Lessons from last mile electrification in Colombia: examining the policy framework and outcomes for sustainability

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1. Introduction

Access to electricity is critical for economic and social development [1,2]. The lack of access to modern energy not only hinders efforts to eradicate poverty, but also limits opportunities for income generation and community development [3]. In recognition of the importance of energy to sustainable development, Sustainable Development Goal (SDG) 7 aims to ensure "access to affordable, reliable and modern energy for all by 2030" [4]. Despite this endeavour, in 2020 nearly 800 million people in the world remained without access to electricity, most of them in Sub-Saharan Africa and developing Asia [5,6]. In Central and South America, almost 16 million people still remain without access to electricity [5]. The problem is particularly acute in rural areas, where 84% of the global population without access to electricity reside [7].

When a country reaches electricity access rates close to 100%, it can be said that it is in the “last mile” of electrification. Providing electricity to the last mile remains a challenge for any country; for example, the Philippines face difficulties electrifying a set of heterogeneous islands [8], while for some villages in India the challenge depends on how sparsely houses are spread [9]. In Colombia, which is the focus of this paper, last mile communities are in remote and hard-to-reach places, typically characterised by low incomes [10–12]. Many last mile communities were also affected by Colombia’s 50-year civil conflict, which has left them politically and economically isolated.

Although Colombia has made a concerted effort to expand access to electricity, achieving full electrification remains a challenge [13–15]. The World Energy Outlook reports that, in 2019 the rate of electricity access in Colombia was 97%; while access rates are > 99% in urban areas, they fall to 86% in rural areas [5]. This means an estimated 1.5 to 2.2 million people currently lack access to electricity in Colombia; many more have only limited availability of electricity and are typically dependent on diesel gensets. Addressing these challenges requires a focus on rural areas [16,17]. In Colombia, ‘off-grid’ is typically associated with the peripheries of the country, rather than the economic and political centres; however, there remain communities without access to electricity that are located within the central grid electrified zone. Grid expansion to these communities is unlikely, which means distributed off-grid solutions will need to be found [7–9,12].

Since 2015, the Colombian government has sought to create an enabling environment for non-conventional renewable energy technologies, i.e. excluding big hydro projects, through Law 1715 (2014). However, as discussed, there are many challenges associated with electrification of off-grid areas [18]. For instance, many communities are isolated, located in dense forest, mountains or along rivers, which raises logistical and technical challenges [19]. Demand for energy in off-grid communities is typically low and many households have low and variable incomes, which makes financing electrification projects challenging [20]. Social challenges relate to the ethnic, cultural and institutional diversity of communities in off-grid areas, as well as to Colombia’s ongoing civil conflict, which has contributed to many areas being characterized by an absence of the state [12,21]. Finally, many of these remote communities reside in protected areas, such as the Amazon and Chocó, which poses environmental restrictions on electrification [18,22]. Despite these challenges, many companies - both national and international - are working to deliver renewable energy solutions in off-grid communities. Research is urgently required to support last mile electrification in Colombia, particularly to understand what institutional set-ups work, what do not and what factors enable more sustainable and durable solutions.

This paper contributes to knowledge on last mile electrification in low and middle-income countries (LMICs), with a focus on Colombia. It asks: what has been done to deliver electricity to last mile communities in Colombia, and with what outcomes for sustainability? To answer this question, the paper first sets out the context for last mile electrification in Colombia, considering the institutional, legislative and financial frameworks, drawing on document analysis and expert interviews. It then focuses on three case studies to examine the factors that shape the outcomes of electrification projects in last mile settings. Recognising the multidimensional nature of sustainability, an analytical framework is applied to synthesise the findings and draw some learnings from the research. This paper argues that changes will need to be made to the legislative and institutional framework in Colombia to create an enabling environment for last mile electrification and enhance the potential multi-dimensional gains of electrification.

2. Material and methods

This research focuses on off-grid electrification in Colombia and seeks to understand the barriers, challenges and opportunities for electrification in last mile settings. This requires an exploratory approach which seeks to provide an understanding of the general nature of the phenomenon under investigation, rather than provide definitive answers. Accordingly, this research adopted a qualitative case study research design which is particularly relevant to answer 'why' and 'how' questions, especially when the parameters and outcomes are still unclear and unexplored [23]. It used document analysis, expert interviews, case study research, and applied an analytical framework to assess the sustainability of electrification efforts in Colombia. The material presented in this paper was collected between 2018 and 2020 and is the result of a sustained collaboration between the authors.

Understanding the governance framework for electrification is vital [24], and the first step in this research was to develop a detailed picture of the policy, regulatory and financial landscape for off-grid access in Colombia. This required identifying and analysing relevant documents and data produced by the Colombian Government and its constituent ministries and institutions, as well as supporting documents written by academics, international organisations and other non-governmental organisations (NGOs). One example is the analysis of government funding for off-grid electrification, which involved searching databases and institutional web pages to find out more about the financing, specific requirements of the funds, and geographies covered by the funds. This step was used to map out the governance framework and current situation regarding off-grid electrification in Colombia.

This phase of the analysis was supplemented by formal and informal key informant interviews. The aim of which was to provide insights into participant's understandings, opinions and experiences of working on electricity access in Colombia. The interviews enabled a deeper understanding of the diverse factors that support or hinder the sustainability of energy interventions in last mile settings. Participants were chosen purposively, since sought experts were sought who had worked on electrification in Colombia either from a policy making or project implementation perspective. A total of thirteen semi-structured interviews were conducted between 2018-2020. Small sample sizes are common in qualitative research, which aims for data saturation i.e. the point at which no new themes or substantive information arises, rather than representative or statistically significant results [25]. The purposive sampling strategy drew on the authors' knowledge of the sector to identify organisations with involvement in or connection to electrification efforts in Colombia, particularly the implementation of non-conventional renewable energy. Depending on the locations of the participants, interviews took place in Bogotá and Medellín, whose occupations spanned private sector, public/private utilities, government and research (Table 1). Consent was obtained prior to beginning each interview to ensure the participants were informed of the research objectives, potential risks from their participation and their right to withdraw.

Table 1. Interviewees by category

Occupational category	Detail	Number of participants	Abbreviation in the text
Private sector	EPC companies for electricity service	6	PRS
Public/private utility	Electricity utilities companies	4	PPU
Government	Government institutions	2	GOV
Research	Research institutions	1	RES
Users	People benefiting from electrification	12	USERS

A topic guide was used to guide the interviews, which drew on open-ended questions wherever possible to enable the participant to talk freely and for the interviewers to follow up on issues raised. The topic guide focused on: motivations for engagement with off-grid communities; project design, implementation, operation and maintenance; outcomes for sustainability, including challenges and barriers; and lessons learned. Interviews lasted between 60 and 90 minutes and were recorded and transcribed. Thematic analysis was used to code and interpret the interview data, identifying key themes and patterns within each theme. All data is presented as anonymous to respect confidentiality and adhere to ethical standards.

The subsequent phase of the research used case studies to examine the factors that shape the outcomes of electrification projects in off-grid communities. A case study approach is ideal for producing context-dependent knowledge of one or more 'subjects of study' or cases [26,27]. With a view to identifying critical factors, three off-grid electrification projects were selected in different geographies in Colombia. These cases were not intended to be representative of all electrification projects or even to provide examples of best practice. Rather the case studies aimed to provide insights into different project modalities and the dimensions that shape the outcomes for sustainability. Logistical factors, particularly the remote location of many off-grid communities, meant that a convenience sample was used to identify and select case studies. Given the policy focus on hybrid microgrids (i.e. solar PV, batteries and a diesel generator) in electrification efforts [28], case studies were selected that had, since 2010, had a hybrid microgrid installed. Projects were also sought that represented different regions of the country to provide insights into the impacts of geography on electrification efforts. The location of the three case studies is shown in Figure 1, with Table 2 providing details about the region, productive activities and size of the case study communities.

Figure 1. Map showing the location of the case study communities. Source: Authors' own.

Table 2. Characteristics of the case study communities.

Characteristic / Attribute	Mountain community	Amazon riverbank community	Arid zone community
Region	Andes	Amazon	Caribbean (North)
Department	Cundinamarca	Amazonas	Guajira
Geographic	Hilly woodland	Tropical rainforest	Semi-desert
Main productive activities	Livestock and dairy production	Tourism, agriculture, handicrafts	Livestock, agriculture, handicrafts
Inhabitants	~90 people	~300 people	~6,000 people
Type of energy supply	Solar + Batteries + Diesel	Solar + Batteries + Diesel	Solar + Batteries + Wind turbines (currently out of service) + Diesel

Field visits were undertaken to the case study communities during July to November 2019. In two cases, the visits were facilitated by the project developer, while one was arranged independently. All field visits involved observations, informal interviews and surveys with project developers and community members to gain deeper insights into the history, implementation and outcomes of each case. While this approach does not allow for replicability of the research, it was necessary given the diversity of contexts examined and the challenges of undertaking field research in off-grid settings in Colombia.

Finally, to support the analysis of the broad lessons learnt from the document analysis, interviews and case studies, an analytical framework was developed. This involved a limited literature survey of articles that focused on assessments of the sustainability of off-grid electrification solutions in LMICs. Of particular relevance were publications on lessons learned from electrification efforts – e.g. [7,11,12,29,30] and sustainability assessment – e.g. [31–35]. The literature survey revealed a multiplicity of approaches to electrification; this is unsurprising due to the social, political, environmental and technical contexts show enormous diversity [11]. However, broad lessons can be learned regarding: initial access [11], the use of off-grid renewable energy technologies [29,36], the replicability of off-grid solutions [7], the impacts of access to electricity [12], economic generation-based solutions and policies for off-grid electrification [30]. On the sustainability of off-grid solutions, research has demonstrated their multi-dimensional nature. It shows that solutions must integrate not only the environmental, social and economic dimensions of sustainability [31], but also technical [31], technical and organizational/ institutional [34], technical, social/ethical and institutional [37], technical and institutional [32], technical and political/regulatory [35], and socioeconomic and institutional [33] aspects.

The analytical framework draws on the criteria reported in the literature in order to assess the sustainability of electricity supply in off-grid communities in Colombia. Since their sustainability will depend on technical (i.e. the technologies and system design), as well as contextual (e.g. community institutions) factors, assessment criteria were chosen that reflect different dimensions of sustainable development. The proposed framework is not intended to provide an analysis to measure the sustainability of a project or to compare which is the most sustainable solution, as can be done through Multi-Criteria Decision Analysis framework, used by e.g. [35,38]. The purpose of the framework used here was to undertake an open-ended analysis across the different dimensions of sustainability [e.g. 33,39], where factors that do or do not contribute to the sustainability of projects are explored. Therefore, we do not assess the same criteria for each case, nor do we have scales of measurement. Rather, the dimensions of sustainability reported in the literature are used to provide a framework to examine the outcomes in each case study.

These factors are described below and illustrated in Figure 2:

- *Social:* promotion of social activities such as sports; enhancement of local services such as education, telecommunication and street lights [32,34]; and improvements to the quality of life through e.g. food preservation, clean water, entertainment and perceptions of safety.
- *Economic*: for the community - creation of new economic activities, enable the increase of the productive capacity of the community and household income [32,34]. For the service provider - guarantee sufficient financial resources for the installation (CAPEX) and provision of an adequate level of service throughout the project's operating period (OPEX) [31,34,35].
- *Environmental*: reduction of CO_2 emissions through the use of renewable energy in electricity generation [32–34]. Replacement of less efficient sources of lighting e.g. kerosene lamps [32,34].
- *Technical*: availability and reliability of electricity supply, throughout the economic life of the project [31,34]. Availability of specialized technical support staff [32,34].
- *Organizational/ institutional*: local participation in the management and operation of the system and the satisfaction of the community with the service [32,34].
- *Legislative and regulatory framework*: legislative provisions of the country such as tax incentives [35], subsidies and funds offered for the provision of the service provision [34]. Existence of a legislative or regulatory framework that promotes the management of different public and/or private institutions in favour of the sustainable development of electrified communities [33].

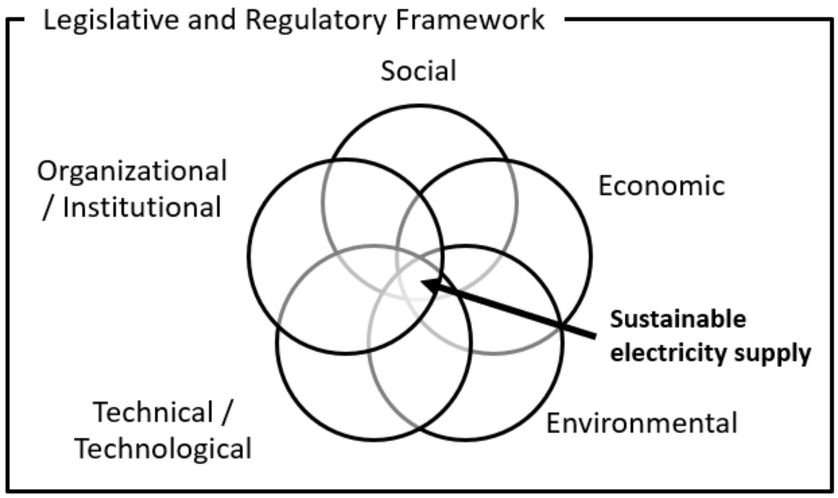


Figure 2. Dimensions to assess the sustainability of off-grid power supply. Source: Authors' own from [31–35]

3. Off-grid electrification in Colombia

The Colombian electricity sector is divided into two main systems: the National Interconnected System (SIN), and Non-Interconnected Zones (ZNI). The SIN represents the country's main transmission system and is composed of generation plants and equipment, the interconnection network, and demand by end-users [40]. The ZNI comprises the municipalities, cities, towns and villages that are not connected to the SIN [41]. The SIN provides electricity to more than 95% of the population and extends over the central region and part of the Caribbean coast. It provides electricity to the main cities, including Bogotá and Medellín, where economic and political power is located [12,22]. The white part on Map A in Figure 3 comprises the ZNI, which occupies 52% of the national territory and has 1.9 million inhabitants [20,42]. The ZNI covers several of Colombia's regions, including the entire Pacific coast, the Amazon, Orinoquia and Guajira regions and the islands. This is mostly rural territory with a complex topography, important ecosystems, such as forests and deserts, and ethnic and cultural diversity [20,42]. The economies of these regions are largely dependent on agriculture, fishing, livestock and tourism. They are also characterized by low income, barriers to the production and delivery of products, low education and human capital, and lack of access to public services, including electricity, sanitation, health and other infrastructure [43].

Although off-grid electrification in Colombia is associated with the ZNI, not all the population living in the SIN are connected to the national grid. Indeed, despite living a few kilometres from Bogotá, the capital city, there are 8,500 households without access to electricity in the department of Cundinamarca [44]. It is not possible to connect these households to the SIN, due to technical and geographical constraints [16]. As a result, some communities in the SIN and all of those in the ZNI require off-grid solutions to achieve access to electricity (see Map B, Figure 3).

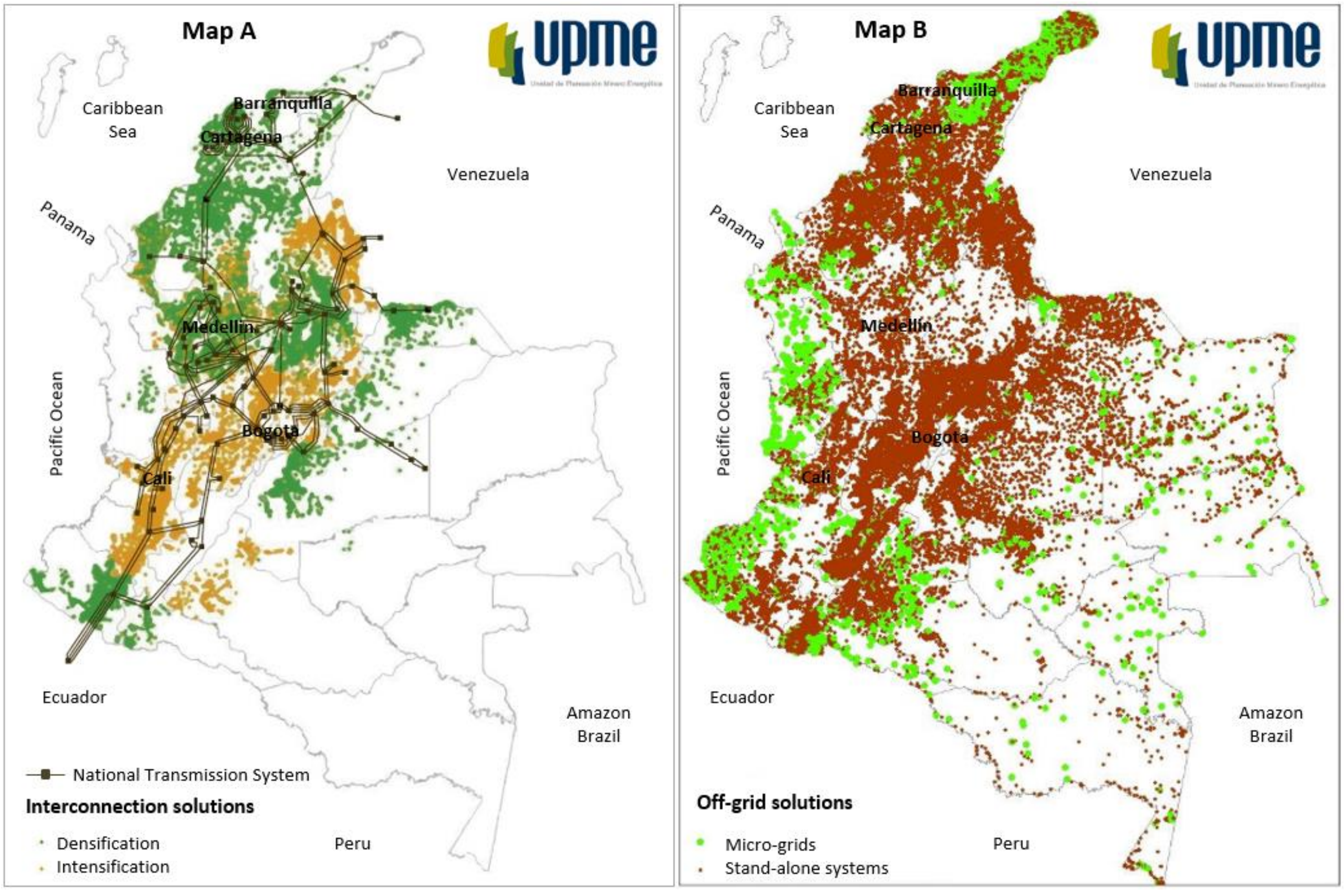
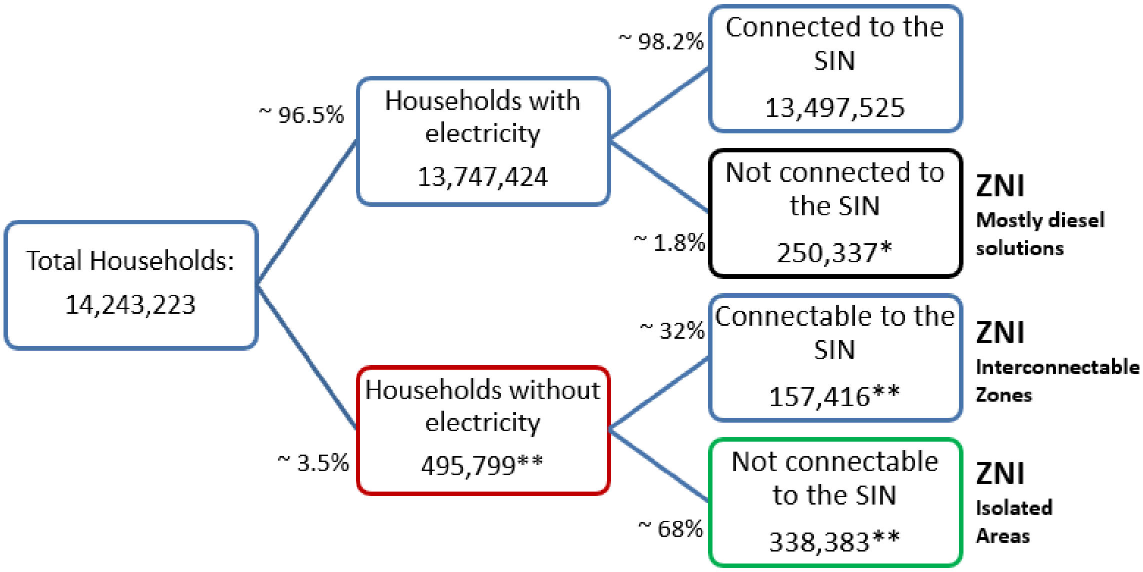


Figure 3. Location of the electrification requirements in Colombia and type of energy solution. Source: PIEC 2019-2023 and STN 2019 [28,45]. Densification refers to the connection of dwellings and other structures to existing medium-voltage grid, while intensification refers to the construction of small extension to medium-voltage lines.

Figure 4 provides a summary of the electricity access situation in Colombia. It shows that of Colombia's 13 million households, 96.5% have access to electricity - the vast majority via the SIN [46] and the remainder via small local grids or stand-alone solutions with diesel generators [12]. Of the 495,799 households that lack electricity, an estimated 32% could interconnect to the SIN while the remaining 68% require an alternative solution [28]. The Colombian government remains committed to delivering electricity access to those households – in both the SIN and ZNI – who currently lack access. According to the Indicative Expansion Plan of Electric Power Coverage, 2019-2023, or PIEC, to achieve universal access will require approximately USD 2.3 billion, of which 9% corresponds to interconnection to the SIN, 48% to hybrid microgrids, and 43% to stand-alone PV solutions [28]. Therefore, the vast majority of last mile connections will be made through off-grid solutions [28].



*PNER 2018-2031 (MME, UPME, IPSE, 2018, pág. 30) and **PIEC 2019-2023 (UPME, 2019, pág. 27)

Figure 4. SIN and ZNI households and electricity access. Source: Authors' adaptation from [28,46,47]

The Colombian government classifies ZNI communities in localities according to the number of 'users' (i.e. households, school) that have electricity: Type 1 localities have more than 300 users and are departmental or municipal capitals; Type 2 have 151-300 users; Type 3 have 51-150 users; and, Type 4 have less than 50 users [48]. While not connected to the SIN, Type 1 localities have better service provision than those in Types 2-4. For example, the municipality of Leticia, which is the capital of the Amazon region, has more than 10,000 users and has electricity 24 hours/day via an isolated grid that runs on diesel [49,50]. Conversely, in 2018, 89% of Type 2-4 localities had less than 6 hours electricity/ day [17]. The vast majority (87%) of localities in ZNI are classified as Type 3 and 4 (Figure 5), which illustrates one of the key challenges for energy providers, namely the small size of many localities, which implies low average consumption [20]. Other challenges providers face include: logistical challenges associated, in some cases, with poor or non-existent transport infrastructure, which leads to high costs of investment and operation; low population density (~3 inhabitants/ km^2); and, unfavourable political and socio-economic conditions, armed conflict, limited institutional capacity and high levels of unmet basic needs [12,20].

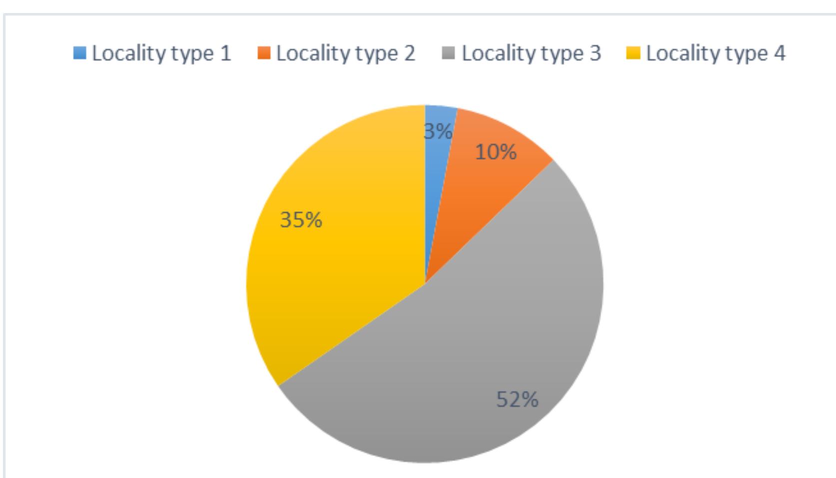


Figure 5. Distribution of ZNI localities. Source: *Authors' own from* [18]

In the ZNI, installed capacity of non-conventional renewable energy sources had increased from 0.6 MW in 2015 to 14.10 MW in 2019 [17,42]. But, the vast majority of localities in the ZNI with access to electricity use diesel - 95%, while the remaining 5% use renewable energy, such as solar or hydro [18,42]. The use of and dependence on diesel has several negative impacts, including local air and noise pollution and high costs. In addition, a significant amount of money is allocated to subsidize electricity in ZNI and analysis of government figures reveals that in 2018 more than USD 33 million was spent on payments to fuel suppliers, typically diesel, in ZNI [50]. Also, the use of diesel often entails limited availability of electricity, especially in Type 2, 3 and 4 localities, where most have a few hours of service usually at night and just 2.27% localities had access 24 hours in 2018 [17].

3.1 The institutional and legal framework for electrification in Colombia

In 1994, the Colombian electricity sector underwent a transformation. Two laws (142 & 143) were published to govern the provision of domestic public services and electrical services in the country. These laws also established several state institutions to govern the sector and Table 3 lists relevant institutions and describes their functions.

Table 3. Institutions involved in electricity governance, Colombia

Institution	Objective	Function
Ministry of Mines and Energy (MME)	Governance (SIN, ZNI)	Formulate and adopts policies aimed at the sustainable use of mining and energy resources to contribute to economic and social development.
Mining – Energy Planning Unit (UPME)	Planning (SIN, ZNI)	Plans mining and energy development, supports the formulation and implementation of public policy and generates knowledge and information for a sustainable future.
Energy and Gas Regulation Commission (CREG)	Regulation (SIN, ZNI)	Regulates energy sectors including electricity, natural gas, liquefied petroleum gas and liquid fuels, to sustain development; regulates monopolies; incentivizes competition and meet the needs of users and companies.
Superintendence of Domiciliary Public Services (SSPD)	Control and vigilance (SIN, ZNI and other public services)	Promotes and protects the rights and duties of users and providers of home public services and the provision of these essential services in a sustainable and quality way.
Institute for Planning and Promotion of Energy Solutions in ZNI (IPSE)	Planning - Structure and implement off-grid projects (ZNI)	Addresses the energy needs of inhabitants who do not have this service; identifying, implementing and monitoring sustainable energy solutions with criteria of effectiveness, efficiency and effectiveness in ZNI.

Source: Authors' own from [51–55]

Since 1994, a legislative and regulatory framework has been developed to deliver electricity access to all in both the SIN and ZNI. Over time Colombian legislation has become increasingly complex, as shown in Figure 6, there is a large number of policies, regulations, decrees and resolutions that govern electricity systems in SIN and ZNI. Rather than facilitating electrification efforts, the regulation has created an overly bureaucratic environment.

National Policy and Legislation – SIN and ZNI

- Law 142 of 1994 - Public Services Law
- Law 143 of 1994 - Electric Law
- NTC 2050 of 1994 - Electric code
- Law 286 of 1996 - Creation FSSRI
- Decrees 847 of 2001 and 201 of 2004 - FSSRI Regulation
- Decree MME 1073-1623 of 2015 - Policy coverage expansion and investment non-conventional energy sources (FNCE)
- Decree 1650 of 2017 - Reduction of taxes on the Areas Most Affected by the Armed Conflict (ZOMAC)
- Decree 884 of 2017 - Norm for the implementation of the National Rural Electrification Plan - the end of the conflict
- Law 1955 of 2019 - National Development Plan 2018-2022

Legislation and Regulation – ZNI

- Decree 2884 of 2001 - FAZNI fund regulations
- Law 855 of 2003 - Official definition of ZNI
- Decree 1591 of 2004 - ZNI subsidy regulations
- CREG Resolution 091 of 2007 - ASE Definition, Rate Formula and Unit Cost of service provision in the ZNI
- MME Resolution 182138 of 2007 - FSSRI Fund for ZNI
- CREG Resolution 074 of 2009 – Modifies Res. CREG 091 of 2007 and Res. CREG 161 de 2008
- MME Resolution 181272 of 2011 - Localities typify
- MME Resolution 91874 of 2012 - Modifies MME Resolution 182138 of 2007 when exceeding subsistence consumption
- CREG Document 002 of 2014 - Electric service in ZNI

Renewable Energy – SIN and ZNI

- Law 1715 of 2014 – Non-conventional Sources of Renewable Energy (FNCER), Efficient Energy Management (GEE) and FAZNI validity extension
- UPME Resolution 045 of 2016 – FNCE incentives
- UPME Resolution 585 of 2017 - Energy efficiency incentives
- Decree 570 of 2018 – FNCER market mechanisms

Exclusive Service Areas (ASE) – ZNI

- Concession Contract MME 052 of 2010 - ASE Amazon
- CREG Resolution 027 of 2014 - Reasons for ASE inclusion
- MME Resolution 40374 of 2016 - Modifies Res. MME 180196 of 2011 - ASE Subsidies
- CREG Resolutions 154 of 2017 and 087 of 2018 - Modify CREG Res 076 of 2016

Self-generation and Distributed Generation – SIN and ZNI

- Decree 348 of 2017 - Small-scale Self-generation National Energy System
- CREG Resolution 030 of 2018 - Regulation of small-scale self-generation activities and distributed generation in the SIN
- CREG Resolution 038 of 2018 - ZNI self-generation surpluses

Plans – SIN and ZNI

- PERS - Sustainable rural energy plan
- PTSP – Plan "Todos somos PAZcífico"
- PND 2018-2022 - National Development Plan 2018-2022
- PNER - National Plan for Rural Electrification 2018-2031 with focus on post-conflict areas (Resolution MME 40809 of 2018)
- PIEC 2016-2020 and PIEC 2019-2023 - Indicative Plan for Expansion of Electricity Coverage 2016-2020 and 2019-2023

Figure 6. A partial depiction of the legal framework for ZNI electrification. Source: Authors' own from the legislation

As shown in Figure 6, the most recent regulations are focused on self-generation and distributed generation, communities affected by the armed conflict, and renewable energy. Also relevant are Exclusive Service Areas (ASE), wherein companies are granted exclusive rights to generate, distribute and market electricity in specific geographical areas [56,57]; at present, there are two - Amazon and San Andres and Providencia islands. While interviewees were supportive of ASE in principle, they argued that in practice it had created a culture of non-payment and dependence on diesel.

In addition to this legislative framework, Colombia has developed financial mechanisms to support electrification and electricity supply in rural areas. These are summarized in Table 4 [58]. Two of the most important funds for the ZNI electrification are FAZNI and FSSRI. FAZNI supports the construction and installation of electricity infrastructure in ZNI and is financed through a charge of USD 0.03 on every kWh dispatched by the wholesale market, and which increases annually with the producer price index [59,60]. Through this fund, USD 420 million was raised between 2001 and 2019 [61] and has led to the electrification of 218,000 households in more than 1,500 communities [17,18]. However, interviewees spoke of a preference for private or donor finance, rather than government funding through e.g. FAZNI, due to an overly bureaucratic process in accessing government funds.

FSSRI distributes subsidies to lower income users and covers administration, operation and maintenance costs [58]; this mainly includes the purchase and transportation of diesel through a tariff subsidy for service provision

(GOV1, GOV2). The tariff subsidy is ten times higher than in SIN - per user [18]. Between 2006 and 2018, the FSSRI spent around USD 707 million only on subsidising tariffs in ZNI [18,50,62].

Table 4. Main financial support (fund and subsidies)

Fund	Area covered	Aim	General information	Annual Amount
FAZNI	ZNI	Construction and installation of electrical infrastructure (CAPEX)	Created by Article 82 of Law 633 (2000) & Law 1753 (2015). Establishes that resources collected correspond to 0.06 USD/kWh dispatched to the wholesale market	USD 41.00 million (2019)
FSSRI	ZNI, SIN	Provides subsidies to low income end-users	Created by Laws 142 (1994) & 286 (1996). For ZNI, established in Law 1117 (2006) and Resolution 182138 of 2007	USD 87.92 million (2018 - only on ZNI)
FAER	ZNI, SIN	Financial Support Fund for the Energization of Interconnected Rural Areas (CAPEX)	Created by Article 105 of Law 788 (2002) and regulated by Decree 1122 (2008) for the construction and installation of new electrical infrastructure in rural areas interconnected to the SIN	USD 39.55 million (2019)
FOES	ZNI, SIN	Social Energy Fund	Created through Article 118 of Law 812 (2003) for Less Developed Rural Areas, Subnormal Neighbourhoods and others	USD 39.56 million (2019)
FENOGE	ZNI, SIN	Non-Conventional Energy Fund and Energy Efficient Management	Created in Article 10, Law 1715 (2014) $0.01 USD/kWh dispatched at the wholesale market	USD 8.58 million (2019)
FNR	ZNI, SIN	National Royalties Fund	Created by the 1991 Political Constitution. Receives royalties not directly assigned to departments and municipalities	Unknown

Source: Authors' own from [58,63]

Regulatory and institutional factors have also slowed the achievement of universal electrification. For example, while state agencies are responsible for planning and implementing projects, it is expected that communities will be responsible for day-to-day operation. As discussed by one interviewee, "*normally in these locations, the school teacher is often the one in charge of energy planning*" (PPU1). With regards regulation, diesel subsidies and very long-term contracts with the ASE lock the country into high generation costs; for example, in 2018, almost USD 17 million was provided to the company that supply fuel to San Andres [18,50]. To address this situation, the government has legislated the use of off-grid solutions with renewable technologies, specifically the use of stand-alone PV systems and hybrid microgrids with less than 15% diesel per year [28]; however, this regulation does not apply to ASEs whose contracts were signed several years ago.

Despite efforts to deliver universal access to electricity in Colombia, the Electric Power Coverage Index (ICEE) only barely improved since 2009 (Figure 7). Furthermore, the rural electrification rate remains at 85% and progress is slow, highlighting the challenges in delivering electricity access to last mile communities. This raises important questions about why Colombia has yet to achieve full electrification, and what could be done to improve access. The subsequent sections draw on the case study research and interviews to provide grounded insights into these questions.

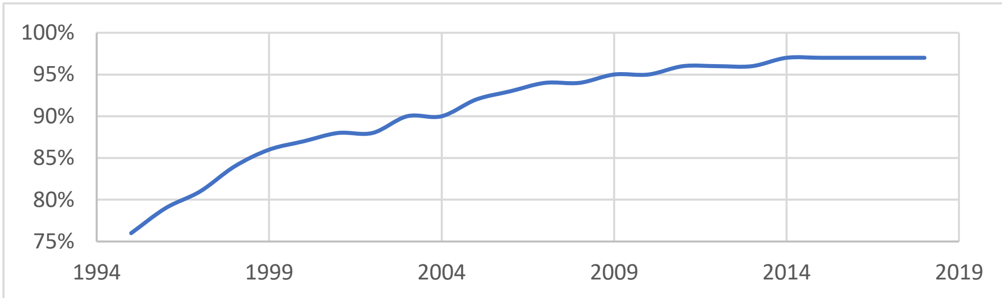


Figure 7. Electric Power Coverage Index in Colombia, 1995 – 2018. Source: Authors' adaptation from [64]

4. Experiences with last mile electrification in Colombia

The motivations for engagement in off-grid electrification varied across the interviews and case studies. Many of the private sector representatives were in the renewable energy business and had been contracted by IPSE, utilities and municipalities to do the technical work. Representatives of the utilities discussed their legislative requirement and spoke of a responsibility to provide electricity to communities within their 'areas of influence'. Utilities were also motivated to maintain good relations with communities in these areas and expressed an interest in piloting new business models and technologies. Government actors were similarly legally obligated, e.g. IPSE was limited to the installation of infrastructure. As one actor commented "*IPSE told us, I can't put up money for operation and maintenance, mine is simply for CAPEX… this is a big problem [for us] because they only have funding for the initial investment"* (PPU2).

This highlights a key challenge for electrification in Colombia, namely that while the government is able to fund the installation of electricity infrastructure, support for the community to operate and maintain the system is limited. This is problematic since local communities often have little to no experience in managing energy systems. Several interviewees mentioned that the once installed a project would be handed over to the community in part because there was little financial incentive to remain engaged; indeed, as one respondent explained '*there is no profit in operating a business just for 20 houses*' (PRS1). This lack of financial incentive meant that, in general, most private companies operating in the SIN had little interest in working in ZNI. In the words of one government actor *"those operating in the SIN are not at all interested in ZNI, because of the high costs of providing the service, low payment capacity, and the difficulties of doing business in these areas*" (GOV1). Having discussed the general motivations for engagement in off-grid electrification, the next sections provide a characterization of the three case studies.

4.1 Case study characterizations

Tables 5-7 provide details about the three case studies: the communities (Table 5); technical solution (Table 6); and operation and management of the system (Table 7).

All three communities were geographically isolated and were categorised as Types 2-4 (Table 5). However, as the size of the community increases, so does access to community services. The average monthly income of these communities is below Colombia's minimum wage, which in 2019 was around USD 281. This highlights the low incomes of these communities and their low capacity to pay for electricity.

Table 5. Community characterization

Characteristic / Attribute	Mountain community	Amazon riverbank community	Arid zone community
Ethnicity	Peasant – Mestiza	Indigenous – Ticuna	Indigenous – Wayuú
Community type (IPSE)	Type 4 (<50 users)	Type 4 (<50 users)	Type 2 (< 300 users)
Users (households with electricity)	22	38	390
Community services	Primary school, open air sports ground, and a community centre	Primary school, open air sports ground, a church and a community museum	A school with indoor sports ground, a boarding school with sports ground, health centre (the last two have their own generation plant)
Local school offerings	Primary School	Primary School	Primary and High School
Travel time and transport mode from the nearest departmental capital	From Villavicencio between 3-4 hours in a 4x4	From Leticia around 2 hours in boat; Bogotá-Leticia by plane	From Riohacha ~9 hours in a 4x4 (during the dry season)
Estimated monthly household income	USD 183	USD 198	USD 76 (rural) – USD 198 (urban)

Table 6 provides information about the off-grid electricity solution provided. As discussed in Section 2, a criterion for case study selection was presence of a hybrid microgrid, which had been installed in the last decade. Prior to 2013, two communities had a diesel-only plant that provided them with 3-6 hours of electricity per day. Table 6 shows that the installed cost for mountain community was around USD 6000/kW, where 50% of CAPEX was spent on logistics and transportation of the system's component parts.

Table 6. Off-grid solutions characterization

Characteristic / Attribute	Mountain community	Amazon riverbank community	Arid zone community
Project objective	Off-grid pilot project	Electrification project in an ASE	Government-led electrification project
Start of operation	2018	2012	2013
Technology used	72 solar panels 24 AGM batteries 18 kW diesel plant	45 solar panels 24 lead acid batteries 36 kW diesel plant	1312 solar panels 480 lead acid batteries 2 wind turbines 364 kW diesel plants
Solar Installed capacity	22 kWp	13.5 kWp	320 kWp
CAPEX (IC Investment)	USD 245,040	Not reported	Not reported

CAPEX Contribution	Regional utility	MME concession to the regional utility - ASE	IPSE using the FAZNI
Annual OPEX	$23,468 USD	Not reported	Not reported
Demand (2019)	1,591 kWh/month	1,900 kWh/month	28,515 kWh/month
Average consumption per household (2019)	72.3 kWh/month-	54.4 kWh/month	73.1 kWh/month-
Solar radiation	4.0 – 4.5 kWh/m^2	3.5 – 4.0 kWh/m^2	5.0 – 5.5 kWh/m^2

Detail on the operation and maintenance of each system is provided in Table 7. This shows that one of the case studies had 24-hour access, one had 16-hour access, and one had just 6-hours electricity per day. In the last case, the low availability was due to a lack of clarity about which entity was in charge of administration and maintenance of the system.

Table 7. Off-grid solutions operation and management

Characteristic / Attribute	Mountain community	Amazon riverbank community	Arid zone community
Legal figure for the provision of the service	SIN Utility Company	ZNI Utility Company with a contract through an ASE	The municipality provides diesel and two operators - IPSE is responsible for remote monitoring
# of hours of service	24 hours	16 hours (06.00-22.00)	6 hours
Reliability	1 disruption per month	1 disruption every 2 or 3 months	1 disruption every 1 or 2 weeks
System operation and basic maintenance	Member of the community hired by electricity utility	Member of the community hired by electricity utility	Contractors
Battery maintenance	Energy utility experts	Energy utility experts	Not reported
Management and monitoring	Energy utility	Energy utility	Management: Mayor Monitoring: IPSE
Type of charge for the service	Rental	Pro-rata of total consumption by the community	Electricity provided free of charge
Fee (in 2019)	Fixed USD 11.25 /month	Dependent on the # of appliances in the household - $0.49 to $17.46 /month	None

4.2.1. Mountain community

Drivers. This hybrid microgrid was installed by an energy utility during 2017 and provided the community with 24-hour access to electricity. The main driver of the project was to pilot the technology and evaluate the factors that contributed to sustainability of the project. The utility chose the mountain community firstly, because it was located within its area of influence and it was not possible to connect it to the grid, and secondly because of community interest for the project.

Although the system used smart metres, this was only for remote monitoring as, for regulatory reasons, the utility could not charge households for energy consumed. Thus, households paid a fixed charge of USD 11.25/month. Since it was a pilot project, an experimental initiative for learning by doing, the utility was not seeking financial closure - the collection of the fixed charge covers less than 20% of the annual operating costs.

Uses of electricity. As a dairy and livestock community, productive activities had been positively impacted by a stable electricity supply. This had encouraged some households to purchase refrigerators to preserve dairy products (e.g. milk and cheese) and to keep food and beverages, some for self-consumption and others (e.g. ice cream and cold drinks) for sale. The microgrid also provided electricity to an artisanal cheese maker and a few local stores, where cooked lunches were sold.

In terms of community uses, the system provided electricity to a community centre, where villagers met to discuss community affairs, and the school, which allowed the teacher and students to make use of laptops donated by the Colombian government a few years earlier. Street lighting was also provided, which had led to a shift in social dynamics as people were able to socialise and play football after dark. In addition, within households, electricity had replaced the use of candles and kerosene for lighting.

Successes. An important factor in the 'success' of the project was the relationship between the utility and the community. The utility had been involved in project development at every stage and remained in charge of administration, billing, monitoring and maintenance. The utility chose to hire community members to work on system installation and trained a member of the community to be responsible for day-to-day operation and basic maintenance. This helped to build trust between the utility and community, as had the stable and reliable supply of electricity and regular visits by the utility.

Challenges. These were largely technical and in particular related to poor battery performance. While the purchase of cheaper, lower quality batteries had created initial savings, project developers explained that poor performance had not only led to a higher than expected use of diesel, especially at night, but also a subsequent increase in OPEX. In 2018, when the system began operating, the utility had to buy back up diesel every 2.5 months, but this had increased to monthly purchasing. For this system we have calculated that a suitable battery pack would have a pay-back of about five[1] years.

Lessons learned. An important learning was the need to build extra generation capacity into the system. This had enabled households not only to meet current household energy demand, but also to support productive activities. Building in extra capacity, combined with the fixed cost for energy consumption, had enabled households to increase energy use.

4.2.2. Amazon riverbank community

Drivers. Under the terms of the ASE concession, the utility was required to install renewable energy technologies in several off-grid communities within their jurisdiction. The Amazon riverbank community was one of the beneficiaries, which in 2012 had had a hybrid solar PV plant with battery storage installed. The hybrid microgrid increased the availability of electricity – from 6 to 16 hours/day. Community members argued this service was sufficient as there was little need for electricity between 22.00 and 06.00. In recognition of the strong governance structures that characterise many indigenous communities, the utility had allocated responsibility for the day-to-

[1] 24 batteries * 1970 USD/battery (bae-opzs-15-pvs-2850) * 2 (logistic increase by isolation) = 94560 USD
According to the utility, diesel expenditure amounts to 19000 USD/year
Finally, 94560 USD / 19000 USD/year = 4.98 years

day management of the plant to two community members. One individual was responsible for operation and maintenance of the plant and the other for collecting payments. The utility oversaw the administration of the plant, including billing, and carried out more extensive maintenance to the system, including of the batteries and distribution network.

Uses of electricity. Patterns of electricity usage had changed since 2012, due to increased availability. Greater availability led households to substitute these less efficient lighting sources, and some households had purchased other electrical appliances such as TVs, fridge and blenders. Tools that support productive uses, such as compressors and drills (for handicrafts) and refrigerators (for shops), were also purchased and had supported increased income from tourism.

Successes. A key factor in the success of this case study was continued commitment of both the community and the utility. This had enabled trust to be built, aided by the responsiveness of the utility to respond to and resolve faults in the microgrid when they materialised. This meant that the microgrid provided a reliable service, enabling households and the community to increase electricity use, for example into productive activities. In terms of system operation, unlike the mountain community, the utility had invested in batteries that could be maintained and carried out preventive maintenance every 6-12 months, which facilitated the durability of the system.

Challenges. There were two meters for the entire community - charging for electricity was pro rata and based on measurements from the two metres and the number and type of appliances each household owned. This disadvantaged some households which owned but did not use their appliances, since the system did not allow the monitoring of actual energy use. For some households, this payment system acted as a disincentive for the purchase of new appliances. Increased consumption was also disincentivised by a complex subsidy and tariff structure. Based on the size of the community, the subsidy and tariff structure established a maximum amount of electricity consumption that could be subsidized and was fixed for 20 years. This meant that when the community consumed less than 1,700 kWh/month, the price of electricity was USD 0.08 /kWh, but when consumption exceeded this amount, the price for surplus consumption was USD 0.39 /kWh. This had negative implications for community demand, who refrained from buying new appliances, and for the development of productive activities. Despite these challenges, electricity demand had grown: in 2012, average daily peak demand was 4-5 kW, and by 2018 this had increased to 9-10 kW. Community members expressed an interest in developing tourism further and had plans to build a hostel.

Lessons learned. While members of the community were able to perform the day-to-day maintenance of the system, more specialised components, such as the batteries and distribution network, required specialist care. The trust that had been established between the community and the utility had facilitated the successful operation of the plant and ensure timely payments. Also important was proper sizing and maintenance of the battery bank, which had reduced the use of diesel - which on average is 2 hours during the night.

4.2.3. Arid zone community

Drivers. Prior to the microgrid, the arid zone community had a diesel generator that provided electricity for 4-6 hours per day. In 2013, IPSE, together with two international companies with experience in off-grid electrification projects, installed a hybrid microgrid. The system was designed to provide electricity 24 hours/day, using a combination of solar PV, wind turbines and a battery bank, supported by a diesel plant. A few years into the operation of the microgrid, IPSE had changed the system administrator and by 2019 it was only providing electricity for a few hours each day, mainly supplied through the diesel generator.

Uses of electricity. At the time of the field visit, most households had adjusted to living with a poor electricity service due to the unreliable and limited supply. Those households with sufficient financial resources had purchased their own diesel generator, as had the health centre and one of the schools.

Successes. A strength of the project had been the inclusion of experts in the design, installation and administration, maintenance and operation of the system during the initial years of operation. Community members commented that they had been very satisfied with the electricity service while the foreign company was in charge, because electricity had been available for most of the day.

Challenges. Maintenance of the microgrid had been limited and, at the time of the field visit, less than half of the batteries were functioning. The power plant operator argued that while the local government was responsible for remunerating the system operators and purchasing the diesel, IPSE was responsible for monitoring. As a result, no-one was responsible for the microgrid, which was continuing to deteriorate. A further consequence of this neglect was a loss of trust by the community in government institutions.

Lessons learned. This case study demonstrates the importance of agreeing on which entities have responsibility for which component of the microgrid over the whole lifetime of a project. This case was hampered by the decision to change the system administrator, which had led to a decline in the availability of electricity and neglect of the microgrid.

4.2 Assessing the multi-dimensional sustainability of last mile electrification in Colombia

The case studies illustrate that, under certain conditions, the installation of hybrid microgrids can support both community development and enhance the sustainability of electricity supply. This section applies the framework described in Section 2 to identify some learnings from the case studies and interviews.

<u>Social</u>. The provision of electricity or the increase in the number of hours electricity is available supported social development in off-grid communities. The research revealed that local services were improved with the provision of electricity to schools, streets and other communal areas. This facilitated a better education as evidenced in the mountain community where the project had enabled the community to make use of laptops provided by the Colombian government. Similarly, streetlights meant community members were able to socialise at night. There were also benefits on the quality of life, with community members highlighting: preservation of food and use of blenders, which affects diets and the ways in which people consume their food; transformation in the forms of entertainment and cultural activities; and improvements in health. As one interviewee explained, previously *"60% of the children had eye problems from studying with candles"*.

Regarding the sustainability of the social dimension, interviewees argued that projects were most successful where communities had expressed a desire for the energy intervention – either initial access to electricity or for longer hours of service. A suggestion was to involve anthropologists and sociologists in the initial community engagement and project planning since "*a project of this type, which in some way will change their culture, their habits, so many things, is a project that has to be bought first"* (PPU2). In Colombia, this was particularly important as many communities have been impacted by the country's protracted civil conflict and maintain a mistrust of outside actors.

Economic. In two of the case studies, the project developers had created local employment from the installation and subsequent operation and basic maintenance of the microgrids. Two communities had also seen an increase in productive uses, including cold storage of dairy products and the use of machinery for the elaboration of handicrafts. In the Amazon community, the increase in the availability of electricity encouraged investment in an eco-hotel. This can help to increase household and community income in a potentially virtuous circle, which is a key factor in terms of economic sustainability since *"communities with the possibility of productive activities or hiring of labour have a greater capacity to pay"* (PPU2).

The remote location of these last mile communities and the lack of adequate road infrastructure represented a key challenge, particularly due to the increase in both CAPEX and OPEX. This was highlighted by interviewees who argued that transport, climatic and soil conditions presented logistical challenges, which drove up project costs. Another economic challenge was collecting payment for the electricity service, particularly given the low incomes of most last mile communities. As a result, the case studies and projects mentioned by interviewees adopted different payment methods to account for local contexts; for example, several private sector actors discussed how they had opted for prepaid methods to avoid non-payment.

Environmental. The displacement of diesel by renewable energy sources, specifically solar PV, not only has positive impacts on GHG emissions, but also on air and noise pollution. In the Amazon, for example, the use of diesel fell from 6 to 2 hours per day of use on average. Another impact was the substitution of inefficient and polluting sources of lighting, such as kerosene and candles, with electricity, which will have reduced household air pollution. However, the case studies also revealed that the use of diesel will not be permanently displaced if the batteries are not well maintained and if sufficient renewable capacity is not built into the system. Finally, while the environmental dimension was important for interviewees, it was rarely discussed by community members; suggesting that the environmental impacts of energy provision is less important at the local level than the social and economic impacts.

Technical. The 'success' of hybrid microgrids was dependent on how the technologies functioned in practice. The case studies illustrate the importance of factors such as battery quality, and operation and maintenance of the system. In the case of the Amazon and Mountain communities, the provision of specialised support to community members responsible for day-to-day maintenance facilitated the availability and reliability of the electricity supply. By contrast, the Arid Zone case illustrates how poor maintenance leads to the deterioration of the system; the bank of 480 batteries, of the same quality as the Amazon case, was at less than 50% capacity due to the lack of maintenance. Across all case studies, the choice of batteries was a key factor since it enabled both electricity service during the night-time and reduced diesel consumption. However, the technical sustainability does not only depend on system design and proper operation and maintenance. Some interviewees also highlighted the importance of proper use by users, and argued that training in the proper and efficient use of energy is vital to avoid overloading and/or damaging the system.

Organisational/ institutional. As discussed in the Mountain and Amazon cases, the involvement of the community throughout the project life cycle, the hiring of local labour and clarity on the roles and responsibilities of each actor supports project sustainability. Enabling local people to take responsibility for daily operation and basic maintenance of the system not only reduces logistical costs, but also creates community buy-in and ownership of the project. As one interviewee argued, with this, "*after installation you leave the equipment and tell the community 'now it is your turn', and return to easily find the batteries in a boat and the solar panel being used as a table"* (RES1). This was echoed by another participant who stressed the importance of creating solutions that fit with community cultures and needs - "*we don't go to change community cultures, but rather to strengthen them*" (PRS6). The Arid Zone case study illustrates that a change in administration – in this case to an inexperienced entity – can have negative consequences for both the microgrid and the community, not only in terms of the electricity service provided and community dissatisfaction, but also trust in outside actors.

Where it is not possible to accompany a community through the electrification process, interviewees emphasised the importance of identifying community institutions capable of managing the system and providing training to support capacity building. However, as interviewees cautioned that this training – particularly of people who have never had access to electricity – can be time consuming. In this respect, one interviewee argued that the more complex the system, the more complex and involved the training "*individual solutions are better because training is simpler and there are no risks with electrical loads"* (PRS1).

Legislative and regulatory framework. Over time, Colombia has created fiscal incentives, subsidies and funds to deliver universal access to electricity. However, as discussed in Section 3, this has yet to be achieved and most off-grid communities are supplied with unsustainable solutions, both in terms of the fuel used and the failure to meet basic community energy needs. There are several reasons for this; for example, the Amazon case demonstrates that the way subsidies are designed may discourage the growth of demand and limit the potential of electricity to support community development. This was echoed by PRS5 who argued that "*the [Government] policy of basic consumption - subsistence consumption - limits demand and doesn't help to create new uses and/or productive activities".* The Mountain case reveals another reason namely that in SIN, unlike ASE, service providers cannot simultaneously generate, market and distribute electricity. In order not to infringe this regulation, they must find alternative solutions to collect payments and the provision of the service in general. However, the current national development plan has provided tools to remove this restriction.

Finally, while it is acknowledged in the literature that energy access can deliver multiple development benefits [65], this has yet to be realised in Colombia. Indeed, efforts to electrify communities is currently limited to the provision of energy infrastructure. If Colombia is to realise some of these broader benefits of electrification, greater collaboration with other ministries and actors is required. As one interviewee argued "*electrification is only one aspect of what is required in the Colombian rural context - income generation must be encouraged and therefore productive processes must be linked and productive chains strengthened"* (PRS5).

This highlights that the sustainability of a project to provide electricity to off-grid, last mile communities depends on interweaving all five dimensions discussed here, underpinned by a support legislative and regulatory environment.

5. Discussion

In order to provide universal access to electricity in Colombia, it is estimated that the country will need to invest USD 2.3 billion [28]. This represents a substantial investment – one far greater than the funds collected by FAZNI and FSSRI combined. . As a result, a legislative and institutional framework is required that provides incentives for electrification not only through subsidies, but also through private investment. Furthermore, the policy framework should encourage the use of renewable energy technologies and discourage, or even penalize, the use of diesel in last mile communities.

As this paper has demonstrated, electrification can provide multiple benefits to last mile communities. This includes household services, such as lighting, cooling and entertainment, as well as opportunities for income generation, such as cold storage for dairy products. However, such opportunities are limited by a legislative framework that punishes increased electricity consumption with wide increases in electricity tariffs when the rate define as 'subsistence consumption' is exceeded. A more flexible regulatory framework is required – one that can be adapted to the conditions of each region and encourages the repowering of systems as local energy demand grows.

With regard to these legislative and institutional improvements, the Colombian Government has been working on a roadmap to close the gaps and ensure a quality supply throughout the national territory. This roadmap describes guidelines and recommendations for increasing coverage between the SIN and the ZNI, where the following is proposed: (1) integrated planning by re-evaluating the SIN - ZNI classification, as new technologies and local generation blur the need for policy and regulatory separation; (2) the territorial concession where a provider with a vocation of indefinite continuity "utility-like" must guarantee service provision through a regulatory framework that favours project stability through regulated remuneration and targeted subsidies; and (3) political and institutional reforms that strengthen sectoral planning, avoiding institutional overlap , as well as reforms in information systems and in the mechanisms and criteria for accessing financing funds, since these have become a stumbling block to progress in achieving the objectives of the sector [66].The roadmap has drawn on relevant international experiences, particularly from South America. This includes, for example, the hybridisation of diesel plants with solar systems in Bolivia (which has increased supply and decreased service costs) and the Renewable Energy in Rural Markets Project in Argentina, which attracts investment through the allocation of land concessions [66]. [67] [68]. These initiatives provide important learnings for Colombia, just as Colombia's experiences with e.g. FAZNI may be adapted and applied in other contexts.

The case studies illustrate the effectiveness of joint utility and community involvement. In the more successful case studies of the Mountain and Amazon communities, the utility was responsible for project design, administration, maintenance and repowering, while the community was in charge of daily operation, basic maintenance and collection of payments. In these two cases, this division of responsibilities had resulted in functioning microgrids and an adequate level of service. Across all the case studies, the importance of ensuring that communities take some ownership of and responsibility for the microgrid is apparent. However, it is vital that communities continue to be supported by providers until such time that skills can be developed and capacities upgraded. . This is vital to ensure that the electricity solution is not perceived as an external intervention that has been imposed upon them, but rather as something that the community has responsibility for and eventual ownership of.

Finally, a recurrent theme has been the need to support productive activities given the socio-economic benefits such activities can provide. This, however, requires the intervention of non-energy actors, since it is not enough for the community to be more efficient in its production processes when using electricity. Rather, improvements in the supply chain will be required, from cold storage to access to markets that connects rural producers to urban consumers. This requires reforms to the legislative and institutional framework to promote broader development programs that place the needs of the community at the centre, where efforts of different actors and institutions are unified, and that encourage the sustainable development of last mile communities. Isolation is not just a geographical issue for last mile communities, but is also a matter of social, political and economic inclusion. While electrification can enhance inclusion, overcoming geographical and political constraints will require greater state presence and better access to infrastructure.

6. Conclusions

Last mile communities in Colombia are characterised by high levels of poverty. This relates not only to incomes, but also to unmet needs (*"when you don't have enough to eat, you go out and sell what you have to find food*" (PPU2)), low levels of schooling, and poor provision of services such as health, sewerage and electricity. Many of these communities are isolated by geography, poor road and telecommunications infrastructure, and the protracted civil conflict. These characteristics make reaching such communities extremely challenging. This situation not only serves to keeping such communities isolated, but also hinders electrification and other development efforts.

In Colombia, there have been many legislative and institutional efforts to deliver universal access to electricity and it is encouraging that these continue. However, this paper has shown that this has created an overly complex and bureaucratic framework, which must be simplified if 100% access is to be achieve. Further, is has shown that the delivery of access to electricity alone will not be enough to deliver the multi-dimensional development benefits that energy can provide. These include positive impacts on health, education, gender equality, community and poverty and will require going beyond the installation of (renewable) electricity infrastructure. Lessons may be drawn from experiences elsewhere, such as tariffs that reflect costs and technological learning curves. Furthermore, technologies and infrastructure should be designed so that electrification systems are flexible and can support growing energy demand and possible interconnection in the longer term; in other words, it is important to think of off-grid electrification as continuous, rather than a one-off intervention. In addition, clear institutional frameworks and cross-sectoral coordination are needed to support rural livelihoods through the creation of new energy uses and to provide income from productive activities in last-mile communities. This is even more important in many of these last mile communities which remain affected by Colombia's protracted civil conflict and there are clear opportunities to integrate electricity access into the country's rural development and post-conflict planning.

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