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Experiences of Community Wind Electrification Projects in Bolivia: Evaluation and Improvements for Future Projects

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1. Introduction

Currently, early in the XXI century, an estimated 2400 million people depend on traditional biomass for heating and cooking and 1500 million people lack access to electricity (IEA, 2009). Lack of electricity particularly affects rural areas of developing countries (Kanagawa and Nakata, 2008), exacerbating the urban-rural gap. In Bolivia, 35% of the population, more than 3.5 million people do not have access to electricity.

Electrification systems based on renewable energy have proved being adequate to provide decentralized electricity to isolated rural communities around the world (Chaureya et al., 2004). These autonomous systems are often much cheaper than the interconnected grid extension and use local resources, avoiding external dependencies which, in turn, promotes long-term sustainability of projects. In particular, micro-wind systems are an alternative with great potential to generate power in rural areas (Lew, 2000), although their use has been limited to date. In South America, a significant institutional effort was made in Argentina to develop rural electrification projects using wind energy in the province of Chubut (Seitz, 2006). In Peru, there are some demonstrative projects of the use of wind power to electrify isolated communities, the first one in El Alumbre (Ferrer-Martí et al., 2010).

In Bolivia, the government's policies on rural electrification are governed by the Rural Electrification Regulation, which states that the Department of Energy is responsible for promoting sustainable development, seeking expanded coverage of electricity services throughout the country. Therefore it has the responsibility to update and develop the rural energy strategy, including the Indicative Rural Electrification Plan to facilitate the work of agents in the development of rural electrification. The basic principles that are taken into account are:

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- Legitimacy of demand, which is to prioritize energy projects according to the law of popular participation and decentralization of administrative management.
- Accessibility, facilitating access to potential consumers to energy services in market conditions.
- Adaptation of technology, using energy resources in accordance with the conditions of each region and the lowest cost alternative.
- Co-financing, which is to encourage public and private funding for energy projects.
- Sustainability, through the application of the principles of environmental conservation.

Despite commitments made by Bolivia at the international level to reverse the rates of coverage in basic services until 2015, the millennium goals are far from being met.

In this context, the NGOs CINER (Bolivia), Mosoj Causay (Bolivia) and Engineers Without Borders (Spain) promoted the "Andean Program for Rural Electrification and Access to Renewable Energy" in Bolivia. This program was initiated by Engineers Without Borders (Spain) in different countries of the Andean Community of Nations (CAN) that present a common and problematic context. The program pursued Universal Access to sustainable energy services, through capacity development and validation of appropriate technologies for Andean environment. In 2005 the program began in Peru and Ecuador; next the program was extended to the Andean region of Bolivia, which presents very similar geographical and socioeconomical characteristics to the Andean areas of Peru and Ecuador. In this framework, in 2007 CINER, Mosoj Causay and Engineers Without Borders developed actions related to access to renewable energy in rural communities, extending the program to Bolivia to implement the knowledge acquired in both countries, and to adapt it to the special characteristics of Bolivia. The overall objective in Bolivia is to develop and disseminate knowledge, as well as human and technological capabilities to initiate demonstration projects, working with different stakeholders from the perspective of utilization of renewable energy sources, and promoting and participating in the selection and management of technology solutions.

Within the overall program, the project "Improving Access to Renewable Energy in Rural Communities in Bolivia" aims to improve the quality of life of rural population by having access to energy in remote areas through renewable energy. The specific objectives of this project were:

1. To improve technical and management capabilities of the Bolivian plateau for access to the energy in the population, local governmental bodies and other stakeholders.
2. To increase access to efficient and sustainable energy through improved use of biomass and the production of electricity through renewable energy sources.

The actions were carried out with specialists in social and technological issues to promote that users, through processes of participation and training, learn to manage, to maintain and to make sustainable their energy systems. These actions will contribute improving their level of human development, life expectancy, increasing opportunities for women, and access to education for children and adults, protecting natural environment through more friendly family economies. All the actions were performed jointly with the efforts of the beneficiaries - in coordination with the municipal government.

Specifically, this paper examines the interventions in the municipalities of Turco and Challapata led by Engineers Without Borders, CINER and Mosoj Causay, with the collaboration of both municipal governments, the financing of the Spanish Agency for International Development (AECID) and the Government of Navarra (Spain). Within the

municipalities of Turco and Challapata, two communities were selected with 13 and 9 households, respectively, that were electrified with individual wind systems. The electrification with renewable energy corresponded to the priorities and needs of the beneficiary population; before running the project, beneficiaries considered the lack of electric power as one of the main problems of both communities. The system installation was completed in December 2009. A year later, an external evaluation was conducted to analyze the performance and progress of the projects and it confirmed the level of satisfaction of the beneficiaries of the renewable energy equipment.

This article aims to describe and evaluate two community projects on wind power generation, both in technical and social aspects. These two examples provide lessons on management models at the community level. Moreover, we analyze the alternative design of projects that try to solve some of the drawbacks identified for the assessment of future project designs and implementations. The experience in Bolivia has shown the interest and willingness of rural indigenous populations to participate in electrification projects.

The remainder of this paper is organized as follows. Section 2 presents the economical analysis of the communities. Section 3 explains the wind resource assessment and section 4 describes the electrification project. Section 5 presents the evaluation methodology and section 6 presents the results and their analysis. Section 7 discusses alternative project designs. Finally, Section 8 summarizes the conclusions.

2. Socioeconomical analysis of the communities

This section presents the socioeconomical characteristics of the two communities, highlighting the differences between them. The purpose of this study was to analyze the characteristics of communities and families: the economy, consumption and energy demand, the level of organization, and individual and group capabilities. The instruments used to collect the information include socioeconomical surveys to each family, interviews with the local authorities and the representatives of the inhabitants, and a focus group with local organizations. This study was a key first step in the design and development of the management model with the administration.

2.1 Rural area in Bolivia

The household energy consumption in rural areas with no conventional energy supply is dominated by the demand for cooking (89% of total energy consumption). Lighting, communication (audiovisual, mobile, etc.) and other energy uses account for 11% of energy demand. Although not large amounts, lighting (5%) and entertainment (2%) are key demands to improve the quality of rural life and the integration of people through media. Productive uses of energy in these families represent a marginal percentage of total consumption; whenever they exist they are very specific, and must be analysed in particular way.

The structure of economic costs of energy source in rural scattered communities is different from population centers: batteries represent the largest amount of expenditure (34.3%), followed by the consumption of diesel (20%), LPG (18.8%), kerosene (15.3%) and candles (11.6%). In the highlands, average annual spending in U.S. dollars on traditional energy sources is the lowest in the country with a total of \$ 40 U.S. for the population in extreme poverty.

Due to low income of people in remote rural areas, the ability to pay is weak. However the amount of money previously used for the purchase of other energy sources (candles, kerosene, batteries, gas, etc.) may now be used to cover the cost of the electricity service. It is estimated that nearly all population strata might pay a US\$ 2.5 monthly fee, considering that the payment will be for more convenient energy services than those previously used. It is noteworthy that the percentage of expenses for energy supply with respect to income is higher when the income level is lower.

Some people have expressed their desire to obtain higher rates of public or international cooperation funding for electrification systems; this is probably due to very welfare practices developed by institutions in the past plans in these rural areas. However, it is obvious the willingness of communities and families to finance their consumption in case of having electricity. Moreover, it is worth to consider that making periodic payments for the energy service is not a common practice; traditional energy sources were acquired on specific occasions when families had available economic resources.

2.2 Area and population

The municipality of Turco is located in the western area of department of Oruro, in the province of Sajama, at an altitude of 3860 m. Turco has an area of around 3873 km², its topography is flat and rugged, with a large flat surface combined with hills and low hills with slopes of 5 to 15% and mountain slopes up to 60%. Most towns and villages of Turco are located at altitudes ranging between 3738 and 4200 meters, the mountain range has peaks reaching 5300 m. In general, the weather is cold, with annual mean minimum temperature of -1.6 °C and maximum of 19.8 °C. Turco is characterized by two very distinct seasons: a dry season from April to September and a rainy season between October and March.

On the other hand, the Municipality of Challapata belongs to the province of Avaroa, in the south-eastern department of Oruro. Challapata has an area of around 3014 km². The municipality has a semi-rugged relief in the mountainous territory of the central plateau, which stretches from north to south. Most towns and villages of Challapata are located between 3700 and 4300 m. The municipality has a cold and dry weather with average annual temperatures of around 4.4 °C in July and 11.6 °C in February, but sometimes can drop to -10 °C in the cold months. The rainy season starts in October or November and runs until March, and is characterized by heavy rains followed by periods of 10-20 days without rain. The remaining months are dry season flows.

According to the national census of population and housing, in 2001 Turco has 3818 inhabitants, composed almost evenly of men and women and represented by young under 25 years that form nearly 50% of the population. However, the estimated population in 2009 was 3771 inhabitants, a slightly decrease is mainly explained by migration to the cities in search of jobs and better opportunities. There are few major population centers and most populations are small villages with few houses. The estimated density of the municipality is 0.98 inhabitants per km². According to the 2001 census, the life expectancy at birth in the municipality of Turco is 49.6 years. Challapata has a much larger population with 24370 inhabitants almost evenly distributed between men and women being 50% of the population under 20 years. In contrast, in Challapata the population is increasing, it was estimated for 2009 a total of 27517 inhabitants. The density of the population of the municipality is 8.08 inhabitants per km². According to the 2001 census, the life expectancy at birth in the municipality of Challapata is 53.7 years.

The 2001 census data showed that the global literacy rate for the entire Turco municipality is 86.4% that is below the departmental average of 94.0%. The average years of study at the municipality are 5.7. Women still are disadvantaged in their access to education, as an example their illiteracy rate is 10.7%, while for men it has decreased to 4.2%. In the municipality of Challapata the situation is even more limited, with the overall literacy rate of 76.9% and the average years of schooling of 4.4.

The lack of permanent jobs and income security causes migration of the population of both municipalities to larger towns and cities from the department of Oruro, other departments of Bolivia, or even neighbouring cities of Chile. According to the Municipal Development Program (PDM) of 2007, 7.48% of the population of Turco has emigrated temporarily or permanently. This occurs more frequently among men (74.59%) from 10 to 50 years, children and youth because of higher level studies and for jobs to supplement the family income. In Challapata, according to the PDM 2002, the migration amounts to 29.21% of the population.

2.3 Basic services

According to the laws of municipal management, basic services are under the responsibility of municipal government. However, the municipality of Turco has not assumed responsibility for developing municipal policies aimed to ensure the coverage of basic services to the population, while the municipality of Challapata, has developed this task with moderate success. It is clear that in both cases the resources are not sufficient to meet the needs of the communities and, moreover, the operational capacity of the technical teams of the municipalities is limited.

The attention of medical services is poor and does not cover the expectations of the population. Firstly, the equipment they have is limited, and secondly, the treatment provided by officials and health professionals to patients does not meet the desired quality. In short, it is estimated that by 2007 there was approximately 1 doctor for 1909 people in the municipality of Turco and 1 doctor to 2437 people in the municipality of Challapata. Most of the population lives in communities of few houses that lack basic services; people must travel long distances to reach education and health services.

According to the PDM (2007), communities, farms and other remote areas have no electricity and rely on the use of kerosene or other methods of illumination at night. A study and evaluation of future energy demand estimated it (to meet the needs of households) as about 180 Wh / household / day. This study assumed a rational and efficient use of the energy and considered the power supply for each benefited the use of little appliances (radio, television, etc.).

2.4 Economy

Given the predominantly rural characteristic of both municipalities, economic activity is based on agriculture (99% of families according to the PDM 2007 in the case of Turco). Cattle ranching has two main purposes: sale and household consumption (to a lesser extent). Both live animals and in meat as well as other products (portion of meat, fiber and leather for processing before being marketed) are used for sale. Own consumption is complemented by an interfamilial exchange. Marketing is carried out fortnightly and annual fairs especially in urban centres. Agricultural activity is highly subject to climate risks, and therefore the incomes of families are in constant insecurity, making families to diversify their economy by

engaging in minor or complementary activities, such as handicrafts. Agricultural production is geared directly to consumption. Potato and quinoa are the products that are prevalent among families in the municipality of Turco and barley in the case of Challapata.

2.5 Community organization and leadership

A community workshop in each municipality of Turco and Challapata was realized to know the institutional actors in municipality that should be considered allies when designing in the management model of the electricity service. These institutions are considered depending on the area in which they operate, from the communal, municipal, provincial, departmental, national and international levels. The participants of the workshop did not identify all the institutions, but only those related to the Municipal Government and Ayllu, the indigenous and original management and decision organization at community level. Therefore, to complete the institutional landscape the PDM was used as well as observations and findings in the towns.

3. Wind resource assessment

Since June 2010 Bolivia has a new Wind Atlas, which identifies the potential of wind anywhere in the country, with the usable energy to generate electricity or direct use in a mechanical way. The Atlas was commissioned by TDE (Transportadora de Energía - nationalized by the Bolivian Government) and the World Bank to the consultancy 3 TIER specialist on meteorological simulation models. The model was developed based on geological, topographic and satellite statistics over the past 30 years, and the results were validated with records from weather stations in Bolivia.

The Atlas is based on data and maps on a platform of universal and indefinite access via the Internet and through entities that have offered themselves as managers of the base (www.3tier.com/firstlook). Bolivia Wind Atlas identifies areas of high potential use of wind, as is the case of the Santa Cruz region, the provinces of North and South Lopez in Potosí, a corridor between Santa Cruz, Cochabamba and La Paz, a northern-southern corridor between the shores of Lake Titicaca, Oruro and west of the city of Potosí, where the project area is.

Although the atlas gives an indication of interesting potential areas and communities, for the study of the project it is necessary to carry out a detailed micro-scale wind resource evaluation in the community. The first identification visits to Turco and Challapata and in particular the communities of the project, confirmed that the area appears to have good wind potential. Anemometers were installed to assess the wind resource in the communities in 10 meters high towers. Given the dispersion of electrified homes, two anemometers were installed in Turco (Figure 1), one in Iruni and one in Villacollo. Another anemometer was installed in Challapata (Figure 2). Wind measurements were taken for over a year. To ensure that generates enough electricity to meet demand throughout the year, wind resource evaluation focused on the periods of the year with less wind resource. Thus, although the energy generation varies along the year, the minimum generation to fulfil demand is always met. The least windy month was March in Turco (in both anemometers) and April in Challapata, with an average speed of about 2.5 to 3.5 m/s. This is the data considered in the project design.

To get the detailed wind map not only from specific points but also for the whole community, a specific wind simulation software WASP, The Wind Atlas Analysis and Application Program, by RISO, were used. This software extrapolates wind data collected by the anemometer located at a point and calculates the distribution of the wind resource throughout the surrounding area, considering the height map of the region. The topographic maps of the area were acquired in the Military Geographic Institute (La Paz, Bolivia). The energy generated by a wind turbine at each point of the community is also calculated by WASP considering the power curves of wind turbines.

Next, we presented the height and maps of Turco (Figure 1) and Challapata (Figure 2) obtained with WASP. As shown in the pictures, the highest elevation points are usually the areas with most wind potential.

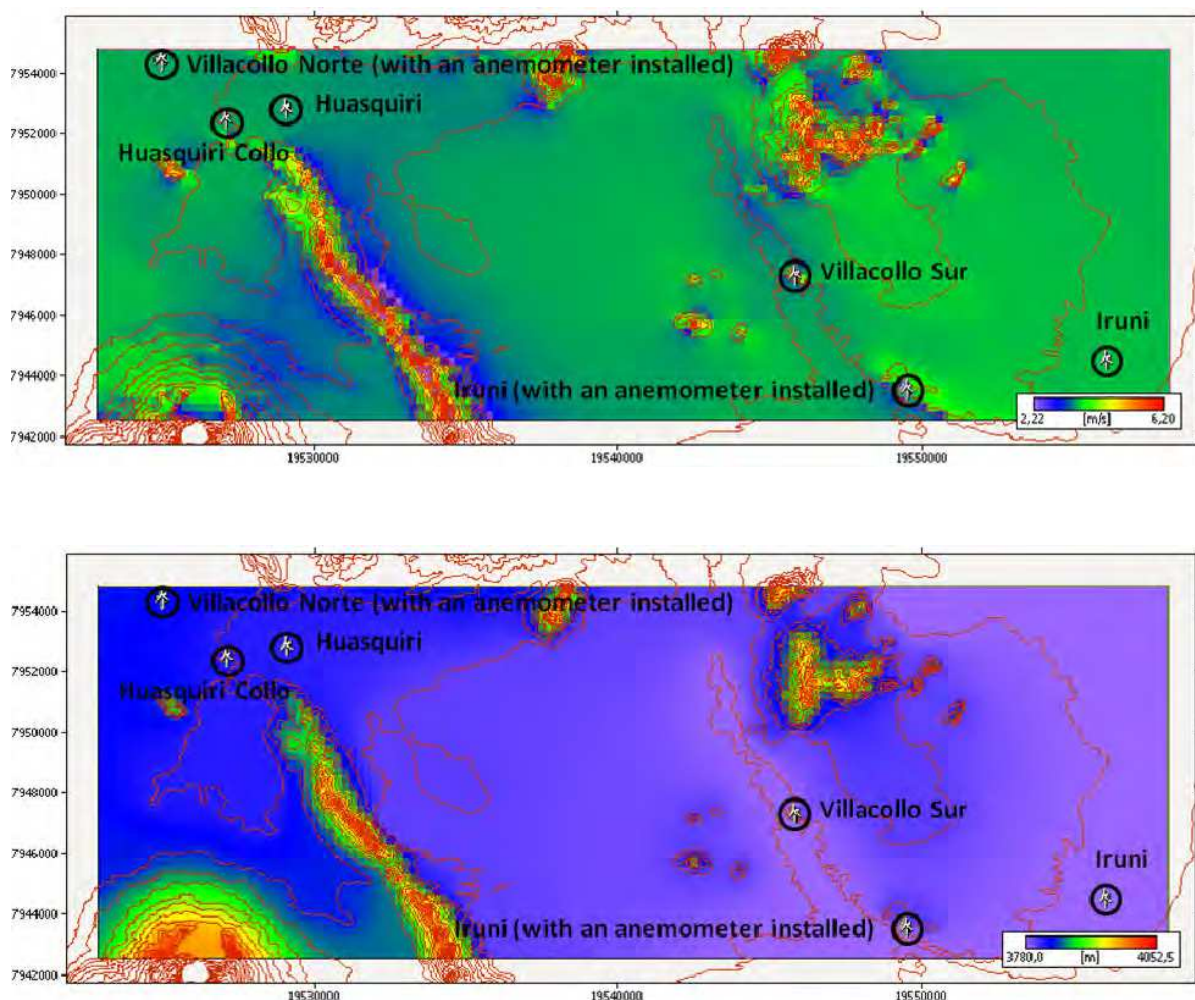


Fig. 1. Wind (up) and height (down) maps of the community of Turco.

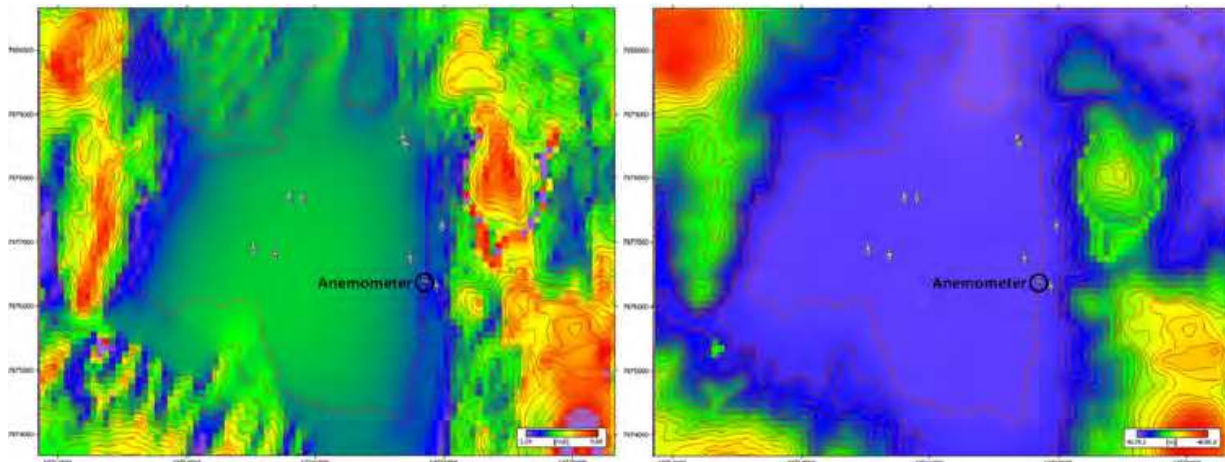


Fig. 2. Wind (left) and height (right) maps of the community of Challapata.

From the different technological options and according to the result of the wind resource evaluation, the promoters of the project decided to use wind energy to electrify these households of the communities (in front of photovoltaic solar systems, for instance).

4. Electrification project description

In 2009, 22 wind turbines were installed, 13 in the municipality of Turco and 9 in Challapata; in total, 80 people were benefited. To ensure proper operation and maintenance of systems throughout the year, only households with permanent residents throughout the year were electrified.

4.1 Technical description

In Turco, the 13 beneficiaries of the project are grouped in five villages: Iruni, Villacollo Norte, Villacollo Sur, Huasquiri and Huasquiri Collo with 5, 3, 2, 2 and 1 households, respectively. In Challapata the 9 beneficiaries are dispersed and only two of them are close to each other. Given the dispersion of the households, the project promoters decided to install one individual wind turbine at each household. The chosen were the AIR-X-South West Windpower, which were distributed by SIE, a Bolivian company which offers the distribution, installation and maintenance service.

The design of wind systems at each household was carried out taking into account that turbines operate at a rated voltage of 12 V direct current-CC, and includes the generation system, regulation (directly incorporated into the wind turbine) and energy storage. The home system components are as follows:

- **Generation.** It consists of a wind turbine that converts the kinetic energy of wind into electrical energy.
- **Regulation.** Regulation to avoid over charging the battery is performed by a controller included in the turbine itself. If necessary, an inverter may be installed to prevent deep discharge by cutting consumption. However, in these projects, simple controllers that act as a viewfinder of the state of battery charge were installed.
- **Storage.** The accumulation and storage of electrical energy is done in batteries. Batteries are loaded when there is generation and discharged to supply power when the generation is insufficient.

- Conversion. Inverters are used to convert direct current (coming out of batteries) to alternating current (which work for most electric devices) to allow the use of conventional devices, but having a power limit.
- Distribution. The electricity is distributed within the household at a nominal voltage level of 220 V.

Figure 3 shows a breakdown of the basic outline of individual wind electrification, with connections between different equipments.

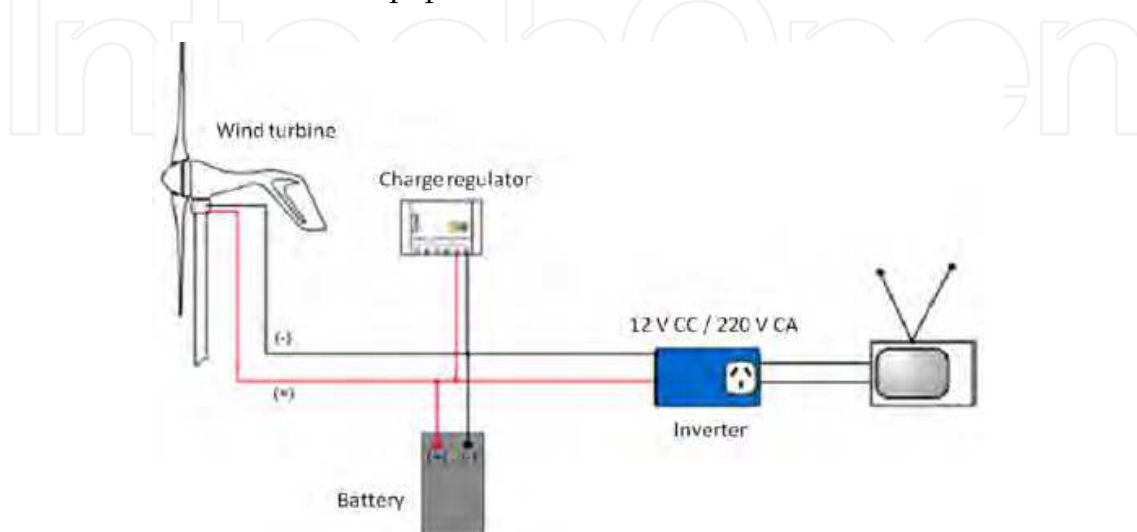


Fig. 3. Configuration of a wind individual electrical system.

4.2 Management model description

A common challenge in isolated electrification systems is to ensure the long-term project, for instance, in terms of sufficient maintenance and access to spare parts. To reinforce this challenge, the organizers of the project focused on developing an appropriate "management model".

The management model is a management tool developed in consensus with all stakeholders involved in the project, which aims to develop business service structure, and skills and abilities for the collective and individual sustainability. It contains regulations and operational rules governing the role of each different actor. Specifically, there is an operator-manager of the community that is in charge of the maintenance and management of all the systems. Users pay a monthly fee that goes to a fund for the maintenance of systems and possible replacements of equipment (batteries, etc.). A committee of users is also formed to supervise the technical and financial performance. The municipalities and town halls are the owners of the systems and are responsible for their long term sustainability.

The coordination mechanisms among stakeholders in these projects are:

- During the design and development of the project a fluid communication was guaranteed within a board of directors composed by beneficiaries and technicians responsible for implementing the planned activities.
- Once the installation finished and once the company that installed the systems and promoter institutions left the communities, the municipality and the town hall became the responsible of sustainability of the systems. The commitment is embodied in an agreement to support the management committees in which they agree to take charge of a consideration when replacing parts of the system (whenever required).

- Once the project finished, the management committees are required to perform preventive maintenance and to collect monthly contributions from users. In addition, each committee has at least one technical operator per municipality, who is also a beneficiary and each member received additional training which has been provided to them focusing on equipment maintenance and financial management.

5. Evaluation methodology

The purpose of external evaluation is to determine and assess the degree of progress of the project in relation to fulfilment of the outcomes of intervention in the implementation period (2008-2010). This analysis allows to detect the strengths and weaknesses of the project and to make corrections of the deviations detected, aiming to improve future interventions in the area. The evaluation team that conducted the evaluation presented in this paper focused most of his work on analyzing the following main sections:

- Real coverage of the project, in terms of direct and indirect beneficiaries, whether individuals or institutions.
- Degree of appropriation of activities by the beneficiaries.
- The scope of the intervention at the regional level and the integration of the logical intervention and complementarities between the different levels.
- The degree of impact of the first actions, depending on the time of project implementation, with special attention to indicators and real achievement.
- The effectiveness of tracking and monitoring mechanisms initially planned, and improvements in relation to the interaction with regional participants throughout the implementation process.
- The level of involvement of local and regional activities planned, as well as the beneficiaries.

5.1 Evaluation activities

The work consisted of office work and field work. The office work consisted of:

- Identification and analysis of available documentation on the context.
- Analysis of available information on the interventions to evaluate: formulation of the project, the technical and economic progress reports, annual programming documents and sources of verification.
- Design of methodological tools for collecting, processing and analyzing information to ensure the reliability of sources and the rigor and analysis in the field.
- Planning of field work and structuring of the surveys.
- Design of indicators for the analysis of the evaluation criteria.

Fieldwork was conducted in October 2010 in the municipalities of Turco and Challapata and essentially consisted of:

- Interviews with key officials of the municipalities involved: the Mayor, Council Members, and the indigenous heads.
- Interviews with technicians of the project team.
- Semi-structured interviews to members of the Management Committee or representatives of their organizations according to their customs.
- Visit to households of the beneficiaries in order to inspect the installed equipment, and collect information via surveys to each of the users.

The data collected from the surveys was processed and systematized in a database; SPSS was the information processing computer software used. In the same way, data collected from interviews was processed and compared providing greater reliability evaluation.

5.2 Definition of the evaluation criteria

The evaluation criteria were defined between the technical and social specialists of the promoter institutions and the external evaluator team. Criteria were defined before starting to collect information and results to ensure maximum objectivity. The defined evaluation criteria were:

1. **RELEVANCE.** This criterion assesses the suitability of the intervention in terms of local needs. It evaluates whether the proposal is technically valid, solves real problems and is appropriate to the context in which it is framed.
2. **EFFICIENCY.** This criterion examines the relationship between enforcement activities and compliance with the results and the relationship of these with the investment.
3. **EFFECTIVENESS.** This criterion measures the degree of compliance with the initial specific objectives of the projects and the actual outcome of the expected benefits to the beneficiaries.
4. **IMPACT.** This criterion examines the net effects of the project from a broad perspective, taking into account all stakeholders, and projects in the medium term.
5. **SUSTAINABILITY.** This criterion analyses the possibility of consistent positive effects of the project once the foreign aid ends, taking into account all relevant factors.
6. **COHERENCE.** This criterion analyses the compatibility between the objectives, activities and expected results of public policies and recommendations of international organizations.
7. **FACILITIES:** This criterion checks the compliance with the Bolivia IBNORCA NB - 1056.

Table 1. summarizes the indicators and related components for each of the criteria.

CRITERIA	INDICATORS	COMPONENTS
Relevance	Adequacy of the project to local needs	Does the intervention correspond to priorities and needs of the population?
		Have the needs of communities changed after the first identification? What changes have there been?
		Have the actions proposed in the project been able to solve the problems identified? Have they taken into account the socioeconomic context?
	Adequacy of the project to local priorities	Which are the priorities of government intervention in the territory and the sector involved in the project?
		Which are the priority interventions of local government in the area?
		Is the project aligned with the priorities of national and local government?
	Complement with other actions	Does the project being completed in a real way in the area?
		Are there mechanisms for coordination between different actors?
	Design of the intervention	Has the project taken into account the views and opinions of local staff? Which have been the levels of participation of them in their formulation?
		Do the planned activities actually lead to the fulfillment of the intended outcomes? Is internal logic of the program the best way to address the identified problems?

CRITERIA	INDICATORS	COMPONENTS
		Are the results feasible and relevant to the achievement of the logical framework? Are they formulated in terms of impact?
Efficiency	Analysis of the achievement of individual results from realized activities	What was the level of compliance with each of the activities? What factors facilitated and hindered compliance?
		What was the degree of compliance with each of the results? What factors facilitated or hindered performance? Were there any unanticipated results? Which ones?
	Analysis of the relationship between results and resources invested	What was the relationship between invested resources and obtained results? What were the results in relation to time spent like ?
		Analysis of management in relation to the results
Effectiveness	Performance analysis of the specific objectives	What is the level of compliance of the specific objectives? Which factors have facilitated/ impeded the fulfilment of the specific objectives?
		Usefulness and availability of the specific objectives
	Impact	Analysis of compliance of logical framework
Factors that have facilitated / impeded the project's contribution to the achievement of logical framework		
Impacts from a broad perspective		Project's positive impacts on beneficiaries, on the economic, environmental, social, and organizational aspects.
		Project's negative impacts on the social, economic, organizational and environmental aspects
Sustainability	Analysis of the possibility that each of the processes and their positive impacts are sustainable	Is there a local government department responsible of the processes established by the project?
	Factors that facilitate / impede the permanence of the positive effects	Political factors, Institutional factors, Gender factors, Economic factors, Technological factors, Other factors
Coherence	Relation with the strategic policies of public sector	Do the identified problems correspond to the purposed objectives?
Facilities	The design of the facilities meet the regulation	The design of the facilities meet the needs of the users and the standard IBNORCA NB-1056
	Facilities are in accordance with the design	Facilities are in accordance with the design and standards
	Facilities are operating according to design	Facilities are operating according to the design

Table 1. Criteria, indicators and assessment components.

6. Results of the evaluation

This chapter provides the information, the analysis and the results of the external evaluation in terms of each of the criteria and carries out global evaluation.

6.1 Relevance

The results of the evaluation confirmed that these projects have made a direct benefit for the families supplying access to electricity in their households. The field assessment after the implementation of the project has revealed that electric service has given them the ability to access telephone communication (cell phones had network coverage only needed electricity to recharge) and audiovisual media (television, radio, etc.).

However, the degree of satisfaction of the beneficiaries is not for all the same. Some of the beneficiaries are completely satisfied with the recent access to electricity, whereas others are only partially satisfied because their expectations were superior to actual performance and possible uses of electricity. Some of the beneficiaries confirm they use electricity for lighting and some low power appliances, as it was planned in the logical framework of the project but, at the same time, they claim that they wish to have more energy for other uses. In Turco, 6 out of 11 beneficiaries are completely satisfied and 5 are partially satisfied. In contrast, In Challapata almost all beneficiaries are completely satisfied, 7 out of 8. Among other factors, the difference is probably due to the difference in wind potential in the communities; the wind potential available in the Challapata is greater than in Turco, thus, the same generation equipment generates much more energy.

6.2 Efficiency

The results indicate that the projects justify the investment and that the management of staff has been adequate. It is noteworthy the commitment of the staff to the beneficiary communities that was reflected in the interviews. Results of the evaluation confirmed that the objectives and results defined in the logical framework of the project were achieved with an optimal degree of compliance.

However, the short time available to carry out the activities has been identified as a negative factor. The key aspects that influence and make the time needs critic are:

- The fieldwork itself needs a lot of time, in particular due to the remoteness of the communities. The need of technological and logistic external support and their availability also constrained the schedule.
- In terms of community activities, the communication process that involves speaking Spanish as well as native language (Quechua, Aymara) requires more time. Moreover, gaining the confidence and trust of the beneficiaries and overcoming some internal conflicts in the communities also require dedication and perseverance. The education and training according to the needs of the community and implementation of management models must be repeated in a lengthy process to ensure the correct appropriation.
- The coordination with municipal governments, as well as making effective their economic commitment was also a long process.

However, the only weakness found caused by the short time spent in the project was that the management committee was concerned about not being self-sufficient to keep equipment running. Although the interviewees say their organization does work, the correct

performance may be threatened by the lack of commitment tools that would help to ensure the fulfilment of the obligations of the users. In particular, they claim more training and time for a proper comprehension of the rules of the new organization because the management committee has no element of coercion to require monthly contributions, and the technical operator receives no remuneration for his work as inspector. These deficiencies are repeated in Turco and Challapata but with different intensity.

6.3 Effectiveness

One of the specific objectives of this project aimed to train the users in the maintenance of wind power systems and organizational management techniques for the sustainability of the systems. A key point is the emphasis on training and awareness of people through workshops and seminars. The results of the evaluation confirmed the population received good training, are aware of the benefits of the project and have a positive perception of usefulness. Users are also aware of the existence and significance of the management committee although no regularity when making the respective contributions has been achieved. These delays have had no negative consequences so far because there have been no need to replace elements, because the projects have been running for a short time.

In terms of uses of electricity, the beneficiaries use the energy depending on their economic possibilities to buy electric appliances, from lighting to communication and leisure. The most noteworthy nightlife activities are spinning, knitting or sewing by women and schoolwork by children. Table 2 shows the number of users per municipality using different types of appliances.

	Focus	TV	Radio	Cell Phone	Battery chargers	Others
Turco	11	0	1	10	1	0
Challapata	8	0	4	2	1	0

Table 2. Number of users of each appliance in each community.

6.4 Impact

In terms of the logical framework, the project has largely achieved its objectives and actually incorporated renewable energy in Turco and Challapata communities as demonstration projects in Bolivia.

The main factors that facilitated the success were:

- Training of all users and technicians from the municipal governments.
- The development of management manuals.

The most noteworthy positive impacts of the project are:

- Improved quality of life, preserving the environment.
- The achievement of an organization to manage the systems designed according to customs.

From the economic point of view, almost all beneficiaries agree that now with the new electricity service they spend less money on the provision of electricity than they used to spend on traditional energy sources (kerosene, candles, etc.). Apart from that, some of them state they no longer have to breathe smoke like when they used kerosene, burners or candles. Beneficiaries state they have a solid and consolidated organization, although this is not directly reflected at the time of monthly contributions.

Table 3 shows the qualitative assessment of the changes resulting from the project in the organizational, economic, social and environmental aspects; it shows the percentage of beneficiaries that state the changes have been positive, negative or non significant (no change). The most significant changes occur in the economic area, thanks to a reduction of costs on energy provision, and in the environmental aspects, by decreasing smoke of candles, lighters and kerosene lamps.

		positive	negative	no change
Turco	Organizational	100%	0%	0%
	Economical	60%	0%	40%
	Social	10%	10%	80%
	Environmental	100%	0%	0%
Challapata	Organizational	100%	0%	0%
	Economical	100%	0%	0%
	Social	0%	0%	100%
	Environmental	100%	0%	0%

Table 3. Assessment of the changes.

The only negative impact found in the evaluation is that people who are not beneficiaries of the project are now in an unequal position and feel they are now in a situation of inferiority. It is noteworthy to remind that only homes with at least one permanent resident throughout the year were electrified, to ensure proper operation and maintenance.

6.5 Sustainability

The promoters (Engineers Without Borders, CINER and Mosoj CAUSAY), and the management committees of the projects signed an agreement with the mayors involved in the projects, where the municipalities assumed to take over the sustainability of actions. The management committees are afraid of not being self-sufficient to maintain the systems of electrification (lack of regular payments, technical operator's temporary absence, etc.) and so the mayors involved agreed to give support and to take over the long term sustainability of projects. However, changes in the technical and municipal authorities, bureaucracy, lack of financial resources, lack of continuity in the training of technicians of the municipality and other stakeholders may hinder the fulfilment of commitments.

Moreover, the future of these systems is contingent on the proper use and proper maintenance of each of the equipments. The company that installed the wind systems is committed to maintain and to repair them for a period of two years. So far, the company repaired the systems when needed but has taken some time, so some beneficiaries have had no electricity during weeks or months.

6.6 Coherence

The results of the evaluation confirmed there is a clear coherence between identified problems in the area and goals of the project. The project has successfully overcome one of the main problems identified in the area: lack of electricity and reliance on traditional energy sources (candles, lighters, wood and other fuels). Now beneficiaries say they no longer breathe smoke (of kerosene or candles), and state they spend less money on energy supply.

In addition, the evaluation confirmed this project is not against any plan, program or policy; on the contrary, it contributes to the government's obligation to provide basic services to the population.

6.7 Facilities

The verification of the quality of the facilities is conducted as part of the field work, making home visits to most users of both Turco and Challapata. To check the correct design and installation of the facilities, the standard guidance document IBNORCA Bolivian NB 1056 was used. All components were verified in each household, taking into account the data of the original design. Most equipment was found to be working properly and user feedback was favourable. Only minor problems were detected which were easily solved (low batteries, bearing noises, light poles with vertical offset).

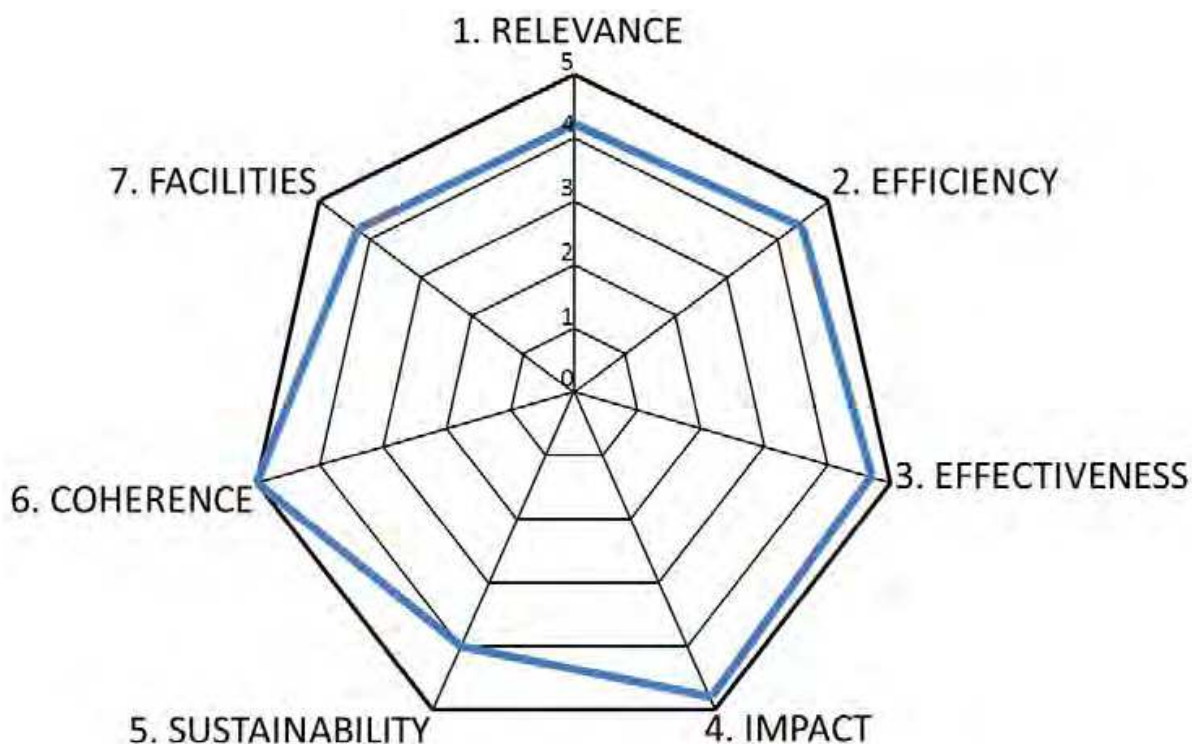
6.8 Evaluation and analysis

The rating scales and the weighting of each criterion were discussed and agreed at a meeting between the evaluation team and CINER and Mosoj Causay. This meeting was held before the start of the collection and analysis of information to ensure maximum objectivity. From the analysis of the results of the evaluation and the defined rating scales (1 to 5), each of the components of each criterion was quantified. The resulting score of each component of each indicator is shown in the following table (Table 4).

Figure 4 shows the results of the evaluation according to each criterion. The project achieved an overall weighted evaluation of 89.33%, which corresponds to a qualitative assessment of "functioning under optimal conditions".

CRITERIA	Total	N ^a	COMPONENT	Value
RELEVANCE	4.35	1	Adequacy of the project to local needs expressed	4.33
		2	Adequacy of the project to local priorities	3.57
		3	Complement with other actions	5
		4	Design of the intervention	4.5
EFFICIENCY	4.50	5	Analysis of the achievement of individual results from realized activities	4.17
		6	Analysis of the relationship between results and invested resources	4.33
		7	Analysis of management in relation to the results	5
EFFECTIVENESS	4.67	8	Performance analysis of the Specific Objectives	4.63
		9	Usefulness and availability of the Specific Objectives	4.71
IMPACT	4.75	10	Analysis of compliance of the logical framework	5
		11	Impacts from a broad perspective	4.5
SUSTAINABILITY	4	12	Analysis of the possibility that each of the processes and their positive impacts are sustainable	5
		13	Factors that facilitate / impede the permanence of the positive effects and the processes	3
COHERENCE	5	14	Relation with strategic public sector policies	5
FACILITIES	4.33	15	The design of the facilities meet the regulation	4.5
		16	Facilities are in accordance with the design	4.5
		17	Facilities are operating according to design	4

Table 4. Evaluation of the external evaluation process.



1. Relevance: 4.35/5 (weight: 25%)
2. Efficiency: 4.50/5 (weight: 10%)
3. Effectiveness: 4.67/5 (weight: 10%)
4. Impact: 4.75/5 (weight: 15%)
5. Sustainability: 4/5 (weight: 15%)
6. Coherence: 5/5 (weight: 10%)
7. Facilities: 4.33/5 (weight: 10%)

Fig. 4. Results from the multicriteria evaluation.

6.9 Recommendations of use and maintenance

The following recommendations are deduced from the evaluation and are proposed to proper use and maintenance of systems and to promote long term sustainability:

- To facilitate the sustainability of the project, the management was transferred to the involved municipalities, and should be monitored periodically by these entities. The mayors should support the preventive maintenance plan for wind turbines and should include training for users at least once a year, especially to the young.
- Management committees in coordination with Installation Company must check the level of the batteries and the wind systems performance. The maintenance plan for wind systems must check the status of bearings, the load control system and the verticality of the poles.
- Users must remember that when they buy a radio or TV their power must be appropriate for the wind systems. The maintenance plan should ensure that the light output of focus fulfils the standard NB IBNORCA -1056 and users should paint rooms in white for greater light efficiency.
- Batteries must be in a suitable container for efficient and secure use. The municipal government should provide a battery charger as a backup system for each community.

7. Analysis of alternative designs

Due to the characteristic dispersion of communities, rural electrification projects tend to install individual systems at each point of consumption, as the cases presented in this paper. Alternatively, design of a single point of generation and distribution of electricity with microgrids (Kirubi et al. 2009) has its advantages:

- Flexibility in use: energy generation and storage is shared among several users, thus one or more users can increase their consumption at a specific moment if needed.
- Easier integration of future users: new users may be electrified just extending a wire.
- Robustness against failure: microgrids facilitate feeding users with more than one generator. Thus, in case of failure of a generator, energy supply decreases but no user is completely left without access.
- Cost savings: microgrids facilitate to use more powerful equipment, which are proportionally cheaper.

In particular, the electrification with microgrids in Turco and Challapata would have avoided some of the problems identified in the assessment:

1. Some users were expecting to have more energy availability. The use of microgrid generation facilitates the use of more powerful and proportionally cheaper turbines, so more energy can be generated and supplied with the same investment. Moreover, higher energy supply scenarios can be considered with lower cost increase.
2. People that do not live permanently in the community were not electrified to avoid operation and maintenance problems. In systems with microgrids generation equipment is not installed at each household and, therefore, not living permanently is not a problem because the maintenance is common and not necessarily the responsibility of each user.
3. The lack of supply during breakdowns. In case of breakdown of a generator, no user is completely left without access, so the time taken to repair the system is not that critic.

7.1 Design models with microgrids

To study the possible use of microgrids in future projects, the electrification options with microgrids in Turco and Challapata are analysed. Although in both communities most households are scattered, there are small groups of households close to each other that could have been electrified with a microgrid.

To optimize the design of these alternatives a Mixed Integer Linear Programming (PLEM) model (Ferrer-Martí et al., 2011) is used. This model is based on the definition of a set of parameters (which specify the input data of the problem), variables (which define the configuration of the solution) objective function (which defines the standard resolution) and constraints (that specify the set of conditions to be satisfied that the solution is feasible). The solution of this model determines the point of generation and micro design to minimize costs, taking into account the demand, the wind resource and power generation equipment available in the area (cost and technical characteristics).

Next, the parameters, variables, objective function and constraints of this model are briefly introduced.

- Parameters
 - Demand: Energy and power consumption of each point and days of autonomy.

- Generation and accumulation: Turbines with built-in controller (type, cost, maximum operating power, and maximum power generated at one point) and batteries (type, cost, capacity and discharge factor).
- Definition of the network: Distance between points, conductors (types, cost including the infrastructure, resistance and current carrying capacity), rated voltage distribution and voltage drop.
- Equipment: Inverters (type, cost and power) and meters (cost).
- Variables
 - Equipment: number of each type of equipment installed at each points.
 - Definition of the network: connections between two points, and energy and power flow between the two points.
- Objective function: To minimize the investment cost considering wind turbines, batteries, inverters, meters and conductors.
- Constraints
 - Generation and accumulation: Energy and power balances at each point, required energy capacity in the batteries at each point of generation.
 - Definition of the microgrid: It establishes the relationship between energy and power flows and the existence of a conductor between two points, compliance of maximum voltage drop and maximum intensity, the structure of microgrid (if any) should be radial.
 - Equipment. Inverters are installed at the points of generation; the meters are installed at points of microgrid.

To specifically assess all the advantages of the microgrids, a constraint that forces to form microgrids to feed the households that were close to each other at each community is included.

7.2 Results of the design of the projects with microgrids

Next, the data and parameters considered in the generation and study of alternative designs are summarized. In particular, this experiment considers the use of the equipment installed in the real projects and more power equipment for their possible use in microgrids that feed several households.

- Demand
 - Two demand scenarios: the first for a basic consumption (energy 140Wh/day, power 100W) and the second to promote the development of productive activities (energy 280Wh/day, power 200W).
 - 2 days of autonomy.
- Generation and accumulation
 - 4 types of turbines: Air X, Whisper 100, Whisper 200 and Whisper 500) at a cost of \$1000-\$4600 and 550W- 3300W, respectively, by South West Windpower.
 - Regulators are incorporated into each type of turbine.
 - 3 types of batteries: \$240-325 and 150-250Ah capacity discharge 60%.
- Microgrids
 - 3 types of conductors: cost \$4.05- 4.4 per meter.
 - 220V distribution voltage and a 5% maximum voltage drop.
- Equipment

- 1 type of inverter: cost \$ 255, power 350W.
- 1 type of meter: cost \$ 50.

Table 5 shows the obtained results. The table is divided into two columns for each demand scenario and two rows for each municipality. The sub-columns show the obtained results considering: 1) the individual solution (one generation equipment per household); 2) the solution with microgrids with one type of wind turbines (the type used in the real projects, Air X) and 3) the solution with microgrids with 4 types of wind turbines (the type used in the real projects, Air X, and 3 more powerful ones). The sub-rows present the investment cost, the difference of the cost of individual generators in the low demand scenario, the total energy, wind turbines used, the microgrids and the number of users in each one and number of individual users.

		Low Energy Demand (140Wh/day; 100W)			High Energy Demand (280Wh/day; 200W)		
		Individual	Microgrid (1 w.t.)	Microgrid (4 w.t.)	Individual	Microgrid (1 w.t.)	Microgrid (4 w.t.)
Turco	Total cost [\$]	19423	17862	16862	26423	26277	22777
	Difference (%)	-	-8,0%	-13,2%	36,0%	35,3%	17,3%
	Energy [Wh/day]	4460	4234	4166	6086	6124	6227
	Wind turbine (type)	13 (Air X)	12 (Air X)	8 (Air X) 2 (Whis. 100)	20 (Air X)	20 (Air X)	7 (Air X) 3 (Whis. 100) 1 (Whis. 200)
	Microgrids (users)	-	1 (4) 1 (3) 2 (2)	1 (4) 1 (3) 2 (2)	-	1 (4) 1 (3) 2 (2)	1 (4) 1 (3) 2 (2)
	Individual users	13	2	2	13	2	2
Challapata	Total cost [\$]	14447	13886	13886	16447	16867	15867
	Difference (%)	-	-3,9%	-3,9%	13,8%	16,8%	9,8%
	Energy [Wh/day]	4641	3381	3381	5185	5196	5161
	Wind turbine (type)	10 (Air X)	8 (Air X)	8 (Air X)	12 (Air X)	12 (Air X)	9 (Air X) 1 (Whis. 100)
	Microgrids (users)	-	3 (2)	3 (2)	-	1 (2)	1 (2)
	Individual users	9	3	3	9	7	7

Table 5. Analysis of the electrification solutions of Turco and Challapata with microgrids.

In Turco, in the low demand scenario, the cost of real implemented project, that installed an individual wind turbine at each household, is \$19423. The design with microgrids reduces the cost by 8% when only one type of wind turbine is available (\$19423 vs. \$17862); the cost reduction is higher 13.2% when 4 types and more powerful wind turbines are considered (\$19423 vs. \$16862). In both solutions one microgrid of 4 households is formed in Iruni, another of 3 households is formed in Villacollo Norte and 2 microgrids are formed in Villacollo Sur and Huasquiri.

In the high demand scenario in Turco, the cost of electrification solution increases by 36% when only individual generators are considered (\$19423 vs. \$26423). This increase is significantly reduced to 17.3% when microgrids and 4 types of wind turbines are considered (\$19423 vs. \$22777); thus, twice energy and power demand only implies a cost increase of 17.3%. The formed microgrids are always the same in all cases.

In Challapata, in the low demand scenario, the cost of real implemented project is \$14447. The design with microgrids reduces the cost by 3.9% (\$14447 vs. \$13886); 3 microgrids of 2 users each are formed. In the high demand scenario, the cost of electrification solution in Challapata increases by 13.6% when only individual generators are considered (\$14447 vs. \$16447). This increase is reduced to 8.8% when microgrids and four type of wind turbines are uses (\$14447 vs. \$15867).

8. Conclusions

This article aims to describe and evaluate two wind generation projects implemented in Bolivia, in the municipalities of Turco and Challapata, department of Oruro. This multi-criteria evaluation was conducted when the systems had been running for one year by an external evaluation team. The results of the evaluation showed that the project has achieved its main objectives giving a weighted mark 89.33%, which corresponds to a qualitative assessment of "functioning under optimal conditions." This confirms that renewable energy is the best choice for access to modern energy in isolated communities.

Among the main strengths of the project s the positive acceptance of the beneficiaries and access to electricity in remote areas must be highlighted. The main weaknesses of the project are the bureaucracy that slows down municipal governments and internal conflicts among beneficiaries. The assessment highlighted limitations in the systems that must be resolved in future projects, for instance, the training should be extensive in time. The biggest risk is long term sustainability if the municipalities do not fulfil their commitments.

Furthermore, alternative designs were analyzed with microgrids to improve some of the drawbacks identified in the assessment: the continuity of supply against breakdowns, supply of electricity to non-permanent residents and the possible increase in energy supply to cover more applications. The results recommend taking advantage of microgrids for projects in future, to feed groups of households, improve the quality of electric service and reduce costs.

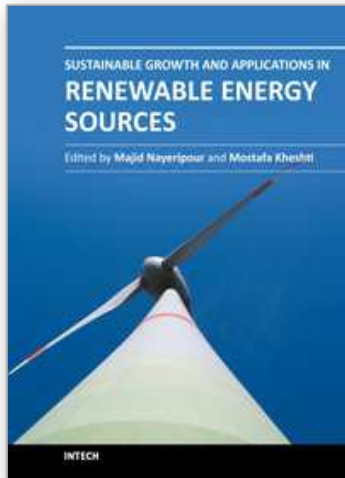
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Worldwide attention to environmental issues combined with the energy crisis force us to reduce greenhouse emissions and increase the usage of renewable energy sources as a solution to providing an efficient environment. This book addresses the current issues of sustainable growth and applications in renewable energy sources. The fifteen chapters of the book have been divided into two sections to organize the information accessible to readers. The book provides a variety of material, for instance on policies aiming at the promotion of sustainable development and implementation aspects of RES.

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