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Electrification for the elite? Examining whether electrification programs reach the poor in Bolivia

Laura M. Hinestroza-Olascuaga [a,*], Pedro M.S. Carvalho [a,b], Célia M.S. Cardoso de Jesus [a,b]

[a] Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal
[b] INESC-ID, Rua Alves Redol 9, 1000-029 Lisbon, Portugal

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ABSTRACT

The Government of Bolivia (GoB) aims to provide electricity coverage for all citizens by 2025. This implies reaching remote areas, where electricity access rates are currently below 90% (as of 2018). To achieve this objective, the country has implemented several initiatives, such as the "Living with Dignity" program (PEVD) launched in 2008 to promote access to electricity for all, targeting the country's poorest areas. Identifying these communities requires relying on different poverty indicators, including the unsatisfied basic needs (UBN) index. This paper focuses on identifying whether the PEVD is targeting the poorest communities. Thus, we explore the criteria that guide the GoB in selecting the areas that should be prioritised. We analyse the suitability of using the UBN index as the social criterion for this purpose. We draw on data provided by the local Censuses of 2001 and 2012. Results suggest that Bolivia's poorest states, namely those having the highest UBN indices for 2001, experienced the largest improvements in electrification between 2001 and 2012. These results could enable policymakers to target future interventions and prioritise the poor for the provision of electricity access. However, using complementary socio-economic indicators, such as the Multidimensional poverty index (MPI), could complement the traditional UBN index by capturing more relevant information that could lead to a more accurate poverty measurement and rural electrification interventions. In addition, Bolivia is not on track to achieve universal access by 2025 and additional investments should focus on increasing electricity access rates in the states of Potosi, Pando, and Beni.

1. Introduction

Electricity access is linked to many positive developmental benefits including: higher quality of life, greater educational attainment, job creation, increased social equity, improvement of health services, access to information, increased productivity, decreased poverty, female empowerment, and improvement of the water-energy-food nexus [1–6]. Unfortunately, there are about 850 million people who cannot benefit from these welfares because they do not have access to electricity (as of 2018) [7]: 87% of them are living in Sub-Saharan Africa and South Asia, and deficits continue to prevail in rural areas, where about 80% of the population without electricity lives [8].

In consequence, this lack of access to modern energy services, namely energy poverty, has become one of the major challenges to overcome by 2030. Governments across the world have identified the need and complexity of achieving universal access by adopting the United Nations Sustainable Development Goal (SDG) 7, which aims to ensure access to affordable, reliable, sustainable and modern energy for all by 2030 [8]. Within this context, many studies have focused on identifying key strategies to increase electricity access in rural areas, especially in Sub-Saharan Africa and South Asia [9–12]. In South America, where electrification rates are above 95% in most countries of the region (99.3% in urban areas and 92% in rural areas, as of 2014), similar studies have also examined the progress on electricity access and the electrification policy in the region [13]. Banal-Estañol et al. [14] analysed the main strategies used in Latin America to increase electricity coverage and argued that off-grid energy technologies have been essential in the rural electrification process. Feron and Cordero [15] evaluated the sustainability of rural electrification programs in Peru, giving special attention to the on-going massive electrification program that aims to deploy a minimum of 150,000 off-grid solar photovoltaic (PV) solutions. Gaona et al. [16] and Rodriguez [17] studied the rural electrification process in off-grid areas in Colombia. They analysed the energy policy for rural electrification and the remaining obstacles to achieving universal access in the country. Gomez and Silveira [18] and Slough et al. [19] identified the achievements and

* Corresponding author.
E-mail addresses: laura.hinestroza@tecnico.ulisboa.pt (L.M. Hinestroza-Olascuaga); pcarvalho@tecnico.ulisboa.pt (P. M.S. Carvalho); celiaj@tecnico.ulisboa.pt (C. M.S. Cardoso de Jesus)

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lessons from the Brazilian electrification program "Light for all" (Luz para todos or LPT in Portuguese). They evaluated the progress in household electrification and also studied the relationship between development and the improvement in rural electrification, as a result of the LPT program.

However, following the existing literature, there is little empirical evidence evaluating the rural electrification policy in Bolivia, the country with the lowest electrification rate in the Amazon Region and who has historically been among the three South-American countries with the lowest rural electrification rate [20]. How is the Bolivian rural electrification policy progressing towards meeting universal access? Are current electrification programs reaching the poorest rural households in Bolivia? To provide some answers, this study presents an overview of Bolivia's rural electrification policy and describes which criteria guide the Bolivian government in identifying the areas that should receive priority in rural electrification programs. In doing so, this paper examines the suitability of using the unsatisfied basic needs (UBN) index, as the social criterion to target the poorest communities. This analysis is relevant not only to Bolivia but also to other developing countries relying on the UBN index.

The main contribution of the article is to inform about current programs and achievements concerning the rural electrification policy in Bolivia. Additionally, we describe the association between the UBN index and the improvement in access to electricity in all the Bolivian municipalities. These results could help Bolivia in moving forward with its rural electrification programs and the goal to achieve universal access by 2025. In particular, using the UBN index as a result of the next census (planned to be held by 2021) could contribute to the definition and prioritisation of future rural electrification projects, expected to be implemented between 2021 and 2025.

2. The energy sector in Bolivia

The Bolivian electric power system consists of the National Interconnected System (NIS), which serves the main cities of the country, and the off-grid system (OS), which provides electricity to scattered or distant communities (See Fig. 1) [21]. This electricity infrastructure, managed by the Ministry of Energies (ME), serves about 2,760,326 households, representing a national electrification rate of about 90.3% (as 2016) [22].

The total installed capacity of the Bolivian electricity system is about 2,141.09 MW (as of December 2016), being 85.65% derived from the NIS and 14.35% from the OS [21]. The NIS comprises the generation, transmission and distribution systems, and serves all the country's nine states except for Pando. Its energy matrix (as of 2016) is

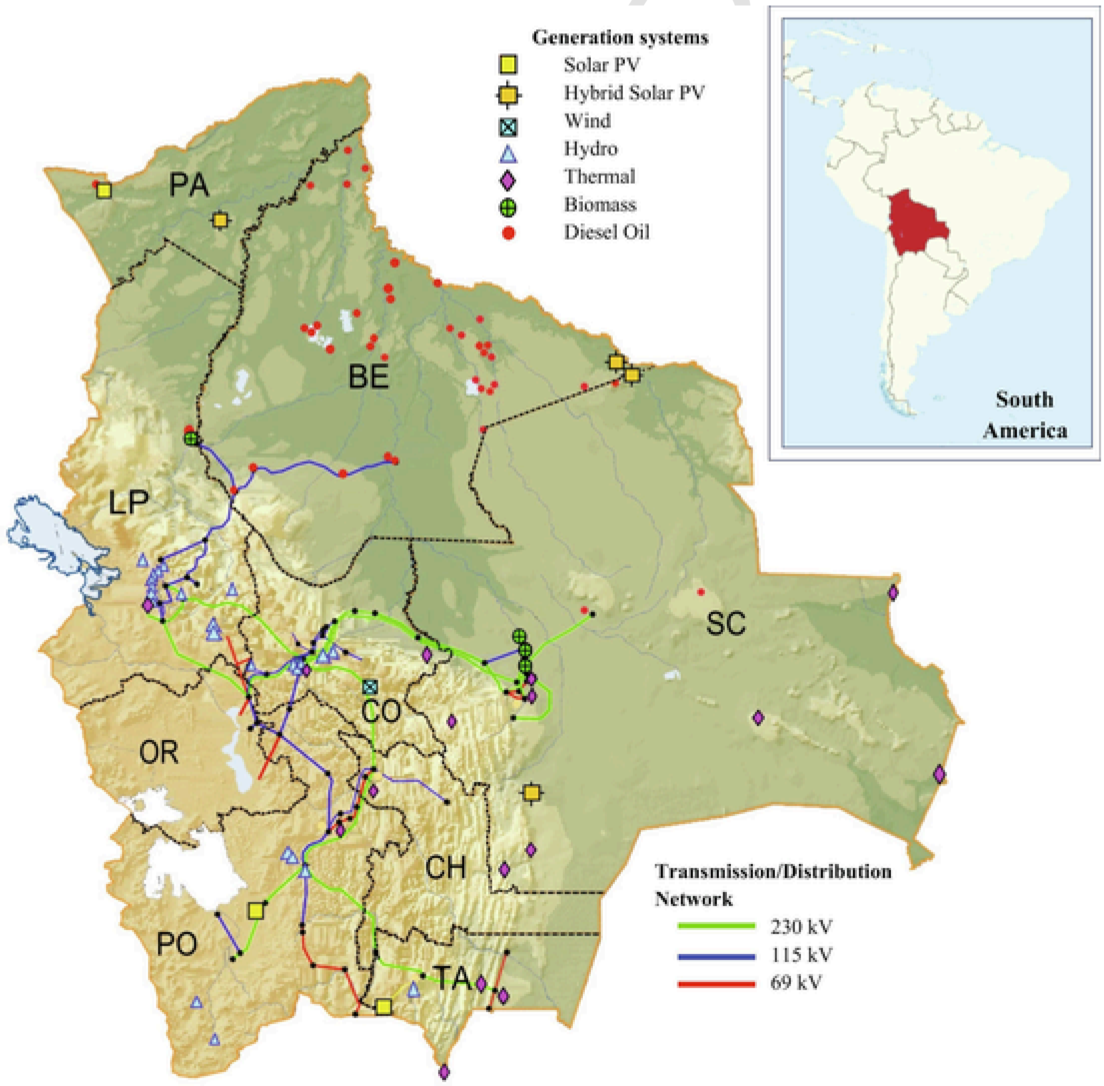


Fig. 1. Interconnected and off-grid electricity systems in Bolivia (2018) covering the states of: PA (Pando), BE (Beni), SC (Santa Cruz), OR (Oruro), LP (La Paz), PO (Potosi), CH (Chuquisaca), TA (Tarija), and CO (Cochabamba). Source: Authors, adapted from [23].

80.02% based on thermoelectric generation (mainly natural gas); 19.58% comes from hydro-power plants and about 0.4% from renewable energy systems (mainly Biomass) [21]. In contrast, 80.6% of the electricity generation in the OS, depends on thermoelectric generation (about 70% is diesel-based) [24]; 0.7% corresponds to hydropower generation and about 18.74% comes from solar PV and biomass systems.

2.1. Rural electrification policy

The government of Bolivia (GoB) acknowledges that rural electrification is the base for rural development and considers it as one of the priority issues in the energy policies of the VMEEA (Vice Ministry of Electricity and alternative energy), the national institution responsible for establishing and facilitating rural electrification policy [25]. Electrification access rates show that rural electrification has increased from 33% in 2005 to 73% in 2016 (See Fig. 2), representing about 745,912 new households with electricity access [24,26]. However, Bolivia is still the country of the Amazon region with the lowest rate of rural electrification followed by Peru and Colombia, as of 2018 [27]. Under this circumstance, the country's electrification efforts have evolved in the last decades and several programs have been implemented to provide better coverage.

In particular, in 2002, the government established the Bolivia's Rural Electrification Plan (PLABER in Spanish) to increase access to electricity in rural areas from 24.5% (in 2001) to 45% (in 2007) and thus, contributing to the socio-economic development of rural areas through access to electricity and its efficient and productive uses. The short-term goal of the program was to make 200,000 new connections within this period, but, due to political and economic crises, about 20,000 households did not get the service [28].

Then, by 2008, the VMEEA launched the Electricity Program "Living with Dignity" (Electricidad para Vivir con Dignidad or PEVD in Spanish), through the Supreme Decree No. 29635, a plan to promote universal access in urban and rural areas, giving national priority to rural electrification [29]. It focuses on reducing poverty, enabling a productive economy, providing electricity access for all by 2025 and fostering the use of renewable energy in rural and urban areas [22]. This program has contributed to bringing electricity service to about 2,303,144 households, involving the participation of the local government and the private sector.

As part of the PEVD, the government defined eight projects (See Table 1), being implemented in 88 municipalities (See Fig. 2) and expected to benefit around 70,000 families, within four stages [22,30]:

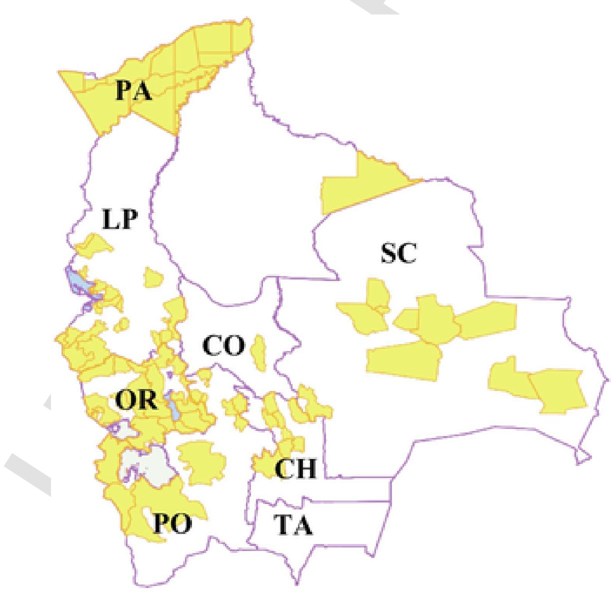
- *Stage I (2006–2010):* increasing electricity access rates from 33% to 53% in rural areas and from 87% to 97% in urban areas;
- *Stage II (2011–2015):* achieving an electricity coverage of 70% in rural areas and 100% in urban areas;
- *Stage III (2016–2020):* achieving an electricity coverage of 87% in rural areas;
- *Stage IV (By 2025):* achieving universal access

The first six projects were completed from 2011 to 2018, and currently, two more are being implemented [22].

It was in 2009 when the Political Constitution of Bolivia defined electricity access as a citizen's fundamental human right (Art.20) and created a set of social initiatives to reduce the gap of energy access between urban and rural areas[32]. In consequence, within this effort to achieve universal access, in 2013, the government set the Bolivia's "Patriotic Agenda of the Bi-century 2015–2025" targeting social and economic development under a five-year development plan (2016–2020). This program contains national goals in 13 categories, including the eradication of extreme poverty and 100% coverage of electricity [33].

Additionally, in 2014, the government launched the 2025 National Plan for the Bolivian electricity sector. It aims at ensuring the supply of electricity in the short-, medium-, and long-term to households and social/official institutions (namely schools, health centres, and community centres) in the country [26]. Within the plan, there are three possible electrification options for urban and rural areas: grid densification, grid extension or implementing off-grid systems. In urban areas, where the population density is high and customers are close to the main grid, the plan favours grid densification in 100% of the projects. In rural areas, 70% of the projects will depend on extending the grid, 20% on the grid densification and 10% on the installation of off-grid renewable energy systems, including mini-grids and stand-alone generation systems.

Based on the projections of this national policy, between 2016 and 2020, 96% of the country's households will have access to electricity:



State	2001 UBN index (%)	2012 UBN index (%)
PO	79.7	59.7
BE	76	58.8
PA	72.4	55
CH	70	56.4
OR	67.9	47.0
LP	66.2	45
CO	55	45.5
TA	50.8	34.6
SC	38	35.5

Fig. 2. Location of Bolivian states under the PEVD program: PA (Pando), BE (Beni), SC (Santa Cruz), OR (Oruro), LP (La Paz), PO (Potosi), CH (Chuquisaca), TA (Tarija) and CO (Cochabamba), and their corresponding 2001 and 2012 UBN indices. Source: Adapted from [31].

Table 1
Overview of rural electrification initiatives within the PEVD between 2011 and 2021. Source: Author's compilation based on [23,30,34,35,36].

Period	Project	Features	Location	No. of beneficiaries	Investment ($ US)	Source of financing
2016–2019	"Reaping life, sowing light" (Energy component) (Cosechando Agua, Sembrando Luz)	*Solar PV systems for households, education institutions, and health centres	(3) Municipalities (Tacobamba, Ocurí and Ravelo) in the state of Potosi	1524 families, 36 education institutions and health centres	10 M	Financial fund for the development of the Countries of the River Plate Basin (FONPLATA)
2015–2016	Program of Solar PV and thermal systems in Health centres of the State of Pando *(Sistemas Fotovoltaicos y Termosolares en Puestos de Salud Departamento de Pando-SFT)*	*Installation of 21Thermal and 21 Solar PV Systems in health centres	State of Pando	21 Health centers	0.188 M	VMEEA
2014–2021	Decentralized Infrastructure for Rural Transformation II *(Proyecto de Infraestructura Descentralizada-IDTR II)*	*Grid extension and grid densification *12,500 Solar PV systems for households and 138 for social institutions: schools and health centres	States of Potosi and Chuquisaca	27,000 (expected)	54 M	Local government (Potosi and Chuquisaca) and the World Bank
2014–2018	Access to modern energy sources Project *(Acceso a Fuentes de Energía Moderna-AFEM)*	*Installation of Pico solar PV systems	(14) Municipalities in the State of Pando	5,500	1.3 M	VMEEA and the Government of Denmark
2013–2018	Renewable Energy Program *(Programa de Energía Renovable)*	*Implementation of 17 micro hydropower systems	*Under Operation (156.8 kW)* in the statesof La Paz (Inquisivi), Potosi (Colcha "K" and Cochabamba (Valle Grande). *Planned (1021 kW)* in the states of La Paz (Inquisivi, Ixiamas, Ichoca, La Paz, and Apolo), Chuquisaca (Incahuasi), and Cochabamba (Mizque)	Under Operation: 581 Planned: 1,897 families	8 M	VMEEA and the Kfw (German Banking group)
2013–2017	Implementation of Rural electrification projects *(Implementación de Proyectos de Electrificación Rural-IPER)*	* Distribution grid extension (11 Projects)	States: La Paz (Municipalities of Santiago de Machaca, Caranavi, Batallas, Yaco, Licoma and Catacora) and Cochabamba	4,000	5.4 M	Local government of La Paz and VMEEA
2011–2018	Rural Electrification with Renewable Energy *(Programa de Electificación Rural con Energía Renovable-PERER)*	*Implementation of hybrid systems (Diesel and solar, wind or micro-hydro generation) *Installation of Pico solar PV systems *Community Solar PV Systems (85 kW) and 500 Thermo solar systems in 350 rural schools, 50 hospitals, and 500 government buildings *3000 Solar lighting systems (LEDs)	States: Beni, La Paz, Potosí, Oruro and Santa Cruz	5,000	NDF: 5.3 M BID: 0.020 M	The Nordic Development Fund (NDF) and the Inter-American Development bank (IDB) and the Bolivian government
2011–2017	Rural Electrification Program- *(Programa de Electificación Rural-PER)*	*Grid extensión *Pilot project based on renewable energy (1800 solar PV systems)	*Grid extension:* States of La Paz, Cochabamba, and Oruro *Solar PV systems:* States of Pando (El Sena and Villa Nueva) and La Paz (Ingavi)	26,000	60.2 M	Inter-American Development Bank (Credit Loan)

100% in urban areas and 87% in rural areas, as presented in Fig. 3. Therefore, achieving universal access by 2025 will imply providing electricity to about 1,484,953 households (563,841of them will be in rural areas), 210 health centres, 1,400 schools and 310 community centres [26]. This effort requires a total investment of about $US 1986 million [26].

However, the average cost to provide access to electricity per household depends on the technology option and differs between rural and urban areas. In urban areas, the average cost required to provide access to electricity through the grid densification is about $US 730 per household. This value contrasts with the average cost for rural areas, which is above $US 1800 when considering extending the grid or $US 1560 in the case of implementing off-grid renewable energy systems [26]. As of 2016, urban areas already achieved 99% of electricity cov-

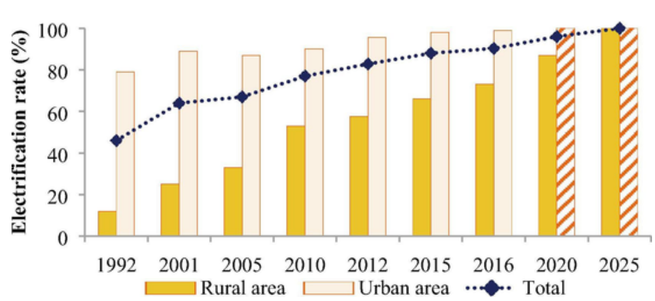


Fig. 3. Comparison of rural, urban and national electrification rates between 1992 and 2025. Figures for years 2020–2025 are projections from the VMEEA. Source: Authors, adapted from: [24,26].

erage, through the densification of the distribution grid. But, in rural areas, as of 2016, 27% of the rural population still lacked access to electricity and full coverage is only projected to be attained by 2025 [22].

Overall, Bolivia aspires to be able to "export energy and position the country as South America's energy hub, supporting scientific and technological sovereignty" [25, p.10]. However, although electricity access rates more than doubled between 2005 and 2016 (See Fig. 3), universal access will require not only continuing with current electrification programs but also maintaining strong government commitment in the monitoring of the projects.

3. Identifying who is poor

In this section, we describe how identifying the poorest communities requires relying on different poverty indicators, including the unsatisfied basic needs (UBN) index. Also, we provide an overview of other poverty measures currently being applied in different countries.

3.1. Describing the basic needs approach (BNA)

Although poverty is most often measured with monetary indicators like income and income-to-needs ratios [37], multidimensional approaches such as the BNA are widely used in developing countries, including Latin America [38]. In particular, the BNA, grounded on Rawls' Theory of Justice (1971), focuses on defining a set of primary goods/services that are constituent elements of well-being and considered necessary to live a good life [39]. It was first introduced by the United Nations Economic Commission for Latin America and the Caribbean (CEPAL in Spanish) in the '80 s, to build up poverty maps, showing the lack of access to basic services, based on the information obtained from the local Censuses [40]. It is also referred to as a *direct method* to measure poverty because it observes and evaluates whether a household has or does not have the goods and services that effectively satisfy its basic needs. It relates wellness with real access to basic services, such as water, sanitation, electricity, education, and health [41,42]. Likewise, the BNA is considered a *counting approach* to identify the poor because it entails "counting the number of dimensions in which people suffer deprivation" or "the number of dimensions on which they fall below the threshold" [37,p.51]. In order to measure this level of deprivation, the BNA relys on the Unsatified basic needs (UBN) index, a composite of the indicators' scores measuring the degree of satisfaction of basic needs. Based on the UBN index, the poor are those who experience at least one deprivation or the proportion of households unable to satisfy one, two, three, or more basic needs [42,44].

Since 1976, the Bolivian government has estimated the UBN index through the data obtained from the national Censuses of 1976, 1992, 2001, and 2012 [45]. Thus, this measure of poverty has been a key criterion to guide funds allocation within policies for poverty alleviation and thus, to succeed in reaching the poor and improving their lives [40]. For instance, the PEVD program has guided Bolivia's rural electrification policy to identify areas where issues of poverty, social exclusion, and access to basic population services represent a priority [29]. Fig. 2 shows the location of the PEVD's areas of influence and their corresponding 2001 and 2012 UBN indices.

The process to calculate the UBN index follows five main stages as presented in Fig. 4 [42,46]. First, identifying a set of indicators of deprivation, *i,* within some dimensions that vary among countries: while Colombia and Venezuela use 5, Paraguay uses 7 and Bolivia uses 10 [38]. Thus, this indicator is not comparable among countries. Second, setting a minimum normal range, X_i^*, for each indicator (values below this level denote deprivation). Based on these thresholds, the variable measured through the census, X_{ij}, is transformed into an index number: $UBN_{ij}^* = \frac{X_i^* - X_{ij}}{X_i^*}$, reflecting the unsatisfied basic need for each indicator *i* and household *j*. Third, for each dimension, a composite index is estimated based on the geometric mean of the indices for each indicator. Fourth, dimensions are grouped within four broad areas representing a basic need: 1) Housing; 2) Basic services; 3) Education and 4) Health [45]. Finally, the overall UBN index score for each household is estimated as the geometric mean of the UBN indices for each basic need, as shown in Fig. 4.

3.2. Using the UBN index to guide electrification policy in Bolivia

The objectives of rural electrification programs are not only to provide people with electricity access but also to promote rural development and tackle poverty reduction in rural areas. One way to achieve this purpose is giving priority to the poorest when selecting areas for electrification programs. Thus, in this paper, we analyse the suitability of using the UBN index as the social criterion that guide the GoB in selecting the areas that should be prioritised for electrification projects.

In Bolivia, the VMEEA is the institution who defines the criteria for prioritization and eligibility for rural electrification projects and also controls these projects' implementation. In this paper, we focus on exploring the key criteria the Bolivian government has considered to achieve this purpose. During the last decades, the GoB has relied on the support of different international institutions to develop strategies for the energy sector. In particular, between 1998 and 2000, the Joint UNDP/World Bank Energy Sector Management Assistance Program (ESMAP) assisted six Bolivian states (i.e. La Paz, Oruro, Santa Cruz, Cochabamba, Chuquisaca, and Potosi) in the planning and analysis of rural electrification projects [47]. As a result, the program defined three main criteria for prioritising rural electrification proposals:

i) The project should have a positive Net Present Value (NPV) for social benefits;
ii) An operator should be responsible for the operation and maintenance of the project; and
iii) The project should decrease by at least 15 percent the production costs of local industry (e.g. mills, water pumping, stations, grain producers).

According to the ESMAP's report, the fulfilment of these criteria is essential for the VMEEA to support or finance the proposals submitted by the states. As a result, a manual for rural electrification projects was prepared and is now used by most states and consulting firms, contributing to expediting the approval and execution of new rural electrification projects [47].

In addition to the ESMAP support, in 1998, the GoB officially requested technical assistance to the Japanese Government to define a rural electrification plan upon different energy supply technologies. In response to this request, the Japan International Cooperation Agency (JICA) formulated a plan for the period of 2002–2011 [48]. Within the plan, the grid extension was defined as the main strategy for rural electrification in Bolivia, as it is also confirmed by the 2025 National Plan for the Bolivian electricity sector. As a result, the JICA proposed three criteria to identify and prioritise candidate projects for grid extension, as shown in Fig. 5.

Out of the three criteria, the highest percentage was given to the population density (i.e. 40%) as the grid line extension required a relatively concentrated population to be electrified. The other two criteria (i.e. the distance from the existing grid line and the indicator for basic human needs) received an individual score of 30 percent. In particular, the breakdown for the BHN criterion had four scores options: the higher level of poverty was in the municipality, the higher was the score assigned in this category and thus, the most assistance was required (See Fig. 6).

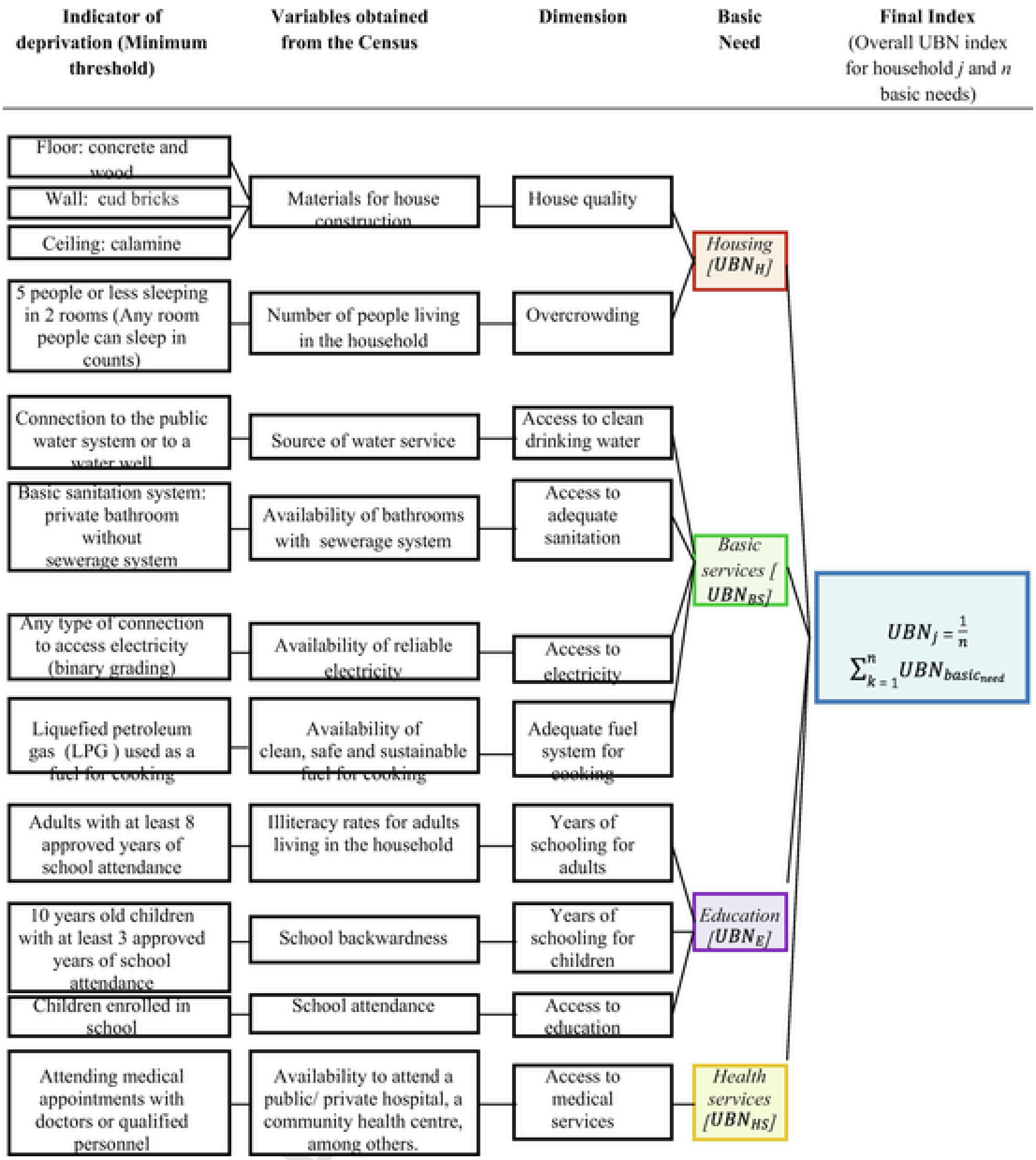


Fig. 4. Algorithm for the UBN index computation in Bolivia. Source: Author's compilation based on [45].

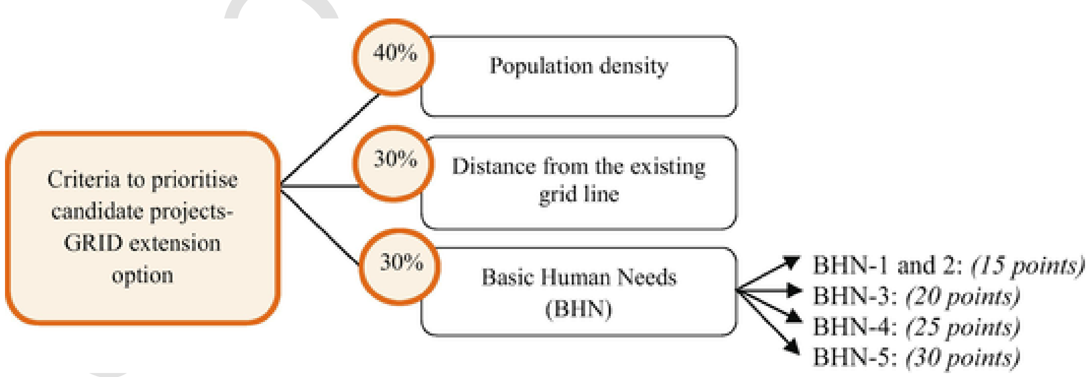


Fig. 5. Criteria to prioritise rural electrification projects for grid extension. Source: Authors, adapted from [48].

However, for isolated rural areas, where grid extension was not the most economic option, the JICA's plan considered three types of energy systems: micro-hydro power generation, wind generation, and solar PV generation. Only those projects with competitive costs compared to the grid extension were finally selected as the priority projects to be included in the Rural Electrification plan. Thus, projects were selected

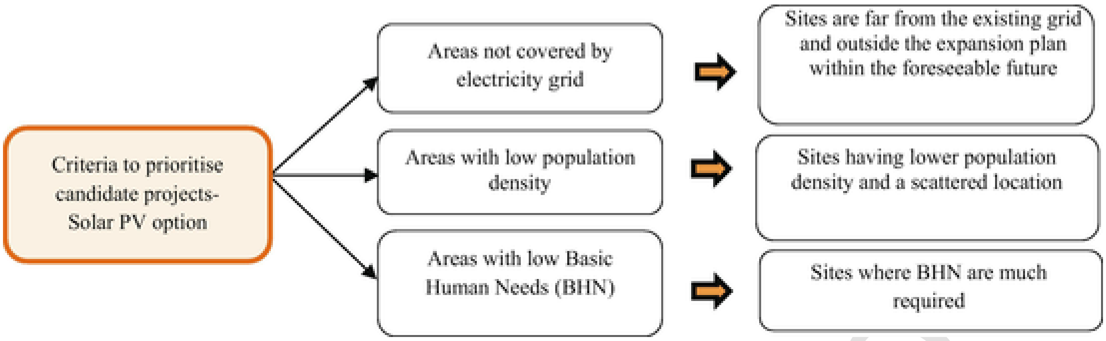


Fig. 6. Criteria to prioritise rural electrification projects based on solar PV generation. Source: Authors, adapted from [48].

only if the energy cost was competitive to that of grid extension. For ranking the selected priority micro-hydro, wind, and solar PV energy projects, the JICA applied different criteria. Regarding the selection of priority areas for solar PV projects, where no other renewable energy sources were available, sites were selected using the following criteria:

Applying the above criteria, scores were estimated for all the selected priority projects. Based on the results and through discussion with the Vice-Ministry of energy and the states, projects were divided into two phases: Phase-I to be implemented during 2002–2006 and Phase-II from 2007 to 2011 [48].

In addition to Bolivia, other countries in Latin America have a long tradition in multidimensional poverty measurement within the Basic Needs Approach (BNA) [38], which is considered as one of the main social indicators used to monitor poverty [38,42]. For instance, Colombia has included the BNA as part of the guideline to prioritise rural electrification projects and reach the poorest communities by extending the existing electricity grid. In particular, through Resolution No. 41,039 of 2016, the Colombia's Ministry of Mines and Energy defined a priority eligibility order for potential projects, OEP_i (See Eq. (1)). Based on this scheme, projects are ranked and prioritised for implementation [49]. This methodology means that giving priority to rural electrification projects, not only depends on economic factors but a social dimension, measured in this context, by the UBN index (with a 20% score).

$$OEP_i = \frac{UBN_B}{UBN_A}(20\%) + \frac{UN_B}{UN_A}(40\%) + \frac{UE_B}{UE_A}(10\%) + \frac{CxU_A}{CxU_B}(20\%) + Mpeace(10\%)$$

Where:

UBN_B is the Unsatisfied basic needs index of the potential community of project$i$
$UBN_A$is the highest UBN index among all the projects under evaluation
UN_B corresponds to the total new users benefited from each project$i$ under evaluation
UN_A corresponds to the highest UN_B among all the projects under evaluation
UE_B is the current number of users benefited from each project$i$ under evaluation
UE_B corresponds to the highest UE_A among all the projects under evaluation
CxU_B is the total cost per user of each project i
CxU_A corresponds to the lowest CxU_Bamong all the projects under evaluation

Mpeace stands for "Municipality of Peace". A value of 1 is assigned to this term if the project includes at least one municipality directly affected by the armed conflict or prioritised under the post-conflict national program. Otherwise, a value of 0 is assigned.

3.3. Comparing the UBN index with other poverty measures

In addition to the basic needs approach, there are other national indicators to measure poverty and development, such as the income poverty measure or the poverty line (PL) approach and the capability approach (including the family of human development indices-the HDI, the Inequality-adjusted Human Development Index (IHDI), the Gender Development Index (GDI), the Gender Inequality Index (GII) and the Multidimensional Poverty Index (MPI) [44,50].

In particular, the HDI has been used to estimate and compare countries' development. This index measures the achievements of human development in three key dimensions: a long and healthy life *(i.e. life expectancy at birth)*, access to knowledge *(i.e. expected years of schooling and mean years of schooling)*, and a decent standard of living *(i.e. GNI per capita)*. Based on the HDI, there are four categories of human development: countries with a HDI higher than 0.8 are considered very highly developed, countries with HDI values between 0.7 and 0.799 are included in the high development category, countries with HDI values between 0.55 and 0.699 are considered having a medium development and those with HDI lower than 0.55 are classified under low development category [51]. More recently, South American countries are using the Multidimensional Poverty Index (MPI) to set the targets to close the country's poverty gaps and second, to track progress towards them. Examples of official permanent national MPIs include: Colombia (launched in 2011), Chile (launched in 2015) and Ecuador (launched in 2016). The MPI wasreleased in 2010 by the Oxford Poverty & Human Development Initiative (OPHI) [37] and also builds on the counting traditions (such as the UBN index), but it combines monetary and non-monetary indicators, not typically measured in Latin America, through the traditional UBN index [40]. In particular, the MPI is an internationally comparable index to measure acute poverty across three dimensions: Education *(years of schooling and school attendance)*, health *(child mortality and nutrition)*, and standard of living *(cooking fuel, sanitation, access to water services, access to electricity, floor and assets ownership)*. Under this approach, a person is multidimensionally poor if he or she is deprived in at least one-third of the weighted indicators, requiring a household to be deprived in multiple indicators at the same time [52].

One of the main advantages of using the MPI is to provide data on multidimensional poverty not only at the national level, but also the MPI can be "decomposed" by sub-national regions to show disparities in poverty within countriesby ethnic group, urban/rural area, and age group, as well as other key household and community characteristics. The MPI also innovates with respect to previous poverty measures in the region in three ways. First, "it combines monetary and non-monetary indicators. Second, among the non-monetary indicators, it updates the deprivation cutoffs of the traditional UBN indicators in order to better align them with current living standards. Third, it goes beyond the traditional UBN indicators by including deprivations in the employment and social protection as well as the schooling gap" [37, pag.4]. In particular, the MPI developed by the Colombian Government and implemented by the national department of planning evidences the way this measure can be used to help inform, monitor and evaluate poverty reduction strategies [37].

Overall, in South America, different countries rely on specific indicators for national development planning, including energy planning: while Brazil uses the PL and the HDI, Bolivia, and Peru rely on the PL and the UBN index [18,19,45,53,54].

4. Materials and methods

4.1. Data sources

This paper relies on the review of four groups of data sources: the first group includes household representative data from Bolivia's Censuses of 2001 and 2012. They were conducted by the Bolivian National Institute of Statistics (INE) and contain information on socio-economic variables for households of the 9 states and 339 municipalities of Bolivia, including the electricity access rates. The two years, 2001 and 2012, were chosen because they correspond to the latest recent versions of the censuses implementation.

We also use cross-sectional data at the municipal level, in particular the UBN index for 2001 and 2012, published by the socio-economic analysis unit of the Bolivian government (Unidad de Análisis de Políticas Económicas or UDAPE in Spanish). We selected this source of information because for many Latin American countries the only mechanism in place to systematically collect information on socio-demographic, economic, environmental and other issues of national importance is the Population and Housing Census. Annual national household surveys, however, have limitations of sample size and therefore do not provide information on relatively rare events nor can it provide small area data. Consequently, the Population and Housing Census is often the only source of valuable information needed for planning and research [55].

The second group includes specialized technical papers, thesis and academic publications. The third group corresponds to reports from local electricity companies, information from the Ministry of Hydrocarbons, the Ministry of Energies, and the INE. The fourth group of sources corresponds to data from international institutions involved in electrification projects including reports from the World Bank and the International Energy Agency (IEA).

5. Research design

Our goal is twofold: First, to identify the criteria that guide the electrification policy of Bolivia in prioritising areas for rural electrification programs (as described in Section 3). Second, we focus on examining the suitability of using the UBN index as the social criterion to prioritise rural electrification projects, namely whether using the UBN index has resulted in increasing electricity access of the poorest communities between two periods: from 2001 to 2012, and from 2012 and 2018. To achieve this purpose, we first identify the location of the poorest communities in Bolivia by 2001. Then, we confirm whether areas (states and municipalities) with the greatest improvements in electricity access by 2012 correspond to the sites with the highest UBN indeces. We use graphical analysis to describe the association between the 2001 UBN index and the improvement in rural electrification access of Bolivian municipalities between 2001 and 2012. Then, we repeat this process, but identifying the UBN poor by 2012 and confirming if these communities had the largest gains in electricity between 2012 and 2018.

We also explore if using the HDI to prioritise where to carry out electrification programs would have prioritised municipalities with the lowest electricity access rate. Finally, we present the policy implications on the role of the government in targeting the poorest, based on the UBN index.

6. Results and discussion

In this section, we present the most significant empirical results from this study. To respond to our research questions, we particularly focus on describing whether electrification programs such as the PEVD targeted the poorest region (in urban and rural areas) based on the UBN index. As we mentioned in Section 2, this massive program was set up in 2008, but the period for the projects' implementation varies from 2011 to 2021. Therefore, if we account on poverty indicators such as the UBN indices obtained from the 2001 and 2012 Censuses, we can identify if the regions targeted within the second phase of the program (2010–2015) corresponded to the poorest ones.

Based on the 2001 Census, the three poorest states corresponded to Potosi, Beni, and Pando. The highest poverty rate was in the state of Potosi, which also corresponded to the state with the highest percentage of the rural population (66.3%) and the lowest electricity access rate (40.4%). These areas have been included in the PEVD program in different proportions, as presented in Fig. 2. While all municipalities of Pando-the state out of the national interconnected energy system- are covered by the program, only one municipality of Beni is included in the PEVD program, under the PERER project (See Table 2). Besides,

Table 2
Bolivia's national indicators between 2001 and 2012. Source: Authors' compilation from [56,57,59] .

State	Total Population	Pop. Density (inh/km ^{2})	% of Population (2012)		The UBN Poor (%) [(a)]		HDI	Electricity Access (EA) (%)			ΔEA (%)	Δ EA (%)
	2012	2012	Urban	Rural	2001	2012	2001	2001	2012	2018	2001–2012	2012–2018
Potosi	828,093	7.7	40.6	59.4	**79.7**	**59.7**	0.52	**40.4**	74.3	87.6	+**33.9**	+**11.8**
Beni	422,008	2.0	73.1	26.9	**76.0**	**58.8**	0.62	**54.6**	83.7	87.6	+**29.1**	+1.9
Pando	110,436	1.7	48.7	51.3	**72.4**	55	0.60	**45.7**	71.8	83.1	+**26.1**	+1.2
Chuquisaca	581,347	11.3	48.7	51.3	70	**56.4**	0.57	47.2	68.5	88.1	+21.4	+**20.0**
Oruro	494,587	9.9	64.0	36.0	67.9	47.0	0.64	60.6	83.1	87.9	+22.4	+**6.9**
La Paz	2,719,344	20.9	66.7	33.3	66.2	45	0.59	65.8	86.0	95.7	+20.3	+1.3
Cochabamba	1,762,761	31.7	68.1	31.9	55.0	45.5	0.62	68.1	85.4	90.0	+17.2	–4.5
Tarija	483,518	12.9	65.0	35.0	50.8	34.6	0.64	69.2	91.3	96.8	+22.1	–0.3
Santa Cruz	2,657,762	7.2	81.3	18.7	38.0	35.5	0.66	76.1	92.0	95.4	+16	+0.1
Bolivia (Total)	10,059,856	9.3	67.5	32.5	58.6	46.3	0.61	64.4	85.4	92.8	+21	+2.3

Percentage of poor population based on the UBN approach.

from the nine projects of the program, three of them are under implementation in the state of Potosi (See Table 2). This difference could be explained based on the indicators presented in Table 2. In terms of electricity access and level of poverty, the three states are in the top three positions. However, there is a clear variation in the percentage of the rural population in each state: while in Potosi and Pando are mainly rural areas (more than 50% of the population), only about 27% of the population in Beni is considered as rural. In contrast, the states of Tarija, and Cochabamba have the lowest inclusion on the PEVD program. These states not only are among the three states with the lowest levels of poverty and highest levels of development (in terms of the UBN index and the HDI) but also they have the highest rates in electricity access.

Results from the 2012 Census show that poverty rates in Bolivia (based on the UBN index) decreased from 58.6% in 2001 to 46.3% in 2012 as presented in Table 2. At the municipality level, 331 out of the 339 municipalities saw reductions in their UBN index [41,45,57,58]. The states of Potosi, Pando, and Chuquisaca continue having the highest percentage of the rural population and at the same time, they correspond to the states with the lowest rural electrification access, as of 2012 (See Table 2). In contrast, Santa Cruz was the state with the highest electrification rate and also corresponded to the state with the lowest percentage of rural population. Therefore, as suggested in Fig. 7, the higher the percentage of rural population is in a municipality, the higher is the percentage of people lacking access to electricity.

However, we also see an increase greater than 20% in electricity access (between 2001 and 2012), in states (e.g. Beni, Oruro, and Tarija) with a high level of urban population (>50%). This could suggest that prioritisation is not only given to rural areas, but the location of the poorest communities and thus, programs are also focused on these areas. In particular, Oruro and Beni (in less proportion) are covered by the PEVD program.

Based on the Censuses of 2001 and 2012, we found that the poorest states for 2001 (Potosi, Beni, and Pando) experienced the largest gains in electrification between 2001 and 2012 (See Table 2). This association shows that high initial levels of unsatisfied basic needs are linked with electrification improvement. This provides indicative evidence that programs such as the PEVD have relied on the municipal UBN index as one criterion for determining which communities to prioritise among candidate municipalities, rather than merely counting on the electricity access rate. In particular, the state of Potosi (the poorest state) experienced the greatest improvement in electricity access and at the same time one of the greatest reductions in the UBN index. This result replicates if we consider all the municipalities, as presented in Fig. 8(a). The graph suggests that there is a link between improvement in electricity access and poverty rates in Bolivia, namely that the poorer the municipality was by 2001, the higher was the improvement achieved in electricity access by 2012.

On the other hand, we found that from the three poorest states for 2012 (Potosi, Beni, and Chuquisaca), Chuquisaca and Potosi experienced the largest gains in electrification between 2012 and 2018 (See Table 2), followed by the state of Oruro, rather than Beni or Pando (states with a higher percentage of UBN poor). One explanation relies on the difference of population density of each area, and its effects on the eligibility criteria for grid extension projects. As we see from Table 2, the state of Oruro has a higher population density than Beni and Pando, which represents a higher score and eligibility in grid extension projects (See Fig. 3.). These results are aligned to the 2025 National Plan for the Bolivian electricity sector, which states that in rural areas, 70% of the projects will rely on extending the grid and only 10% on the installation of off-grid renewable energy systems (i.e. mini-grids and stand-alone generation systems). This means that prioritising electrification projects will depend mainly on the population density of the community rather than on the level of poverty. In consequence, additional investments should focus on increasing electricity access rates in Potosi, Pando, and Beni, the states with the lowest values of density population (See Table 2) and where levels of electricity access continued to be below 90% (as of 2018) (See Table 2) [59].

Fig. 8(a) also shows that municipalities with a low UBN index in 2001 were more likely to have already achieved high rates of electrification by 2001. As a result, there was relatively less room for improvement in these municipalities. For instance, as marked in Fig. 8(a), La Paz, Cochabamba, and Colcapirhua corresponded to the three municipalities with the lowest improvement in energy access for 2012 (less than 6%), but in 2001, these areas already had electricity coverage over 93% [56–58].

In contrast, Fig. 8(b) shows the comparison between the 2001 Human Development Index and the improvement in electricity access from 2001 to 2012, in 313 municipalities of Bolivia. Based on the HDI,

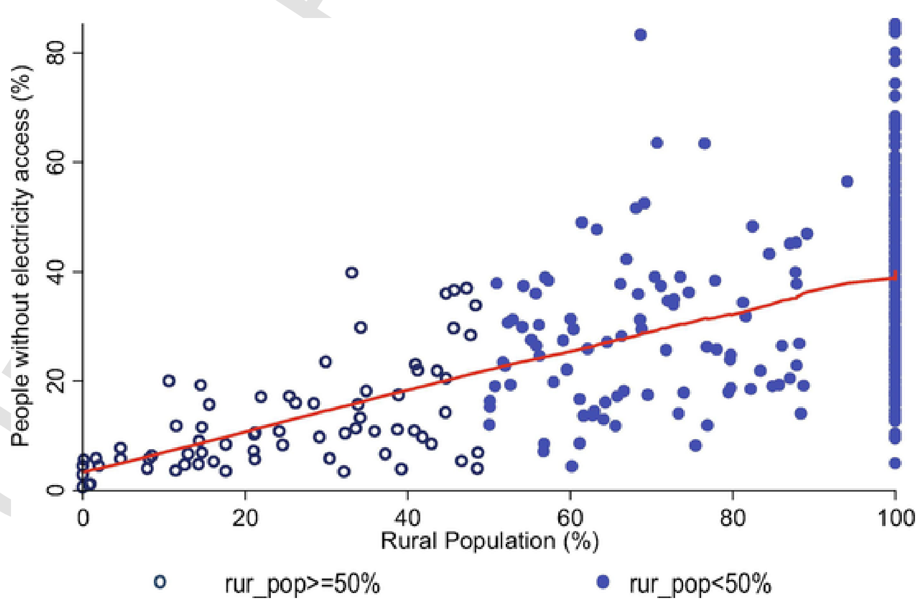


Fig. 7. Relationship between the percentage of rural population and people without electricity access in Bolivia (2012). The orange line presents the lowess regression that fits the data. Source: Author's compilation from [56–58].

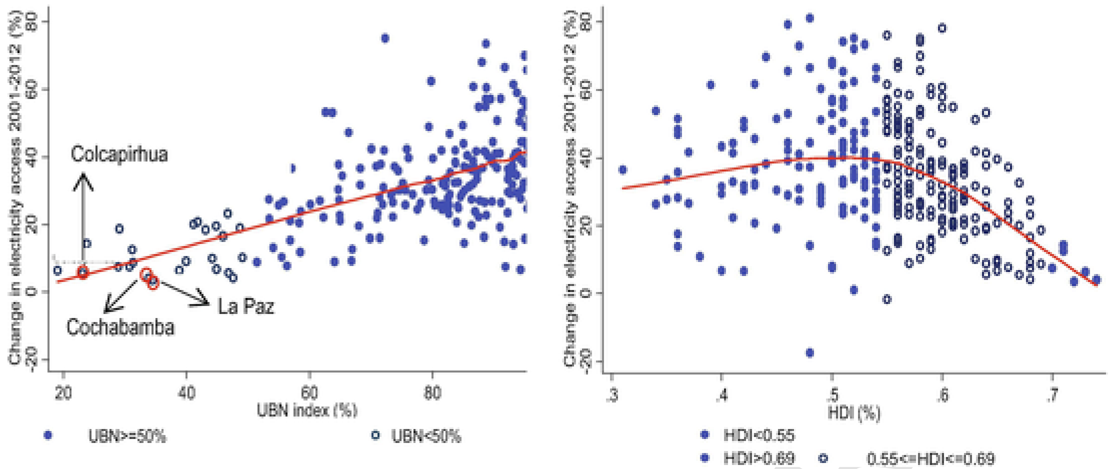


Fig. 8. (a) 2001 UBN index and variation in households' electrification rates between 2001 and 2012 by municipalities, (b) 2001 HDI and variation in households' electrification rates between 2001 and 2012 by municipalities. The red line presents the lowess regression that fits the data. Author's compilation from [56–58].

54.6% of the municipalities exhibited a medium development level, 52.7% had a low development level and only 1.9% had a high development. Results from Fig. 8(b) suggest that in contrast to the UBN index, there is no clear relationship between the improvement in electricity access for the period of 2001–2012 and the HDI. These statistics primarily make the point that a high proportion (54.6%) of rural population is associated with medium human development indicators. Eight out of the nine Bolivian states had a medium development level in 2001 and not all the least developed municipalities (according to the HDI measure) corresponded to the UBN poorest municipalities, as presented in Table 2. Therefore, using the HDI to prioritise where to carry out electrification programs would not necessarily have targeted municipalities with the lowest electricity access. However, we have to highlight that the HDI in Bolivia has grown from 0.535 in 1990 to 0.693 in 2017, which corresponds to an increase in about 22% [60], which evidences the effect of recent policies in reducing poverty in the country.

In particular, the basic needs approach has also received criticisms because one deprivation alone may not represent poverty. Alsobecause updated information from censuses is not always available, since they collect data for all the population and depending on the country, they are conducted every five to ten years. In consequence, the availability of household surveys, regularly implemented in Latin American countries, has made it possible to gather more recent information, and therefore, to use other methods to measure poverty and development, such as the MPI and the HDI [37].

In Bolivia, there are no official poverty indicators that combine income measures and quality of life variables to measure a multidimensional phenomenon. Castellani and Zenteno (2015) [61] proposed an approach to estimate the MPI for Bolivia. In consequence, this indicator could be used in the country as a tool for the allocation of future electrification projects, to monitor regional policies, and also to define goals on specific interventions. It could "complement traditional basic needs and income-based poverty measures by capturing the deprivations that each person faces at the same time concerning education, health, and living standards. The more policy-relevant information there is available on poverty, the better-equipped policymakers will be to reduce it" [52].

Something we have not stressed so far but that is important to keep in mind is the quality of the service and the effect of geographic characteristics (i.e. areas located on the Alti-Plano plateau, the mountains or the Amazon jungle and/or the easiness to access each area from La Paz city) on improving access to electricity in rural areas. However, a detailed discussion of these aspects is outside the scope of this paper.

7. Conclusions

This paper has provided an overview of the rural electrification policy in Bolivia, where the government aims to achieve universal access by 2025. We have identified the government of Bolivia's criteria for prioritising areas for electrification, and analysed the suitability of using the unsatisfied basic needs (UBN) index as a social criterion for this purpose. In doing so, we explore whether electrification programs such as the PEVD are reaching the poorest communities in urban and rural areas.

We found that the level of poverty (measured by the number of unsatisfied basic needs) of potential communities is considered as one of the criteria to select priority areas, regardless of the technology option chosen. However, other aspects such as the population density receive a higher score (i.e. for the grid extension option), as extending the grid requires relatively concentrated population to be electrified. So far, the PEVD has prioritised not only the poorest communities, such as Pando and Potosi, but also those municipalities with a population density above the national average, namely, Cochabamba, La Paz, Chuquisaca, and Oruro. In consequence, in order to reach the last mile for universal access, future projects should focus on the areas of Potosi, Pando, and Beni, which were the poorest states by 2012 and where levels of electricity access continue below 90% (as of 2018).

In addition, our results suggest a positive association between the 2001 UBN index and the improvement in electrification rate between 2001 and 2012. These findings imply that if electricity access is provided to those with a high UBN index, a significant improvement in electricity access can be achieved, especially in remote and scattered rural areas, where extending the grid is not economically viable. In fact, based on the percentage of the UBN poor in Bolivia (as of 2001), the highest improvement (by 2012) was achieved in municipalities with the highest UBN indices rather than those with the highest deficits in electricity access. Thus, prioritising electricity service expansion based on the UBN index represents a valid criterion to achieve largest gains in electricity access for the poorest communities. In particular, using other type of poverty measurement, such as the HDI, could have resulted in prioritising other areas.

Our analysis has relied mainly on our descriptive insights of the improvement in electricity access and the poverty rates in Bolivia. However, this study has a few limitations worth discussing here. Most importantly, our dataset is based on the national censuses of 2001 and 2012, corresponding to the years with available information about the UBN index. Future estimation of this index will be released from the next census, expected to be conducted by 2021. Besides, estimating poverty rates through the UBN index also depends on access to water, sanitation, education, and health. Unfortunately, poor people are prone to experience multiple deprivations at the same time. This means that someone who falls short in one indicator of well-being (e.g electricity access) is quite likely to fall short also in another indicator (such as education). Also, disparities between urban and rural areas continue to prevail. As a result, an area in which most people are deprived of education requires a different poverty reduction strategy from an area in which most people are deprived of housing conditions. In consequence, focusing on one factor alone, such as the electricity access rate, is not enough to capture the true reality of poverty. Therefore, using complementary socio-economic indicators, such as the MPI (implemented in other South American countries, such as Colombia and Chile), could complement the traditional basic needs approach by capturing more relevant information that could lead to a more accurate poverty measurement and rural electrification interventions. In particular, the MPI goes beyond the traditional UBN indicators by including deprivations in the employment and social protection as well as the schooling gap.

For energy access researchers and policy makers, our general findings may offer some direction for future research. First, these results could help Bolivia in prioritising future electrification programs. In particular, the country is on the verge of beginning Stage IV (2020–2025) of the PEVD program and using the UBN index (from the next estimation, expected by 2021) could contribute to prioritise the poorest communities who still do not have access to electricity. Second, we provide evidence of how other developing countries could identify and prioritise geographical areas for provision of electricity access, accounting for the type of electricity supply technology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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