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Rural Electrification Efforts Based on Off-Grid Photovoltaic Systems in the Andean Region: Comparative Assessment of Their Sustainability

Sarah Feron [1,2,*], Raúl R. Cordero [2] and Fernando Labbe [3]

1 Institute for Sustainability Governance, Leuphana University Lüneburg, 21335 Lüneburg, Germany
2 Department of Physics, Universidad Santiago de Chile, Santiago 9170124, Chile; raul.cordero@usach.cl
3 Department of Mechanics, Universidad Técnica Federico Santa María, Valparaíso 2340000, Chile; fernando.labbe@usm.cl
* Correspondence: sarah.feron@stud.leuphana.de

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Abstract: In this paper, we comparatively assess the sustainability of rural electrification efforts based on off-grid solutions in Chile, Ecuador, and Peru. Our assessment considers four dimensions of sustainability (institutional, economic, environmental, and socio-cultural). We found that Ecuador and Chile have consistently failed to ensure mechanisms for the operation and maintenance of the deployed off-grid systems, which has made these solutions in poor Chilean and Ecuadorian communities inevitably unsustainable. Although Peru has adopted a cross-tariff scheme, the Peruvian case shows that ensuring the funding of off-grid PV solutions is not enough. Peruvian officials appear to be unaware of the importance of local participation (local values and lifestyles are constantly disregarded) and most of the projects have been designed without the participation and engagement of the communities, which has often led to project failures and payment defaults. However, although each country has its particular challenges, we found that the three Andean countries have consistently neglected the importance of strong formal institutions with a flexible and decentralized structure, which in turn significantly compromised the rural electrification effort in these countries.

Keywords: off-grid PV systems; rural electrification; developing countries; sustainable energy; Andean countries

1. Introduction

Out of the approximately 1.2 billion people who still lack electricity worldwide, the vast majority live in rural areas [1]. In 2015, the United Nations (UN) declared global access to clean and reliable energy one of its 17 Sustainable Development Goals (SDG) [2]. In remote areas of Developing Countries (DCs), where a grid expansion is unviable, off-grid Photovoltaic (PV) systems can be a feasible alternative to reach this goal.

In recent decades, Chile, Ecuador, and Peru have significantly improved their rural electrification rates (reaching 97.8% in Chile, 92.3% in Ecuador, and 63% in Peru) [3,4]. Rural electrification efforts included the deployments of off-grid PV solutions in remote areas such as the Ecuadorian and Peruvian Amazon basin [4,5], as well as in isolated Chilean peripheral locations [6]. Communities of these areas are characterized by low energy demand, low income, high dispersion, and difficult accessibility (see e.g., [7,8]).

Unfortunately, rural electrification projects based on off-grid PV systems have been plagued by technical failures and payment defaults, which has seriously compromised their sustainability [9–12].

In this paper, we critically assess the sustainably of rural electrification programs (based on off-grid PV systems) in the Andean countries. We aim to better understand drivers of success as well as to highlight flaws that have compromised the sustainability of these efforts. Our assessment was based on a set of indicators (adopted from [13]; see Table 1) corresponding to the four dimensions of sustainability considered in this paper: institutional, economical, environmental, and socio-cultural. A definition for each of these sustainability indicators is provided in Table 1.

Table 1. Definition of indicators of sustainability adopted in this study (adapted from [13]). The different colors in the first column stand for the different dimensions of sustainability considered in this paper.

Sustainability Dimension	Indicator	Definition
Institutional	**Stability (Durability)**	Stability concerns the durability of the (national and local) formal institutions of a country. This may refer to the organization itself, its legal existence, as well as the stability of personnel within the organization (staff turnover).
	Regulation and Standards	Regulations embrace the legal framework of a country including its consistency, coherence, and liability. Standards refer to the implementation and verification of technical standards for off-grid PV systems and their accessories including the legal bounding for quality assurance.
	Adaptability	Adaptability implies the formal institutions' ability to adapt to the needs of the population and its socio-cultural circumstances. The concept embraces flexible, decentralized institutional structures that have the (technical and socio-cultural) know-how and the (de facto and de jure) power to effectively steer rural electrification.
	Decentralization/ Participation	Decentralization and participation refer to the degree to which formal and informal institutions work jointly together on the local projects. The participation of a local community usually requires a degree of decentralization of the agents in charge of the rural electrification project.
Economic	**Funding (Initial investment/O&M)**	Funding consists of both the funds provided for the initial investment of the off-grid PV systems (including its components, installation costs, costs for user training and handbooks) as well as the funds to operate and maintain the systems over their entire lifetime (including operational costs for repairing services and substitutions (e.g., batteries), the administration of the systems (such as tariff collection), the provision and storage costs for spare parts, all kinds of travel expenses to the dwellings and back, and disposal costs).
	Cost effectiveness	Cost-effectiveness of a solution is defined by the degree to which monetary resources are efficiently invested by the deployment of an accurate (see indicator accuracy below) energy system for a community with the lowest costs over the system's lifetime.
	Reliability	Reliability requires the systems to be constantly operational. Defects are corrected in a short (and previously defined) time span. Reliability requires spare parts and know-how to be available at the local site.
	Productive Use	Energy systems are expected to contribute to the economic development of the users. This can be achieved by (partially) using the systems for productive uses, which generates user income (users might then even bear O&M costs) due to a higher productivity/performance associated with energy.
Environmental	**Environmental Awareness**	Environmental awareness is defined as the consciousness of the society on the importance of the environment. It often requires an understanding of the connections between environmental, energy, and social/economic issues and its value for wellbeing.
	Environmental impact	Environmental impact refers to the positive as well as negative effects that a technology has on the environment. These impacts may be local or global in nature. Examples for the former are the handling of disposals (such as batteries) from the systems, noise disturbances, pollution aesthetics, etc. The latter refers to impacts on the climate system (due to greenhouse gases) or the loss of biodiversity worldwide. Positive impacts may, e.g., be the avoidance of these gases due to the adoption of "clean" renewable technologies.

Table 1. *Cont.*

Sustainability Dimension	Indicator	Definition
Socio-Cultural	**Equity**	Equity (disparity) is the degree of equal (distinct) treatment for different groups of a population, e.g., rural and urban populations or different ethnic groups on the one hand, and within groups (i.e., similar rural populations from one vs. another community) on the other hand. Equity relies on the underlying concept of justice. Equity (disparity) issues may refer to the point in time when a community is electrified (temporal equity), the provided energy quality and quantity (system size) for/within each group, and the differences between energy tariffs.
	Accuracy	Accuracy in sustainable rural electrification is defined as the degree to which the solutions are conforming to the lifestyle and needs of the users. Accuracy often refers to the off-grid system capacity for present and future energy demand, as well as technological specifications that consider socio-cultural factors (such as ease of use, community lifestyle, etc.).
	Social Acceptance	Social acceptance in sustainable rural electrification is understood as the degree to which a community agrees with a project and the installed technology, approves it, and ideally identifies with it. Social acceptance is often facilitated by involving and engaging the users in the project and by making them part of the solution, such that they understand its advantages and limitations and agree on the conditions (their rights and obligations).
	Cultural Justice	Cultural justice refers to the consideration of/and respect for the culture, motivations and values of the population (e.g., concerning environmental awareness).

Institutional sustainability has been acknowledged as a precondition for the sustainability of rural electrification initiatives (see e.g., [14,15]). For institutions to be sustainable, they need to be stable and durable [16–18]. In that context, Gollwitzer [19] highlights the importance of adopting and enforcing norms and regulations. Authors further agree on the relevance of the openness to people's participation [20–22] and of decentralization [23,24], which favors the adaptability to local needs [14,17,21,25].

Economic sustainability of electrification solutions requires ensuring the affordability of the systems [25,26]), which implies adopting cost-effective solutions and procuring (in the case of poor communities) funding for both the initial investment and the operation and maintenance (O&M) of the systems [17,27–29]. Sustainability of energy projects further requires ensuring the reliability of the systems [30]. Dunmade [28] and Chaurey and Kandpal [31] therefore allude that spare parts must be locally available to reduce downtimes, such that productive uses can contribute to an increase in the user income [32,33].

Environmental sustainability demands for citizen participation and environmental awareness [34], which is then again relevant for the prevention of negative environmental impacts [17,21,26]; improper disposal of batteries may make presumably clean technologies such as off-grid PV systems unsustainable [35,36].

Socio-cultural sustainability [14,17,18,26] implies favoring equity regarding the amount of energy provided to different groups (e.g., according to gender, ethnical background, etc.) as well as regarding the accessibility to energy [15,16,26,37]. Moreover, socio-cultural sustainability of energy solutions requires gaining the acceptance of society by respecting their culture and traditions [28,38], and ensuring the participation of the local community [15,21,39].

The dimensions of the sustainability (institutional, economical, environmental, and socio-cultural) are strongly interwoven and are deeply interdependent. Therefore, ensuring the sustainability requires adopting an integrated and holistic approach. Indeed, as shown below, successful rural electrification projects (based on off-grid PV systems) in the Andean countries are those within which all the dimensions of the sustainability are ensured.

2. Materials and Methods

We applied a multiple-case study approach (for details on this methodology, see [40,41]) for an inter-country comparison between Chile, Ecuador, and Peru. The material used to conduct the case studies was obtained from a variety of data sources that included legal/public statements, energy policies and regulations, statistical databases (on energy uses and technologies), strategic energy documents and roadmaps, ex-post project evaluations from independent parties, and scientific papers. Quantitative data for comparisons were retrieved from the World Bank Indicator Database, from diverse Ministries such as the respective Ministry of Energy of each country, the Ministry of Development and Social Inclusion (Peru)/Ministry of Social Development (Chile); Ministry of Foreign Affairs Coordinating Ministry of Strategic Sectors (MICSE by its Spanish abbreviation) in Ecuador; from several public energy agencies/regulators (e.g., National Energy Commission (CNE by its Spanish abbreviation) in Chile; Agency for Regulation and Electricity Control (CONELEC, by its Spanish abbreviation) in Ecuador; and Organization for Investment in Energy and Mining (OSINERGMIN, by its Spanish abbreviation) in Peru; and from the National Statistical Institutions of the three countries.

We also analyzed 57 semi-structured interviews to key stakeholders that we had previously conducted in Chile, Ecuador, and Peru (see [13,42,43]). Interviews were held between 2014 and 2015, and since our main interest was to unveil the overall institutional and organizational conditions in the Andean countries, the interviewees were of higher hierarchical positions such as directors, project managers, leading researchers, and division leaders in each country. The interview guideline was identical for the three countries, and our interview partners in Chile, Ecuador, and Peru held similar positions. This structured proceeding assured an unbiased comparison of the three countries.

The conjunction of the analyzed data was used to assess the sustainably of rural electrification programs (based on off-grid PV systems) in the Andean countries. Our assessment was based on a set of indicators (see Table 1) that were rated relative to an ideal situation.

3. Country Comparison Brief

3.1. Geography and Demography

As shown in Table 2, Peru's population is almost twice as high as Chile's and Ecuador's. However, given its smaller surface, Ecuador has a much higher population density. In addition, in relative terms, Ecuador's rural population is three times higher than Chile's, and twice as high as Peru's rural population. Whereas the Ecuadorian rural population has been growing during the last five years, it has decreased in Chile and Peru. It is also worth noting that the three countries all have a very diverse geography with different climate zones. These geographical features, including mountain areas above 5000 m, tropical forest in the Amazonian basin (Peru and Ecuador), islands (Chile and Ecuador), and fjords (Chile) with difficult access, contribute to the isolation of some rural communities in these countries.

Table 2. Key Demographic Data.

	Chile	Ecuador	Peru
Total Population (2015)	17,948.14	16,144.36	31,376.67
Rural population (% of total; 2015)	10.47	36.26	21.39
Population density (people per sq. km of land area; 2015)	24.20	65.00	24.51
Rural population growth (%; average during last 5 years)	−0.7	0.98	−0.2
Surface Area (km^2)	756,950	283,500	1,285,216

Source: Own elaboration based on data from [3].

3.2. Politics and Economy

The administrative organization of the three countries remains highly centralized despite of their efforts for power distribution [44–46]. While Ecuador has been more reluctant, Chile and Peru have enthusiastically embraced neoliberalism (since the 1990s in the case of Peru and since the 1980s in the case of Chile). As discussed below, this difference had strong implications for the energy sector and its organization.

Table 3 shows some key economic data for the Andean countries: According to the World Bank [3], Chile's economy is by far the wealthiest, followed by Peru and Ecuador; still, the GDP growth-rates during the last five years have been remarkable in all three cases. Chile's economic edge is also reflected in the higher Foreign Direct Investment, which is more than twice as high as in Peru and about eight times higher than in Ecuador [3]. Chile's GINI Index (a measure of inequality within a country; see [47]) is the highest (i.e., Chile has the greatest income/consumption disparity), albeit inequality seems to be an issue in each of the three nations [3]. The countries share their high dependency on commodities that account for more than 50% of their exports: Chile mainly depends on the mining sector, Ecuador on its petroleum reserves, and Peru on mining and petroleum, respectively [48–50].

Table 3. Selected Economic Data.

	Chile	Ecuador	Peru
GDP per capita, PPP (constant 2011 international $; 2015)	22,145.10	10,717.60	11,672.14
Annual GDP Growth (%; average of last 5 years)	3.8	4.4	4.8
GINI Index (2013)	50.5	47.3	44.7
Foreign Direct Investment net inflows (percent of GDP; 2015)	8.5	1.1	3.6
Exported Commodities (in percent of total exports)	54.2	56.5	62

Source: Own elaboration based on data from [3,48–50].

3.3. Energy

The energy sector differs notably between the three Andean countries, as shown in the overview of Table 4. Ecuador has a primary energy surplus, with the main destination of its energy exports being United States, followed by Chile, Peru, and Panama [51]. Despite of this surplus, Ecuador's energy sufficiency index is actually negative. This is due to the fact that its exports are crude oil, while it still needs to import diesel, gasoline, and liquefied petroleum gas (LPG) [52]. It should be noted that Ecuador currently subsidizes these imports: for example in 2014, subsidies on energy fuels represented 3.89% of the country's GDP, amounting to US$3.907 million [53].

In Peru, the energy generation is approximately equal to its consumption, while Chile is highly dependent on energy imports that accounted for about 61% of the total energy consumption in 2013 [3]. At the same time, the per capita electricity consumption is more than three times higher in Chile than in Ecuador and in Peru [3], which can be partially attributed to its higher GDP per capita (as energy consumption is correlated with income [37,54].

For energy consumption, Peru's and Chile's share of RE (including hydro energy) is almost 1/3 of the total energy consumption, whereas in Ecuador it accounted for only about 13.4% in 2012 [3] (World Bank, NA); however, several major hydro-power plants are currently constructed in Ecuador with a total power capacity of about 2.5 gigawatts (GW) [55]. This will increment the power production by 50% and also substantially adjust the RE consumption rate upwards (as the government is also promoting a policy to foster a shift in its energy consumption from gas to electricity to curb the enormous subsidies on fuels).

As far as Non-Conventional Renewable Energies (NCRE) are concerned, their energy generations have a minor share of the total power generation in Ecuador and Peru, but a more important role in Chile [56–58].

Table 4. Key Energy Data.

	Chile	Ecuador	Peru
Net Energy Imports (percent of energy use; 2013)	61.3	−93.8	−0.2
Electricity consumption (kilo Watts hours (kWh) per capita; 2013)	3879	1333	1270
Generation rate of NCRE for electricity (percent of total generation of electricity)	13	2	3.1
RE consumption (percent of total final energy consumption; 2012)	30.3	13.4	28.3
Rural Electrification Rate (%; 2012)	97.8	92.3	63

Source: Own elaboration based on data from [3,4,56–58].

3.4. Rural Electrification

Figure 1 shows the progression of the rural electrification rate of the analyzed Andean countries between 1993 and 2012. In 1990s, their rural electrification rate was quite low (with Peru significantly lacking behind), though the Andean countries were able to make up leeway after tremendous electrification efforts in the 1990s and 2000s. The improvements have mainly been due to grid expansions, although off-grid solutions were adopted when grid expansions were found to be unviable.

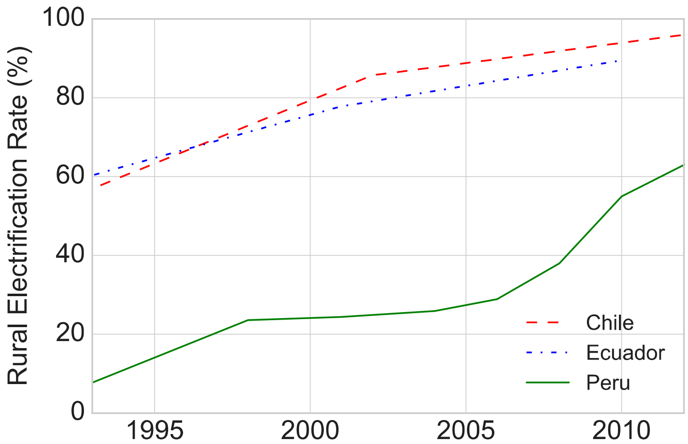

Figure 1. Rural Electrification Rate in Chile, Ecuador, and Peru. Source: Own elaboration based on data from [4,59,60] (for Ecuador data are only available until 2010).

Rural electrification is usually unprofitable in DCs due to a high dispersion of dwellings, a low energy demand, and a difficult access to these areas. Therefore, in the Andean countries, electrifying rural areas has primarily been responsibility of the public sector (mainly through the respective Ministry of Energy or equivalent [61–63].

In Ecuador, all Electric Distribution Companies (EDCs) are state-owned; in Peru, they can be public or private (EDCs that operate outside big urban areas are all public except for those under the control of Non-Governmental Organizations (NGOs)); and in Chile they are all private.

In the case of on-grid solutions, the EDCs in the three countries provide the electricity to the end-users, but none of them generates electricity from its own plants (due to policies in the 1990 that fostered the separation of generation, transmission, and distribution in the three countries). In the case of off-grid PV solutions however, the EDCs can also generate the electricity by installing the systems themselves.

In Ecuador, the public EDCs are prompted by law to provide electrification to the whole country, such that they have been deploying off-grid PV solutions in remote rural areas (especially in the Amazon basin) since the early 1990s. In the case of Chile, the national government pays private companies (selected via call for bids) to electrify dwellings in remote areas, although local authorities such as municipalities can also commission the deployment of small-scale PV systems without the supervision of the Chilean Ministry of Energy. In Peru, public EDCs are also leading electrification efforts in rural areas by using off-grid solutions, but their responsibilities are constrained to certain areas of the country. To take electrification beyond these areas, the Peruvian government issued call for bids to install at least 150,000 off-grid PV systems through a public-private partnership [64]; the private company will be in charge of the installation as well as the O&M across Peru's remote areas for 15 years, whereas public EDCs will cover the administration (e.g., fee collection) [64]. NGOs, NPOs, and universities have also conducted off-grid installations in the Andean countries.

4. Results

4.1. Institutional Sustainability

4.1.1. Stability/Durability

Institutional sustainability requires strengthened and stable formal institutions. However, stability is quite problematic in Ecuador and in Peru [65]. In Ecuador, new Ministries, regulators, and EDCs were created and later disappeared, which ultimately led to the failure of entire off-grid PV programs (when the responsible entity just vanished) [13]. Similar issues were found in Peru, where according to an expert from a NGO (and verified by the regulatory trajectory), permanent staff turnovers in leading positions as well as changes in energy policies inhibited the implementation of a strategic policy line. The lack of institutional stability has moreover seriously affected the creation of know-how and human capital training in these countries.

Moreover, the prevalent neoliberalism in Peru and in Chile has prevented the development of strengthened formal institutions by reducing their role to a minimum [66]. For example, the Chilean Ministry of Energy enthusiastically embraced the concept of "technology neutrality" (since in its view any form of facilitation or promotion of RE may lead to market distortions) [42]; the Peruvian Ministry of Energy is meanwhile committed to outsourcing: in Peru, the installation of off-grid PV system is outsourced, O&M of off-grid PV system is outsourced; even the supervision of the outsourced activities is outsourced, as confirmed by several government agents.

4.1.2. Regulations and Standards

In Ecuador, there is a lack of coherence between the Constitution and the regulations. Several interviewees (including scholars and NGO experts) stated that this incoherence had direct consequences on rural electrification, as for instance the right for energy declared in the Constitution was not anchored in the law, and consequently it is often not enforced. Moreover, rural electrification lacks any kind of technical and quality standards, such that different EDCs frequently deploy incompatible off-grid systems [13].

In Chile, technical standards for rural electrification have been defined, but project managers from energy companies admitted that in the projects they are not enforced, especially in the case of off-grid PV systems. The lack of enforcement of technical standards has often compromised the sustainability of small-scale programs conducted by private entities as well as public agencies or municipalities. Indeed, according to the current regulation, when the investment cost of a rural electrification project is lower than approximately US$140,000, it can be carried out without the supervision of the Ministry of Energy [42].

In Peru, although technical standards were formally adopted from the International Organization for Standardization (ISO), representatives of the agencies in charge of the quality control assured that they have been neglected by the Ministry of Energy and Mining in their rural electrification projects. Consequently, these technical standards were also found to be outdated.

A major issue for rural electrification in these countries is that the regulatory framework does not clearly reveal what actions to take and who to hold responsible if the off-grid PV systems stop operating. This fundamental drawback contributes to the unreliability of off-grid PV system in the Andean countries.

4.1.3. Adaptability

Rural electrification requires that the institutions are able to adapt to the (changing) circumstances in a country, which implies in the context of rural electrification, having a strong formal institution (such as an agency) with a flexible and decentralized structure (see e.g., [67]).

Chile and Ecuador lack a decentralized public agency focused on rural electrification. Such an agency may support local authorities and users, and it could be in charge of O&M as well as of the quality assurance of the systems. In the case of Chile, several small-scale projects failed because their sponsors (local authorities such as municipalities in remote rural areas) were unable to keep the systems operating in the long-term (e.g., because of the deployment of low quality parts, the lack of technological skills in remote area, missing spare parts, etc.) and they did not receive timely support or training from the Chilean Ministry of Energy [42].

In the case of Ecuador, a decentralized public agency could help to improve coordination among the Ecuadorian EDCs, and to facilitate the transfer of know-how from EDCs that have successfully deployed off-grid PV systems (for example, the "CentroSur" EDC) to less successful EDCs (for example the "Sucumbíos" EDC) [13]. Therefore, the ongoing reorganization of the Ecuadorian electricity sector, which implies merging the current 11 EDCs into a single company (see [68]), may help to foster the exchange of valuable know-how.

In Peru, there are two agencies (the Direction of Grant Funds (DFC by its Spanish abbreviation) and the Project Management Direction (DPR by its Spanish abbreviation)) both conducting off-grid PV projects for rural electrification under the Peruvian Ministry of Energy. Competences of both agencies (DFC and DPR) appear to be overlapping, which has caused rivalry between them and contributed to the dispersion of know-how.

The main problem in all three countries that impedes a better adaptability of formal institutions to the needs of the population seems to be the lack of a flexible, decentralized institutional structure with the (technical and socio-cultural) know-how and the (de facto and de jure) power to effectively steer rural electrification. The lack of coordination between the institutions dealing with rural electrification in these countries has often constrained the transfer of know-how (although Ecuador is trying to correct this flaw by merging its EDCs).

4.1.4. Decentralization and Openness to Participation

In Ecuador, the energy sector, in particular the distribution of electricity, is subject to a process of recentralization, which means that the 11 EDCs in the country will be merged to a single company. Recentralization may lead to short-term benefits in the Ecuadorian energy sector (by facilitating the adoption of coherent technical and quality standards of service; see above). However, recentralization may also weaken local institutions (inhibiting in turn local participation; see for example [69].

In Chile and Peru, decentralization has allowed local or regional governments to implement electrification projects by themselves. However, as mentioned above, these projects have often failed. NGO representatives and social scientists have attributed this issue to the fact that decentralization efforts were merely understood as a redistribution of funds to elected local governments, which did not include any transfer of know-how or training.

In Peru and Ecuador, most of the electrification projects based on off-grid PV systems are still sponsored by the corresponding Ministry of Energy. These projects have primarily been designed and conducted without the participation of the local population (usually indigenous communities). As explained below, this lack of engagement and participation has led to inaccurate solutions (such as insufficient system capacities unable to match the actual needs of the population).

Although in Chile the Ministry of Energy appears to be aware of the importance of openness to participation [42], a participative approach (involving user training and transfer of technical know-how) is not always applied. For example, harming system interventions from users due of a lack of user training has plagued small-scale PV projects in rural areas of Chile [42,70,71].

The problems detected in the three countries show that ensuring the sustainability of off-grid systems requires, in addition to decentralization and openness to participation that local know-how and capabilities are built.

4.2. Economic Sustainability

4.2.1. Cost Effectiveness

Off-grid PV systems are a cost-effective alternative for rural electrification in areas where the grid expansion is too difficult or too expensive. However, in Chile the Ministry of Energy failed to recognize this fact for years. Indeed, diesel generators were often preferred in the past, since only the initial investment costs were considered in the decision-making [72] without taking the significantly higher O&M costs, including fuel costs and its transport to remote areas into account. Fortunately, this flaw has been corrected in recent years, such that a lifecycle cost calculation is now used, and diesel generators are substituted by off-grid solutions [42,73]. In Ecuador, the potential of off-grid PV systems has also been ignored as a cost-effective alternative for the countries' remote areas, as e.g., the expansion of the national grid has been preferred even if direct and indirect costs (e.g., environmental impacts) were substantial. This could mainly be attributed to political promises to bring the national grid to the specific locations (as the grid was considered a more popular solution) [13].

On the other hand, the Peruvian Ministry of Energy did recognize the potential of off-grid PV systems for remote areas. This is why it recently approved the installation of at least 150,000 systems across the country. The systems will all be installed by a single private company, which allows for significant economies of scale, and the price per system can be reduced significantly. However, the lack of coordination between DPC and DPR (as well as with municipalities) in previous projects has seriously affected the cost-effectiveness in rural electrification: project managers arrived at remote communities that were already electrified because the DPC, the DPR, and the municipalities had not communicated with each other, which has caused substantial costs due to wasted efforts.

The three countries should update the evaluation of their electrification projects properly by considering the costs over the system's lifetime (including the O&M costs).

4.2.2. Reliability

Economic sustainability requires that the solution remains operational during its lifetime. This is particularly important for off-grid PV systems, as their initial investment is high, while O&M costs are very low compared to other solutions. In Chile, PV systems often became unreliable (particularly in small-scale projects), not only because technical standards are voluntary, but also because of the lack of a decentralized agency (see above) to ensure O&M.

In Ecuador, several EDCs have also deployed off-grid PV systems with mixed results; successful projects (in terms of reliability of the systems) were conducted by Ecuadorian EDCs that formed a well trained team or special units focused on off-grid solutions [13]. However, the lack of local know-how coupled with missing spare parts seriously compromised the reliability of the majority of off-grid PV systems in Ecuador [74].

In Peru, the reliability of off-grid PV systems is still an issue. For instance, in two inspections conducted by the energy regulator in 2011 and 2013, out of the 1110 systems, 34% were inoperative, with the majority of broken systems stemming from public EDCs [75]. Part of the problem is the widespread outsourcing: all Peruvian EDCs have outsourced both the installations and O&M services to local firms or to users while disregarding the indispensable supervision and training of these firms.

4.2.3. Initial Investment

Sustainability of off-grid PV systems requires ensuring funding for the initial investment and the O&M of the systems over their lifetime. In the Andean countries, government intervention is in many cases inevitable for ensuring funding, because the rural populations in remote areas are usually extremely poor and cannot afford the systems or their O&M on their own (especially when access to the rural households is difficult and the population density is particularly low).

The Andean countries have allocated significant resources to rural electrification in recent decades, which has contributed to the great increase of the rural electrification rate (see Figure 1). However, these sources of funding are generally not permanent, which makes it dependent on political changes. This is particularly problematic in Chile and in Ecuador where initial investments for off-grid-systems solely rely on the government budget.

In Chile, rural electrification funding can be changed every year by the regional governments (that sponsors most of the off-grid projects in the country) when distributing its annual budget [76]. Although Ecuador used to have a cross-subsidy (the initial investment for rural electrification projects was funded by a 10% tax added to the electricity tariff of urban inhabitants), since 2008 funds for rural electrification depend on the national budget and have missed out for several succeeding years [77].

By contrast, funds for rural electrification in Peru come from a broader variety of sources (e.g., state budget, utilities of energy companies of the electricity sector, external funds, sanctions, donations, etc.) [4,78], which makes them less exposed to political changes.

4.2.4. Operation and Maintenance

According to numerous interviewees, O&M costs of off-grid PV systems significantly exceed the spending capacity of inhabitants in remote areas of the three countries. Although their governments appear to be aware of this fact, Chile and Ecuador have largely failed to ensure O&M funds even in the case of government-sponsored off-grid projects. By contrast, Peru implemented a cross-subsidy aimed at covering O&M costs of off-grid PV users. The system is based on a fee for clients with higher energy consumptions (>100 kwh; usually from urban areas), and it favors poor households with a monthly energy consumption of below 100 kWh [79].

The Peruvian cross-subsidy allows users of a 70 Wp off-grid PV system to pay a tariff of only about US$2 (US$3 for users from private companies) per month [80]. Indeed, the Peruvian Ministry of Energy has properly regulated the tariffs for both grid-connected and off-grid users. Moreover, when O&M costs exceed the tariffs, the EDCs are compensated according to their real expenditures (including costs of transportation to the communities, personnel costs, costs for spare parts, etc.). The situation is different in Chile and Ecuador where no tariff regulation for off-grid users exists [42].

In Chile, the sponsor of the project (usually a regional government or municipality) may choose the tariff. Often, the tariff per kWh for off-grid users is the same as that charged to grid-connected neighbors [81]. Since the O&M costs of off-grid-systems in remote areas are relatively high, there is a gap between the user tariff and the actual O&M costs that is not automatically covered in Chile. Regional governments—being the sponsor of the off-grid projects in most cases—need to annually request compensation to the CNE [82], which makes the programs vulnerable to political priorities.

In Ecuador, the sponsor and operator of off-grid projects is normally the EDC. These companies use to apply the so-called "dignity tariff" for poor on-grid and off-grid users, which means that users with a consumption below 130 kwh/month (110 kWh/month in the Andean highlands), only pay half of the tariff charged to grid-connected users with higher consumptions [83]. However, several EDC representatives in Ecuador complained that the gap between the user tariff and the actual O&M costs is expected to be assumed by the EDC, which strongly disincentives the deployment of off-grid solutions by these companies.

4.2.5. Productive Use

Chile exhibits some successful cases of off-grid PV-powered water pumps that have been adopted by poor farmers in remote areas of the northern territory. Contrary, in Peru and Ecuador, off-grid solutions for productive uses have so far been limited to projects of grid expansions and some isolated pilot projects.

In Chile, a subdivision of the Chilean Ministry of Agriculture, the Agency for Agrarian Development (INDAP by its Spanish abbreviation), promoted the substitution of water pumps powered by diesel generators by PV-powered pumps [84]. Around 1400 systems were installed from 2012 to 2013 (investment: US$7.5 million). The success of the program may be related to the decentralized structure of INDAP, whose personnel is in close and permanent contact with the farmers. This permanent contact facilitated the basic training to the final users, and ultimately ensures the success of the program [42]. Apart from INDAP, the Ministry of Agriculture has implemented a wide variety of pilot projects aiming to repeat the success of the PV-powered pumps program.

In Ecuador, government initiatives of rural electrification aimed at productive uses are limited to one microgrid project (10 mega Watts peak (mWp)) for households, schools, public lightning, and health centers [85]. NPOs have also implemented several pilot projects for productive uses such as corn dryers powered by PV energy, solar boats for transportation, and energy for milk collection centers. However, representatives of the Ministry of Energy acknowledged that the main issue with productive use projects is that the users still lack basic knowledge on energy uses and its potentials on the one hand, and administrative skills to manage them on the other hand. To attain these skills, interdisciplinary projects across different sectors (health, education, housing Ministry, etc.) become essential [86]. Unfortunately, the Ecuadorian Ministry of Energy appears to be unaware of this fact.

In Peru, the Ministry of Development and Social Inclusion (MIDIS by its Spanish abbreviation) was created in 2010 to eradicate extreme poverty by implementing interdisciplinary projects (for water and sanitation, electricity, local roads, and telecommunication) in the poorest and most remote areas of the country [87]. However, according to a MIDIS representative, the Ministry's initiatives have so far focused on the project implementation without accompanying the community after the project finished.

4.3. Environmental Sustainability

4.3.1. Environmental Awareness

Most interviewees of Ecuador and Peru agreed that environmental awareness is not widespread in their country, neither on a government level, nor in civil society. In Ecuador, although environmental protection is anchored in its current Constitution, the government recently decided to drill for oil in the Yasuni National Park, one of the most biologically diverse forests located in the Ecuadorian Amazon [88]. Similarly, in Peru, neither the creation of the Ministry of Environment (2008) nor the host of the 20th Conference of the Parties (COP 20) in 2014 could foster major progress in environmental awareness. For example, overfishing, deforestation, degradation of soil and water bodies continue to be substantial issues in the country [89,90]. Although part of the problem is the lack of experts on environmental issues (e.g., in the Ministry of Environment) [91], social scientists reported that there is also a lack of environmental awareness in civil society. Despite numerous environmental reforms and educational programs, people's behavior change towards more environmental friendly practices did not occur yet [92].

In Chile, civil society (mainly the younger population) shows rising environmental awareness, which resulted in several social movements opposing energy generation projects [93,94]. Nonetheless, their motivation is still commonly limited to reducing local environmental effects (as people are directly affected by some energy projects) [42]. Moreover, resistance is often not against non-RE generation projects, but against any form of generation (RE and non-RE), like e.g., hydro-energy [95–99] or even PV systems [42]. Like in Peru and Ecuador, Chilean politicians often lack awareness on broader and long-term impacts related to climate change for example, and they are usually driven by ideological and neoliberal ideas [100].

The lack of environmental awareness is particularly obvious in rural electrification efforts conducted in the past by these three countries. Although the use of off-grid PV systems generate long-term benefits for the environment in terms of pollution abatement, noise reduction, and climate change mitigation (as opposed to contaminating technologies), the representatives in charge of rural electrification acknowledged in all three countries that they do not account for these benefits in the evaluation of rural electrification investments. Indeed, only direct costs determine the decision for a rural electrification technology.

4.3.2. Environmental Impact

The oil drilling in the Peruvian and Ecuadorian Amazon basin has led to devastating impacts on the rich biodiversity of this area, while the mining industry in the Chilean Atacama desert has affected local/indigenous communities by exploiting the scarce water resources in the area [88,101–103]. The rural electrification efforts based on off-grid systems may help to reduce the environmental co-impacts in these areas. However, off-grid PV systems can also do harm, especially if waste (particularly the batteries) disposal or treatment is not considered.

The battery disposal of the off-grid PV systems is not even regulated in Ecuador and Peru, while it is voluntary in Chile. As a result, in Peru numerous batteries have been found abandoned in communities of remote areas [75], and in Ecuador batteries have even been buried by the users [13]. The nonexistence of a recycling infrastructure for the batteries and the low environmental awareness of users seem to be the main reasons for this behavior.

Negative environmental impacts arise not only from batteries. Unreliable systems (see above) have also led to additional problems related to a proper disposal of solar modules. Unfortunately, recycling of the systems is not regulated (neither considered in project designs) in the three countries, leading to additional negative environmental impacts.

4.4. Socio-Cultural Sustainability

4.4.1. Equity (Disparity)

Though Peru is still behind, the rural electrification rates of all three countries have registered substantial increases since the 1990s (see Figure 1). In spite of this positive trend, equity issues have emerged, particularly in Peru: Indeed, despite of notable electrification achievements, awareness regarding equity remains low in Peru, and the (EDCs) rejection of electrifying remote rural areas became obvious during the interviews. Consequently, regions that are most vulnerable and hard to reach have by far the lowest electrification rate [4].

In Chile, most rural communities have been electrified, but a (minimum) system capacity is not legally fixed. Therefore, representatives of the Ministry of Energy confessed that communities that are better organized and who placed higher requirements to the government usually received solutions with higher capacities than those who did not make specific requests. This trend has led to indigenous communities with a much lower electrification rate than other better organized ethnic groups [104].

In Ecuador, there is broader consensus on the importance of providing electricity for all. This may explain why, in the early 1990, the rural electrification rate in Ecuador already exceeded Chile's rate despite of a much lower GDP per capita. An equity issue remains, however, as microgrids have been installed to very few communities, while other communities without electricity still have to wait to leave behind matches and candles [13].

In all three countries, energy tariffs still diverge between different user groups despite of the subsidies for off-grid PV systems from the governments. For example, in Chile, users that were further away from urban centers had to pay higher tariffs (on-grid and off-grid), because tariffs were based on market conditions, and costs are higher in remote areas; this inequality has however been recently corrected by a new law on tariff equity [105]. In Peru, notwithstanding the cross-subsidy tariff, off-grid users with similar incomes but from different geographical areas still have varying electricity prices per kW/h. In Ecuador, inequities persist since user tariffs are not even regulated for off-grid PV systems, such that tariffs are fixed individually by each EDC.

4.4.2. Accuracy

Meeting the specific local needs and considering the socio-cultural reality of each community to assure accurate solutions has been an issue in the three countries for different reasons. In Ecuador, for instance, the government installed microgrids (which are more difficult to maintain) in communities where the necessary management skills to operate them are still lacking, thus making them inappropriate for the local circumstances [106]. In other Ecuadorian projects, Solar Home Systems (SHS) were installed without taking requirements of the community or needs of particular users (e.g., gender specific necessities) into account [74].

Chile and Peru faced accuracy issues regarding the capacity of the systems, which was usually too low and hence not sufficient for the energy needs of the households. In Chile, this led to situations where the users only had 1.5–2 h of electricity per day and were forced to use their traditional energy sources (candles, matches, or batteries) [71]. Nonetheless, Chile has recently acknowledged this shortcoming, and is shifting from basic electrification to a more holistic "energization" approach. The latter also targets the electrification of schools and health centers, providing systems with greater capacities according to the users' needs [42]. Furthermore, in Peru, the selection of technologies was often random due to the lacking technological know-how of the sponsors.

4.4.3. Social Acceptance

Experiences with social acceptance were mixed in the three countries, depending on the extent to which the local community was involved and participated in the projects.

In Ecuador, one of the few EDCs that successfully deployed off-grid PV systems got the community involved by creating an electrification committee (consisting of the head of each beneficiary household), a steering committee (members of the community to represent the EDC), and an elected local officer in charge of accounting [83]. Although this successful approach was considered an interesting model for the rest of country, it was not vigorously adopted by other EDCs [13].

In Chile, projects where communities were engaged, got organized, and actively helped to carry out the project were the most successful ones. However, many Chilean communities rejected off-grid PV systems because they previously heard about technical problems or restricted system capacities from neighboring communities. The negative word of mouth and the imposition of solutions they did not agree on made off-grid PV systems unacceptable for them [42].

In Peru, social scientists and NPOs explained that the difficult relation between the communities and the mining industry had caused reluctance from the rural population towards "strangers", such that social acceptance of energy projects implemented by foreigners (i.e., NPOs or EDCs) is problematic as a result of mistrust. Moreover, many projects conducted by Peruvian public EDCs that did not properly engage the users (e.g., for clearing the users' doubts) have been plagued by social acceptance issues that turned into high default payments. The most successful off-grid projects in Peru have been conducted by NPOs that worked with the communities, and adapted the technology to local needs.

4.4.4. Cultural Justice

The three Andean countries are culturally diverse, with multiple indigenous communities living in remote and rural areas [107,108]. This diversity has been recognized in Chile, where public officials and NPOs highlighted the need of respecting the local culture when implementing rural electrification projects.

The situation is different in Peru and Ecuador where officials involved in national electrification programs are unfortunately not yet aware of the relevance of culture for rural electrification [13]. In Peru, cultural aspects are hardly mentioned in national rural electrification programs designed by Peruvian officials (see for example [109]). In Ecuador, although the Constitution recognizes the rights of ethnic groups, their cultural values are in fact not taken into account. For instance, nomad indigenous communities in the Ecuadorian basin have been re-located to community centers built by the government to reduce the dispersion of the inhabitants and to facilitate electrification more easily [13].

4.5. Direct Comparison between the Andean Countries

Ecuador, Peru, and Chile have understood the need of a government intervention for providing electrification by off-grid PV systems to inhabitants of remote areas, but their approaches have been different. We have compared and rated these approaches regarding the indicators of sustainability considered in this paper. A summary of the comparisons of the rural electrification efforts in the three countries is illustrated in the spider graph in Figure 2, where the wider each point (for each indicator) is to the outside, the better its performance.

For instance, as shown by the indicator "funding" in Figure 2, we have highly rated the enormous efforts that Peru has made to ensure the affordability of off-grid PV systems for rural electrification. Indeed, the Peruvian administration has adopted a cross-subsidy scheme (which also aims to reduce economic inequities), which makes the tariff affordable to the users by providing funds for both the initial investment and the O&M of the systems. As opposed to Peru, Ecuador has no mechanism at all aimed at subsidizing O&M costs over the lifetime of the off-grid PV systems, while in Chile funds aimed at O&M are not ensured and need to be annually approved. Therefore, we rate the policies of Chile and Ecuador lower than those in Peru regarding the indicator "funding" (see Figure 2).

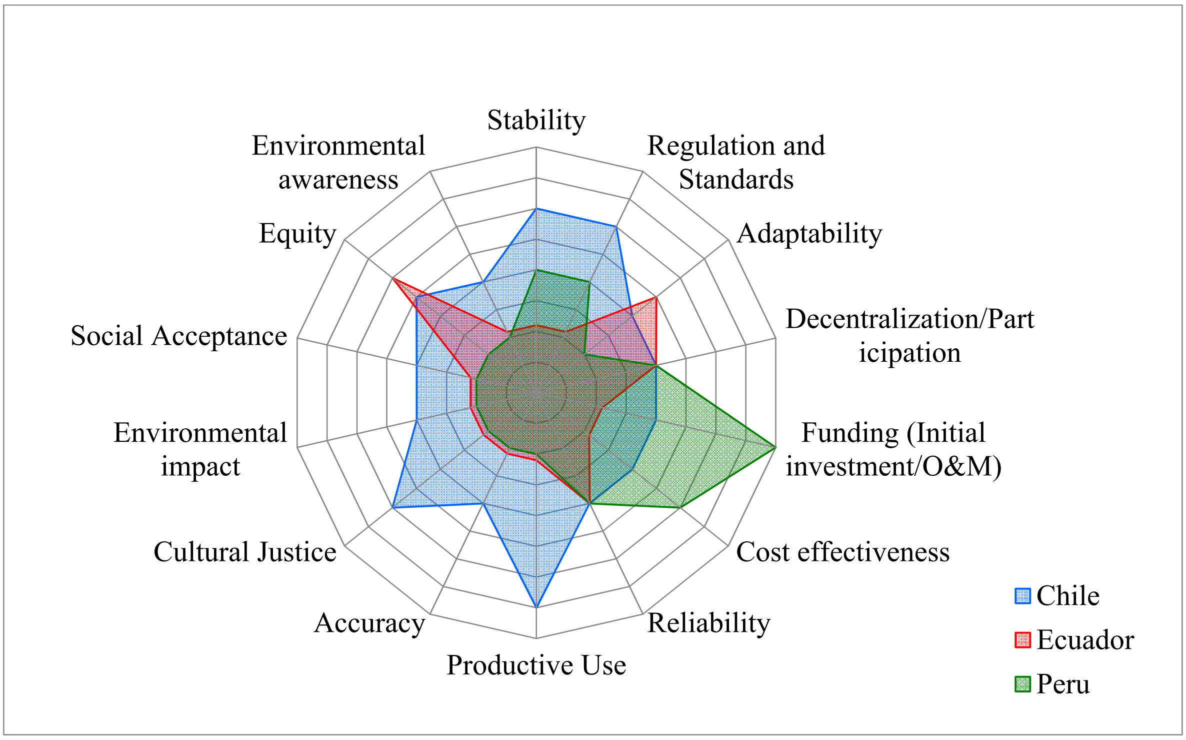

Figure 2. Assessment of approaches/policies in Chile, Ecuador, and Peru for rural electrification regarding each of the indicators of sustainability considered in this paper. Source: Own elaboration.

Failure in ensuring funding for O&M makes off-grid PV systems for rural electrification inevitably unreliable. This is why we have poorly rated the approaches/policies in Chile and Ecuador regarding "Reliability". However, the Peruvian case shows that ensuring the funding is not enough. Indeed, Peru provides financial assistance for O&M, but the off-grid PV systems deployed in Peru have still been unreliable. Causes are manifold, but the widespread outsourcing may have played a role; in Peru, installation, O&M, and even supervision and control have been outsourced to small private firms, which often do not have the required technical know-how.

Off-grid PV systems may be a cost-effective alternative for rural electrification in remote areas of the Andean countries. This fact was recognized first by Peruvian authorities. In addition, lifecycle cost calculations recently promoted by Chilean officials are leading to the substitution of diesel generators by off-grid solutions. In Ecuador, authorities have not conducted any cost studies yet, such that we evaluate the indicator "cost effectiveness" as poor.

As shown in Figure 2, we have rated the rural electrification approaches/policies for "Environmental awareness" and "Environmental impact" as poor in Chile, Ecuador, and Peru. Indeed, environmental awareness is still low in the three cases, though Chile came off better thanks to its younger population. However, due to lacking awareness, potential negative environmental impacts from off-grid PV systems (such as the battery disposal) have not been considered in the three countries.

Successful projects for rural electrification based on off-grid PV systems show the importance of respecting and taking the socio-cultural reality of each community into account. However, this has not yet been acknowledged in Peru and Ecuador. In these countries, the culture of the communities is often not considered in the design and implementation of the projects, which in turn has led to inaccurate solutions (i.e., too small power capacities), mistrust, and ultimately to the rejection of projects in Peru. Although in Ecuador the Constitution proclaimed special rights to indigenous people for cultural justice, these rights are not considered in the projects, such that de facto they do not exist. Indeed, there is a discrepancy between their claims (what is officially stated) and reality (how the policies are implemented). This is why we have poorly rated the approaches/policies in Ecuador and Peru for rural electrification regarding "Cultural Justice", "Social acceptance" and "Accuracy". Chileans on the other hand perform better on these indicators, since they appear to have understood the importance of respecting the cultural values of the communities not only on paper, but also in the implementation of the projects. Moreover, Chile is currently improving the accuracy of its solutions for rural electrification by considering the users' energy needs in the design of the projects.

We evaluate the Chilean and Ecuadorian "Equity" policies positively, given the awareness among all actors of the need to electrify the whole country. However, disparities remain in the power capacity of the deployed systems in Chile, as better-organized communities have greater chances of receiving off-grid solutions with a higher power capacity. Peru on the other hand performs poor on this indicator despite of the cross subsidy tariff, as awareness on equity in rural electrification was found to be low among the actors who implement the projects. Neoliberal policies embraced in Chile and Peru may partially explain the lack of awareness for equity in Peru, and the approach used in Chile to privilege better-organized communities.

Strengthened and stable formal institutions have shown to be a precondition for ensuring the sustainability of projects for rural electrification based on off-grid PV systems. Chile outperforms Peru and Ecuador in the "stability" of its institutions. The instability of institutions in the latter cases became apparent in terms of changing decision makers (Peruvian case) or the substitution of whole organizations (several Ministries in Ecuador). Institutional instability has resulted in inconsistent laws or lacking regulations; furthermore, it has made the enforcement of the few adopted regulations difficult and provided incentives for opportunistic behavior (since people expect rules and regulators to disappear). The causes of institutional instability are often complex and manifold, but, in both countries, it seems that mistrust in institutions may be playing an important role. This is why we poorly rate both Peru and Ecuador on their institutional "stability" and "regulations".

Successful off-grid PV projects for rural electrification have shown the importance of having a strong formal institution (such as an agency) with a flexible and decentralized structure, able to adapt to the (changing) circumstances. A decentralized agency may contribute to the transfer of know-how to rural areas and better engage the communities. The lack of such an agency in Peru explains its poor score on "adaptability". In this regard Ecuador is in better shape, since the ongoing merging of the 11 EDCs may allow them to create a stronger institution, but only if a decentralized structure is maintained and the operation at a local level remains reasonably flexible. Chile also missed to establish a decentralized rural electrification agency for residential systems, but it has some agencies (such as INDAP) that have shown remarkable adaptability and have promoted the successful adoption of off-grid solutions aimed at productive use in rural communities. The program of PV-powered water pumps successfully sponsored by INDAP therefore explains Chile's high rate on "productive use".

Decentralization (understood as the transfer of funds and responsibilities to local officials) may facilitate the engagement of the communities and improve the accuracy. However, projects sponsored by local official (such as municipalities) in the Andean countries show that if decentralization is not accompanied by the transfer of know-how, projects can quickly become unsustainable. All three countries have made attempts of decentralization to different degrees, but all of them have failed to accompany their financial/administrative decentralization with the indispensible transfer of know-how to local players. Moreover, numerous NGO initiatives in the three countries have demonstrated that a participative approach and the engagement of the communities prevent alienation and contribute to the sustainability of the rural electrification projects based on off-grid systems. However, openness to participation of the communities is not widespread in the Andean countries and therefore additional efforts are required regarding "decentralization and participation".

5. Discussion

Ecuador, Peru and Chile share similar challenges for electrifying remote areas where a grid expansion may be unviable. In these areas, the countries have deployed off-grid solutions for electrification. Inhabitants of these areas are culturally diverse and have dissimilar necessities, but they are predominantly poor and unable to afford neither the initial investment nor the O&M of off-grid PV systems.

In this paper, we critically assess the sustainably of rural electrification programs (based on off-grid PV systems) in these Andean countries. Our assessment was based on a set of indicators corresponding to the four dimensions of sustainability considered in this study: institutional, economical, environmental, and socio-cultural. These dimensions are strongly interwoven and are deeply interdependent.

Therefore, ensuring the sustainability of off-grid PV systems requires a multidimensional and integrated approach. For instance, Peru strongly focused on parts of the economic dimension by allocating funds to the systems' initial investment costs as well as to the O&M costs. However, this one-dimensional approach frequently led to project failures, payment defaults, and inhibited seizing opportunities regarding productive uses of off-grid PV systems. Part of the problem was that Peruvian officials consistently ignored the participation and engagement of the communities such that, despite the allocation of O&M funding, the systems turned to be unreliable. As the short operational period of the systems could not compensate for the investment, the lack of attention to the socio-cultural dimension of sustainability has in turn made the projects in Peru economically unsustainable.

Those cases in which a multidimensional and integrated approach was applied exhibited remarkable success. For example, the PV-powered water pump program conducted by INDAP in Chile boosted the productivity of small farmers in remote areas of the country, thus increasing their income, and allowing them to cover the O&M costs of the systems. The multidimensionality of the program explains its success. It was sponsored and conducted by a decentralized agency whose employees work in close contact with farmers. Its structure, adapted to the farmers' local conditions, allowed the agency to quickly respond to issues, and to provide accurate solutions according to the users' real needs, which in turn led to social acceptance.

The success of the PV-powered water pump program in Chile shows how strong and decentralized formal institutions are fundamental for ensuring the accuracy and reliability of the systems, transferring the required know-how, facilitating the productive use of the energy, and gaining the social acceptance. Indeed, the decentralized structure of INDAP with its employees working in close contact with final users, could serve as a model for other countries. These lessons are particularly important considering the recentralization plans in Ecuador (where the 11 EDCs are merged to one EDC). Although this fusion may facilitate the sharing of know-how and economies of scales, it may be significantly negative for rural electrification efforts in Ecuador if it implies losing adaptability of the resulting single EDC, further restricting the engagement between the ground operatives and final users.

Boosting productive activities explains Ecuador's plans to deploy microgrids for rural electrification (whose capacity may power a community of dozens of inhabitants). Although increasing the income of the community appears to be laudable, it arises an equity dilemma: If project funds for rural electrification are limited, a more expensive solution with a higher capacity could only be provided to a very limited number of communities, while others may have to wait for years to get electrified. This dilemma underlines the interdependency of sustainability dimensions and highlights the need for a balanced multidimensional approach for ensuring the sustainability of off-grid PV systems. However, as shown in Figure 2, some countries have paid more attention to some dimensions than others, but the three analyzed countries have consistently ignored the importance of the institutional dimension.

Indeed, the absence of strengthened and stable formal institutions appears to be a major drawback in the Andean countries that, by inhibiting law enforcement, also compromises the environmental and socio-cultural sustainability of rural electrification efforts. This problem is particularly apparent in Ecuador where institutional instability has led to changing regulations that are often inconsistent with the Constitution. For instance, although anchored in the Constitution, both environmental protection and indigenous rights are frequently disregarded by Ecuadorian decision makers. Moreover, in Peru, people's distrust in formal institutions has negatively affected the social acceptance of rural electrification projects. Chile, in contrast, has more stable institutions than its peers, but its highly centralized policies as well as a neoliberal vision embraced by the Chilean administrations constrain the operative role of its formal institutions. Some small-scale projects in Chile failed due to the lack of a decentralized public agency focused on ensuring the O&M of the installed systems.

The analyzed cases highlight the fact that the dimensions of the sustainability (institutional, economical, environmental, and socio-cultural) are strongly interwoven and are deeply interdependent. As shown above, successful rural electrification projects (based on off-grid PV systems) in the Andean countries were those within which all the dimensions of the sustainability are ensured. Therefore, ensuring the sustainability of rural electrification projects in Ecuador, Peru and Chile (and likely in any other country) requires an integrated and holistic approach.

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References

1. International Energy Agency (IEA). World Energy Outlook. Electricity Access Database. 2015. Available online: http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/ (accessed on 16 December 2015).

2. United Nations General Assembly. *Transforming Our World: The 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly on 25 September 2015*; United Nations: New York, NY, USA, 2015. Available online: http://www.un.org/ga/search/view_doc.asp (accessed on 14 October 2016).
3. World Bank. *World Bank Indicators*; Producer and Distributor; The World Bank: Washington, DC, USA, 2017. Available online: http://databank.worldbank.org/data/home.aspx (accessed on 21 February 2017).
4. Ministerio de Energía y Minas (MEM). *Plan Nacional De Electrificacion Rural (PNER) Periodo 2016—2025*; El Peruano: Lima, Peru, 2015. (In Spanish)
5. Ten, M. *Revisión de los Resultados de la Operación 2608/OC-EC: Electrificación Rural y Urbano-Marginal del Ecuador*; Programa de Electrificación Rural y Urbano-Marginal (FERUM) (IADB): Washington, DC, USA, 2013. (In Spanish)
6. Ministerio de Desarrollo Social. Banco Integrado de Proyectos (BIP). 2016. Available online: http://bip.ministeriodesarrollosocial.gob.cl/bip-consulta/ (accessed on 14 September 2016). (In Spanish)
7. Ministerio de Energía y Minas (MEM). *Proyecto De Mejoramiento de la Electrificación Rural Mediante Aplicación de Fondos Concursables II (FONER II). Manual de Operaciones del Proyecto*; Reviewed August 2015; Controlaría General de la República: Lima, Peru, 2011. (In Spanish)
8. Estay, C. *Remoción de Barreras para la Electrificación Rural con Energías Renovables. Informe Catastro de Campo XI Region*; Comisión Nacional de Energía: Santiago de Chile, Chile, 2006. (In Spanish)
9. Nieuwenhout, F.D.J.; Van Dijk, A.; Lasschuit, P.E.; Van Roekel, G.; Van Dijk, V.A.P.; Hirsch, D.; Wade, H. Experience with solar home systems in developing countries: A review. *Prog. Photovolt. Res. Appl.* **2001**, *9*, 455–474. [CrossRef]
10. International Renewable Energy Agency (IRENA). Accelerating Off-Grid Renewable Energy. Second International Off-Grid Renewable Energy Conference. Key Findings and Recommendations. 2014. Available online: http://www.irena.org/DocumentDownloads/Publications/IRENA_2nd_IOREC_2015.pdf (accessed on 3 March 2017).
11. Elusakin Julius, E.; Olufemi, A.O.; Chuks, D.J. Challenges of sustaining off-grid power generation in Nigeria rural communities. *Afr. J. Eng. Res.* **2014**, *2*, 51–57.
12. Mabuza, L.; Brent, A.; Mapako, M. The Transfer of Energy Technologies in a Developing Country Context towards Improved Practice from Past Successes and Failures. 2007. Available online: https://repository.up.ac.za/handle/2263/4854 (accessed on 11 October 2016).
13. Feron, S.; Heinrichs, H.; Cordero, R.R. Are the Rural Electrification Efforts in the Ecuadorian Amazon Sustainable? *Sustainability* **2016**, *8*, 443. [CrossRef]
14. Ilskog, E. Rural Electrification Sustainability Indicators—Manual for Field Workers. 2008. Available online: http://swepub.kb.se/bib/swepub:oai:DiVA.org:kth-9132?tab2=abs&language=en (accessed on 27 June 2014).
15. Derakhshan, F. On Sustainability in Local Energy Planning. Ph.D. Thesis, Lund University, Lund, Finland, 2011.
16. Sharma, T.; Balachandra, P. Benchmarking sustainability of Indian electricity system: An indicator approach. *Appl. Energy* **2015**, *142*, 206–220. [CrossRef]
17. Wimmler, C.; Hejazi, G.; de Oliveira Fernandes, E.; Moreira, C.; Connors, S. Multi-Criteria Decision Support Methods for Renewable Energy Systems on Islands. *J. Clean Energy Technol.* **2015**, *3*, 185–195. [CrossRef]
18. Reddy, B.S. *Measuring and Evaluating Energy Security and Sustainability: A Case Study of India*; WP-2015-08; Indira Gandhi Institute of Development Research: Mumbai, India, 2015.
19. Gollwitzer, L. *Community-Based Micro Grids: A Common Property Resource Problem*; STEPS Working Paper 68; Steps Center: Brighton, UK, 2014; ISBN 978-1-78118-192-8.
20. Frame, D.; Tembo, K.; Dolan, M.J.; Strachan, S.M.; Ault, G.W. A community based approach for sustainable off-grid PV systems in developing countries. In Proceedings of the 2011 IEEE Power and Energy Society General Meeting, Detroit, MI, USA, 24–29 July 2011; pp. 1–7.
21. Retnanestri, M. The I3A Framework–Enhancing the Sustainability of Off-Grid Photovoltaic Energy Service Delivery in Indonesia. Ph.D. Thesis, University of New South Wales (UNSW), Sydney, Australia, 2007.
22. Holland, R.; Perera, L.; Sanchez, T.; Wilkinson, R. Decentralised Rural Electrification: The Critical Success Factors. Experience of ITDG (Intermediate Technology Developmental Group). 2006. Available online: http://www.its.caltech.edu/~e105/readings/Rural_Electrification.pdf (accessed on 2 August 2015).

23. Sims, R.E.H.; Schock, R.N.; Adegbululgbe, A.; Fenhann, J.; Konstantinaviciute, I.; Moomaw, W.; Nimir, H.B.; Schlamadinger, B.; Torres-Martínez, J.; Turner, C.; et al. Energy supply. In *Climate Change 2007: Mitigation*; Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.
24. Fischedick, M.; Borbonus, S.; Scheck, H. Towards Global Energy Governance-Strategies for Equitable Access to Sustainable Energy. *Policy Pap.* **2011**, *34*, 12.
25. Brent, A.C.; Rogers, D.E. Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context. *Renew. Energy* **2010**, *35*, 257–265. [CrossRef]
26. Mainali, B. Sustainability of Rural Energy Access in Developing Countries. Ph.D. Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2014.
27. Dincer, I.; Acar, C. A review on clean energy solutions for better sustainability. *Int. J. Energy Res.* **2015**, *39*, 585–606. [CrossRef]
28. Dunmade, I. Indicators of sustainability: Assessing the suitability of a foreign technology for a developing economy. *Technol. Soc.* **2002**, *24*, 461–471. [CrossRef]
29. Mainali, B.; Pachauri, S.; Rao, N.D.; Silveira, S. Assessing rural energy sustainability in developing countries. *Energy Sustain. Dev.* **2014**, *19*, 15–28. [CrossRef]
30. Garniati, L.; Owen, A.; Kruijsen, J.; Ishadamy, Y.; Wibisono, I. Interface between appropriate technology and sustainable energy policy in vulnerable societies. *Sustain. Cities Soc.* **2014**, *12*, 9–15. [CrossRef]
31. Chaurey, A.; Kandpal, T.C. Assessment and evaluation of PV based decentralized rural electrification: An overview. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2266–2278. [CrossRef]
32. Cook, P. Infrastructure, rural electrification and development. *Energy Sustain. Dev.* **2011**, *15*, 304–313. [CrossRef]
33. Khandker, S.R.; Barnes, D.F.; Samad, H.A. Welfare impacts of rural electrification: A panel data analysis from Vietnam. *Econ. Dev. Cult. Chang.* **2013**, *61*, 659–692. [CrossRef]
34. Stringer, L.C.; Paavola, J. Participation in environmental conservation and protected area management in Romania: A review of three case studies. *Environ. Conserv.* **2013**, *40*, 138–146. [CrossRef]
35. Polack, A. Drivers and Barriers of Renewable Energy in the Electrification of Vanuatu. Ph.D. Thesis, Murdoch University, Murdoch, Australia, 2010.
36. Rosen, M.A. Energy sustainability: A pragmatic approach and illustrations. *Sustainability* **2009**, *1*, 55–80. [CrossRef]
37. Bhattacharyya, S.C. Energy access programmes and sustainable development: A critical review and analysis. *Energy Sustain. Dev.* **2012**, *16*, 260–271. [CrossRef]
38. Ribeiro, F.; Ferreira, P.; Araújo, M. The inclusion of social aspects in power planning. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4361–4369. [CrossRef]
39. Lähtinen, K.; Myllyviita, T.; Leskinen, P.; Pitkänen, S.K. A systematic literature review on indicators to assess local sustainability of forest energy production. *Renew. Sustain. Energy Rev.* **2014**, *40*, 1202–1216. [CrossRef]
40. Stake, R.E. *Multiple Case Study Analysis*; Guilford Press: New York, NY, USA, 2013.
41. George, A.L.; Bennett, A. *Case Studies and Theory Development in the Social Sciences*; MIT Press: Cambridge, MA, USA, 2005.
42. Feron, S.; Heinrichs, H.; Cordero, R.R. Sustainability of rural electrification programs based on off-grid photovoltaic (PV) systems in Chile. *Energy Sustain. Soc.* **2016**, *6*, 32. [CrossRef]
43. Feron, S.; Cordero, R.R. Sustainability of Rural Electrification Programs based on off-grid Photovoltaic Systems in Peru. *Int. J. Sustain. Dev.* **2017**. submitted.
44. Pressacco, C.F.; Rivera, S. Democracia, participación y espacio local en Chile. *Papel Político* **2015**, *20*, 65–89. (In Spanish) [CrossRef]
45. Ministerio de Economia y Finanzas (MEF). Proyecto de Presupuesto. Anexo 2. Available online: https://www.mef.gob.pe/index.php?option=com_content&view=article&id=4129&Itemid=101156&lang=es (accessed on 29 January 2016). (In Spanish)
46. Escudero-Sánchez, C.C.L. Desafíos de la descentralización para la gestión del patrimonio cultural en el Ecuador. *Santiago* **2015**, *136*, 197–213. (In Spanish)
47. Yitzhaki, S. Relative deprivation and the Gini coefficient. *Q. J. Econ.* **1979**, *93*, 321–324. [CrossRef]

48. Ministerio de Relaciones Exteriores. Informe Anual Comercio Exterior de Chile 2014–2015. 2015. Available online: https://www.direcon.gob.cl/wp-content/uploads/2015/07/Informe-anual-de-Comercio-Exterior-de-Chile-2014-2015.pdf (accessed on 4 February 2016). (In Spanish)
49. Ministerio de Energía y Minas (MEM). *Anuario Minero 2015. Estadística Minera*; Biblioteca Nacional de Peru: Lima, Peru, 2016; Available online: http://www.minem.gob.pe/_publicaSector.php?idSector=1&idCategoria=19 (accessed on 20 August 2016). (In Spanish)
50. Ministerio Coordinador de Sectores Estrategicos (MICSE). Políticas Energéticas en Ecuador. 2014. Available online: http://www.nist.gov/iaao/upload/3-_Presentacion_Politica_Energia__v2-pptx_DARWIN_COSTA.pdf (accessed on 24 August 2015). (In Spanish)
51. World Integrated Trade Solution. Ecuador Fuels Exports by Country 2015. 2015. Available online: http://wits.worldbank.org/CountryProfile/en/Country/ECU/Year/LTST/TradeFlow/Export/Partner/by-country/Product/27-27_Fuels (accessed on 20 September 2017).
52. Secretaría Nacional de Planificación y Desarrollo (Senplades). *Plan Nacional de Desarrollo/Plan Nacional para el Buen Vivir 2013–2017*; Gobierno Nacional de la República del Ecuador: Quito, Ecuador, 2013; ISBN 978-9942-07-448-5. (In Spanish)
53. Sánchez, L.; Reyes, O. *La Demanda de Gasolinas, Gas Licuado de Petróleo y Electricidad en el Ecuador. Elementos Para una Reforma Fiscal Ambiental*; CEPAL: Santiago de Chile, Chile, 2016; p. S.16-00529.
54. Vera, I.A.; Langlois, L.M.; Rogner, H.H.; Jalal, A.I.; Toth, F.L. Indicators for sustainable energy development: An initiative by the International Atomic Energy Agency. In *Natural Resources Forum*; Blackwell Publishing Ltd.: Oxfort, UK, 2005; Volume 29, pp. 274–283.
55. Ministerio de Electricidad y Energias Renovables (MEER). Available online: http://www.energia.gob.ec/coca-codo-sinclair/# (accessed on 28 August 2015). (In Spanish)
56. Comision Nacional de Energia (CNE). Balance Nacional de Energía. Available online: http://energiaabierta.cne.cl/visualizaciones/balance-de-energia/ (accessed on 19 September 2015). (In Spanish)
57. CONELEC. Centrales Renovables No Convencionales. Available online: http://www.conelec.gob.ec/images/documentos/doc_10238_CENTRALES_RENOVABLES_NO_CONVENCIONAL.pdf (accessed on 18 June 2015). (In Spanish)
58. Comite de Operacion Economica del Sistema Interconectado Nacional (COES) (NA). Producción de Energía Eléctrica por Tipo de Generación del Coes 2013–2014. Available online: http://www.coes1.org.pe/post-operacion/Publicaciones/WebPages/estadisticaanual.aspx (accessed on 30 January 2016). (In Spanish)
59. Instituto Nacional de Estadisticas y Censos (INEC). REDATAM. Available online: http://www.inec.gob.ec/estadisticas/?option=com_content&view=article&id=104&Itemid=76 (accessed on 3 December 2015).
60. Instituto Nacional de Estadisticas (INE) (NA). Chile: Censo de Población y Vivienda. Available online: http://www.ine.cl/canales/chile_estadistico/censos/censo_poblacion_vivienda.php (accessed on 17 January 2014). (In Spanish)
61. Central de Energía (NA). Autoridad—Coordinación. Available online: http://www.centralenergia.cl/actores/autoridad-energia-chile/ (accessed on 30 April 2016). (In Spanish)
62. Ministerio de Electricidad y Energias Renovables (MEER). Plan Estratégico Institucional 2014–2017. Available online: http://www.energia.gob.ec/wp-content/uploads/downloads/2014/09/PLAN-ESTRATÉGICO-2.pdf (accessed on 17 October 2014). (In Spanish)
63. Ministerio de Energía y Minas (MEM). *Reglamento De Organización y Funciones (Rof)*; El Peruano: Lima, Peru, 2007. (In Spanish)
64. Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN). Informe N° 063-2015-GART Gerencia Adjunta de Regulación Tarifaria División de Distribución Eléctrica. Fijación del Cargo RER Autónomo Para el Suministro de Electricidad con Recursos Energéticos Renovables en Áreas No Conectadas a Red Publicación del Proyecto de Resolución. 2015. Available online: http://www.osinergmin.gob.pe/seccion/centro_documental/gart/procesosregulatorios/electricidad/fijacion-cargo-rera/2015/INF_063_2015_Fijación_del_Cargo_RER_Autónomo.pdf (accessed on 8 November 2016). (In Spanish)
65. Levitsky, S.; Murillo, M.V. Construyendo instituciones sobre cimientos débiles: Lecciones desde América Latina. *P. Rev. Cienc. Polít.* **2012**, *3*, 17–44.
66. Aguilar, J.; Zepeda, R. Política neoliberal y democracia en América Latina. In *Contextualizaciones Latinoamericanas*; No.9; Universidad de Guadalajara: Guadalajara, Mexico, 2013.

67. Stern, J.; Cubbin, J. *Regulatory Effectiveness: The Impact of Regulation and Regulatory Governance Arrangements on Electricity Industry Outcomes*; World Bank-Free PDF; World Bank: Washington, DC, USA, 2005; Volume 3536.
68. Asamblea Nacional República del Ecuador. Ley Orgánica del Servicio Público de Energía Eléctrica. Tercer Suplemente. Año II—No 418. Quito, 16 January 2015. Available online: http://www.regulacionelectrica.gob.ec/ley-organica-de-servicio-publico-de-energia-electrica-da-paso-a-la-creacion-de-la-arconel/ (accessed on 21 February 2017). (In Spanish)
69. Pyhala, A. Institutions, Participation, and Protected Area Management in Western Amazonia. In *Commons in an Age of Globalisation, Proceedings of the Ninth Conference of the International Association for the Study of Common Property, Victoria Falls, Zimbabwe, 17–21 June 2002*; IASCP: Victoria Falls, Zimbabwe, 2002; pp. 17–21.
70. Deuman. Evaluación Ex-Post del Primer Proyecto de Electrificación Mediante Sistemas Fotovoltaicos en las Comunas de Tortel, Villa O'Higgins y Cochrane de la Provincia de Capitán Prat, Región de Aysén del General Carlos Ibáñez del Campo. 2012. Available online: http://dataset.cne.cl/Energia_Abierta/Estudios/Minerg/23_Evaluación%20%20Expost%20Sistemas%20FV%20Provincia%20Capitán%20Prat%20Reg%20%20Aysén_Serv%20Ing%20Deuman_584105-10-LE12.pdf (accessed on 11 January 2015). (In Spanish)
71. Covarrubias, F.; Irarrázaval, I.; Galáz, R. *Programa de Asistencia a la Gestión del Sector de la Energía: Desafíos de la Electrificación Rural en Chile*; Banco Internacional de Reconstrucción y Fomento: Washington, DC, USA, 2005. (In Spanish)
72. Gobierno Regional de Aysén. Sistemas de Generacion Fotovoltaicos Varios Sectores Comuna de Aysen CODIGO BIP: 30125568-0. Available online: https://www.mercadopublico.cl/Procurement/Modules/Attachment/ViewAttachment.aspx?enc=POxTpc8k5kEehmdX82SavZIQCfSKkB5w%2fMuND7DysolmQMtod18DSfVAjxSA77MOtaEelk6qsw6Y804hSA6nr45%2b8ndDK%2b3WmB23KeufdQIbaBcUcpmlF9E9Z5TiT00pEgAvs1lvZFCICIDRphX58IpxZyTMBIE5zvsj1il2HWizs4gLOxZyAfrovwOwyuFqPN6TJw%2bUKvPU0x08o6ZStxBbIsfOB9ibwT8rQoSADfPOjWko4sZCKexwXnIlpzGoaBPHPa3ci527OsAIP7qYdcSAcRApjPp3lhdwjfq QieKylQ%2fSUyz6IEGSYceVDRfs (accessed on 22 September 2016).
73. Rodriguez, H. Programa Remoción de Barreras Para la Electrificación Rural. UNDP-GEF Project (Project CHI/00/G32 (11799). 2012. Available online: https://www.thegef.org/sites/default/files/project_documents/843_1320_Chile_CCM_TE.pdf (accessed on 4 April 2015). (In Spanish)
74. Fundación Ecuatoriana De Tecnología Apropiada (FEDETA). *Modelo de Gestión para Sistemas Energéticos Aislados—Articulación Energética Territorial para Poblaciones Indígenas de la Región Amazónica Ecuatoriana*; FEDETA: Quito, Ecuador, 2014. (In Spanish)
75. Jané La Torre, E.; Palacios, D. *Estado Situacional de la Prestación del Servicio Electrico Mediante Sistemas Fotovoltaicos Autónomos*; Gerencia de Fiscalización Eléctrica, Osinergmin: Lima, Peru, 2015. (In Spanish)
76. Argomedo, R. Financiamiento Estatal en Chile. In Proceedings of the Programa Electrificación Rural (PER) Workshop on Energy Storage for Sustainable Development, Rio de Janeiro, Brazil, 16–17 April 2015. (In Spanish)
77. Consejo Nacional de Electricidad (CONELEC). *Plan Maestro de Electrificación 2012–2021*; CONELEC: Deland, FL, USA, 2012.
78. Congreso de la Republica. *Ley General de Electrificación Rural LEY No 28749*; El Peruano: Lima, Peru, 2006. (In Spanish)
79. Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN). *Resolución de Consejo Directivo N° 235-2010-OS/CD*; OSINERGMIN: Lima, Peru, 2010. (In Spanish)
80. Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN). *Fijación de la Tarifa Rural para Sistemas Fotovoltaicos 2014–2018*; Publicación del Proyecto de Resolución. Expediente N° 0248-2014-GART; OSINERGMIN: Lima, Peru, 2014. (In Spanish)
81. Ministerio de Desarrollo Social. Metodología de Formulación y Evaluación de Proyectos de Electrificación Rural. 2015. Available online: http://sni.ministeriodesarrollosocial.gob.cl/fotos/11%20Metodolog%C3%ADa%20de%20Electrificación%20Rural%202015.pdf (accessed on 11 November 2015). (In Spanish)
82. Comision Nacional de Energia (CNE). Resolucion Exenta No. 137. 2009. Available online: http://www.cne.cl/archivos_bajar/Resolucion%20Exenta%20%20N137.pdf (accessed on 9 September 2016). (In Spanish)

83. Urdiales Flores, L.E. Procedimiento para la Electrificación en Zonas Aisladas: Caso Cantón Taisha, Morona Santiago. Master's Thesis, Universidad de Cuenca, Cuenca, Ecuador, 2015. Available online: http://dspace.ucuenca.edu.ec/handle/123456789/21428 (accessed on 5 May 2015). (In Spanish)
84. Doberti, G. ERNC en la Agricultura familiar campesina y Programa Nacional de Bombeo Fotovoltaico INDAP. 2013. Available online: http://docplayer.es/3949063-Ernc-en-la-agricultura-familiar-campesina-y-programa-nacional-de-bombeo-fotovoltaico-indap-ministerio-de-agricultura-indap.html (accessed on 5 June 2015). (In Spanish)
85. Ministerio de Electricidad y Energias Renovables (MEER). *Informe—Rendición de Cuentas*; Ministerio de Electricidad y Energias Renovables (MEER): Quito, Ecuador, 2014. (In Spanish)
86. Feron, S. Sustainability of Off-Grid Photovoltaic Systems for Rural Electrification in Developing Countries: A Review. *Sustainability* **2016**, *8*, 1326. [CrossRef]
87. Ministerio de Desarrollo e Inclusion Social (MIDIS). *Manual de Operaciones Fondo para la Inclusión Económica en Zonas Rurales (FONIE)*; MIDIS: Lima, Peru, 2013. (In Spanish)
88. Fileccia, C.M.; Caravaggio, N.; Conte, E. Buen Vivir: Sumak Kawsay and reality. In Proceedings of the 25th Annual EAEPE Conference, Paris, France, 7–9 November 2013. Available online: https://www.academia.edu/15369034/Buen_Vivir_between_Sumak_Kawsay_and_reality (accessed on 22 March 2015).
89. Liebenthal, A.; Salvemini, D. *Promoting Environmental Sustainability in Peru: A Review of the World Bank Group's Experience (2003–2009)*; IEG Working Paper 2011/1; IFC, MIGA, World Bank: Washington, DC, USA, 2011.
90. De Queiroz, J.S.; Silva, F.; Ipenza, C.; Hernick, C.; Batallanos, L.; Griswold, D.; Rogers, A.E. *Peru Tropical Forest and Biodiversity Assessment*; US Foreign Assistance Act, Section 118/119 Report August; Sun Mountain International and The Cadmus Group, Inc.: Quito, Ecuador, 2014.
91. Lanegra, I. Institucionalidad ambiental peruana. In *Agenda de Investigación en Temas Socioambientales en el Perú: Una Aproximación Desde las Ciencias Sociales*; CISEPA-PUCP | INTE | Facultad de Ciencias Sociales | GEA: Lima, Peru, 2014.
92. United Nations Economic Commission for Latin America and the Caribbean (ECLAC); Organisation for Economic Cooperation and Development (OECD). Environmental Performance Reviews Peru. Highlights and Recommendations. 2016. Available online: https://www.oecd.org/environment/country-reviews/16-00312-environmental%20performance%20review-peru-web.pdf (accessed on 12 September 2016).
93. Scherman, A.; Arriagada, A.; Valenzuela, S. Student and environmental protests in Chile: The role of social media. *Politics* **2015**, *35*, 151–171. [CrossRef]
94. Schaeffer, C. Democratizing the Flows of Democracy: Patagonia Sin Represas in the Awakening of Chile's Civil Society. In *Social Movements in Chile*; Donoso, S., von Bülow, M., Eds.; Palgrave Macmillan: New York, NY, USA, 2017; ISBN 978-1-349-95091-1.
95. Hernando, A. *El sector Energético en Chile y la Agenda de Energía 2014: Algunos Elementos Para la Discusión*; Centro de Estudios Publicos: Santiago de Chile, Chile, 2014. (In Spanish)
96. Comisión Ciudadana-Técnico-Parlamentaria para la Política y la Matriz Eléctrica (CCTP). Chile Necesita una Gran Reforma Energética. 2011. Available online: http://www.patagoniasinrepresas.cl/final/dinamicos/chile_necesita_una%20gran_reforma_energetica.pdf (accessed on 17 June 2016). (In Spanish)
97. Barton, J.R. Climate change adaptive capacity in Santiago de Chile: Creating a governance regime for sustainability planning. *Int. J. Urban Reg. Res.* **2013**, *37*, 1916–1933. [CrossRef]
98. Comunidades Energeticas (NA). Luces y Sombras Para las Comunidades Energéticas Aisladas en Patagonia. Documento de Trabajo. REDES-Conicyt. N° 14001. Available online: http://www.comunidadesenergeticas.com/wp-content/uploads/2016/04/Luces-y-sombras-para-las-comunidades-energéticas-aisladas-en-Patagonia.23-marzo.pdf (accessed on 10 September 2016).
99. Newbold, J. Balancing economic considerations and the rights of indigenous people. The Mapuche people of Chile. *Sustain. Dev.* **2004**, *12*, 175–182. [CrossRef]
100. Parker, C.; Letelier, M.; Muñoz, J. Elites, climate change and agency in a developing society: The Chilean case. *Environ. Dev. Sustain.* **2013**, *15*, 1337–1363. [CrossRef]
101. Bass, M.S.; Finer, M.; Jenkins, C.N.; Kreft, H.; Cisneros-Heredia, D.F.; McCracken, S.F.; Di Fiore, A. Global conservation significance of Ecuador's Yasuní National Park. *PLoS ONE* **2010**, *5*, e8767. [CrossRef] [PubMed]
102. Damonte, G. Ciencias Sociales y gran minería: Una agenda de investigación. In *Minería, Turismo y Agroindustria. Nuevos Ejes Económicos*; Damonte, G., Fuller, N., Valcárcel, M., Eds.; PUCP: Lima, Peru, 2009; pp. 7–31.

103. Romero, H.; Méndez, M.; Smith, P. Mining development and environmental injustice in the Atacama Desert of Northern Chile. *Environ. Justice.* **2012**, *5*, 70–76. [CrossRef]
104. Ministerio de Desarrollo Social. Encuestra Casen. 2012. Available online: http://www.redatam.org/redchl/mds/casen/casen2011/Index.html (accessed on 28 January 2016). (In Spanish)
105. Ministerio de Energia. Congreso Nacional aprueba proyecto de Equidad Tarifaria. 2016. Available online: http://www.energia.gob.cl/tema-de-interes/congreso-nacional-aprueba-proyecto (accessed on 1 June 2016). (In Spanish)
106. Leid, L.H. Llegó La Luz: A Case Study of the Impacts of Solar Photovoltaic Electricity in Las Balsas, Ecuador. Ph.D. Thesis, University of Texas, Austin, TX, USA, 2014. Available online: https://tdl-ir.tdl.org/tdl-ir/handle/2152/26125 (accessed on 31 March 2015).
107. Rexel Foundation and Microsol. Study of the Potential to Spread Energy Efficiency's Carbon Programs in Andean Countries. Available online: http://www.microsol-int.com/recursos/2014_0627_Microsol_Rexel_study_final_report_(WITH_conclusions)_rev.pdf (accessed on 9 November 2016).
108. Means, P.A. Race and Society in the Andean Countries. *Hisp. Am. Hist. Rev.* **1918**, *1*, 415–425. [CrossRef]
109. Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN). Tender Documents for Auction of Electricity Supply with Renewable Energy Resources in Areas Not Connected to Network. 2014. Available online: http://www2.osinerg.gob.pe/EnergiasRenovables/contenido/1eraSubastaOffGrid.Bases.html (accessed on 1 February 2016).