and government. The report's definition of sustainability refers to "development that meets present needs without compromising the ability of future generations to meet their own" (WCED 1997). This definition stresses the multidimensional character of sustainability and the equitable distribution of resources. In this regard, Elkington (1999) proposed a "triple bottom line" model, and Mebratu (1998) proposed "the cosmic interdependence" model; both models define sustainability using economic, environmental, and social aspects. These three pillars are widely used on sustainability assessment and policymaking.

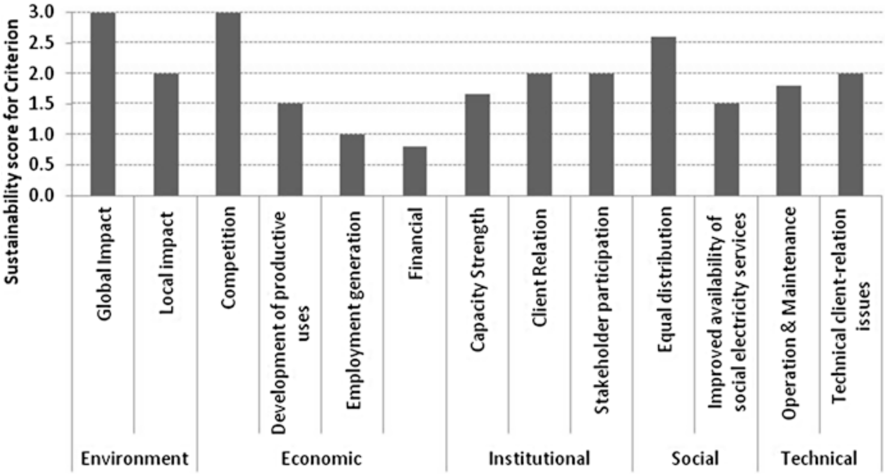

Fig. 7.2 Sustainability dimensions of Yantsa Ii Etsari project

Regarding the energy sector, "sustainable energy development will require electricity services that are reliable, available and affordable for all, on a sustainable basis, world-wide" (Johansson and Goldemberg 2002). Again, this definition implies the consideration of economic, environmental, and social dimensions for sustainability assessment. However, literature (Ilskog 2008; Brent and Rogers 2010) suggests that two additional dimensions should be integrated in rural electrification projects: technical and institutional pillars. These are important since reliability, human capacity, and local management of energy systems are key aspects in rural areas where technology and specifically renewable energy market are in the early stages (Mainali and Silveira 2015).

As part of a doctoral research project in progress (ZEF-University of Bonn and Centrosur), Jara-Alvear and Urdiales (2014) attempted to do a rapid sustainability assessment of Yantsa Ii Etsari project using the framework proposed by Ilskog (2008), which uses 5 dimensions and 13 criteria associated with 37 indicators to capture the complexity of sustainability in rural electrification projects (Fig. 7.2). This framework provided a holistic starting point to discuss project sustainability and guide the research agenda.

Even though Yantsa Ii Etsari represents an alternative to increase Centrosur rural coverage objectives, the project also faces several important challenges. These deal with economic, environmental, institutional, technical, and social dimensions all related to the project sustainability.

Table 7.4 presents a summary of how previous results (Fig. 7.2) have guided the definition of research projects in order to enhance information and knowledge to move toward sustainability in rural electrification in the Ecuadorian Amazon region.

Table 7.4 Sustainability assessment and research projects for Yantsa Ii Etsari

Dimension	Focus for sustainability assessment of decentralized rural electrification projects	Research project
Environmental • Global impact • Local impact	Replacement of polluting source of energy (kerex, candles, dry batteries, diesel, gasoline). Waste management system during installation, operation, and decommission At global scale, reducing the contribution of greenhouse emissions and the indirect impact on Amazon forest conservation	Integrated waste management system
Economic • Competition • Development of productive uses • Employment generation • Financial	High cost of installation and maintenance, and the fixed fee ($1.46/month) established by existing regulation, makes the project not profitable. Financial mechanism, efficient subsidy mechanism, and reduction of maintenance cost are key issues to make rural electrification with SHS less dependent on external source of funding or subsidies. Accessibility and transportation costs (air, river) have an important influence on the final cost of energy production but also on socioeconomic development of indigenous people	Development of a solar boat prototype Design of an automatic reliability centered Maintenance model
Institutional • Capacity strength • Client relation • Stakeholder participation	Capacity strength of the electric company and stakeholder participation are interconnected issues that need to be addressed. There is a need to strengthening the existing multicultural stakeholder network made of electricity company staff, local technicians, authorities, and clients Being modern energy a new actor in daily activities of people, “the rules of the game” can change dramatically in communities. This new institutional order is indeed a challenge that all project stakeholders are facing	Local utility involvement and stakeholder participation
Technical • Operation and maintenance • Technical client-relation issues	Operation and maintenance need to improve. The failure rate of SHS jeopardizes not only project economy but also the environment due to electronic waste generation. Increasing the reliability of SHS and adopting an integrated asset management strategy could help to reduce maintenance cost and enhance the service quality. However, during the design phase and planning, quality of studies and reliability of information are crucial to ensure suitable solutions for local context	Reliability Centered Maintenance model
Social • Equal distribution • Improved availability of social electricity services	There is a need to improve electricity service toward social benefit goals at household and community level like schools and health centers but also administrative and cultural centers. Knowledge communication is highly important to ensure users and services provider understand each other	This crosscutting area is involved in all the developed research projects

Alternatives for the Project Sustainability

Based on the results shown in the previous section, Centrosur has been looking to deepen the understanding of sustainability of the Yantsa Ii Etsari project, and strategic alliances were set up with the academia. For instance, the University of Cuenca and the Center for Development Research (ZEF), University of Bonn (Germany) have been collaborating through the development of undergraduate and graduate research projects in thematic areas linked with the above discussions on sustainability challenges. The results of these research experiences are presented in this section.

Local Utility Involvement and Stakeholders' Participation

Introduction

In 2010, when Centrosur began the Yantsa Ii Etsari project in the Amazonian province of Morona Santiago, it was necessary implementing internal changes in the structure of the company. For nearly 60 years of institutional life, the subject of the company was the distribution and commercialization of electricity through substations, distribution networks, transformers, meters, and so on, in short, through physical infrastructure that interconnects sources of electric generation "directly" with the end user.

In a joint effort between CONELEC and Centrosur, the project' scope was defined in isolated areas of Morona Santiago province within the concession area of the distribution company. It was initially estimated 2300 families to supply with electricity from SHS, which represented a new technology and way to provide electricity for both the company and the inhabitants of the area.

The first action consisted in creating a specific department within the company for carrying out the project implementation. The Renewable Energy Unit (UER) was conformed at the beginning by four electrical engineers who were trained to learn about experiences and status of various renewable energy projects developed in the country. During 2009 and 2010, the UER visited the communities in areas of difficult access where it was impossible to access to conventional electricity through networks. The main task of the UER was to get inputs for conducting a technical study about the best alternative of electrification. Also during this period, regulations for equipment, model contracts and community agreements, contract service provision, and the tariff were established.

In order to carry out the project, Centrosur defined the following stages of implementation:

- Preliminary survey to determine the current situation of the community
- Establishment of a community electrification committee
- Preparation of technical study
- Financing management

- Acquisition of equipment (technical specifications)
- Installation contract
- Transportation and equipment warehousing in the community
- Installation
- Training to the community on SHS management (by the contractor)
- Contract settlement
- Customer follow-up (by the electricity distributor)

The Yantsa Ii Etsari project had its first systems set up from January to June 2011. Two hundred ninety (290) SHS were installed in the parish Seville Don Bosco, Canton Morona. By July 2012, when the installation of the second phase finished, mostly in Canton Taisha, there was a significant block of new customers with SHS, totaling 2063. In subsequent years, the number of new facilities continued to increase (Table 7.2).

Centrosur's commitment is to ensure the service through the contract, which makes the user a regulated customer. Therefore, the follow-up performed by the company is essential for continuous operation and maintenance of SHS. During field visits, the work of the electrification committee, formed by community members, is verified, and the company supports the activities of this new actor. Knowledge and management of administrative and technical operators are strengthened as well as the concepts of minor maintenance and care for each SHS.

Relationship Between the Beneficiaries and the Electric Company

Centrosur looked for a model for sustainable rural electrification, where the community would be in close relationship to the company. The model should define the company management as a very strong influence to achieve institutional sustainability in coordination with community organizations. This institutional dimension is one of the five sustainability dimensions shown in Table 7.4.

Institutional sustainability refers to the organizational structures and processes that influence the success of the project within the local community. The stakeholders of this dimension include not only the distribution company and beneficiaries but also government officials such as mayors and parish presidents, opinion leaders as teachers, priests, and doctors, as well as traditional authorities and local associations represented by its president and trustee of each community. Even though this relationship worked before inclusion of the electrification project, the distribution company proposes a new scheme by introducing an additional actor: the electrification committee.

This scheme of strategic bridging (Garcia and Vredenburg 2003), between Centrosur and the user, proposes a new joint working relationship with the beneficiary community, behavior that in the past had only been present during the implementation stage of a project. A traditional paradigm is thus broken: the way in which the distributor used to be the electricity provider. These external factors (dispersed customers with no access to conventional network) are influencing changes that the distribution company must assume.

At this point, it is necessary to identify the most important changes that the electricity company had to make to face the Yantsa Ii Etsari project, in order to maintain its commitment to service and acceptance of the community' customers:

- Creating the Renewable Energy Unit (UER), a working group in charge of SHS projects
- Including in the training plan of the company topics such as renewable energy, community work, safety, and first aid in the Amazon
- Changes in the commercialization system of the company and creation of the residential photovoltaic rate (RF)
- Standardization of SHS equipment and their inclusion in the list of materials available at the company
- Creating a specific service contract for the service with SHS
- Creating regulation for the operation of the electricity committees and for administrative and technical staff

A Model for Sustainable Rural Electrification.

To promote sustainable rural electrification, first it is necessary to recognize the different dimensions of project sustainability, as shown in Fig. 7.2 and Table 7.4. These dimensions contribute to propose a model through three catalysts: a SHS design focused on the community, a sense of community ownership, and an active involvement of the distribution company.

SHS Design Focused on the Community

In order to design the most appropriate equipment for the community, one must know the kind of users that is intended to serve, their type of home, their habits (i.e., Shuar people are seminomadic), the economic income, service aspirations, etc.

Sense of Community Ownership

The understanding that the electrical service is possible through an SHS that uses a local resource gives to the community the feeling that it "owns" the project.

Distribution Company Involvement

The participation of the distribution company starts from identifying the community, supporting for the formation of the electrification committee and its operation, technical design, implementation of the project, and service customer management. The relationship between the sustainability dimensions and the catalysts is presented in Table 7.5 and Fig. 7.3.

Table 7.5 Dimensions and catalysts of a model for sustainable decentralized rural electrification

Catalyst	SHS design focused on the community	Sense of community ownership	Involvement of the distribution company
Dimension			
Economic	The design guarantees adequate service with the necessary investment. The equipment meets standards to operate in places where they are installed, which ensures lower maintenance costs	When customers meet the payment of the prescribed fee and take care of equipment (less maintenance costs)	When company obtains resources for project implementation as well as for operation, maintenance, and replacement. The task of tariff collection is also important
Institutional	The design allows the beneficiaries involvement. For example, cleaning the panel and acknowledging of messages at the regulator display. SHS becomes a "new actor" in people's life	From electrification committees who "represent" the distribution company in their communities and have the acceptance of other local authorities	Operation and implementation of created structures such as the electrification committee and its representativeness in the community. This is reinforced by the application of regulations, contracts, meetings, etc., which are activities that show the operability of the committees
Technical (includes environmental)	Design is based on standards that provide equipment reliability. Besides, preventive maintenance depends on the training given to both each user and the technical operator in order to face minor maintenance problems	When customers use adequately the SHS and care equipment and perform preventive maintenance	From system design, standardization, and maintenance that can provide through the technical operator or its own staff. In addition, replacement and removal of equipment are in charge of the distribution company
Social	The design can promote both an equal distribution of electricity and opportunities for family/productive activities	When users care their installed systems as they recognize that through them it is possible to have electricity service	The company is able to educate people on the use and care of the system as well as on the rights and obligations assumed by the service contract

Conclusion

The local utility involvement seems crucial for sustainable decentralized rural electrification in the Ecuadorian Amazon region context. In the Yantsa Ii Etsari project, what the distribution company does is managing legitimacy (Schuman 1995) through formal institutional mechanisms (committees, regulations, contracts) and informal mechanisms ("culture of payment," "sense of community ownership," etc.).

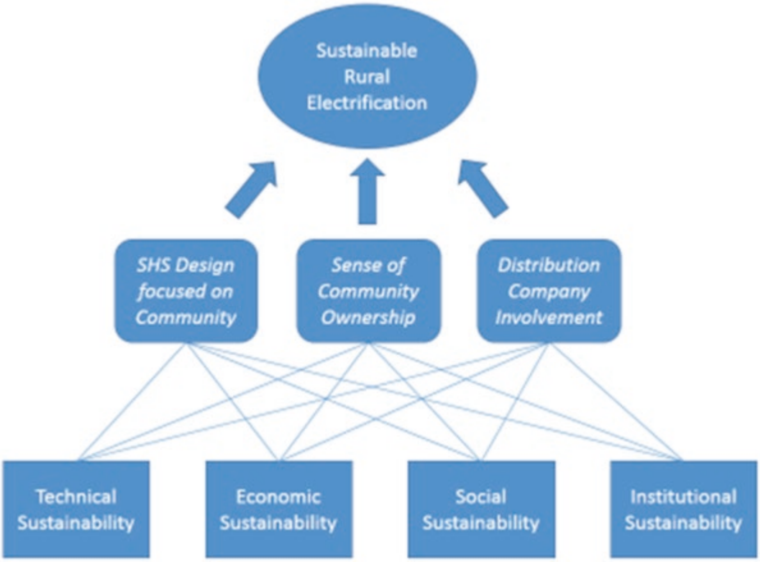

Fig. 7.3 Model of sustainable rural electrification. Source: Urdiales (2015)

Development of a Solar Boat Prototype

Introduction

The high level of isolation and lack of infrastructure makes accessibility to the Amazon region a very critical issue for development. It restricts people's mobility to long walks, riverboats, or small planes in order to reach markets and social services. Finding alternatives for transportation without endangering the Amazon ecosystem is an urgent challenge toward sustainability (Ordóñez and Guaman 2014). River transport in the Ecuadorian Amazon is one of the primary means of mobility in places where there are no roads (Jara-Alvear et al. 2013a, b). Rivers are used for navigation of people and goods in small boats with outboard motors. However, this mode of transportation causes significant environmental problems such as greenhouse gases – GHG emission – noise, fuel spills, and felling of large trees for manufacturing canoes (Ordóñez and Guaman 2014).

These problems can be mitigated by replacing gasoline outboard motors by electric propulsion systems. The application of these systems is not new. In 1839 Moritz von Jacobi Herman built one of the first electric boats (Morachevskii 2001), and today these systems have made significant progress worldwide as demonstrated by transatlantic crossings. Moreover, in 2013, the first Ecuadorian electric-solar boat was built and demonstrated its usability in Galapagos Islands, Ecuador, as a means for environmental education and sustainable tourism (Jara-Alvear et al. 2013a, b).

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Fig. 7.4 Map of the study area. Souce: Guamán et al. (2015)

Ordóñez and Guaman (2014) developed a techno-economic study for replacing traditional outboard motors for electric outboard motors coupled with solar energy systems to recharge batteries within the electric propulsion systems. Their study aimed to assess the feasibility of a solar canoe adapted to the Amazon rivers.

Field Research and Data Collection

By the end of 2014, the Yantsa Ii Etsari project had 500 indigenous families settled on four riverbanks. A field trip along these four rivers was made for data collection on travel conditions in order to determine the design parameters of solar canoes (Fig. 7.4). The main origin and travel destinations were identified as well as the average speed and travel time for existing canoes (Table 7.6). It is important to note that routes 1–4, 2–5, and 3–6 represent a round trip, whereas route 7 represents the distance between two charging points, with an average travel time of 3 h.

Currently, 45 canoes provide transportation service along the above routes all year around. Based on 25 interviews, it was found that typical length of canoes is 12 m, they have an average load capacity of 1400 kg, and the most traditional equipment is a 13-horsepower (HP) outboard motor (Fig. 7.5).

Table 7.6 Main river routes, Morona Santiago, Ecuador

Route number	From	To	Name of river	Time (h)	Average speed (km/h)	Distance (km)
1	Kashpaim	Antun	Morona-Mangosiza	4	9	42
2		Taisha	Morona-Cangaime	9	9	92
3		Santa Rosa	Morona-Macuma	9	9	90
4	Antun	Kashpaim	Mangosiza-Morona	4	11	42
5	Taisha		Cangaime-Morona	9	11	92
6	Santa Rosa		Macuma-Morona	9	11	90
7 (charge center)	Kashpaim	Panientza	Morona	3	9	30

Source: Guamán et al. (2015)

Fig. 7.5 (Left) Traditional canoes, (right) traditional outboard motor “peque-peque”. Source: Ordóñez and Guaman (2014)

Design of a Solar Canoe for the Amazon

The configuration for the electric-solar boat is based on the design of Jara-Alvear et al. (2013a), since it has demonstrated the technical capacity to displace up to 4000 kg in sea conditions. The configuration includes an electric outboard motor which is responsible to transform electricity into mechanical power to displace the boat, electrochemical batteries that are responsible to storage and provide the energy required by the electric outboard, and a photovoltaic system (onboard or onshore) which is responsible to recharge the batteries (Fig. 7.6).

The sizing of solar canoes was adapted from Jara-Alvear et al. (2013a) for displacement-type boats and includes seven steps:

Step 1: Define the design speed.
Step 2: Estimate the resistance for propulsion.
Step 3: Estimate propeller power.
Step 4: Estimate electric power needed.

Step 5: Estimate energy consumption.
Step 6: Size the battery bank.
Step 7: Size the photovoltaic generator.

Results: Configuration and Economic Analysis

Based on the sizing steps and using the data collected, Table 7.7 shows the resulting configuration of an electric 12-m canoe to cover the travel distance described in Table 7.6. The results show that the electric energy needs to cover the travel distances will require an area of solar panels bigger than the available on the canoes. Therefore, solar recharge stations should be placed on strategic locations along the travel route.

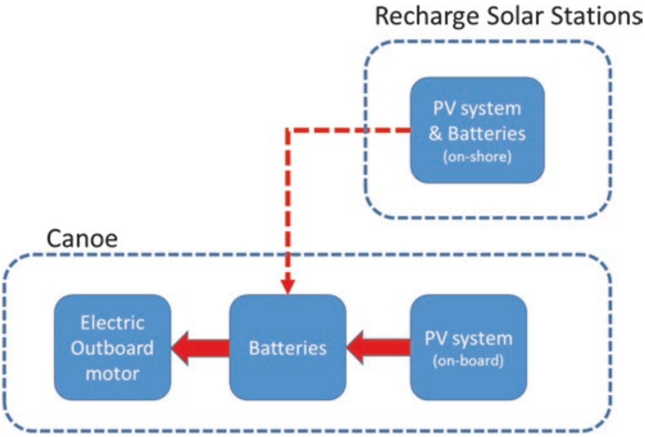

Fig. 7.6 Design concept solar canoes. Source: adapted from (Jara-Alvear et al. 2013a)

Table 7.7 Electric 12-m canoe configuration for each route

Route number	Power electric outboard (kW)	Capacity battery bank (kWh)		Solar generation (PVS)		Total weight of equipment (Ton) *PVS and boat are not considered*	
		La[a]	Li[b]	kWp (required)	kWp (onboard)	La	Li
1	4	18	13.42	4.3	1.61	0.39	0.14
3	4	42	26.85	9.8	1.61	0.87	0.28
7	4	15	10.74	3.3	1.61	0.33	0.12

[a] La: lead acid battery
[b] Li: lithium battery
Source: Ordóñez and Guaman (2014)

Table 7.8 Estimated cost for traditional vs. solar-electric 12-m canoe

	Route 1	Route 3	Route 7
Time of traveling (h)	4	9	3
Traditional canoe			
Investment outboard motor 13 hp. every 6 years ($)	$1030.00	$1030.00	$1030.00
Fuel ($/year)	$1929.78	$4342.00	$1447.33
Canoe investment every 4 years ($)	$600.00	$600.00	$600.00
Maintenance ($/year)	$200.00	$200.00	$200.00
Estimated annual reduction of CO_2 *2.38 kg of CO_2 per liter of gasoline*	8.29 ton	18.65 ton	6.21 ton
Solar-electric canoe			
Investment outboard motor 4 kW ($)	$3809.00	$3809.00	$3809.00
Investment 12 m fiberglass canoe ($)	$4000.00	$4000.00	$4000.00
Cost of Li-battery every 9 years ($)	$13,225.00	$26,450.00	$10,580.00
Cost of La-battery every 4 years ($)	$1623.60	$3788.40	$1353.00
Electricity cost—PV system ($)	$14,375.00	$31,050.00	$10,750.00
Maintenance ($/year)	$200.00	$200.00	$200.00

Source: Ordóñez and Guaman (2014)

Table 7.9 Economic feasibility of solar canoes

Results	Route 1	Route 3	Route 7
NPV (traditional canoe)	$31,228.00	$61,289.60	$25,215.61
NPV (solar canoe with La-Battery)	$28,277.89	$52,000.07	$23,772.00
NPV (solar canoe with Li -Battery)	$49,320.88	$92,324.24	$40,430.21
Payback period (traditional canoe)	11.6 years	>30 years	6 years
Payback period (solar canoe, Li- battery)	12 years	18.9 years	7.6 years
Payback period (solar canoe, La-battery)	6 years	8.5 years	4.1 years

Source: Guamán et al. (2015)

The weight and space onboard is a critical factor during the design phase. Considering that batteries are the heaviest and biggest component (see Table 7.7), the selection of lead-acid (La) or lithium (Li) batteries is a key aspect for the techno-economic study. La batteries are cheaper but heaver and less efficient, while Li batteries are lighter and more efficient but expensive.

The investment, operation, and maintenance cost for gasoline and electric outboard motors were estimated from interviews with canoe owners and literature review (Table 7.8). Using this information, the net present value (NPV) and payback period were estimated using an interest rate of 5% for a 20-year period (Table 7.9).

Conclusions

The selection of the best alternative depends mainly on the cost of the batteries, the type of boat, and the route to cover. The proposal would be economically viable for any battery technology in fiberglass boats with navigation time between 3 and 4 h.

From the economic point of view, the lead-acid battery is the best option but, from a technical viewpoint, lithium-battery is better since it has higher energy density (kWh/kg). This reduces weight and onboard space.

For the routes with travel times of 4 and 3 h, it is possible to navigate with the boat configuration presented in Table 7.7, and recharge centers should be located at the beginning and end of the routes. For longer travel times (i.e., 9 h) it is recommended to have recharge centers in strategic locations along the routes (Fig. 7.4). This will reduce the number of batteries and solar photovoltaic panels required for autonomy, reduce weight on board increasing space for more cargo and passenger loads, and reduce propeller power consumption (lower system cost).

The limitations for electric boats are the high up-front cost of technology, reduced travel autonomy, and low speed, all limited mainly by existing storage technology (Del Pizzo et al. 2010). Nevertheless, coupling electric boats with onboard renewable energy generation and charging stations along the travel route could potentially help to surpass these barriers and facilitate their adoption in isolated areas of the Amazon region.

The electric-solar boats might also serve as a means of transport to Centrosur technicians so they can follow up the installed SHS. More important, along the analyzed routes there are communities' beneficiaries of the Yantsa Ii Etsari Project; thus, the electric-solar boats will also provide a safe and clean way of transport for people in the region. This research project shows that electric-solar canoes provide not only techno-economic advantages but also social and environmental benefits, becoming a sustainable alternative for the Yantsa Ii Etsari project in particular and for river transport in the Ecuadorian Amazon region in general.

Design of an Automatic Reliability-Centered Maintenance Model

Introduction

From maintenance reports of the project Yantsa Ii Etsari, it was found that 32.7% of the SHS have failed in the period 2012–2014 for some technical reason (Fig. 7.7). Compact fluorescent lamps (CFLs), regulators, and inverters are the components with the highest failure rate (Table 7.10). Centrosur is enforced to provide a good quality electricity service with a highly subsidized electric tariff (user's fee payment is $17.56/year). This amount is not enough to cover operation and maintenance of SHS, and it makes the project dependent on external funding to be sustainable in the long term. In addition, a high failure rate of equipment combined with the absence of a waste management system in Amazon communities threatens the ecosystem, since toxic substances from electronic waste could be released to the environment, for instance, mercury, which is contained in CFLs.

A reliability-centered maintenance (RCM), which started in the airline industry in the 1960s, is a structured framework that helps to improve maintenance decision through the analysis of functions and potential failures of physical assets (e.g., SHS) and schedule maintenance task in order to enhance reliability at the lowest cost

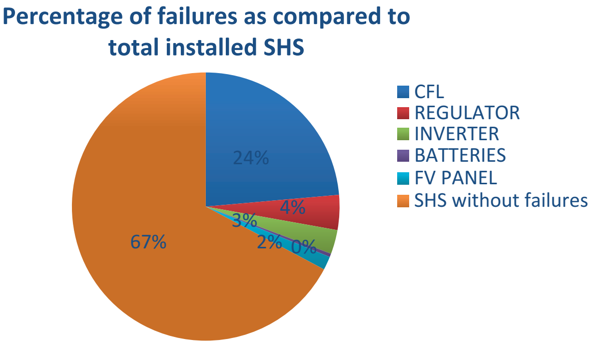

Fig. 7.7 Failures as compared to total installed SHS. Source: Urdiales (2015)

Table 7.10 Failure rate of SHS, period 2012–2014

Equipment	Frequency of failure	% Share
Compact fluorescent lamps (CFLs)	683	72.05
Regulator	233	12.87
Inverter	84	8.86
Solar panel	47	4.96
Battery	12	1.26
Total	948	100

Source: Urdiales (2015)

(Orellana and Porras 2014). The standard SAE JA101 establishes the minimum criteria to implement a RCM, which has to systematically answer the questions presented in Table 7.8. In order to assist decision-makers on implementing a RCM strategy, Orellana and Porras (2014) developed an automated system that could help to answer such questions in the context of the project Yantsa Ii Etsari (Table 7.11).

Research Approach and Results

The research approach included three phases. First, data collection of written maintenance reports was reviewed, and a household survey in 25 communities was conducted for field investigation of SHS status and users' experience. Second, FF, FM, FE, and FC were identified using criticality analysis (Moss and Woodhouse 1999), root cause analysis (RCA), and failure mode and effects analysis (FMEA). Third, based on this analysis, an entity-relationship (ER) model was implemented to facilitate the execution of RCM in Centrosur.

Figure 7.8 shows the resulted ER that has the following purposes in order to assist for the implementation of a RCM strategy:

1. Functional diagram of the SHS and its components, including principal and secondary functions.
2. Register FMEA results, which include system and component's function, operational context, FM, FE, and FC.

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3. Calculation of the reliability index called Risk Priority Index (IPR) in order to prioritize the most critical components in terms of safety, environmental, and operational security.
4. Define and register corrective, preventive, and predictive maintenance tasks.
5. Elaborate maintenance reports and work orders for maintenance staff.

Entities of the model (i.e. users, SHS components, FM, FE, and FC) have associated attributes that provide further relevant information for RCM and maintenance decisions. For instance, user's name, code, and geographical location are key to connect with other database of Centrosur. SHS were disaggregated in their different components in order to define FF, FM, FE, and FC, which are used to perform a FMEA. The results are the IPR for each SHS component (Orellana and Porras 2014). This provides the basis to plan and prioritize maintenance tasks (preventive, corrective, predictive).

The implementation of the ER model was done in Microsoft Access, where entities tables were connected (Fig. 7.9) and an interface was designed for each table in order to facilitate data input and also retrieve information by Centrosur staff at administrative and technical level (Fig. 7.10). In addition, this tool facilitates the elaboration of reports about the status of the installations and work orders for maintenance staff (Fig. 7.11).

Centrosur staff checked and confirmed the usability of this tool. For instance, Table 7.12 shows the resulted IPR for all SHS components of Yantsa Ii Etsari. It provided valuable information to focus maintenance efforts. For example, it was found that solar regulator is the most critical component though it has an acceptable frequency of failure (Table 7.10). A regulator controls the state of charge of the battery, which has a limited lifetime and requires periodic replacement (3–4 years). If batteries have frequent and deep discharges due to regulator failures, its lifetime is highly affected, and the time for replacement could be reduced considerably (1 year or less). Therefore, it will have negative effects on planned maintenance cost

Table 7.11 RCM framework and questions

Criteria	Question in the context of SHS
Functions	1. What are the functions and desired performance of SHS in the Amazon?
Functional failures (FF)	2. What are the functional failures that might occur that prevent SHS to perform its expected function?
Failures modes (FM)	3. What are the events that likely cause a functional failure in SHS?
Failure effects (FE)	4. What happens when a functional failure occur in SHS?
Failure consequences (FC)	5. In what way does each SHS's functional failure matter in terms of safety, environment, operational, and nonoperational consequences?
Planning proactive tasks	6. What can and/or should be done to predict or prevent SHS failure?
Default actions	7. What should be done if a suitable proactive task cannot be determined?

Source: Orellana and Porras (2014)

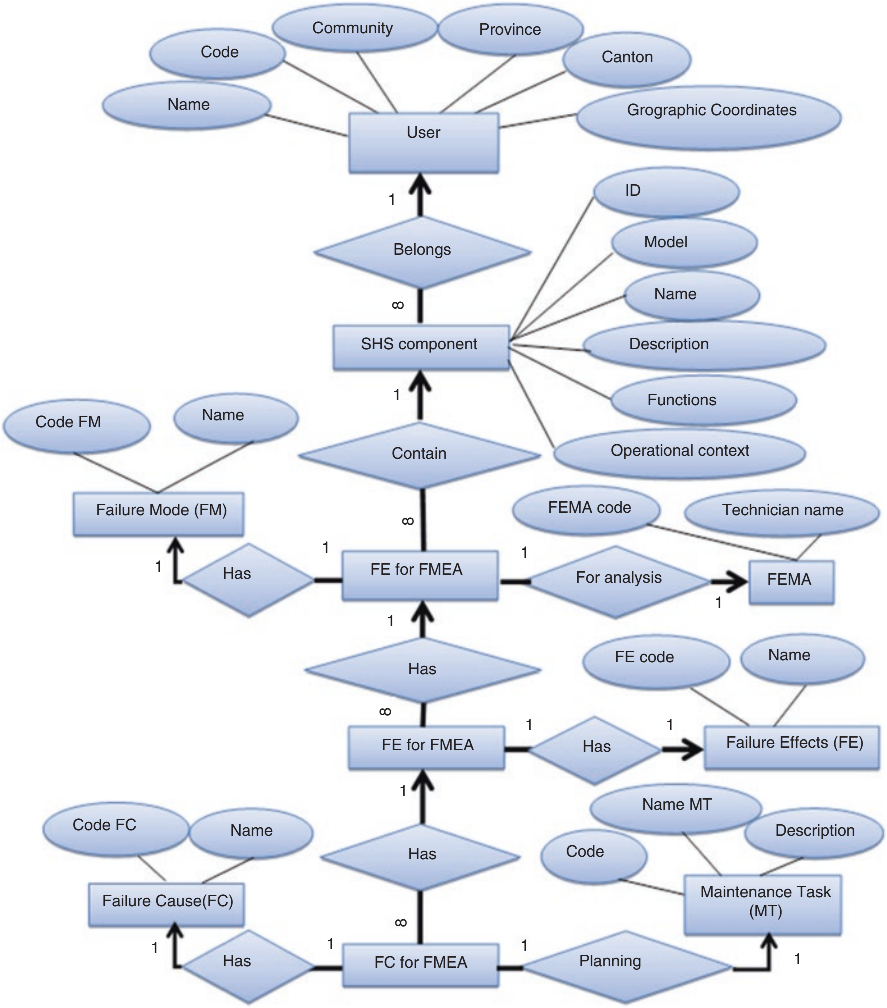


Fig. 7.8 ER model for RCM in the project Yantsa Ii Etsari. Source: Orellana and Porras (2014)

and the production of an unexpected waste. Consequently, regulators are key elements for maintenance and SHS reliability.

Conclusion

This research work proposes an automatic model to assist in the implementation of RCM strategies for rural electrification projects. The purpose of this tool is enhancing system reliability at the lowest cost, through the analysis of likely failures, their causes, effects, and consequences on safety, environment, and budget, to improve plan maintenance tasks and their frequency.

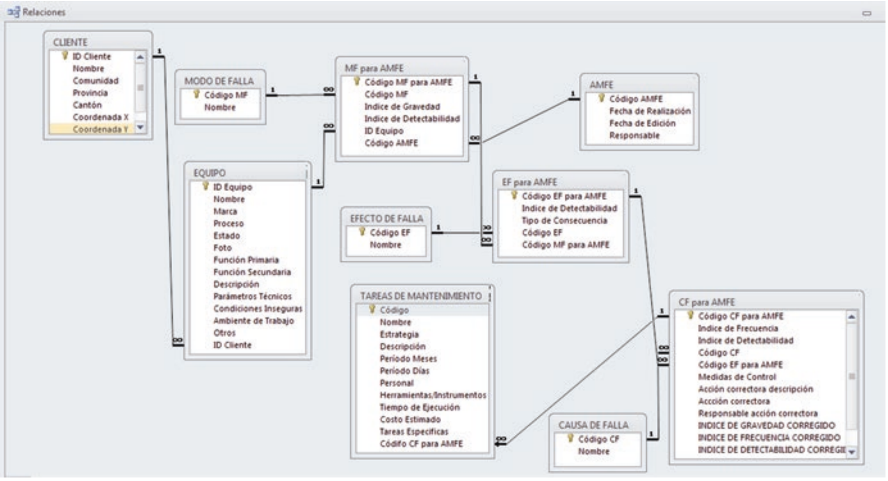
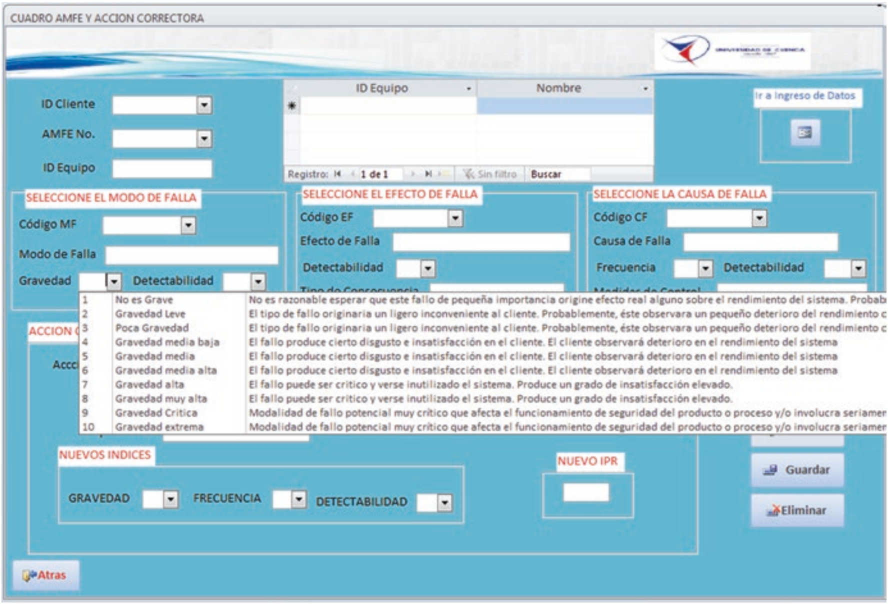


Fig. 7.9 Database construction of the RCM model. Source: Orellana and Porras (2014)



1	No es Grave	No es razonable esperar que este fallo de pequeña importancia origine efecto real alguno sobre el rendimiento del sistema. Probab
2	Gravedad Leve	El tipo de fallo originaria un ligero inconveniente al cliente. Probablemente, éste observara un pequeño deterioro del rendimiento c
3	Poca Gravedad	El tipo de fallo originaria un ligero inconveniente al cliente. Probablemente, éste observara un pequeño deterioro del rendimiento c
4	Gravedad media baja	El fallo produce cierto disgusto e insatisfacción en el cliente. El cliente observará deterioro en el rendimiento del sistema
5	Gravedad media	El fallo produce cierto disgusto e insatisfacción en el cliente. El cliente observará deterioro en el rendimiento del sistema
6	Gravedad media alta	El fallo produce cierto disgusto e insatisfacción en el cliente. El cliente observará deterioro en el rendimiento del sistema
7	Gravedad alta	El fallo puede ser critico y verse inutilizado el sistema. Produce un grado de insatisfacción elevado.
8	Gravedad muy alta	El fallo puede ser critico y verse inutilizado el sistema. Produce un grado de insatisfacción elevado.
9	Gravedad Critica	Modalidad de fallo potencial muy crítico que afecta el funcionamiento de seguridad del producto o proceso y/o involucra seriamen
10	Gravedad extrema	Modalidad de fallo potencial muy crítico que afecta el funcionamiento de seguridad del producto o proceso y/o involucra seriamen

Fig. 7.10 Interface example of RCM model, FMEA windows

High reliability power systems usually mean more investment on high quality and robust equipment. This could affect the already high cost of SHS. However, in the long term, it could have an effect on reducing operation and maintenance costs, especially in the Amazon region context where accessibility is restricted and expensive. Moreover, SHS reliability could enhance components lifetime and therefore

DESCRIPCIÓN TAREA DE MANTENIMIENTO

Descripción de la tarea de mantenimiento de cada cliente

CLIENTE: GUALINGA NANTIP YAMPIS AGUSTIN

Código: 4479747

TAREAS DE MANTENIMIENTO: CAMBIO DE REGULADOR

Código TM: TM-R-0001

EQUIPO: REGULADOR

ID Equipo: 060548

Estrategia: CARGAR BATERIA

Descripción: CONECTAR DIRECTAMENTE EL PANEL A LA BATERIA PARA REACTIVARLA

Tareas Específicas: NINGUNA

ID Equipo Nuevo: 60620

Herrats/Instrum: MULTIMETRO
ALICATES
DESTORNILLADORES
NAVAJA

Personal: ELIAS PAPUE JUANK

Tiempo de Ejecución: 5 horas

Período: 3 meses 0 días

Costo Estimado: 36 $

Fig. 7.11 Automatic report, work order. Source: Orellana and Porras (2014)

Table 7.12 Critical elements of a SHS

Components	Criticality index	Ranking
Regulator	164	1
Inverter	120	2
Lamps (CFL)	96	3
Battery	45	4
Solar panel	45	5
Battery fuse	58	6
Loads fuse	29	7
Electric kit installations (cables, interrupters)	29	8

Source: Orellana and Porras (2014)

reducing the production of electronic waste and the risk to release toxic substance in the ecosystem. However, a further research on RCM is needed in order to understand both the optimal levels of reliability and its cost-benefit in the Amazon region.

Integrated Waste Management System

Introduction

This section summarizes the proposal for an integrated waste management generated in the stages of pre-installation, installation, operation, and abandonment of the Yantsa Ii Etsari project developed by Urdiales (2014). The main objectives of this research were:

- Define the baseline of the study area, determining the environmental factors that may be affected by project activities.
- Identify, evaluate, and categorize potential environmental impacts.
- Formulate an environmental management plan (EMP) for each stage of the project.

Baseline Definition

After obtaining the main environmental factors, the project activities that could affect these factors were identified through field visits, photographs, interviews, and conversations with Centrosur staff and SHS users. This allowed developing flowcharts for each project process: pre-installation, installation, operation, and abandonment. Each process considers inputs, activities, outputs, and waste/emissions. Being a project with less than 5 years of operation, abandonment activities were not considered. The flowcharts are presented next.

Pre-installation Flowchart

In terms of environmental impact of this process, the only activity considered is “working test” whose input, output, and waste are presented in Table 7.13. The other activities of the process, purchasing, receiving, offloading, and warehousing, do not generate significant environmental impacts (Fig. 7.12).

Installation Flowchart

Most activities of this process generate environmental impacts, mainly waste and/or emissions, as shown in Table 7.14 that represents the flowchart of the process. Figure 7.13 shows the main activities of the installation process.

Table 7.13 Flowchart of pre-installation

Input	Activity	Output	Waste/emissions	Note
Components of the off-loaded SHS	Working test	Components of the tested SHS	Defective components or in poor conditions (hazardous solid waste)	

Source: Urdiales (2014)

Fig. 7.12 Receiving equipment (left) and working tests (right). Source: Urdiales 2014)

Operation Flowchart

The most significant environmental impact of this process has to do with the corrective maintenance of the systems, particularly with the activities of "replacement of defective parts" and "transport" (Table 7.15). The other activities related to preventive maintenance (cleaning panels, installation checking, etc.) do not generate impacts (see Fig. 7.14).

Identification and Significance of Environmental Impacts

In year 2014, a survey to 65 households out of 2060 was conducted for obtaining necessary information from the environmental aspects, strengths, and weaknesses regarding the solid waste management of SHS in the communities. The main results of the survey were the following (Urdiales 2014).

All respondents knew the utility of SHS, and 72% said they have basic knowledge on how to operate and do basic maintenance; 45% of respondents did not want to connect any additional devices to their SHS, and the remaining want to buy and connect new equipment that could surpass SHS capacity.

More than half of respondents (56%) said that they did not face problems with SHS; the remaining 44% had maintenance/operation problems. When the problems are not minor, Centrosur solves them in a maximum of 4 months. The components with the higher failure rate are CFLs (Table 7.10). From survey, 77% said they know

Table 7.14 Flowchart of installation

Input	Activity	Output	Waste/emissions	Note
Components of packed SHS	Transportation from warehouse	Components of transported SHS	Air emissions by type of transport. Domestic solid waste	
Components of transported SHS	Offloading in destination	Off-loaded SHS in final destination	Plastics, cardboard, etc. (industrial nonhazardous solid waste)	
Off-loaded SHS in final destination	Excavation of poles	Erect poles	Snatches of poles, debris (industrial nonhazardous solid waste)	Installation outside housing
Erect poles, panels	Location of panels	Panels located and fastened	Packaging (plastic, cardboard), trees, debris	Installation outside housing
Panels located and fastened, battery	Battery connection	Connected battery		Installation inside housing
Connected battery	Equipment connection	Connected equipment	Scraps of metal, wires, and tapes (industrial nonhazardous solid waste)	Installation inside housing
Connected equipment	Cabling	Installed equipment	Snatches of cables, tapes, etc. (industrial nonhazardous solid waste)	Installation inside housing

Source: Urdiales (2014)

how to dispose the lamps according to instructions until the new equipment arrive for replacement. Regarding batteries, which will require periodic replacements, 64% of respondents did not know how to dispose them.

About environmental impacts of SHS, 100% of respondents asserted that there is no noticeable pollution affecting water, air, and soil factors in their communities; 76% believe that the installation and use of SHS generate a positive impact on their daily activities. In addition, 59% said that the installation and use of SHS generate a positive visual impact to the environment, while 30% did not reply, and 11% said that this impact is not positive.

In order to contrast survey results, environmental impact identification and assessment were performed using a double-entry matrix (Leopold matrix), which in one axis includes the main phases of project activity, while the other axis includes the environmental factors.

The main negative environmental impacts are (Urdiales 2014):

- Air emissions from internal combustion engines of aircrafts, vehicles, and boats, in which the components of SHS are transported to the communities
- Potential degradation of soil quality during both offloading of equipment and digging of poles

Fig. 7.13 Transportation and offloading of equipment. Source: Urdiales (2014)

Table 7.15 Flowchart of operation

Input	Activity	Output	Waste/emissions	Note
Spare parts	Replacement of defective parts	Components with parts in good condition	Defective components or in poor conditions	Corrective maintenance
Defective parts, packing	Transport	Transported parts or components	Plastic, cardboard, etc. (nonhazardous solid waste)	

Source: Urdiales (2014)

- Alteration of vegetation and natural habitats during transportation by river or land and offloading, as some of the communities are within fragile ecosystems
- Proliferation of insects and weed invasion in warehousing activities as well as in external and internal connections of equipment and their final disposal
- Change on cultural models (customs) in activities of transport, installation, cleaning, and washing of panels when preventive maintenance, replacement of damaged parts, and/or final waste disposal are performed
- Possible impacts on the population health by faulty or no final waste disposal when the components are changed (batteries, CFLs, etc.)

After building the matrix of (negative) impact significance, the conclusions were:

- Irrelevant impacts (54%): minimal deterioration of the landscape when SHS are transported and installed; affectation to bugs species and/or archeology when

Fig. 7.14 Electrified houses of the Yantsa Ii Etsari project. Source: Urdiales (2014)

excavating for poles; invasion of weeds, insects, and vectors in the system components when there is no proper cleaning

- Moderate impacts (34%): disturbance to natural vegetation, wild species, and protected areas during the processes of transport of materials by the increased use of people of trails to access to communities; air emissions depending on whether the transport is by river or air; potential impact on the health of workers that handle components in both transport and installation
- Severe/critical impacts (9%): solid waste generation (hazardous and nonhazardous) during the different stages of the project

Finally, an important positive impact is the source of employment for local people as canoeists, stevedores, and installers. Both electricity itself and employment contribute to local sustainable development.

Environmental Management Plan (EMP)

Once you have identified and assessed the environmental impacts of the project in its different stages, it is necessary to undertake an "action plan" or EMP. A project's environmental management plan (EMP) consists of the set of mitigation, monitoring, and institutional measures to be taken during implementation and operation to eliminate adverse environmental and social impacts, offset them, or reduce them to acceptable levels. The plan also includes the actions needed to implement these measures" (WB 1999).

The EMP will allow an optimal integration between different processes of the photovoltaic project and environmental factors identified in the area of influence. This Plan should be understood as a dynamic tool and therefore variable over time. This means that it should act as a continuous improvement mechanism on the project's environmental aspects and their impacts.

The proposed EMP for the project Yantsa Ii Etsari contains the following programs, each with its specific activities or subprogram, schedule, budget, and responsible people (Urdiales 2014):

- Prevention and mitigation
- Occupational safety and health
- Contingencies and risks
- Waste management
- Community relationships
- Abandonment and restitution of the area
- Monitoring, control, and environmental follow-up
- Training, education, and diffusion

Since the production of solid waste (hazardous and nonhazardous) at different stages of the project has been categorized as severe/critical impact, it is important to tackle this problem holistically. Improper handling of waste causes contamination of water, air, and soil, landscape deterioration of the area of influence, as well as possible effects on people health.

Toward an Integrated Solid Waste Management

Even though Centrosur has both an instructive for handling materials and wastes (Code I – DIGARS-349) and specific forms for handling materials and waste during the construction, operation, and maintenance of SHS, a deeper analysis that allows integrating the impacts identified and the measures presented in the EMP is necessary (Urdiales 2014).

Integrated solid waste management is ruled by the current legislation regarding the control and waste management, summarized in laws and regulations issued mainly by the Ministry of Environment. Besides, the Ecuadorian Standard Construction NEC-10 Part 14.02 (Renewable Energy) Generation Systems with Photovoltaic Solar Energy for Isolated Systems and Network Connection (up to 100 kW) in Ecuador is taken into consideration (INEN 2010).

Six stages in the integrated waste management proposal were established, from the waste identification at the source to final disposal. They are (Urdiales 2014):

- Primary disposal
- Transport
- Secondary disposal
- Classification
- Treatment
- Final disposal

Each stage has clearly defined those responsible for its implementation, depending on the different players who develop the project (contract managers, contractors, technicians, staff, etc.)

The main wastes produced in the Yantsa Ii Etsari project are (Urdiales 2014):

- Domestic solid waste: due to food consumption, remains of packaging paper, plastic, cardboard, and other inert inputs.
- Industrial solid waste: remains of construction materials from assembly and disassembly activities. These residues are classified as:

- Nonhazardous industrial solid waste: products from disassembly of equipment such as uncontaminated scrap
- Hazardous industrial solid waste: batteries, panels, CFLs, and other components that contain heavy metals that can pollute or create pollution risks

Considering both the EMP (waste management program) and Centrosur's instructive for handling materials and wastes, two forms that allow a project integrated waste management were developed:

1. Management of domestic solid waste and nonhazardous industrial solid waste
2. Management of hazardous industrial solid waste

Conclusion

The integrated waste management of the Yantsa Ii Etsari project is an important step toward environmental sustainability. The effective implementation of the EMP will help to prevent and control all negative impacts as well as socializing the project and encouraging environmental responsibility in beneficiary communities.

Sustainability Assessment of Rural Electrification: Further Steps

From previous results and as part of a research in progress carried out by ZEF-University of Bonn in cooperation with Centrosur, sustainability assessment protocols of decentralized rural electrification in the Amazon region should include the following aspects.

Environmental Dimension

Weigh the environmental impacts of the electricity distribution with renewable energy on the Amazon ecosystem from planning, installation, maintenance, and decommissioning phases. A key aspect to take into account is waste production and management. In addition, the side effects of electricity uses in fragile ecosystems are critical as they could foment environmental degradation and deforestation (e.g., sawmills). Finally, the contribution of decentralized rural electrification on mitigation and adaptation to climate change is also a global concern to take into account.

Economic Dimension

Appraise the financial and economic viability of deploying renewable energy technology in rural and low-income areas. It is perhaps the most studied issue on rural electrification research. However, deepening the understanding on cost-benefit analysis of electricity access on social improvements and environment protections is an area that could shed light on the externalities to take into account in financial analysis of projects.

Institutional Dimension

Institutions are the key drivers for development and stakeholder engagement; therefore, sustainability models should appraise stakeholder capacity and engagement but also participation on projects development.

Technical Dimension

Appraise availability, reliability, and affordability of technology for the Amazon region context. Perhaps renewable energy is not affordable for low-income people, but it is the only solution available today to provide electricity to scattered households with low energy demand. Focusing the analysis on reliability and meeting users demand for development are key areas for decision-making from the technical viewpoint.

Social Dimension

It is perhaps the most complicated dimension to assess, since it is dependent and influenced by development as a whole, and not only on the provision of electricity service (Ilskog 2008). However, assessing the social benefits and equity issues are highly relevant for project evaluation and monitoring. This crosscutting area is involved in all the previous dimensions. Some of the social key issues are:

- The impact of electricity on income generation
- Support for communal services (health centers, educational centers, etc.)
- Preservation of traditional knowledge and practices of the cultural diverse indigenous population of the Amazon
- Participation and integration of all relevant stakeholders in the process of rural electrification

Spatial Dimension of Sustainability

Isolation has been the main physical barrier to boost socioeconomic development in the Amazon region and other parts of the world. Perhaps this isolation has protected the Amazon from urbanization and agriculture expansion. Moreover, the spatial distribution of different types of ecosystems and indigenous people living in different levels of socioeconomic development create a diverse range of human-environment interactions. In this regard, making explicit this spatial variation could expand the level of analysis but overall the communication and participation of stakeholders in order to progress toward sustainable energy development in fragile ecosystems. For instance, maps that shows how electricity access has improved accessibility through the reduction of travel time and cost to reach health and education services will have an impact on people development but also on reducing greenhouse gas emissions from transportation (air, car, boats).

Stakeholders' Participation

The multidimensionality and fuzziness of sustainability concepts demand the understanding and integration of the different viewpoints. Table 7.4 was an initial effort in that direction. However, any sustainability assessment model should consider the active participation of different stakeholders from government, indigenous communities, and civil society that have an interest or influence on decentralized rural electrification. Their knowledge and needs will make any protocol or model for sustainability assessment relevant and salient for policymaking.

In order to monitor and guide the transition toward sustainability in rural electrification projects, clear objectives have to be defined and assessed. However, measuring sustainability is a challenge that has mobilized the scientific community to propose a diversity of tools to support decision-makers. Ness et al. (2007) provide a categorization of existing tools classified in three big groups: indicators, product-related assessment, and integrated assessment methods.

- Indicators are extensively used for sustainability assessment. In this chapter, by using an existing sustainability framework of indicators (Ilskog 2008), a research plan was proposed in order to shed light on how to promote sustainability of rural electrification projects.
- Product-related assessment focuses on assessing flows of resources and services. For instance, a "Life Cycle Assessment" of SHS could help to understand the contribution of rural electrification in greenhouse emissions scenarios. In addition, a "product material flow analysis" could help to assess the material input per unit of energy delivered, which is a key aspect on waste management.
- Integrated assessment looks at system analysis approaches. It means that rural electrification should not be treated as a technical or economic problem, but as an interconnected entity. This type of analysis is more interested on relationship rather than elements of the system. For instance, "system dynamics" provide a potential platform for research on modeling rural electrification as a system, where social, environmental, and technical variables are integrated and simulated.

Conclusions and Discussion

The ecological importance of the Amazon region for climate regulation but also as a source of high biological and cultural diversity is generally accepted. Human development in this region is very low, and improving their living conditions could help to counteract the environmental degradation of this sensible ecosystem. Providing electricity service sets the background for the provision of other services like health, education, and telecommunication. However, deploying technology for electricity supply in isolated and low-income areas represents a challenge still unsolved worldwide.

This chapter introduces the project Yantsa Ii Etsari, which has almost reach universal access to electricity in the southern Ecuadorian Amazon. In the sake to improve the sustainability of electricity provision, a cooperation with the academia of Ecuador (University of Cuenca) and Germany (ZEF-University of Bonn) was set in order to research on key areas that could provide better understanding on how to improve the sustainability of the project.

Four research projects were presented "local utility involvement and stakeholder participation," "development of a solar boat prototype," "design of an automatic reliability-centered maintenance model," and "integrated waste management system." Each focused on different sustainability dimensions and provided the basis for discussion and policy.

This chapter demonstrates that cooperation between practitioners (Electricity Company) and researchers (University) provides a unique opportunity to discuss and understand how to promote sustainability in isolated and fragile areas. However, how to translate research outcomes into energy policies is a challenge.

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