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Luces Nuevas Experience Lighting Rural Bolivia: A Way to Reach SDG 7

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Abstract: United Nations SDG 7 is that, by 2030, there will be an affordable, reliable and clean universal access to energy (UAE). To reach this goal, technological and social issues should be considered jointly. In this paper, the approach used by the Non-Governmental Organization "Luces Nuevas Internacional" is presented. Luces Nuevas has successfully provided basic electricity access to sparse rural communities in rural Bolivia. This paper emphasizes the methodological aspects of the approach. The key ingredient to the success is the involvement of all the stakeholders in all steps of the solution. In this way, end users feel the solution as their solution. Therefore, they are willing to use and properly maintain the devices that they buy to obtain electricity access. The case of the Tipas community shows that this approach can provide access to energy to every family that desires it. The experience shows that reaching SDG 7 requires taking into account not only the technological and economic aspects, but also the social aspects of the problem. End users involvement, from the beginning, of an electrification project is key to its success.

Keywords: rural electrification technologies; social sustainability; energy sustainability; access to electricity; universal energy access; clean energy access

Citation: Vela-Cobos, F.J.; Cavero, R.; Platero, C.A.; Sánchez-Fernández, J.A. Luces Nuevas Experience Lighting Rural Bolivia: A Way to Reach SDG 7. *Sustainability* **2021**, *13*, 10041. https://doi.org/10.3390/su131810041

Academic Editor: Tomonobu Senjyu

Received: 3 August 2021
Accepted: 6 September 2021
Published: 8 September 2021

1. Introduction

Access to energy is an enabler and a precondition for socio-economic progress [1]. However, many people in the world lack this access. Most of them live in rural areas where the cost of grid extension is high. Recognizing this fact, the United Nations Sustainable Development Goal (SDG) 7 proposes that, by 2030, there will be affordable, reliable and clean universal energy access [2]. In addition, electrification contributes to female empowerment [3].

Between 2010 and 2018, it was estimated that the global number of persons without any access to electricity had fallen from 1.4 billion to 900 million [4]. In order to conduct a reliable analysis of household electrification progress, robust datasets are needed. To solve this issue a dataset covering the period 1949–2015 is available [5].

There are many initiatives around the globe to provide electricity to rural communities and businesses. Therefore, there are, also, initiatives to evaluate those approaches from several points of view [6]. Taking into account the social and cultural issues of target communities is essential to their long-term success [7–9]. Notwithstanding, these authors Urmee and Md [7] and Feron [9] do not provide any clue about how to take into account these issues.

Most of these initiatives are based on public funding. Although each country has its own strategy, usually it is based in a combination of grid-tied and off-grid solutions. An assessment made in Kenya suggests that private-led off-grid initiatives have the best performance [10].

As different technologies have different costs, it is important to select the most appropriate technology for each case. To this aim, the most important parameters are [11]:

a. Target level and quality of energy access
b. Population density
c. Local grid connection characteristics
d. Local energy resources availability and technology cost

In order to gather part of these data, in the case of Amazonian Indigenous Populations an approach based on satellite imagery data and surveying on some communities has been proposed [12].

Although there are complex computational frameworks to plan electricity access [13], there are also more simple ones. An open source tool can help in making a technology choice [14]. This tool has been developed for Sub-Saharan Africa, but it can be applied to other regions. In some areas not connected to the power system, the electrification should be accomplished by the use of small generation isolated systems or micro-grids [15].

Another tool developed for Peru was SEPLAN [16]. It is based on multicriteria optimization techniques. It was applied to the Cajamarca province, and the proposed solution for isolated rural communities was photovoltaic solar energy.

Another question that should be considered is the maintenance costs. To contribute to their estimation a model has been built and applied in Morocco [17].

In the SDG 7 achievement, the use of photovoltaic panels is essential. From the 1980s, photovoltaics power generation has improved drastically. Nowadays, the Third Generation Solar Home Systems (3G-SHSs) are highly efficient and use LED lamps, lithium batteries, microelectronic control, and plug and play connections [18].

However, these solar energy systems should be maintained by their end users. For this reason, local communities' involvement is needed. This has been corroborated by several case studies in India [19,20] and in Zimbabwe and South Africa [21]. It was found that, through appropriate capacity building, end users engage in photovoltaic energy sources long term use and maintenance.

In this paper, the authors' experience in providing some Bolivian communities access to energy is presented. Electricity coverage in Bolivian rural areas was 79.3% in 2019 [18]. The Non-Governmental Organization "Luces Nuevas Internacional" has developed a method to successfully provide Universal Access to Energy (UAE) to Bolivian rural communities.

In Section 2 the method used is exposed. In Section 3, the results obtained after the application of the described method to a community located in the Cochabamba Department are described. Section 4 discusses these results and finally, in Section 5, some conclusions are drawn.

2. Materials and Methods

Universal Access to Energy (UAE) is an opportunity to improve life quality, as all families have the opportunity to access this basic service. Due to the magnitude of the problem, technological alternatives should be evaluated taking into account the economic capacity of a country, its energy reality and a reasonable implementation schedule.

In the search for paths that lead us to obtain universal access to energy, there are four general conditions that should be met, either in a country or in smaller geographic regions such as Municipalities, Provinces, Departments, etc. Each Country has a defined and different political organization, but these four general conditions continue being valid according to the circumstances: political decision, available technologies, family acceptance, and management model (and methodological guide). They are described below.

(a) **Political decision**: since UAE is a citizen's right, it may be legally expressed in the Country Constitution (as is the case of Bolivia). Therefore, the political authority must consider the decision to implement mechanisms and actions leading to UAE. This political will is a necessary condition, but not sufficient.

(b) **Available Technologies**: what technologies can solve the energy deficiency problem? In many countries, solutions based on electrical grid extensions do not constitute a real alternative (because of inaccessible costs). Part of the rural population live in remote areas and families belonging to a human group or community are dispersed. Therefore, viable technological options, alternative to a traditional electrical grid, are needed.

(c) **Family acceptance**: will families accept the technology selected to implement a Universal Access to Energy? Electrical grid extension, without any doubt, constitutes the solution desired by most population groups. However, because of current experience, other alternatives accepted by the population are required, for example islanded domestic solar systems.

(d) **Management Model and methodological guide**: the three previous steps are simple to comply with or adopt. The most important issue is how to assemble a solution for a country that contemplates the legal, technological and perception aspects along with their implementation. Execution tools are needed. These execution tools are comprised of a Management Model that will be implemented following an ordered sequence of steps (methodological guide). Figure 1 shows a sequence of six steps that synthesizes a UAE process. As population groups change every year, either with new human settlements or migratory processes, periodic actions are needed to provide an energy service to these new human groups. Therefore, UAE should be a continuous process.

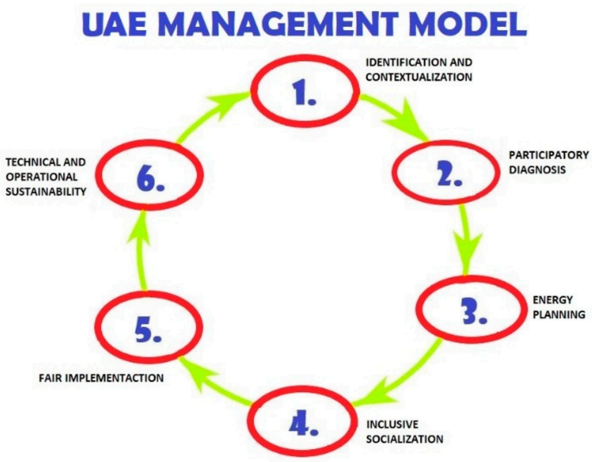

Figure 1. UAE management model.

2.1. Identification and Contextualization

In the proposed management model to get UAE, the first task is "identification and contextualization". Knowing the general socioeconomic indicators of the considered geographical region (extension, number of communities, ways to access them, type of organization and social structure) are prerequisites. In addition, involving the political and social authorities is required to generate a consensus that enables the initiation of a process of Universal Access to Energy.

In the consensus, it is very important to obtain the willingness of the incumbent local authorities to participate in solving the problem. On the other hand, guiding the communities and, finally, empowering the families to demand a solution to the problem and to support, with their individual effort, the UAE goal.

To generate these consensuses, they need to understand why it has not yet been possible to overcome the candle and the lighter, having modern technologies of high reliability. Long distances and dispersion of family units in a community make traditional solutions unfeasible, especially those based on electrical grid extension.

In the radar-chart shown in Figure 2, twelve possible causes are identified. A qualitative weighting of these factors and a comparison of their progress through what was the situation in 2000 and that in 2020 is shown.

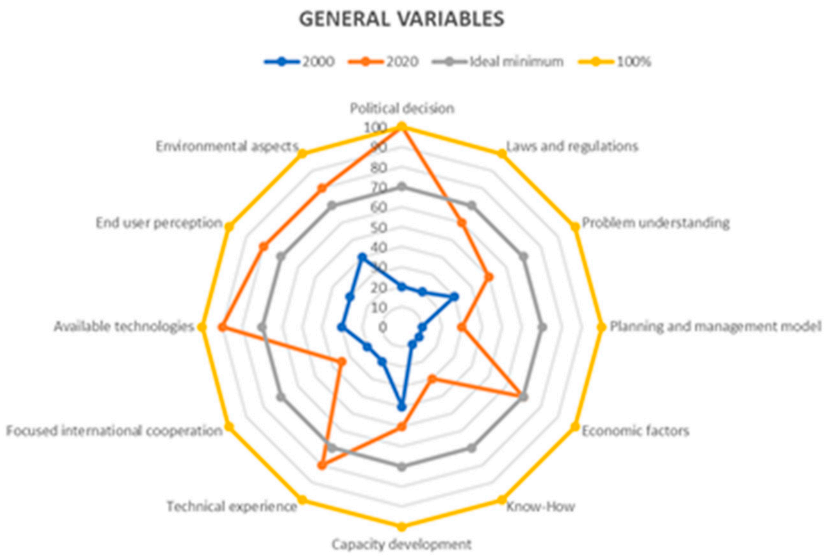

Figure 2. The 12 general conditions that allow the analyzing of UAE progress.

Of these twelve variables, the ideal is that the qualitative compliance weighting of each variable exceeds some limit established around 70% to trigger a process of Universal Access to Energy.

Analyzing variable by variable, five of these twelve variables are truly critical (Figure 3): the political decision of the competent authority, explicit laws and regulations, planning and management models, know how to execute or know how to do, and capacity development under UAE concepts.

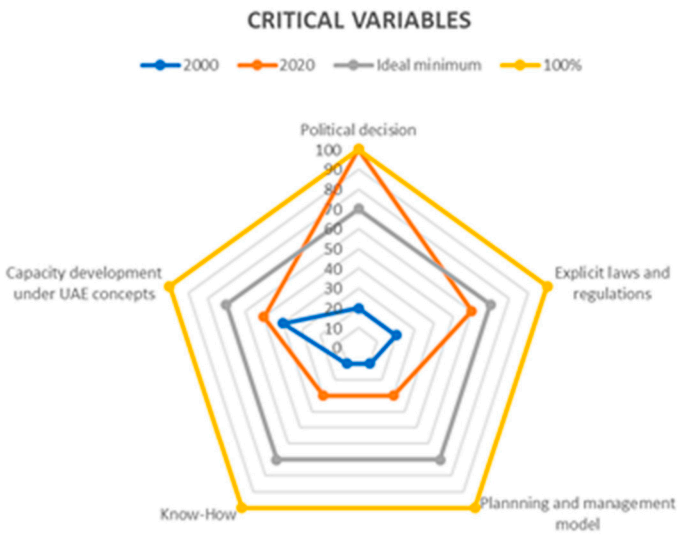

Figure 3. The main 5 conditions that allow the analyzing of UAE.

These radar charts are built for a Bolivian context. Each country can have different characteristics and weightings. The task is to analyze the problem and make viable approaches that can provide solutions according to the particular situation of each country.

2.2. Participatory Diagnosis

The solution and implementation in a UAE environment must start with the knowledge of the target audience, how many and where are they? This information provides a clear idea of how large the problem is. Additionally, it will help to choose technologies to propose viable solutions. In most countries, there is no updated or reliable information on the number of families without energy service. Therefore, mechanisms for the elaboration of fast and reliable diagnoses, combining existing technology (georeferenced identification) and active participation of municipal technicians and families, including gender perspective, were developed. Knowing how many and where they are, a valuable source of information is to get to proceed to the next planning stage. The participation of university researchers is of special importance, although they must have had an immersion in UAE concepts and adequate speech.

2.3. Energy Planning

With the location data of the families in need of energy services, basic energy planning starts. Here, a recommended technological solution and a tentative time schedule based on available economic resources will be identified. There are software tools that makes possible designing an electrical network for an entire area. The analysis of this preliminary design will allow resolve a first big question: what technology is more appropriate to implement a solution in the case studied?

Let us analyze the following energy ladder chart (Figure 4). Author experience shows that any of these solutions is accepted depending on the socioeconomic reality of a region. The most basic solution is the solution based on the picolamp, but understood as a "temporary solution", or the "first step of the solution".

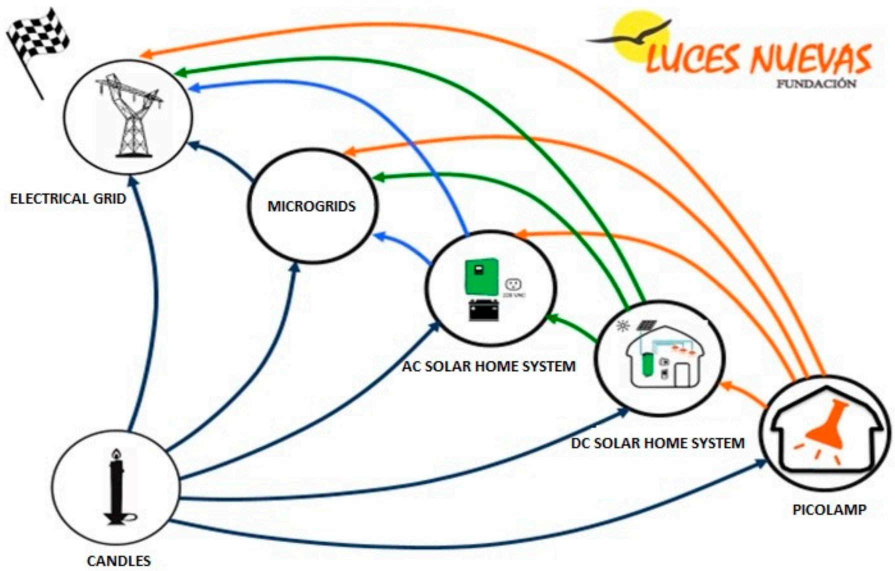

Figure 4. Energy ladder chart.

Any selected technology can be improved when the necessary conditions are met. The main idea is that it is a scalable and improvable program.

The technologies proposed in the energy flow chart are based on solar generation with photovoltaic panels and storage in lithium batteries. Only larger systems such as the electricity grid or microgrids may have different sources of electricity generation. Photovoltaic systems were proposed because these systems do not require expensive maintenance. There is a great experience and families probably do not have the capability of taking care of, for example, wind or small hydroelectric systems.

Let us briefly describe the characteristics of each solution:

- Picolamp: system similar to a lantern with an internal battery that is recharged by means of a photovoltaic cell. It is a small system, but it provides good quality light and it also has the capacity to charge the batteries of mobile phones and radios.
- DC Solar Home System (SHS): lithium battery home system. It is a direct current system at 12 V. It allows recharging mobile phones, radios, several lighting points, TV, laptops, etc.
- AC Solar Home System (SHS): system similar to the previous one, but with more photovoltaic panels. It allows creating an alternating current system with characteristics similar to those offered by energy distributors in cities (110–220 VAC). The biggest problem is still cost. Nevertheless, they are already consolidated technological solutions, probably used in developed countries. For developing countries, authors think that it is not a viable way to provide UAE. One of the main advantages of this system is the accessibility to devices (led, televisions, etc.) compatible with alternating current.
- Microgrids: microgrids are isolated systems useful for generating larger amounts of electrical power. They must have some specific characteristics to be able to use this system, such as a centralized population. The generation of energy in microgrids can be from different energy sources, it does not necessarily have to be solar. The cost per family remains high.
- Electrical grid: the last step in the flow chart is the electrical grid. It is the desired goal. The grid allows equal conditions in the population, in the sense of being able to install the same devices as a user in the city. According to the testimony of experts from distributing companies, the grid may have capacity limitations. To increase this capacity, a series of steps that increase the budget even more are needed. This solution is appropriate for those homes that are at a short distance of existing networks. For the rest of the population it will be a scalable solution when UAE is solved.

This phase concludes knowing what technology, when and where can be used. After it, the proposed solution will be explained to the community. As in Participatory Diagnosis, for Energy Planning the Development of Capacities in the specific professionals and/or those assigned in the incumbent local institutions will increase the effectiveness and short-term impact of the UAE process.

2.4. Inclusive Socialization

The relation of families with society is a natural consequence of being part of a community. Despite this there is also individualism, where everyone thinks about his or her own needs. The aim of inclusive socialization is to generate a path towards a solidarity society. Families are encouraged to think about the needs of the families that surround them (universal access processes), so that the community develops jointly, thus improving the quality of life of all their families.

The aim of this model of inclusive socialization is to generate greater participation among the decision-making actors involved. They range from state authorities to community leaders, with the sole objective of achieving universal access processes. In this way, closer and more integrated social relations between the state (entities that represent it: governments, municipalities) and social organizations (population and/or families to benefit) is promoted.

Inclusive socialization will be presented throughout the Universal Access to Energy management model. That is, from the first approach to the authorities and the diagnostic process, until the implementation and culmination of the project.

In the first step, authorities (communal and municipal) should be contacted to schedule a meeting to make them aware of the existing energy problem in their municipality. Because of this first approach, the elaboration of a participatory diagnosis will be approved. In this diagnosis, the communal authorities will take part. A group designated by the community will also take part in order to provide social control.

In the second step of inclusive socialization, the aim is to reach all families. This socialization will be carried out through participation in their monthly meetings, advertising spots, posters, letters or other methods that allow reaching all families, disseminating diagnosis results and proposing possible existing solutions.

After the socialization, lists that must be endorsed by the community are elaborated. In them, each family will choose to participate in the project that corresponds to their community (electrical network or solar system). A schedule with dates and place of delivery is elaborated.

The case of families that do not want to participate should be analyzed. The reasons for refusing to participate may be as diverse as lack of resources, distrust, participation in other projects, not the right time, desire of a total donation, like living with candles, etc.

2.5. Fair Implementation

Fair implementation will take place after energy planning and socialization. In it, the type of solution that corresponds to the community will be defined. In addition to having an economic structure already defined for projects based on solar systems, the ideal is that the municipality looks for a way to channel resources to help families with a counterpart, either in investment or in a partially subsidized service.

Another important aspect to take into account in the implementation phase is the training on solar systems installation aimed at the beneficiary families. It is necessary to coordinate with the community and designate someone to help the elderly in the installation, or in any case, appoint or have a technician available for these cases.

2.6. Technical and Operational Sustainability

For a project to be successful, sustainability must be emphasized, which has two meanings:

Technical sustainability—refers to the existence of a technical point where families can go in case their solar systems present a technical problem. Be it an investment in equipment or a service, long-term operation should be ensured without involving high operating costs for the families and/or the operator. The proposed technical solution must be highly reliable and maintenance-free, and, in the case of batteries, with a very long useful life.

Information sustainability—for the project to be sustainable, updated information on the energy situation of the municipality should be available. Population growth and formation of new families or their migration must be taken into account. To this aim, the municipality, through its municipal technicians, must carry out the diagnosis from time to time (two or three years). Therefore, a solution to these families or a review of the energy planning can be made.

Once the first cycle is finished, it should be reviewed from time to time. Depending on each community capacity, the review will be made sooner or later. Reviewing means redoing the whole cycle again. The aim is to detect changes in the community, since censuses or the distribution of the population, etc., can change. In addition, the option already implemented in the first cycle can be improved, climbing upwards in the energy flow chart of Figure 4. Revisions are faster than the first cycle. Additionally, the cycles will repeat until reaching the best possible solution.

Once known the problem and how to address it, effective management models are needed. To solve this issue, a guide is elaborated.

3. Results

According to the 2012 census [22], electrical energy supply is provided to 82.89% of the Bolivian population. Therefore, 17.71% of the Bolivian population lacks electricity access. More specifically, 95.96% of the population living in urban areas have electricity access. However, only 57.48% of the population living in rural areas have electric energy access. Table 1 shows the total number of rural homes in each Bolivian Department and their electricity access coverage.

Table 1. Bolivian departments' rural access to electricity in 2012 [22].

Departamento	Rural Homes	Access to Electricity (%)
Chuquisaca	75,801	41.81
La Paz	308,844	60.87
Cochabamba	186,557	54.10
Oruro	60,444	56.88
Potosí	149,012	54.85
Tarija	44,266	77.61
Santa Cruz	115,465	62.84
Beni	25,292	48.46
Pando	11,821	50.88

The mean annual family spending on lighting and communications is $68 in the Bolivian Plateau, $107 in Bolivian valleys, and $114 in the plains. Monthly traditional (candles, kerosene, batteries) energy spending in these zones is around $5 [22].

Another important dataset that must be taken into account is irradiation levels in Bolivia. In the southwest, near the Atacama Desert, there are between 5 and 8 kWh/m^2 a day. These data support using solar energy solutions in this area [22].

In order to test the proposed methodology, a case in Tipas community, located in Totora municipality, will be presented. Totora belongs to Bolivia's Cochabamba Department.

Tipas is a community that does not have access to the electricity grid. The population was upset because they must continue using candles as a light source and need to recharge their mobiles in the town. A delegation from the community asked for electric energy supply to the electricity distributor. However, this possibility was quickly discarded due to the high cost and the difficulty or impossibility of financing it. At the Bolivian level, there are about 13,000 communities without electrical grid connectivity.

When contacted to explore other possibilities, the steps taken based on the approach previously presented will be briefly summarized:

(a) Identification and contextualization: information from the municipality and its communities were taking from a zone planning document: the PTDI (*Plan Territorial de Desarrollo Integral*). These PTDIs are development documents that each municipality has. From them, Tipas community location and ways of accessing it, social organization, dates of meetings and a proper approach with the community to propose alternatives were obtained. As a starting point, 88 houses without electricity access were identified.

(b) Participatory diagnosis: the community was explained the importance of knowing the actual number of families that lack electricity. In a participatory manner, the houses of families living permanently in the community were georeferenced. From the original 88 houses, only 43 families that permanently inhabit the community could be identified. The other 45 houses were either abandoned or were temporarily occupied. As resources must be optimized, solutions were presented only to these 43 resident families. The construction of the georeferenced map was completed in collaboration with community members, as Figure 5 shows.

(c) Basic Energy Planning: with the georeferenced data, the closest grid connection points were identified, possible solutions are analyzed and a first georeferenced approximation was studied to obtain the community spatial distribution.

In this case, 42 inhabited houses and one community educational center were identified.

Knowing location of homes and grid connection points, a design for the electrical grid distribution could be estimated. In this way, project viability could be assessed.

Figure 5. Several Tipas community members help first author (second from the left) identify actual inhabited houses.

The grid extension study for all resident families determined that about 3500 dollars of investment per family was required. As this figure was unattainable, other alternatives would have to be considered.

(d) Inclusive socialization: the results obtained from the study were reported to the community. In a friendly environment the energy problem, its impact on health, education and the urgent need to do something different were exposed. Since the electrical network solution was not feasible, the energy flow chart was presented and there was consensus that an immediate solution was required. The community chose the picolamp option. Each picolamp provided 120 lm and has a 5 VDC output connector. It was sold with a 3 Wp solar panel. This set allowed, besides charging the picolamp, the charging of a cellphone and a radio. They understood that although it was a basic solution, it was the "first step of the solution" and a solution far superior to continuing using candles. After this socialization, the community understood and supported the solution that would be implemented.

(e) Fair implementation: once all the previous steps had been carried out, the solution by means of picolamps was accepted in this community of Tipas. Therefore, the project was executed.

Thirty-four of the 42 resident families opted for the picolamp solution in the first instance. As Universal Access to Energy is the opportunity to access a benefit, the opportunity was given to the 42 families (all). However, only 34 chose to take it immediately. Everything was completed in two community meetings. To date, there are 39 families with this solution based on picolamps.

In any case, the families' choice does not preclude their access to a scalable solution, as indicated in the energy ladder chart (Figure 4).

(f) Technical and operational sustainability: the other challenge is to create technical attention centers easily accessible for the families. Ideally, in addition to being technical attention centers, they can be energy provision, use and application points. The biggest challenge is to obtain a critical mass that justifies this activity and makes it economically attractive as a private commercial activity.

4. Discussion

An "ideal" energy solution should provide energy not only for basic applications (lighting/communication), but also for productive applications. However, the current reality shows us three important questions.

a. Having enough energy resources for productive applications in a community or region DOES NOT imply that productive processes develop. Nowadays, a large percentage of the rural population that have access to an electricity grid continue using it for basic domestic applications. Will it be worthwhile to make investments in grid extension, knowing that the grid per se will not trigger production processes? Will it not be convenient to prioritize a "first and quick solution"? It seems more efficient to provide basic solutions as quickly as possible, and grid extensions when reasonable.
b. According to the authors' experience (more than 700 communities), the energy ladder chart has full validity. Even basic solutions, such as the picolamp, are fully accepted by the users, as long as there is a proper understanding that it is a high-quality temporary solution. Although these temporary solutions can last several years, they are better that having no electricity at all. Obviously, the desire to migrate to a better solution is always present.
c. The planning methodology developed for obtaining Universal Access to Energy can be useful to face other SDGs; for example, in the case of Universal Access to Sanitation. In the town of Cayapas (Ecuador), the ideal solution would be a Sanitation Project with a sophisticated network such as in any developed city. However, for cultural reasons, the population does not accept solutions for shared areas. Therefore, individual solutions by home must be considered. Listening to the beneficiary is very important.

5. Conclusions

There are more 900 million human beings on planet Earth without electricity [4]. From this data, new planning and implementation methodologies should be proposed. Traditional knowledge and actions alone will not solve the problem. Statistically speaking, reaching 92% electricity coverage is not a major difficulty for any country. The difficulty is how to close the gap until reaching the desired 100%. "The Last Mile" requires innovative solutions.

The developed methodology, which has not previously described, has been successfully used in several communities in rural Bolivia. According to the experience presented, involving all stakeholders in the decision making process is key to this success. The way of obtaining this involvement is through the participatory diagnosis described for the case of the Tipas community. End users help in adapting the energy solution to their needs and economic capabilities. Additionally, teaching end users how to better use and maintain the energy equipment is key to the long term success of any solution.

The authors think that, by following the approach proposed in this paper, achieving the SDGs are within reach. It is better to focus on achieving end users involvement in every project than apply "best solutions" from other contexts.

Author Contributions: Conceptualization, R.C.; methodology, R.C. and F.J.V.-C.; writing—original draft preparation, F.J.V.-C., C.A.P. and J.A.S.-F.; writing—review and editing, C.A.P. and J.A.S.-F.; supervision, J.A.S.-F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by Universidad Politécnica de Madrid and by the NGO Luces Nuevas.

Conflicts of Interest: The authors declare no conflict of interest.

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