The Energy Sufficiency Concept and Its Impact on Energy Demand Estimation in Rural Communities from Developing Countries

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ABSTRACT

Achieving universal electrification is a complex task because the populations that still do not have access to electricity are usually located in remote areas. The sizing of adequate energy systems requires a detailed study of the energy demand in the communities to be electrified. In this sense, the aim of this work is to explore the evolution of the electricity demand if rural communities follow a development path towards a state of 'energy sufficiency'. With this aim, a series of plausible scenarios are modelled using a bottom-up stochastic model to obtain the electricity demand. Main findings show the importance of considering three main sector of consumers (residential, community services and income generating activities) at the moment of analysing the demand. The demand increases significantly between scenarios and the contribution of each considered sector is different. There are also substantial differences between the lowlands and highlands of Bolivia in terms of the energy demand of rural communities.

KEYWORDS

Rural Electrification, Energy Sufficiency, Developing Countries, Electricity Demand

INTRODUCTION

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 Sustainable Development Goals, access to clean and affordable energy (goal 7) [1] has proved to have strong links to other dimensions of socio-economic development. Much research in recent years, show a link between poverty reduction and energy access [2]; 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 [3]. Furthermore, the link between energy, water and food has been established and explored extensively in the literature as well [4, 5].

However, there are still people who do not have access to electricity and most of them 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 [6]. Off-grid solutions, including solar lighting, solar home systems and with increasing frequency, micro 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 [7].

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 [3], the same authors conceptualize the nexus between evolution of electricity demand and local rural development, suggesting that system-dynamics is 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 definition 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 [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. This paper attempts to expand this theoretical concept to fit in the rural energy access logic since few studies have focused in applying the concept in developing countries. According to [13], having consciousness of what it means to have energy sufficiency is a fundamental energy justice challenge. In a previous work, the concept of energy sufficiency has been explored and the structure of a rural community has been defined based on the basic needs of the population. Additionally, it shows how much electricity demand and peak loads can be underestimated if the demands corresponding to income-generating activities-that help diversify the community economy-are not considered [14]. 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. In this sense, the aims of the present work are as follows: 1) To discuss possible appliance ownership and energy mobility at a residential level in a rural community; 2) To explore the evolution of electricity demand when rural communities experiment a growth path, improving the living conditions towards a 'energy sufficiency state'.

THE ENERGY SUFFICIENCY CONCEPT

The concept of energy sufficiency has been introduced by [15]. 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. However, since the concept of 'energy sufficiency' has mostly been conceived and explored in the Global North, a considerable number of recent studies considers the concept as an strategy for reducing energy service consumption. In the Global South case, there are communities that still do not have electricity and once they gain access, consumption remains low. It is known that access to electricity can boost the development of disadvantaged communities. Thus, the possible evolution in the consumption patterns of the communities must be taken into account when studying the electricity demand for the design of adequate systems; in other words, to allow the 'energy mobility'. The later concept makes reference to the ability of households to increase their energy demand due to an increase in the number of electrical appliances they own or extension in usage of already owned electrical appliances [16].

The 'sufficiency' line seems to coincide with the minimum amount of energy required by people to live a dignified life. In this sense, 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 with all their complexities. As explained before, the appliance diffusion can take several years to reach urban levels. This and the uncertainty associated with other drivers and complexities 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 [17].

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 [18]. 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.

METHODS

To achieve the goal proposed in this work, the main sectors grouping electricity users defined in [14] are considered. For the case study, different possible types of users are defined within each sector, according to the characteristics of the regions under study. Table 1 presents a summary of the sectors users and types of users considered. The characteristics of the users are defined according to the requirements of the open-source bottom-up stochastic model RAMP.For that purpose, national reports, surveys and previous works in the area are consulted. The RAMP 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 [19]). Subsequently, plausible rural community scenarios are constructed with the defined users. With this aim, possible growth paths towards an assumed 'energy sufficiency state' for rural communities of different sizes are considered, since it is known economic development and reduction of poverty is linked with access to electricity, and consequently, with the increase in electricity demand [20]. In this sense, the RAMP tool is used to generate load curves for each scenario, and to analyse the electricity demand behavior in each case. Note that RAMP uses the word 'user' to refer to an electricity consuming entity (i.e. a household, a business, a school or other) and not to individual persons. The same meaning will be used throughout this paper.

Figure 1 shows the adopted method.

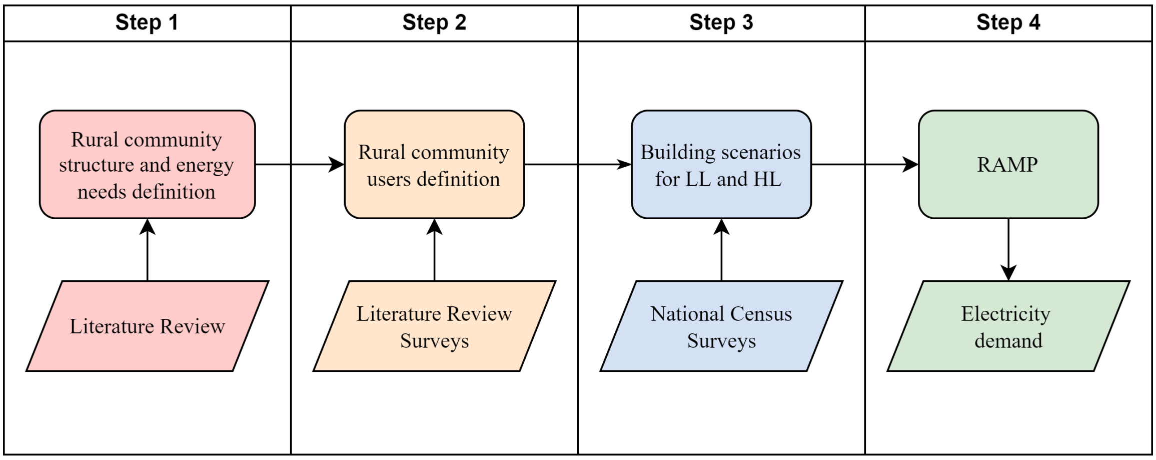


Figure 1: Flow diagram of the process.

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 [21]. In a previous work, communities smaller than 50 households are identified to be mostly low-income and thus may not have sufficient demand to make micro-grids 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 (or already have a connection). In total, 903 communities are identified with 50-550 households without access to electricity in 2025 [22]. Such communities are distributed among the Bolivian territory. In this work, only the highland and lowland regions are considered.

The Bolivian lowlands (LL) 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 agro-business 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 are carried out to conduct interviews with the inhabitants of these communities, to obtain information about the use of electrical appliances, once they gained

Table 1: Defined users

Sector	User	Type
Residential	Household	Low consumption households
		High consumption 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)

access to electricity through isolated systems [19]. In the other hand, this study also considers the Bolivian highlands (HL), which corresponds to regions at an altitude above 3000 meters above sea level. This region is situated in the west side of the country and is also home to numerous remote indigenous communities. Temperatures reach a lower level than lowlands and consequently, humidity decreases from north to south. Rainfall is generally stationary; its distribution decreases from northeast to southwest. In this zone, surveys on electricity use are conducted, specifically in the community of Raqaypampa [23, 24]. A diversity of agricultural crops have been observed in the different ecosystems both in lowlands and in the highlands. It should be noted that temperature, precipitation and altitude fundamentally define the productive potential and their production systems [25].

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 [26]. The determinants of household energy use can be classified into endogenous and exogenous factors, according to [26]. The former refers to economic and non-economic characteristics, as well as cultural and behavioural characteristics and the later encompass the physical environment, policies, energy supply factors and the characteristics of energy appliances.

According to the Electricity Authority's 2020 Statistical Yearbook [27], the residential sector accounts for the largest part of the national electricity demand (National Interconnected System and Isolated Systems), with 43,56% of the total, followed by the industrial sector (22,2%), the general category (18,8%), mining (6,4%), public lighting and others (9%).

The National Demographic and 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 LL and HL households, in municipalities with low and high poverty. The survey presents evidence that the most frequently used appliances in low poverty and high poverty municipalities (where most of the rural communities are located) are radios, televisions and cellphones. Refrigerators are more used in low poverty regions from the lowlands than in the highlands, where average temperatures reach lower levels. Another important difference is that in the HL, the use of radios (instead of TVs) is more frequent than in the LL. High poverty regions hardly have access to modern appliances. [28]. This is also reflected in the information from the surveys conducted in rural communities in previous works (El Espino, El Sena, Raqaypampa). Regarding family composition, the average number of persons per household in rural areas of Bolivia is 3,1, according to the Household Survey 2016-2017 [29]. This data is important for estimating the number of households based on the population of the communities.

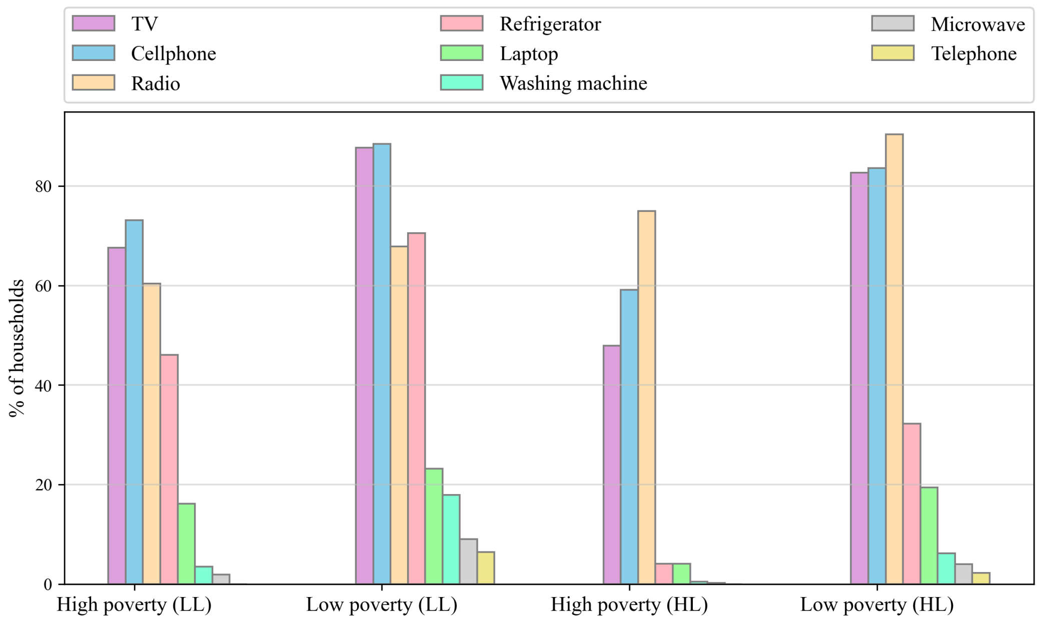


Figure 2: Appliances commonly used in the Bolivian lowlands and highlands, based on data from the National Demographic and Health Survey 2016 [28].

Among the government policies to encourage the use of electricity in the less favoured communities, the Dignity Tariff has been established for residential consumption, which consists of a 25% discount on the total bill for household users who consume less than 70 KWh per month [30]. However, for rural communities, this value has been reduced to 50 KWh per month due to their low consumption registered. Through a brief analysis, carried out with RAMP, reaching a monthly consumption of 70 kWh per month corresponds to a typical household equipped with lights, a television, a radio, mobile phones and a small refrigerator.

Rural municipalities in Bolivia have been classified 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 poverty in these groups reach 96%, and 90%, respectively [31]. Additionally, according to the data base of the National Census 2012, the average poverty among the rural communities, reaches 70% and the minimum poverty rate among rural communities is 53%, which is close to the poverty level in urban areas.

Two types of households have been defined for this sector: low-income households and high-income households. The former is associated with low electricity consumption because the most outstanding feature is the possession of few appliances with low nominal power. The latter is associated with a high electricity consumption because it reaches the 'decent' consumption set by the government (50 - 70 KWh/month), which in this study, is considered as 'sufficient'. The main difference observed between these types of users is the use of modern appliances, mainly refrigerators, according to the surveys.

Community services

The community services comprises the activities necessary to satisfy the population's right to education, good health and clean water. The most common infrastructure for this activities to take place, both in urban and rural communities, includes hospitals and schools (of different capacities), drinking water supply systems and sports facilities or coliseums. The National Norm for the Characterisation of Primary Health Care Facilities [32] establishes a 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, 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 capacities. 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 [33]. 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 classrooms and 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 [34]. The presence of at least one type of educational establishment, according to the characteristics of the community, is considered 'sufficient'.

Finally, it is 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, drinking water supply systems are the vital importance for remote rural communities for the direct impact in health and other aspects of importance for a dignified life, as recognize by the SDG 6. Of course, the type of drinking water supply system will depend on the characteristics of the community, how isolated it is and what water bodies are available nearby.

Income Generating Activities

Income-generating activities (IGA) are all agricultural (and livestock) or non-agricultural activities that allow the inhabitants of a community to generate the necessary income for subsistence.

In the Bolivian rural areas, the most important economic activities are agriculture and livestock, with 78% of the employed population working in this sector; however, 22% of the population works in non-agricultural activities, including manufacturing, sales and repairs, and construction [35]. Nevertheless, agricultural production has low productivity and generally faces low prices in the market, in spite of which the self-consumption of agricultural products constitutes a source of food security for rural households. Households living in rural areas are not exclusively engaged in agricultural work but also have livestock production: more than 12% of rural household income comes from livestock activity and derived products, both in the form of sales and self-consumption. Livestock activities are important sources for improving the income of rural households, because they directly increase their consumption capacity [36, 37].

According to [36], in all regions, agricultural production (both for sale and self-consumption) has the greatest contribution to the structure of household income. In the HL, the value of the products is lower, which determines that the contribution of commercial agricultural activity to household income is also reduced, and is probably one of the determinants of the higher proportion of self-consumption and the incursion into non-agricultural activities. In the LL, the contribution of commercial agricultural activities and self-consumption, as well as the value of livestock production, is high. It is likely that agricultural and livestock products in the LL have a higher value. Non-agricultural and non-labor income is substantially lower in the LL. Table 2 shows the main characteristics of both regions with respect to income generating activities, based on [25, 38, 39].

In this context, different types of irrigation are used for agricultural activities, which may or may not require electric power. Most of the irrigated agriculture in Bolivia (97%) uses flood/gravity irrigation; however, in the last few years, technical methods such as sprinkling and drip irrigation have been introduced, reaching about 9,000 hectares, which represent 3% of the irrigated area. The climate characteristics of the lowlands make irrigation less necessary than in the highlands. According to the national inventory of irrigation systems 2021 [39], 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 are recorded in the department of Santa Cruz. It should be noted that tubers, mainly potatoes, are the crop that occupies the largest area under irrigation, followed by cereals and vegetables. In this sense, these products are grown mostly

Table 2: IGA's characteristics in both regions.

	Lowlands	Highlands
Climatic conditions	Warm and humid	Cold and dry
Agriculture and livestock	Tropical fruits, cereals, coca leaves, vegetables, timber. Beef cattle.	Potatoes, cereals, quinoa. Camelid livestock.
Derived products	Milk, meat, washed fruits and vegetables.	Flours, milk, dry grains, wool.
Irrigation	Low irrigation systems required	High irrigation systems required
Non-agricultural IGA	Entertainment businesses, restaurants, workshops, grocery stores, butchers.	Grocery stores, restaurants, workshops.

in the highlands where the availability of water resources is limited compared to the lowlands. La Paz and Potosí (located in the highlands) are two of the departments with the most irrigation systems in Bolivia.

The transformation of agricultural products is an important form of economic diversification in rural communities. These activities involve the support of machinery to obtain by-products. Governmental and non-governmental support programs focused on the provision of equipment necessary to transform agricultural products have been reported. Appliances associated with transformation activities of the main lowlands and highlands agricultural products, as defined by Funes [38], are considered.

Regarding non-agricultural IGA's, a previous analysis by Funes [38] points out that each region of Bolivia reflect the characteristics of the local idiosyncrasy. For example, the recreational and food businesses acquire significant importance in the LL. The same study shows that the new businesses established 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; while in the HL are grocery stores, followed by dairy shops and restaurants.

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 [40]. 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 [40].

Based on the above information, a number of typical users have been defined (Table 1). Note that the number of different types of users will depend on the characteristics of the rural communities, such as size and climatic region.

Table 3: Four scenarios considered for each community size.

N°	Poverty (%)	Community Services	Agricultural IGA's	Non-agricultural IGA's
1	96	No community Services	No irrigation or transformation	No commerce
2	90	Public lighting + water supply system	No irrigation or transformation	Grocery stores + restaurants
3	70	Public lighting + water supply system + school	Irrigation	Grocery stores + restaurants
4	53	Public lighting + water supply system + school + hospital + other community services	Irrigation + transformation	Grocery stores + restaurants + workshops + entertainment business

Scenarios

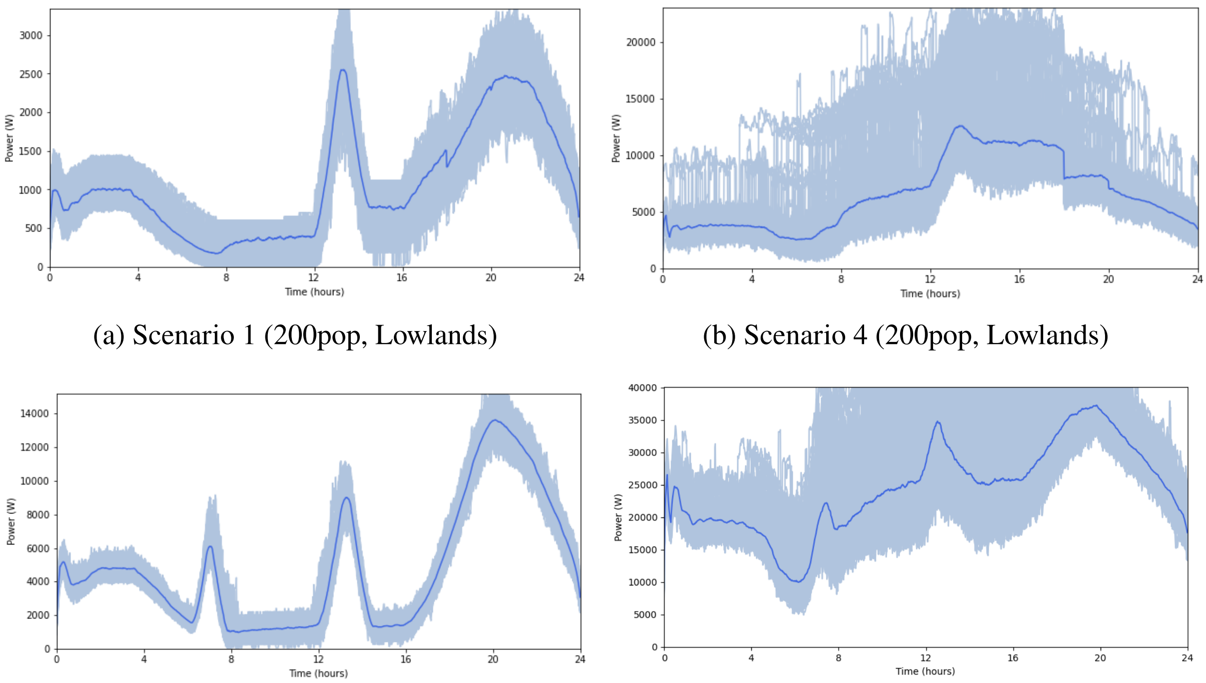
In Bolivia, there are still rural communities that lack access to basic services and have high levels of poverty. The share of people living with unsatisfied basic needs in these rural communities is above 80% [31].

To define the scenarios in this work, characteristics of rural communities in Bolivia are considered, as reflected in the 2012 National Census database. Forty scenarios are examined for the analysis, 20 for each region. Both for lowlands and highlands, five community sizes are considered, in terms of population (200, 500, 800, 1000, 1500 people). For each community size, the four cases shown in the Table 3 are contemplated, varying the poverty level as mentioned in Residential Sector sub-section.

The first scenario contemplated for a rural community has a high poverty level (96%), no community services or support for agricultural activities (irrigation and processing). There are also no other important economic activities. In the second scenario, since the poverty is reduced, there is residential 'energy mobility' and improvement in the quality of life to a level where there is access to public lighting and an adequate drinking water supply system. There is no support for agricultural activities, as in the previous case, but the economy is slightly diversified with non-agricultural commercial activities. The third scenario presents - in addition to the characteristics of the previous scenario - medical services and education, as well as irrigation systems for agriculture. Finally, the fourth scenario is considered as a state of 'energy sufficiency', because it presents access to complete basic community services, as well as irrigation and transformation of agricultural producers with machinery support.

Each scenario is modelled in RAMP to generate stochastic load curves and to analyse 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].

[1] https://github.com/CIE-UMSS/RAMP_Bolivia/tree/main/Rural_Communities_ES



(a) Scenario 1 (200pop, Lowlands)

(b) Scenario 4 (200pop, Lowlands)

(c) Scenario 1 (1000pop, Highlands)

(d) Scenario 4 (1000pop, Highlands)

Figure 3: Average daily load profiles.

RESULTS AND DISCUSSION

The results allow to analyze what happens when rural communities in Bolivia experience energy mobility towards a state of energy sufficiency, considering the three main user sectors.

The RAMP tool allows obtaining daily average load profiles. In total, 365 profiles (1 year) are modeled for each scenario. Figure 3 shows, as an example, the results for four cases, where the stochasticity of the model can be observed. Also, the variation in the average daily profile between scenario 1 and 4 is shown, for communities of 200 and 1000 inhabitants. From these results, it is possible to obtain the aggregate electricity demands in KWh for the whole year and the peak loads for all the considered scenarios, as will be shown in the following analysis.

Figure 4 shows the evolution of the average monthly electricity consumption per household along the 4 scenarios for a 1000 people community. Logically, increasing family income (reducing the poverty) allows households to access new modern appliances or change the frequency of use of those they already own and, consequently, the electricity demand grows. Additionally, the figure shows how, in the fourth scenario, the average lowlands-household reaches the consumption limit where the dignity tariff is applicable, that is 50 KWh per month while the highlands average household fall far behind almost reaching the value of 40 KWh per month. Clearly, LL show higher electricity consumption than the HL, even in scenarios with the same characteristics. This is due to the higher consumption linked to the refrigerator, which is the only modern appliance considered in this study. The average temperature in the LL is higher than in the HL, which is an important factor in the variation of the electrical consumption of this type of appliance, and thereby explains this higher electrical consumption [41]. Increasing the use of modern appliances among rural communities implies improvements at the socio-economic level, since it is necessary to increase family income. Since rural families derive most of their income from agriculture, it is vital to diversify the community economy [35].

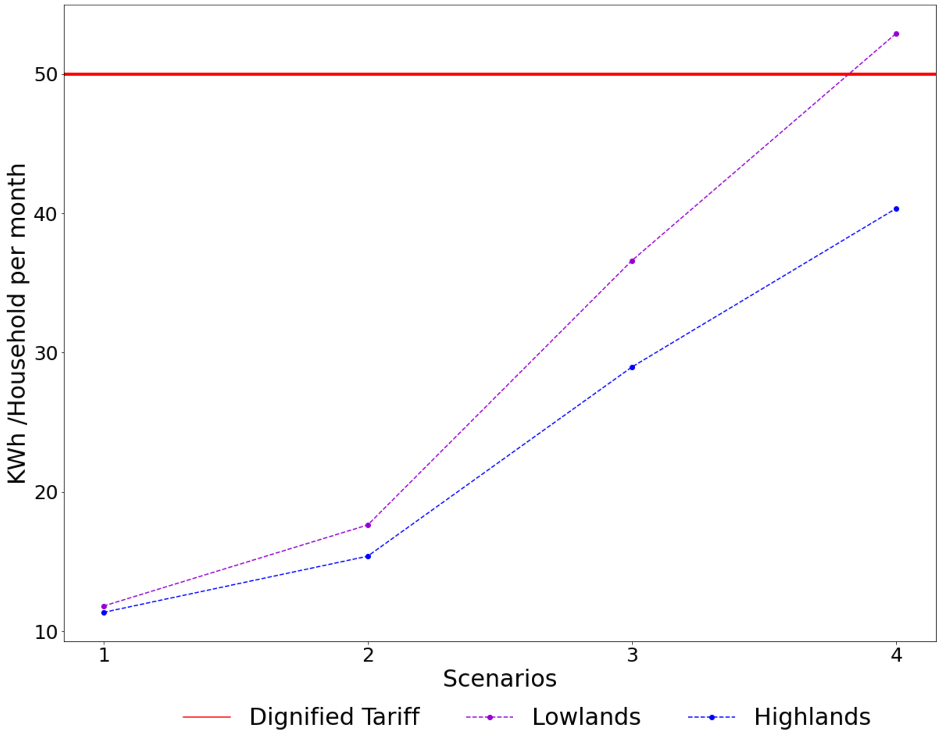


Figure 4: Residential demand comparison between LL and HL

Figure 5 shows that increasing the size of the community produces changes in the framework of the community services sector with the introduction of better health facilities, schools, and other services. For the LL, going from scenario 1 to scenario 2 doubles the demand. In parallel, in the HL, this increase is slightly lower. From scenario 3 to 4, a similar phenomenon occurs. The jump between scenarios 2 and 3 causes demand to approximately triple in the LL. In this case, again the increase is smaller for the highlands. This indicates that the increase in demand is significant when the scenarios experience greater access to community services, agricultural and livestock machinery support, as well as improved household incomes.

Nonetheless, the evolution of the electricity demand of each size of community within its four scenarios - through the growth path towards an 'energy sufficiency' state - shows that the shape of each curve keeps a regular and repetitive behaviour. Therefore, it is possible to argue that the size of the community does not impact the relative developing path towards a better energy access but only on the absolute values of the total energy consumption for each community sector. Thus, it is possible to underline how the absolute growth follows an almost proportional behaviour with the increasing of the number of the households; that could be explained by the dominance of the residential sector in terms of energy consumption and peak power over the IGA and Community services sectors.

In parallel, in the highlands, this increase is slightly lower. The jump between the second and third scenarios causes demand to approximately triple in the lowlands. In this case, again the increase is smaller for the highlands.

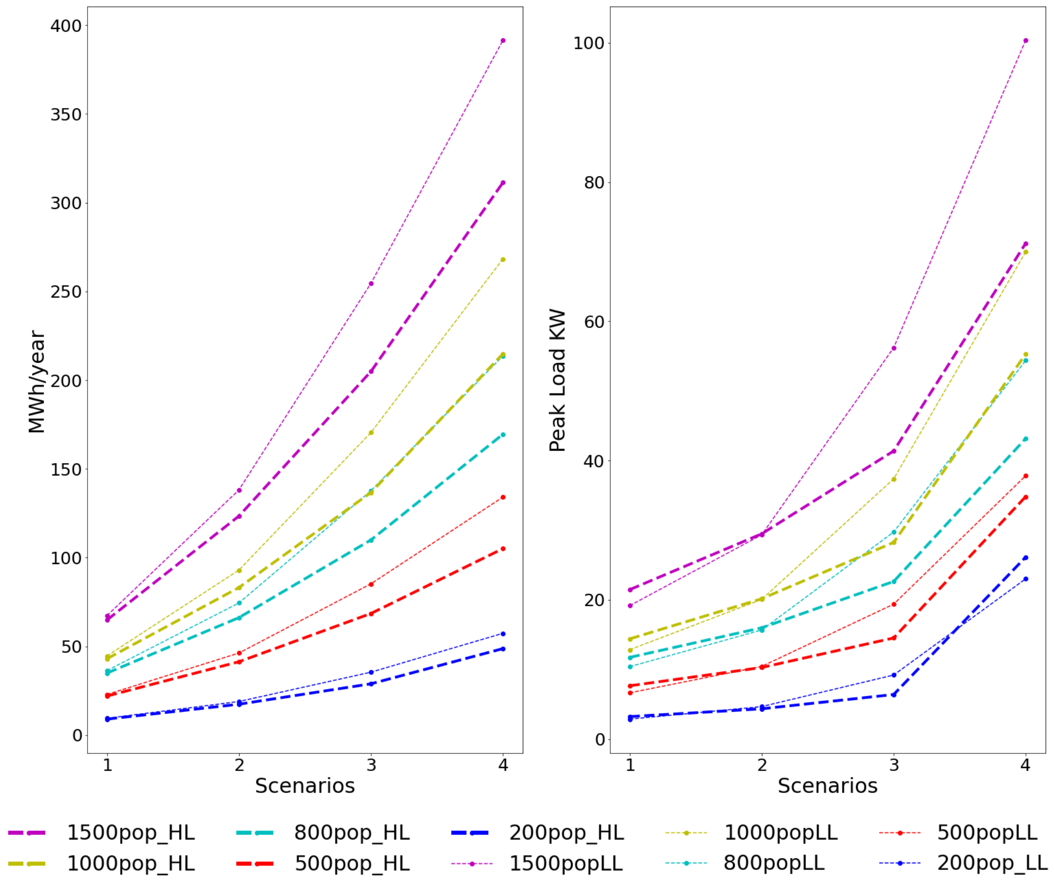


Figure 5: Variation in annual electricity demand and peak load for all the scenarios.

The three main sectors (residential, community services and income-generating activities) considered within the structure of a rural community seem to cover the energy needs to maintain an adequate standard of living. A number of interesting observations can be made, focusing on a community of 1000 inhabitants in the lowlands in Figure:6

- The contribution of the residential sector increases with the decreasing of the poverty rate due to the higher percentage of high consumption households that have a relative weight in terms of energy consumption consuming almost 7 times the energy of the low consumption households.
- The Residential sector, as expected, has the main contribution both in terms of total energy consumption and peak power.
- The IGA sector total contribution is always greater than the Community Services sector, both in terms of energy consumption and peak power, showing a great increase in the angular coefficient when the transition from the scenario 3 to the 4 happens.

- Regarding the peak power, this particular behaviour is even more pronounced reflecting an important change when new business and agricultural activities make their appearance (transformation agricultural activities, business enterprises and workshops).
- The percentage total energy demand contribution of the community services is always lower than 10% percent throughout all the scenarios. The residential sector instead, always represents a share that is higher than 70% leaving the IGA sector with a share between 15 and 25% in most cases.

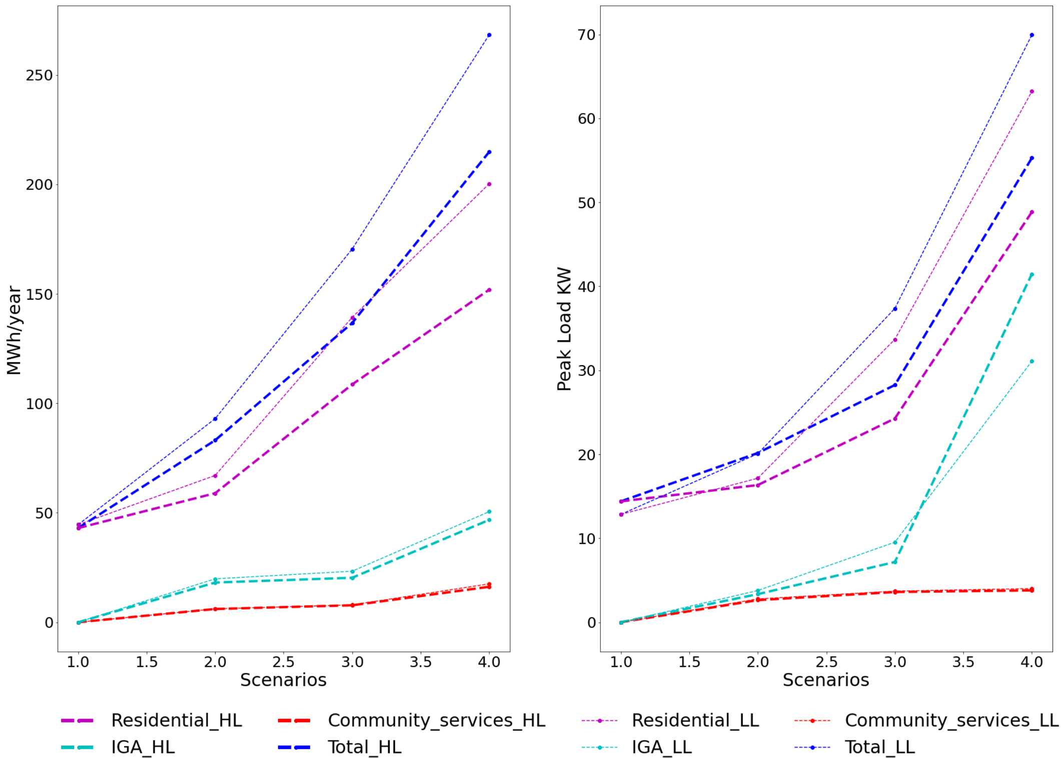


Figure 6: Variation in annual electricity demand and peak load for each sector in 1000 people communities from LL and HL.

In the other hand, in a community of similar size but in the highlands, the contribution of the IGA sector both in terms of total energy demand and peak power is higher than the one of the lowlands. This reflects how the different cultural and climatic factors (and consequently, agricultural potential) impact the different usage and ownership of appliances mainly for what concerns the income generating activities devoted to agriculture. Also the difference in the number of IGA's users devoted to the business activities play a part in this difference.

Following the same behaviour of the lowlands, it is possible to notice how the passage from the 3 to the 4 scenarios implies a relative high change in the absolute values of the peak load and total energy demand for the IGA sector (see Figure:6). In this case there is a difference in the peak load values with respect to the lowlands. The reason is that the IGA sector contribution is different from one to another region because the transformation activities are different and therefore, the used machinery is different as well. Certainly, the nominal power of the appliances used for transformation activities can vary according the type of transformation process. This causes higher peak loads and consumption for the IGA in the highlands. In this sense, it is possible to show the different daily load curves for what concerns the IGA sectors and make a comparison in Figure 7. The variation and the absolute values of peaks are more pronounced in the highlands, reflecting different appliance ownership and activity patterns.

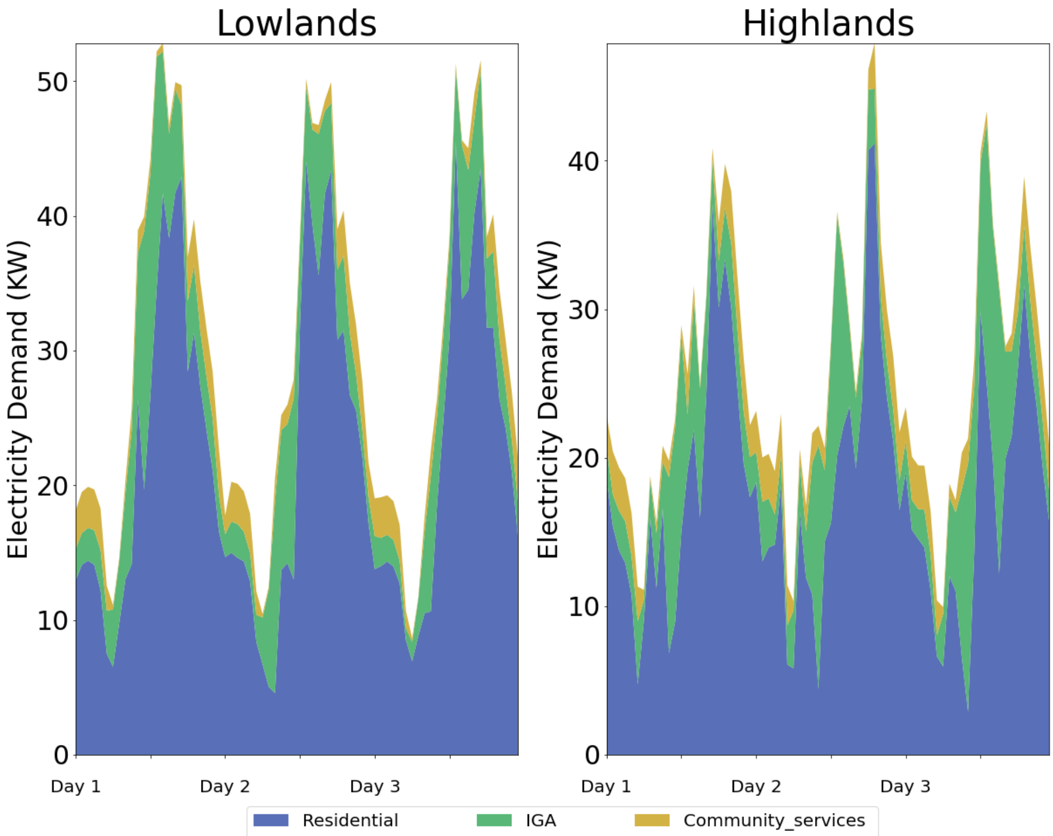


Figure 7: Contribution of each community sector to the daily load curve.

The lowlands development steps have a major impact in terms of energy needs with respect to the highlands. In terms of total energy consumption, the highlands require almost 20% less energy with respect to the total energy consumed by the lowland's community (1000 people community).

CONCLUSION

The study of future demands is an important issue energy planning for rural areas. In this work, four types of communities are considered corresponding to different levels of energy services. The first type correspond to a high poverty rate with no access to community services and no diversification of the economy, while the fourth type corresponds to a state of "energy sufficiency" with better living conditions. Each community type is simulated in the RAMP bottom-up stochastic load generator, allowing to highlight the most important features of the electricity demand. The results show there is a significant increase in electricity demand between scenarios 1-4 of the same community size. For a 1500 people LL community, going from scenario 1 to scenario 4, generates an increase of 500%. This increase is slightly lower in the HL. In this sense, the climatic region proved to be an important factor influencing demand. The contribution of the residential sector is higher in the lowlands, while the contribution of IGA is higher in the lowlands.

Depending on the type of energy supply system that is installed in rural communities, it is important to consider the changes that socio-economic development implies as a result of access to electricity. In rural communities of Bolivia, poverty levels are high, although there is heterogeneity within these regions. The effect of the access to certain types of facilities (e.g. health facilities) on the electricity demand is notorious. Furthermore, it is observed that omitting income-generating activities can lead to a considerable underestimation of the peak load (by about 45%). 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.

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NOMENCLATURE

Acronyms	
SDG	Sustainable Development Goals
LL	Lowlands
HL	Highlands
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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