Energy Sufficiency for Rural Communities: The Case of The Bolivian Lowlands

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ABSTRACT

Access to energy has proved to have strong links to other dimensions of socio-economic development. As a first step to ensure electricity coverage in developing countries' rural communities, a minimum energy access must be settled. To do this, the theoretical concept of energy sufficiency is expanded to fit in the rural energy access logic. Ideally, un-electrified communities must move from low energy consumption states to a position where they consume enough to have a continuous development without risking global environment goals. For that purpose, a bibliographic review is performed to define the components of an ideal rural community where people's basic needs for energy services are met equitably. Main findings show that besides the household component, public lighting, education, health, water and production services must be considered at the moment of estimated energy demands for rural electrification. To test the implication of this, a series of plausible village configurations of the Bolivian lowlands are proposed and simulated using a bottom-up stochastic model. Not considering community services and income generating activities, carries a 45 % underestimation on peak demand. In addition, improving people's living conditions has a considerable effect on the electricity demand of Bolivia's rural lowland communities.

KEYWORDS

Rural Electrification, Energy Sufficiency, Developing Countries, Electricity Demand

INTRODUCTION

The global electrification rate reached 89 % and 131 million people gained access to electricity each year on average since 2010 [1]. Most of the people who still lack access to electricity reside in rural areas of developing countries. The use of locally available renewable resources combined with modern technologies constitute an interesting solution but their deployment requires technological and organizational innovations [2].

As acknowledged in the Agenda 2030, sustainable development is linked to the simultaneous accomplishment of interconnected objectives that creates synergies between them. From all the SDGs, access to energy (goal 7) [3] has proved to have strong links to other dimensions of socio-economic development. Studies show a link between poverty reduction and energy access [4]; likewise, electricity access is interconnected with multiple dimensions of socio-economic development, such as income generating activities, household economy, health, education, habits, and social networks [5]. The combination of electricity and heating systems could lead to a higher energy independence of rural communities in diverse contexts [6]. Furthermore, the link between energy, water and food has been established and explored extensively in the literature [6, 7].

Off-grid solutions, including solar lighting, solar home systems and with increasing frequency, mini grids, are crucial to provide electrical energy to the poorest and hardest to reach households. Globally, at least 34 million people in 2017 gained access to basic electricity services through off-grid technologies [1]. Given the importance of studying energy demand to provide adequate access through off-grid solutions, Riva et al. [8] stress the need to introduce an appropriate modelling framework for assessing long-term projections of electricity demand within rural energy planning. In [5], the same authors conceptualize the nexus between evolution of electricity demand and local rural development, suggesting that system-dynamics can represent an appropriate method to investigate this issue from a quantitative point of view. Inaccurate demand projections can lead to unexpected situations, as showcased by Ulsrud et al. [9] .

There is not a globally accepted concept for energy access, however, in the literature, the term is used to refer to the situation where people can have access to modern energy and improved end-use devices at affordable prices [10, 11]. Certainly, providing access to improved energy carriers is clearly a necessary, but insufficient condition for overall poverty alleviation and socioeconomic growth [11]. Pachauri et al. [11], abstain from defining the minimum amount of energy needed to meet basic needs, quantitatively. The reason is that basic needs are normative and vary significantly geographically, depending on the climate, social customs, norms and other factors inherent to the region and society. In fact, governments and policy makers in some countries made efforts to define basic or lifeline energy entitlements for their poorest citizens to cover basic lighting, communications, and entertainment needs. However, the defined entitlements fall far below what is required for income generating activities to empower growth and development. Not taking into account the energy needs for income generating activities increases the risk of energy ‘peripheralization’ in rural communities [12].

As a first step to ensure electricity coverage in developing countries’ rural communities, a minimum energy access must be defined. To do this, the concept of energy sufficiency is introduced. In [13], the authors propose that energy sufficiency is a state in which people’s basic needs for energy services are met equitably and ecological limits are respected. Focus is on services that meet needs for shelter, health, work, mobility and communication. Such needs will vary according to local conditions. For example, concepts in health, shelter, mobility and work are being rethought along ‘sufficiency’ lines and tested in different contexts. This paper attempts to expand this theoretical concept to fit in the rural energy access logic. Ideally, unelectrified communities must move from low energy consumption states to a position where they consume enough energy to have a continuous development without putting at risk global environment goals. To that aim, the following specific objectives are proposed: 1) To define the structure of a rural community, taking into account basic needs; 2) To discuss possible appliance ownership of a rural community; 3) To explore the effects of improving the quality of life (towards a ’energy sufficiency’ state) of the inhabitants of lowland rural communities on electricity demand.

METHODS

A literature review was conducted to identify the energy needs in a rural community. categorized by sector. For the case study, different possible types of users were defined within each sector, according to the characteristics of the region under study. For that purpose, national reports, surveys and previous work in the area were consulted. The user characteristics were defined taking into account all the necessary requirements to be able to use them as input to the open-source bottom-up stochastic model RAMP. This tool requires the definition of types of users and the characteristics of use of the electrical appliances they own (for further details on RAMP model, see [14]). Plausible rural community scenarios were then constructed with the defined users to observe the behaviour of demand in different situations. In this way, the RAMP tool was used to generate load curves for each scenario, and to analyse the effect of different factors on electricity demand. Figure 1 shows the adopted method.

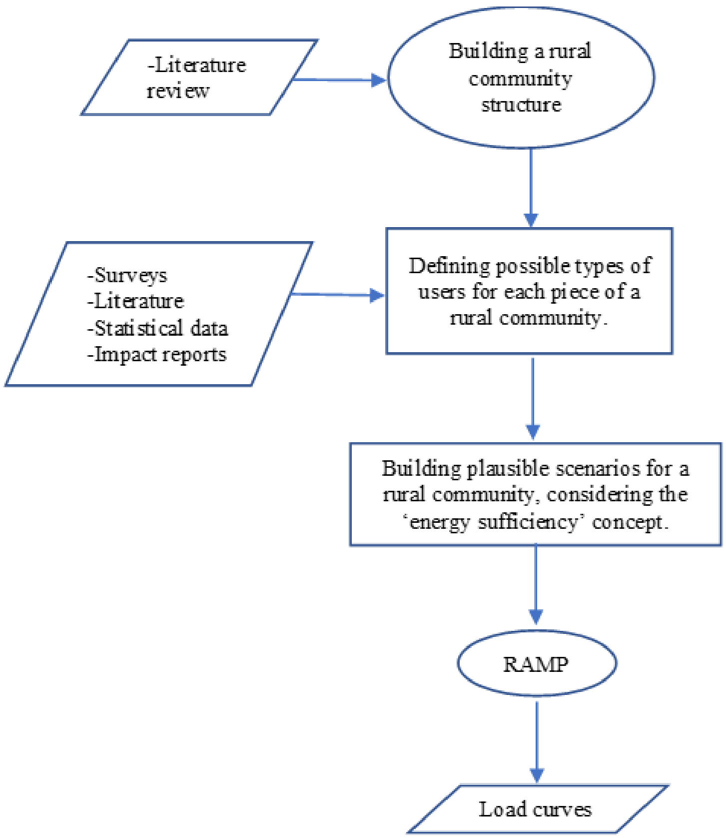


Figure 1: Flow diagram of the process.

RESULTS AND DISCUSSION

Rural community structure

From the human rights perspective, a link has to be considered between electricity access and the right to: 1) An adequate standard of living, including access to food, clothing and housing and to the continuous improvement in living condition, 2) the highest attainable standard of physical and mental health, 3) work, 4) education, 5) a healthy environment to live and to have access to basic public services [15]. In this context, Muhumuza et. al [16] considers six categories to clearly identify the energy needs of rural communities in developing countries. These categories are: lighting and ICT, refrigeration/freezing, cooking/cooling, process power and water pumping. Clearly, these categories are in line with the human rights perspective outlined above. Several studies define sectors associated in one way or another with the above-mentioned categories [8, 15–18]. In this work, three main sectors are identified: 1) residential, 2) community and 3) income generating activities. Within each sector, different users can be identified, as well as the activities they need to fulfil. Table 1 presents a summary of the sectors, users and activities taken into account in the literature.

Energy sufficiency The concept of energy sufficiency was introduced by [13]. The authors proposed that energy sufficiency is a state in which people's basic needs for energy services are met equitably, while ecological limits are respected. Basically, the focus is on energy services to meet needs for shelter, health, work, mobility and communication. These needs vary according to local conditions and concepts such as health, shelter, mobility, and work are being rethought along 'sufficiency' lines and tested in different contexts.

According to the definition presented above, the 'sufficiency' line seems to coincide with the minimum amount of energy required by people to live a dignified life. However, since the concept of 'energy sufficiency' has mostly been conceived and explored in the Global North (with the aim of reducing consumption), it is a challenge to apply it in developing countries, where it is necessary to look for ways to increase provision and consumption in less favoured rural areas. As explained before, the appliance diffusion can take several years to reach urban levels. This and the uncertainty associated with other drivers of demand growth make it difficult to predict the exact moment when energy growth will stabilize on urban levels. Although this is a hard task, what is certain is that the energy sources must be able to supply it as efficiently as possible [19].

The supply side is not a problem in places where a connection to the main grid is an alternative, as it has been proven to be able to provide the needed energy in a reliable way. On the other hand, isolated systems have limited production capabilities. Depending on the specific characteristics of the system, they may have problems meeting unexpected high demands. In this context, there is a need to ensure adequate access to energy to individual households to not cope with their development.

Case study

Bolivia is a South American country that has not yet achieved full electricity coverage throughout its territory. Until 2018, a national electricity coverage of 93% has been registered, with 99% of coverage in urban areas and 80% in rural areas [20]. In a previous work, communities smaller than 50 households were identified to be mostly low-income and thus may not have sufficient demand to make microgrids economically viable. Some of these communities are also scattered, which complicates the installation of a local grid. One the contrary, the economic optimization shows that most communities with more than 550 households could preferentially benefit from a connection to the main grid. In total, 903 communities are identified with 50-550 households without access to electricity in 2025 [20]. Such communities are distributed among the lowlands,

Table 1: Sectors that need to meet their energy needs.

N°	SECTOR	USER	ACTIVITIES
1	Residential	Household	Lighting Cooking Space heating Space air-conditioning Food preservation Other Studying/working Water pumping Communication
2	Community (public institutions)	Medical centre	Lighting Space heating Space air-conditioning Powering appliances Water pumping
		School	Lighting Water pumping
		Church	Lighting Powering appliances
		Sports field	Lighting
		Public infrastructure	Public lighting Water pumping
3	Income Generating Activities	Agriculture	Watering
		Livestock	Livestock watering
		Industry/transformation processes	Wool harvesting Crop processing
		Comerce (Small shops)	Food refrigeration
		Comerce (restaurants)	Cooking Food refrigeration
		Workshops	Repair/construction

highlands and valleys that comprise the Bolivian territory.

The Bolivian lowlands are defined as all land in Bolivia below 500 meters above sea level, covering 670,000 km^2 between the Andes in the West and neighboring countries in all other directions. This comprises a diverse mosaic of tenure systems, land uses and actors. These range from indigenous peoples and communities to agribusiness and traditional cattle ranchers, along with small-scale farmers increasingly engaged in commercial agriculture. In this region, the communities of El Espino and El Sena have been the object of previous works by the authors. Campaigns were carried out to conduct interviews with the inhabitants of these communities, to obtain information about the use of electrical appliances, once they gained access to electricity through isolated systems [14].

Residential sector Within the residential sector, several studies have been carried out to understand the complexity of household electricity use. Nevertheless, the understanding of behaviour and energy consumption patterns remains limited especially in rural areas of developing countries [21]. The determinants of household energy use can be classified into endogenous and exogenous factors, according to [21]. The former refers to economic and non-economic characteristics, as well as cultural and behavioural characteristics. Exogenous factors comprise the physical environment, policies, energy supply factors and the characteristics of energy appliances. Basically, they are the characteristics within and outside the household.

The National Health Survey conducted in Bolivia in 2016, provides information about the electrical appliances owned by households in different regions of the country. Figure 2 shows the most common electrical appliances used in lowlands households, in regions with high and low poverty.

Among the government policies to encourage the use of electricity in the less favoured communities, the Dignity Tariff has been established, which consists of a 25% discount on the total bill for household users who consume less than 70 KWh per month [23]. However, for rural communities, this value has been reduced to 50 KWh per month. Through a brief analysis, carried out with RAMP, reaching a monthly consumption of 70 kWh per month entails using only a limited number of electrical appliances such as lights, a television, a radio, mobile phones and a small refrigerator.

Rural municipalities in Bolivia have been grouped into different groups, of which two are distinguished for rural areas: extremely rural poor (ERP) and rural poor (RP). The communities within these municipalities reach high levels of poverty, which have been measured according to the degree of unsatisfied basic needs. The percentages of unsatisfied basic needs (UBN) in these groups reach 96%, and 90%, respectively [24]. Therefore, two types of users have been defined for this sector: low-income households and high-income households. The latter reaches the 'decent' consumption set by the government (50 - 70 KWh/month), which in this study, is considered as 'sufficient'.

Community services The public sector is associated with the services necessary to satisfy the population's right to education and good health, among others. The National Norm for the Characterisation of Primary Health Care Facilities [25] establishes minimum criteria for the presence of health facilities in rural areas. For communities between 500 and 1000 inhabitants, it establishes that there must be a health centre. In the case of localities with smaller populations,

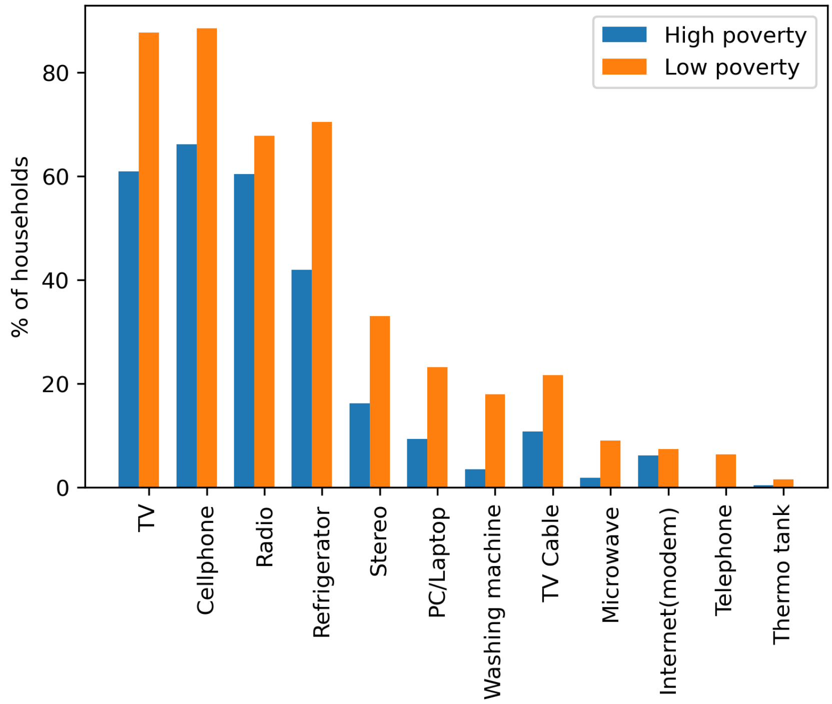


Figure 2: Appliances commonly used in the Bolivian lowlands, based on data from the National Demographic and Health Survey 2016 [22].

the criterion of geographic accessibility is considered, which establishes that there should not be more than 2 hours (by car) from the health facility with the lowest resolution capacity to the one with the highest reference capacity. On the other hand, there should be a health centre with hospitalisation in communities with 1000 to 10.000 inhabitants. The same document sets out the minimum requirements for these health facilities regarding infrastructure and equipment. In this context, With the drafting of this regulation, the government sets the minimum requirements for the provision of first-level health services, i.e. it establishes 'sufficient' conditions, according to the characteristics of rural communities, such as the number of inhabitants and the distance to larger communities.

Likewise, educational facilities need to be accessible to people living in rural communities. However, in the Bolivian lowlands, education coverage still stands at 73-83%. This reflects the fact that there are still rural communities that do not have access to educational facilities, despite the significant progress made in recent years [26]. Three types of educational facilities have been identified as prevalent in rural areas. The first, called Type A school, corresponds to small multi-level establishments, located in the smallest and most remote communities. Type B schools include a larger number of rooms and house different levels of instruction, from primary to secondary, and double-shift operation is possible. Finally, type C schools correspond to much more equipped educational establishments, able to accommodate a larger number of students. These establishments are mostly found in larger rural communities, close to cities and main roads [27]. The presence of at least one type of educational establishment, according to the characteristics of the community, is considered 'sufficient'.

It is finally important to note that most rural communities dispose of sport facilities according to the health policies implemented by the government in recent years. In addition, it is common to find the presence of churches and drinking water supply systems in the larger communities.

Income Generating Activities Income-generating activities (IGA) are all agricultural or non-agricultural activities that allow the inhabitants of a community to generate the necessary income for subsistence. A previous analysis by Funes [28] points out that non- agricultural IGA in each region of Bolivia reflect the characteristics of the local idiosyncrasy. For example, the recreational and food businesses acquire significant importance in the lowlands of Beni. This explains why the lowlands exhibit a higher specific consumption in relation to the highlands. The same study shows that the main businesses in the lowlands - from most to least important - are entertainment businesses (karaoke, bar), workshops (wood and mechanics), grocery stores, butchers and ice cream shops, and restaurants (see figure 3).

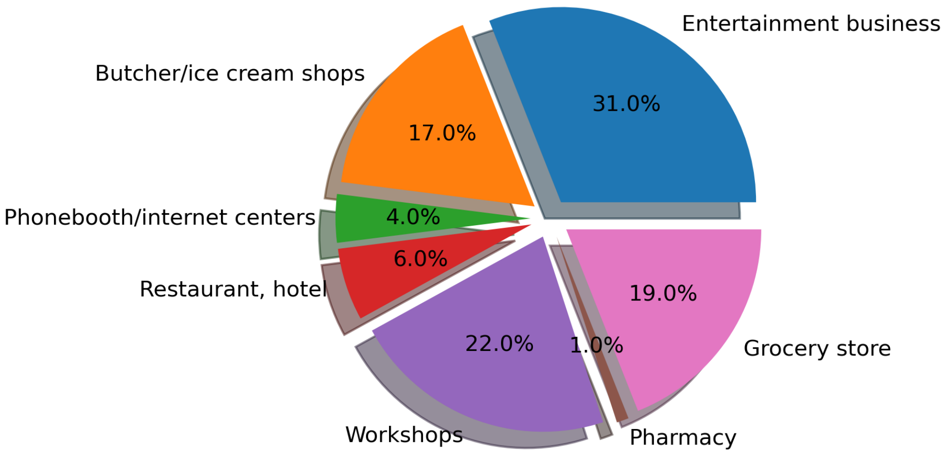


Figure 3: Commercial activities in Beni.

Acoording to [29],household income from agriculture is most important in the Bolivian highlands and valleys. On the other hand, in the lowlands, income from agricultural activities is less important, but still represents a slightly higher percentage than non-agricultural income.

Regarding agriculture IGA, the tropical foothills of Beni and La Paz have great potential for sustainable cultivation systems for palm heart, high-value agroforestry crops and tropical fruits. The Beni savannas are home to the country's largest beef cattle producers. In the Chapare region (Cochabamba), agricultural activity is based on small mixed production systems of tropical fruits, some cereals and coca, among others; although experts point out that the best use of Chapare lands would be for forest management and agroforestry. Santa Cruz comprises the region of the country where a dynamic commercial agriculture with some export crops has developed. The region is where basic inputs are produced for the preparation of concentrates and balanced feed for poultry and animal feed. There are extensive crops of sugar cane, soya, cotton, maize, rice, wheat and beans, fruit crops (mango, pineapple, avocado, tamarind and citrus) and vegetables. In the Amazon region, finally, timber extraction predominates [30].

In summary, the Bolivian lowlands have a lot of potential for agricultural activities. The climate characteristics of the area make irrigation less necessary than in the highlands and valleys.

According to the national inventory of irrigation systems 2021 [31], until then, no irrigation systems had been registered in the regions of Beni (due to the rainfall characteristics of the region) and Chaco. Small, medium and large irrigation systems were recorded in the department of Santa Cruz. According to the inventory, there is about one irrigation system for every 65 families in the Santa Cruz plains. This data is useful to estimate the number of irrigation systems in the lowland communities, since irrigation systems represent an important electricity consumption associated with agricultural activities. Additionally, appliances associated with transformation activities of the main lowland agricultural products, as defined by Funes [28], were taken into account.

Not taking into account the energy needs for IGA, increases the risk of energy 'peripheralization' in rural communities [12]. There is evidence that access to electricity for small enterprises has an impact on economy, although it is relatively small compared to the impact on village life linked to the provision of new services and products [32]. However, it has been shown that, even after access to electricity, most economic activity remains agriculture in rural areas. The transformation processes of agricultural products therefore represents an opportunity for growth and diversification of the rural economy [32]. In this context, since the 'sufficiency' line considers the minimum amount of energy required by people to live a dignified life, taking into account the electrical energy necessary to develop activities that allow the generation of income is crucial.

Based on the above inventory of activities throughout the country, a number of typical electricity users have been defined (Table 2). The presence of each type of user in a community depends on the number of inhabitants, the considered region in the lowlands, and the proximity to cities or larger communities.

Scenarios Many of Bolivia's rural lowland communities still lack of community services and have high levels of poverty. The share of people living with unsatisfied basic needs in these rural communities is above 80% [24]. Two realistic scenarios corresponding to this situation were defined, according to municipalities classification, as 'Extremely Rural Poor' (ERP) and 'Rural Poor' (RP). In these scenarios (S1 and S4), the poverty percentages corresponding to each group are considered. The presence of health facilities is omitted since this is the most typical case, while very basic educational facilities are considered. Drinking water supply services and agricultural activities supported by electrical equipment are also omitted.

Scenarios 2 and 5 retain the percentage of poverty established by the socio-economic classification of municipalities. However, in these scenarios, the presence of community services and electrical appliances associated with agricultural activities are taken into account.

Finally, two parallel scenarios (3 and 6) were built, considering 'energy sufficiency' implications, which means improved living conditions. Regarding to the residential sector, the percentage of people that do not meet their basic needs is reduced to the percentage in urban areas (58%, according to [24]). This means an increase in households considered as high income households, which in turn, reach 70 kWh/month of consumption, which corresponds to the limit of the 'dignity tariff', set by the central government. Community services previously established are included in these scenarios. Additionally, an adequate water supply system for the population was considered, as well as agricultural activities supported by irrigation systems and processing

Table 2: Defined users

Sector	User	Type
Residential	Household	Low income households
		High income households
Community services	Medical centre	Health post
		Health center
	School	School A
		School B
		School C
	Public infrastructure	Public lighting
		Sports field/coliseum
		Church
		Water supply system
Income generating activities	Agriculture and livestock	Irrigation system
		Transformation
	Commerce	Grocery store
		Restaurant
		Workshop
		Entertainment (karaoke, bar)

Table 3: Scenarios

N°	Socio-economic classification	Population	Households	% UBN	Community Services	IGA
S1	ERP	500	126	96	N	N
S2	ERP	500	126	96	Y	Y
S3	ERP improved	500	126	58	Y	Y
S4	RP	1000	252	90	N	N
S5	RP	1000	252	90	Y	Y
S6	RP improved	1000	252	58	Y	Y

devices. Table 3 shows scenarios features. Each scenario was modelled in RAMP to generate stochastic load curves and electricity demand patterns. The model source code together with the number of users, the appliances and the characteristic of use, as defined in each scenario, are available in the project repository [1].

The generated daily load profiles are provided in 4. The results show considerable variations between parallel scenarios. Three main observations can be made from the results. First, comparing the peak load of scenario 1 and scenario 2, we can see that if IGA and community services are not taken into account for the estimation, the peak load can be underestimated by up to 45%.

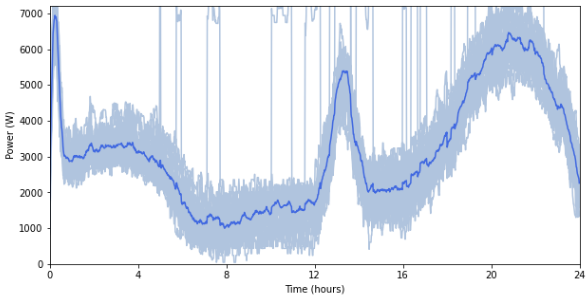
Regarding the second observation, comparing scenarios 1 and 2, 4 and 5, the effect of the provision of improved community services is visible, as well as the use of electrical appliances to support agricultural activities. The level of economic income remains the same, and this could be reflected in the implementation of government programs for the improvement of basic services and support for agricultural activities. In other words, taking into account community services and the electricity load associated with agricultural activities for the estimation of demand doubles the monthly consumption in the first case, and triples it in the second case.

Finally, comparing scenarios 1 and 3 (extremely poor rural), and scenarios 4 and 6 (poor rural), the increase in consumption when people's quality of life improves can be noted. That is, when electricity demand increases, as people acquire more electrical appliances and when adequate community services and support of electrical equipment for agricultural activities are considered. In this case, both comparisons lead to a four-fold increase in monthly consumption, and the percentage of people who do not meet their basic needs decreases.

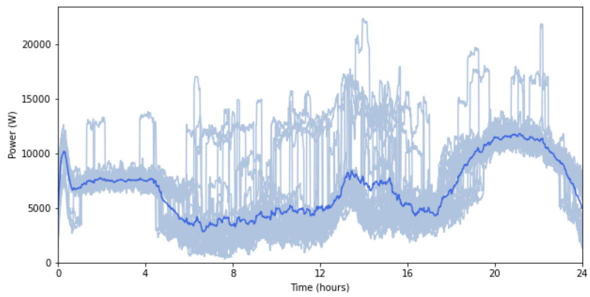
CONCLUSION

The study of demand and its estimation is a very important issue energy planning and rural electrification in remote areas. In this work, the construction of staged scenarios, was supported by literature focused on the lowland region of Bolivia. In this way, it was possible to identify

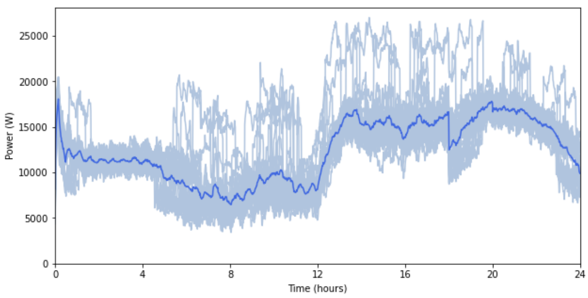
[1] https://github.com/CIE-UMSS/VLIR_Energy_Demand/tree/main/Bolivian_Lowlands



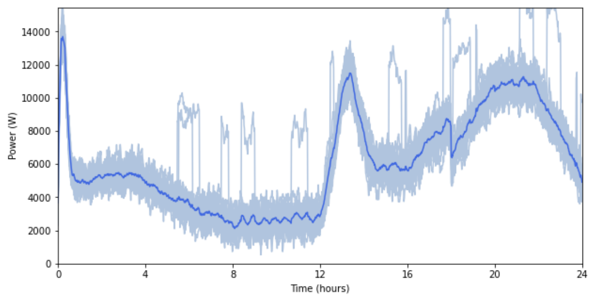
(a) Scenario 1



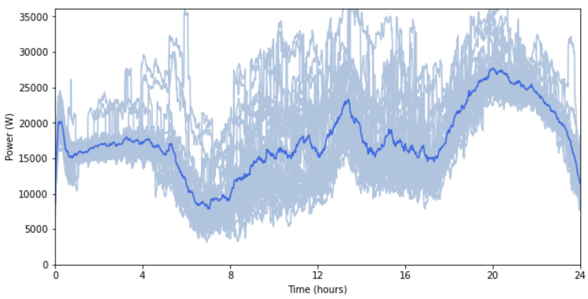
(b) Scenario 2



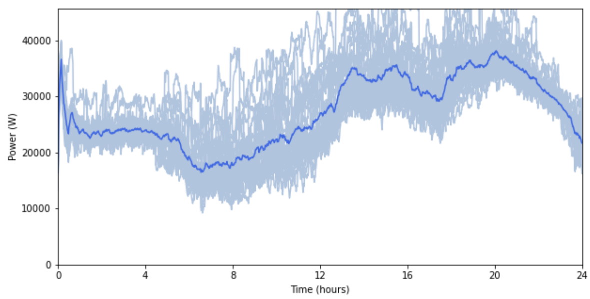
(c) Scenario 3



(d) Scenario 4



(e) Scenario 5



(f) Scenario 6

Figure 4: Monthly-averaged daily load profiles (November) for the six scenarios.

Table 4: Quantitative comparison between scenarios.

	S1	S2	S3	S4	S5	S6	S7
Peak load (W)	12439	22355	33476	16597	42428	58373	93047
Aggregate demand (KWh)	2278	4869	9007	4398	12629	19644	33097

characteristics of the region under study, which may influence electricity consumption and, subsequently, to define different types of users within the community that correspond to deficient levels of electricity access, as well as levels considered ’sufficient’. Since the concept of ’energy sufficiency’ was conceived as a state in which people’s basic needs for energy services are met equitably, the comparison between the realistic scenarios and the improved scenarios (towards an ’energy sufficiency’ state) demonstrates the considerable gap between the least favoured rural communities and the mentioned state.

In rural communities of lowland Bolivia, poverty levels are high, although there is heterogeneity within the region. The effect of the access to certain types of facilities (e.g. health facilities) on the electricity demand is notorious. It was observed that omitting income-generating activities demand can lead to a considerable underestimation of peak loads. Similarly, a general improvement in both the quality of life of people within households and the provision of adequate community services, as set by national standards, can significantly increase electricity consumption. The quantification of these effects is of primary importance for energy planning purposes in the country, and can serve as input for various types of energy system models.

Future work will concentrate on the extension of the proposed methodology to the whole country. Bolivian lowlands indeed exhibit very different characteristics from the highlands, and this directly influences electricity consumption patterns. For example, electricity consumption associated with irrigation for agricultural activities may be higher in the highlands because this area lacks rainfall for more months of the year compared to the lowlands.

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NOMENCLATURE

Acronyms	
SDG	Sustainable Development Goals
UBN	Unsatisfied Basic Needs
RAMP	Remote-Areas Multi-energy systems load Profiles
ERP	Extremely Rural Poor
RP	Rural Poor
IGA	Income Generating Activities

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