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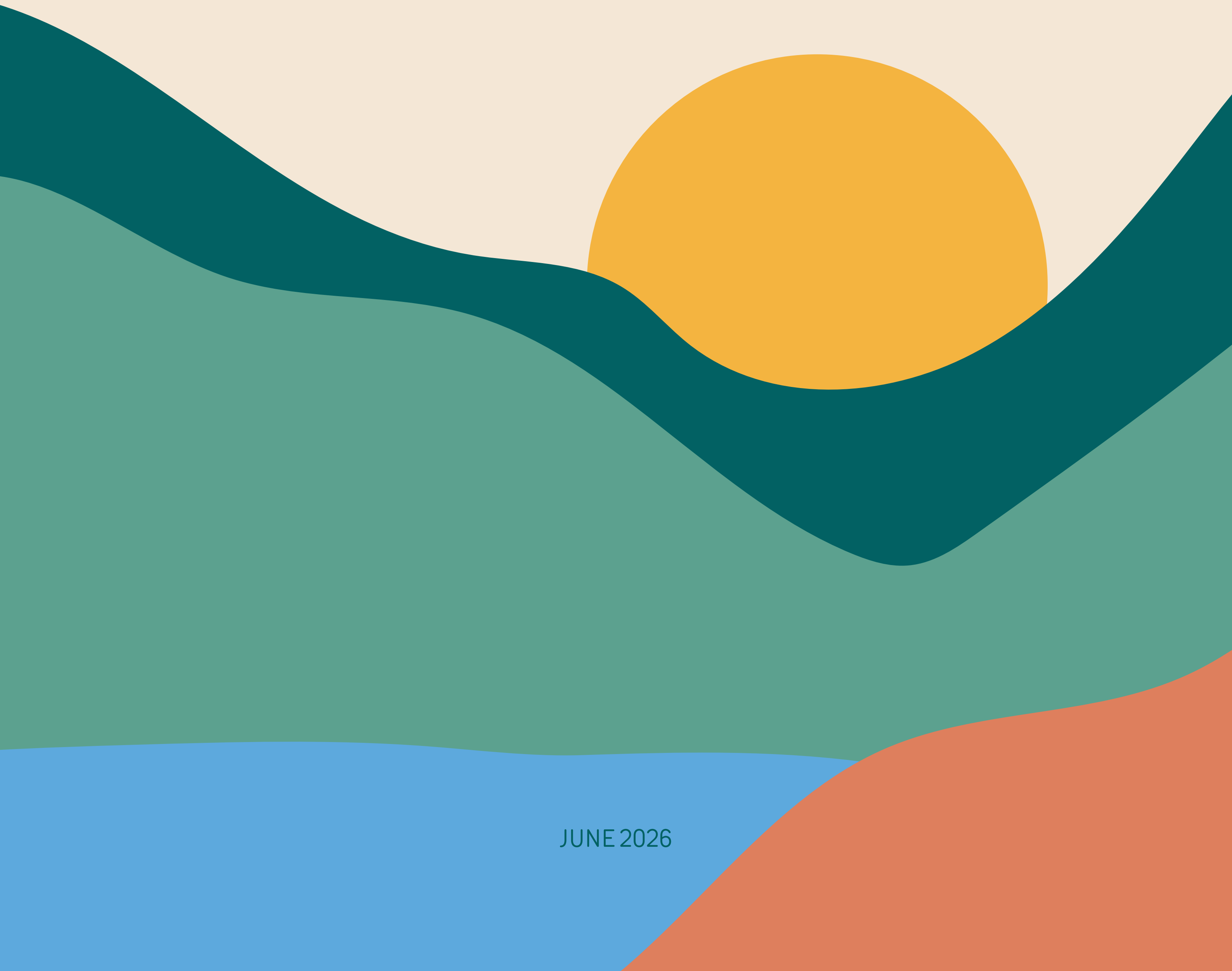
PUBLIC POLICIES AND ENERGY ACCESS EXPERIENCES:

FROM THE INTERNATIONAL AGENDA TO COMMUNITY SOLUTIONS IN THE PAN-AMAZON REGION



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EXECUTIVE SUMMARY

This technical-scientific report presents the results of an in-depth analysis of public policies and experiences related to access to renewable electricity in the Pan-Amazon region, with a focus on overcoming energy exclusion among Indigenous Peoples, Quilombola communities, riverine populations, and extractivist communities. The research was motivated by persistent inequalities in access to electricity, a right internationally recognized as fundamental to the exercise of other rights—such as health, education, food security, and productive inclusion—and an essential condition for promoting social justice, as established by Sustainable Development Goal 7 (SDG 7) of the 2030 Agenda.

The objective of this study was to analyze the structural barriers that limit access to electricity for Amazonian communities. The methodology combined a review of scientific and technical literature, an analysis of national and regional public policies, and an assessment of the impacts of **renewable energy pilot projects funded by the Charles Stewart Mott Foundation**, with the aim of extracting lessons learned from practical implementation experiences. The use of data from these pilot projects proved particularly relevant, as it constitutes a comprehensive empirical basis on energy access in remote Amazonian territories, bringing together systematized information from dozens of projects implemented over a ten-year period in different countries, socio-territorial contexts, and technological arrangements. This evidence base enabled a longitudinal analysis of outcomes, success factors, and structural limitations, supporting recommendations aimed at scalability, replicability, and the improvement of public electrification policies.

Consolidated data indicate that geographic isolation, low population density, high infrastructure costs, and dependence on biomass and fossil fuels are the main barriers to the universalization of access to renewable energy in the Pan-Amazon region. **Although global electricity coverage increased from 84% in 2010 to 91.7% in 2023, approximately 666 million people still lack access to electricity, of whom around 5 million live in the Pan-Amazon**. It is estimated that 1.8 million are in Peru, 1.4 million in Colombia, 650,000 in Bolivia, and up to 1 million in Brazil, despite official data indicating approximately 400,000. Energy exclusion is concentrated in rural areas and disproportionately affects Indigenous populations (10.5%), Afro-descendant populations (2.4%), and the poorest 20% of the population (8.2%), compared to only 0.8% among the wealthiest 20%.

The **comparative analysis of public policies** shows that programs such as the Renewable Energy Project for Rural Markets (PERMER, Argentina), Luz para Todos (Brazil), the National Rural Electrification Plan (PNER, Colombia), FERUM (Ecuador), PNER (Peru), and Sembrando Luz (Venezuela) combine hybrid institutional solutions that integrate technical regulation, shared governance, stable funding mechanisms, and social subsidies to enable universal access to electricity. However, the lack of consolidated energy justice and gender metrics limits the effectiveness and monitoring capacity of these programs.

The **evaluation of pilot projects** focused primarily on solar photovoltaic systems aimed at community electrification, residential lighting, sanitation, and other uses, benefiting 223 communities and more than 70,000 people, including direct and indirect beneficiaries. **Social impacts** include a reduction of up to 50 hours per week of manual labor in Indigenous territories, expanded access to essential services, and an average monthly increase of US$361 in household income in productive initiatives. Despite progress in women's participation in governance structures, their involvement in technical roles remains limited. From an **environmental perspective**, 99.7% of the communities reduced diesel use, and 32% completely eliminated fossil fuels, avoiding the consumption of more than one million liters. **Microgrids and hybrid systems** demonstrated greater reliability and sustainability, particularly when associated with community self-management models. Nonetheless, significant gaps remain regarding financial sustainability, system operation and maintenance, and the systematic

EXECUTIVE SUMMARY

incorporation of a **gender perspective**, requiring specific regulatory frameworks, permanent financing, and adequate monitoring instruments.

The **literature review**, public policy analysis, and pilot project evaluation highlight the need to consolidate universal access to electricity as a State policy, ensuring regulatory predictability and institutional continuity. To this end, it is essential to institutionalize microgrids and hybrid solutions within national and regional policies, with multiannual targets, specific regulatory frameworks for isolated systems—including reverse logistics guidelines—and standardized technical requirements according to territorial typologies (SIGFI/MIGDI). In addition, priority should be given to more reliable technologies with lower life-cycle costs, ensuring technical efficiency and system sustainability.

In **terms of financing and governance**, the creation of permanent funds and stable credit lines for initial investments, operation and maintenance—including battery replacement—is recommended, combined with risk mitigation instruments, social subsidies, and differentiated tariffs for isolated and vulnerable communities. Projects should incorporate life-cycle planning from the design phase, including O&M and expansion, and promote community-based models such as cooperatives and energy communities. Community participation must be ensured at all stages, with particular emphasis on training women and youth for technical and leadership roles, valuing local knowledge, and establishing gender equity targets.

Finally, it is essential to strengthen data, monitoring, and oversight systems through georeferenced registries, public indicator dashboards, and ex-ante, mid-term, and ex-post evaluations, incorporating energy justice and gender metrics, as well as independent audits. Energy policy should be integrated with sectors such as health, education, communications, sanitation, and bioeconomy, adopting Tier 4 as the minimum standard to ensure essential services and productive uses. **Philanthropy and international cooperation** can act as catalysts by supporting innovation, mapping excluded populations, monitoring, and multilateral governance, in alignment with national energy plans.

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INTRODUCTION

1.1 CONTEXTUALIZATION OF THE PAN-AMAZON REGION

The Amazon biome extends across nine South American countries and encompasses significant portions of their territories. Bolivia, Brazil, Colombia, Ecuador, Guyana, French Guiana, Peru, Suriname and Venezuela share the largest continuous tropical rainforest on the planet, as illustrated in **Figure 1**, as well as the most extensive hydrographic basin in the world. With an area of approximately 6.7 million km², the Amazon Forest represents one of the most biodiverse ecosystems on the planet (ACTO, 2018).

Brazil holds the largest portion of the Amazon, with about 3.28 million km², which corresponds to approximately 60% of the total forest and covers 49% of the Brazilian national territory. Peru possesses about 720,000 km² (13% of the Amazon), which represents 56% of its national territory; Colombia, with 480,000 km² (10%), covers 42% of its territorial extension. Venezuela holds 310,000 km² (6%), equivalent to 35% of its territory, while Bolivia, with 220,000 km² (5.5%), covers 22% of its national area. Guyana, Suriname, Ecuador and French Guiana represent, respectively, 3.1%, 2.5%, 2% and 1.5% of the Amazon Forest. In these territories, the Amazon occupies the majority of the national area: 98% in French Guiana, 95% in Suriname, 90% in Guyana and 48% in Ecuador (ACTO, 2006), as presented in **Table 1**.

Figure 1. Pan-Amazon.
Source: Wikimedia Commons contributors, 2024.

Table 1. Characteristics of the Amazon by country.

N	Country	Area of the Amazon Biome [10³ km²]	Accumulated Area of the Amazon Biome [10³ km²]	Percentage of the Amazon Forest [%]	Accumulated Percentage of the Amazon Forest [%]	Percentage of the National Territory [%]
1	Brazil	3,280	3,280	58.8%	58.8%	49%
2	Peru	720	4,000	12.9%	71.7%	56%
3	Colombia	480	4,480	8.6%	80.3%	42%
4	Venezuela	310	4,790	5.6%	85.8%	35%
5	Bolivia	220	5,010	3.9%	89.8%	22%
6	Guyana	210	5,220	3.8%	93.5%	90%
7	Suriname	150	5,370	2.7%	96.2%	95%
8	Ecuador	120	5,490	2.2%	98.4%	48%
9	French Guiana	90	5,580	1.6%	100.0%	98%

Source: The World Bank (2025c) and WWF (2024).

1.2 ELECTRIC ENERGY AS A FUNDAMENTAL RIGHT

Access to energy must be understood as the capacity to dispose of an adequate energy service, available whenever necessary, reliable, of quality, affordable, legal, convenient, healthy and safe, intended to meet all energy needs in the household, productive and community spheres. This conception aligns with the new definition of access to energy, based on the performance of the energy supply, which considers not only availability, but also quality, reliability and the capacity of the service to respond effectively to different social demands – individual and community – and economic (ESMAP 2014).

In this sense, universal access to electricity constitutes an enabling condition for rights and social opportunities. The majority of regions not yet served are located in areas remote and isolated – characterized by geographical isolation, absence of basic infrastructure, low population density and predominance of subsistence economies –, in which the expansion of the centralized electricity distribution grid tends to be technically difficult and economically unviable (Almeshqab and Ustun 2019). In small island States, for example, geographical restrictions reinforce the need for smaller-scale systems (Silva et al. 2024).

The absence of electric energy is associated with multiple deprivations – health, education, security, social participation and income, as systematized in **Table 2** – and acts as a barrier to socioeconomic development and access to public services, especially in rural and remote areas (Orlando et al. 2018). In these localities, the dependence on traditional biomass for cooking and heating increases exposure to household pollutants (Spalding-Fecher 2005), disproportionately impacting women and children (Leduchowicz-Municio et al. 2023), in addition to putting pressure on forest cover (Leduchowicz-Municio et al. 2022). The substitution of kerosene and firewood with electricity reduces health risks, improves quality of life and allows the continuity of essential health and education services (Daka and Ballet 2011), at the same time enabling new productive and agricultural activities (Hampl 2024).

Table 2. Energy as a means to well-being.

DIMENSION	MAIN BENEFITS
Public health	Reduction of exposure to biomass smoke; lower incidence of respiratory and ocular diseases; fewer accidents and burns; more reliable health services (night lighting, cold chain, operation of equipment).
Education and human capital	Household lighting extends study time; internet enables pedagogical resources, hybrid teaching and professional training.
Gender equity and social protection	Lower workload and exposure of women and children to smoke and firewood transport; public and household lighting increases safety in night travel.
Local economy and employment	New ventures (refrigeration, digital services, workshops); extension of operating hours; reduction of losses and operational costs by substituting expensive fossil fuels.
Agriculture and production chains	Pumping/irrigation; refrigeration and post-harvest storage; local processing (drying, grinding), adding value and income.
Social cohesion and community life	Electrified community spaces favor meetings, communication and collective services (community centers, schools, health posts).
Environment and climate	Lower pressure on forests by reducing traditional biomass; mitigation of emissions by substituting diesel/kerosene with renewables; integration with energy efficiency and demand management.
Public services and governance	Improvement in the quality and continuity of essential services (water, health, education); facilitates administrative digitization and access to social policies.
Digital transformation	Connectivity; financial inclusion (digital payments); access to market information and online government services.

Although decentralized diesel generators are still employed as an emergency solution, the recurring costs of fuel and maintenance, combined with greenhouse gas (GHG) emissions and atmospheric and noise pollutants, limit the sustainability of this alternative (Ferreira and Silva 2021). For this reason, renewable solutions for isolated systems, such as solar microgrids, hybrid and off-grid, have been increasingly adopted in areas where grid extension is not viable (IEMA 2023).

These alternatives align with the principle of universal, modern, reliable and sustainable access, but depend on regulatory frameworks and public policies capable of reducing technical and financial barriers and internalizing social and environmental benefits (Silva et al. 2024).

In the Amazon region, the energy issue is intrinsically associated with the history of the occupation of the territory. The settlement process - characterized by the exploitation of natural resources, expropriation of territory and displacement of populations from other regions of the country - resulted in large urban centers, consolidated as enclaves of infrastructure in the middle of the forest, while the other areas of the Amazon territory were occupied by traditional populations or remained under millennial occupation of Indigenous peoples, historically marginalized by the absence of infrastructure and precarious access to essential public services (Corrêa et al., 1994).

This historical asymmetry is reflected in access to electric energy, particularly in rural areas and isolated communities, where universalization remains a challenge. In Brazil, Bolivia and Peru, the economic cycles of rubber and mining attracted groups in search of social mobility, which resulted in the formation of various urban centers (Becker, 2005), such as Iquitos in Peru and the capitals of the states of Acre, Amazonas and Pará, in the process known as Amazonian transhumance (Furtado 1957).

In the Pan-Amazon countries, the challenges for the universalization of this essential service for contemporary life persist, even given that national rates of electricity coverage are relatively high, varying between 91.6% and 99.8%, levels mostly superior to the global rate of 91.7% (IEA et al. 2025). Electric energy is widely recognized as a basic and fundamental right, which is why it integrates the 2030 Agenda of the United Nations, specifically Sustainable Development Goal 7 (SDG 7 – Clean and Affordable Energy), which establishes the goal of ensuring, by 2030, universal access to energy in an affordable, reliable, sustainable and modern manner (UN 2023).

Considering this scenario, this report proposes a qualitative assessment, comprising a joint and comparative analysis of pilot electrification projects aimed at peoples and traditional communities in Amazon territories, and to analyze policies and initiatives for universalization of access implemented in different countries, with a view to the systematization of lessons learned and the elaboration of a guiding profile of renewable energy systems for integration into public electrification policies.

The document is structured into six chapters in order to fulfill these objectives. **Chapter 1** presents the introduction and contextualization of the topic, highlighting the importance of electricity as a fundamental right for both contemporary and traditional societies. **Chapter 2** addresses electricity exclusion from a global perspective, outlining historical trends and projections through 2030, and analyzes exclusion in Latin American countries and Pan-Amazonian territories, with emphasis on territorial, social, and ethnic dimensions. **Chapter 3** examines universalization policies and initiatives across different national and regional contexts. **Chapter 4** presents a bibliometric and systematic review of the scientific literature on the subject, consolidating relevant contributions and identifying key gaps. **Chapter 5** provides a quantitative and qualitative assessment of pilot projects funded by a philanthropic foundation and implemented over a ten-year period in Amazonian communities, discussing their impacts, limitations, and lessons learned. Finally, **Chapter 6** synthesizes the main findings and presents recommendations for strengthening sustainable electrification public policies, both globally and within the Pan-Amazon region.

2

ELECTRICITY EXCLUSION: A LOOK AT THE INDICATORS

2.1 ELECTRICITY EXCLUSION IN GLOBAL PERSPECTIVE

The global rate of people with access to electric energy in the world went from 84% in 2010, or 1.1 billion people without basic access, to 91.7% in 2023, when the contingent of excluded was reduced to 666 million people, demonstrated in **Figure 2**. Even so, 63 countries present more than half a million people living without access to electricity (ESMAP 2025).

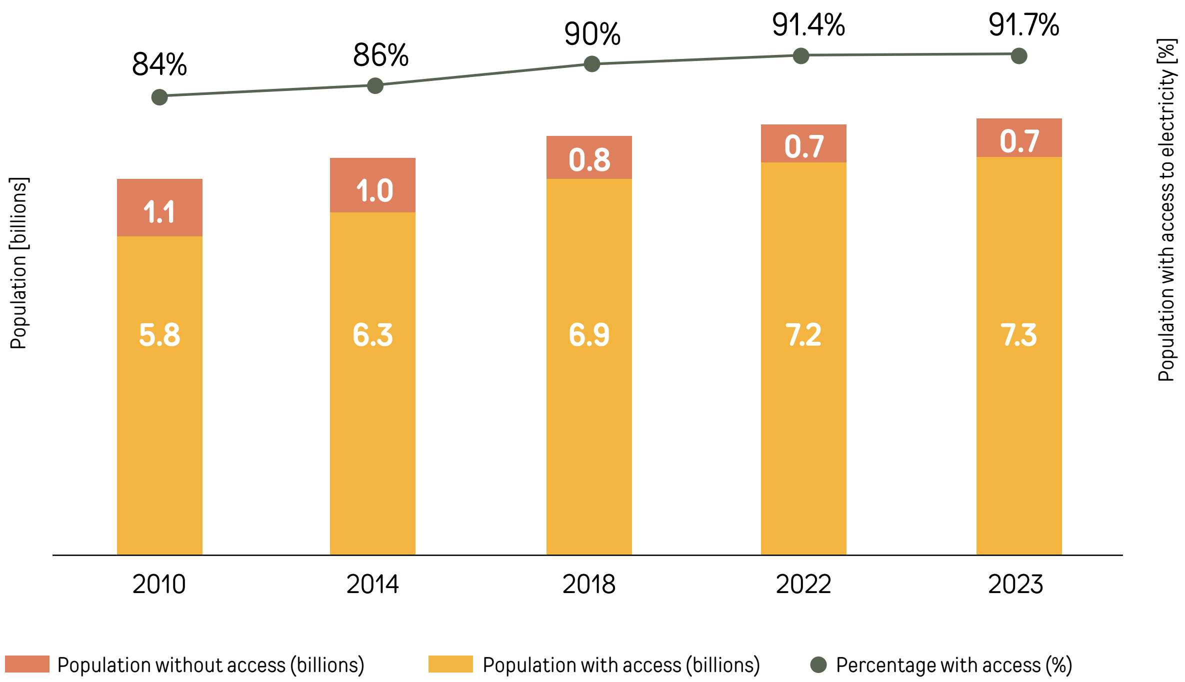


Figure 2. People with and without access to electric energy in the world, 2010-2023.
Source: Data from The World Bank (2025c) and IEA (2025).

According to the IEA (2025), maintaining the recent trajectory of universalization of global access, in 2030 there will still be 645 million people without access, of which 565 million will be in Sub-Saharan Africa, a region that will concentrate approximately 85% of global exclusion. These numbers evidence not only the magnitude of the challenge, but also its increasing geographical concentration in countries with low income and infrastructure and high territorial dispersion, which reinforces the difficulty of ensuring the fulfillment of the SDG 7 (Sustainable Development Goal 7) target by 2030.

To fulfill this goal, the annual access expansion rate must reach 1.2 percentage points (pp) per year. However, between 2010 and 2020, the annual average was 0.77 pp, and, in the most recent period, 2020–2023, the average increase fell to 0.39 pp. Therefore, the current pace would need to be tripled, as indicated in **Figure 3**, precisely at a moment when the remaining population is more difficult to serve and faces greater restrictions on payment capacity (IEA et al. 2025).

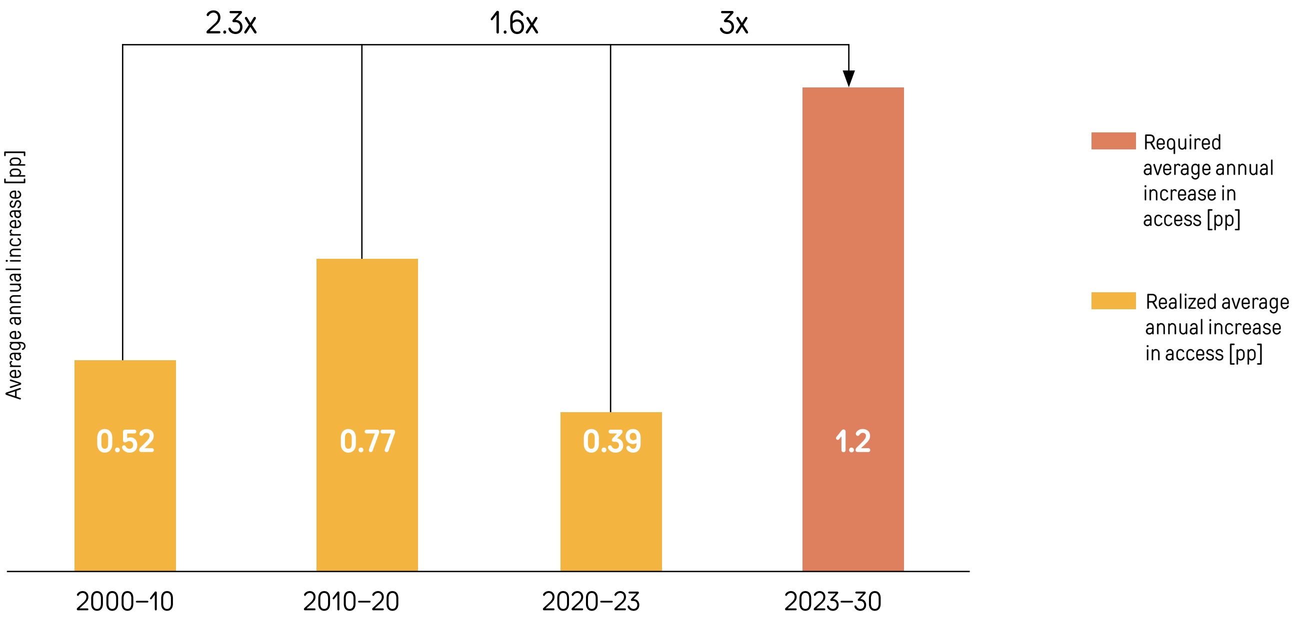


Figure 3. Annual average increase of access to electric energy, 2000-2023.
Source: Data from The World Bank (2025c) and IEA (2025).

From a regional point of view, there were global net gains of 73.1 million new people served per year between 2021 and 2023, slightly above the average population growth of 68.5 million people per year. In Sub-Saharan Africa, however, the annual addition of 30.2 million people with access marginally exceeded the demographic increase of 29.2 million/year, which helps to explain the low access rate in the region – in some countries little above 50% of the population – and the relative stagnation of the regional indicator, as shown in **Figure 4**. However, Central and South Asia reduced its share in the global deficit from 36%, in 2010, to 4%, in 2023, supported by income elevation and grid expansion.

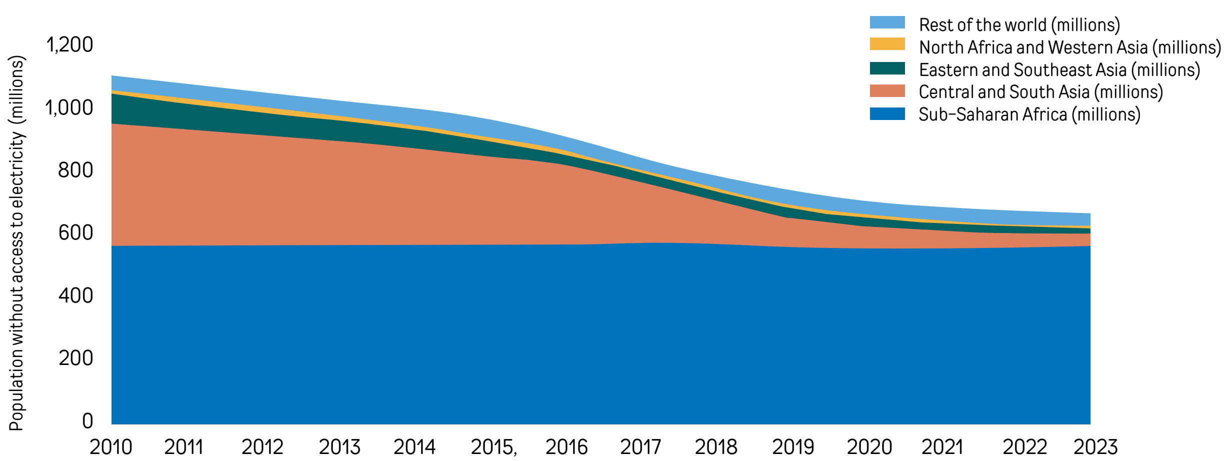


Figure 4. Population without access to electric energy by region, 2010-2023.
Source: Data from The World Bank (2025c) and IEA (2025).

A fundamental indicator to understand energy exclusion is the spatialization of the population based on the urban–rural cleavage[1]. Globally, the access rate in the urban environment varied from 96% in 2010 to 97.8% in 2023, as illustrated in **Figure 5**.

URBAN AREA

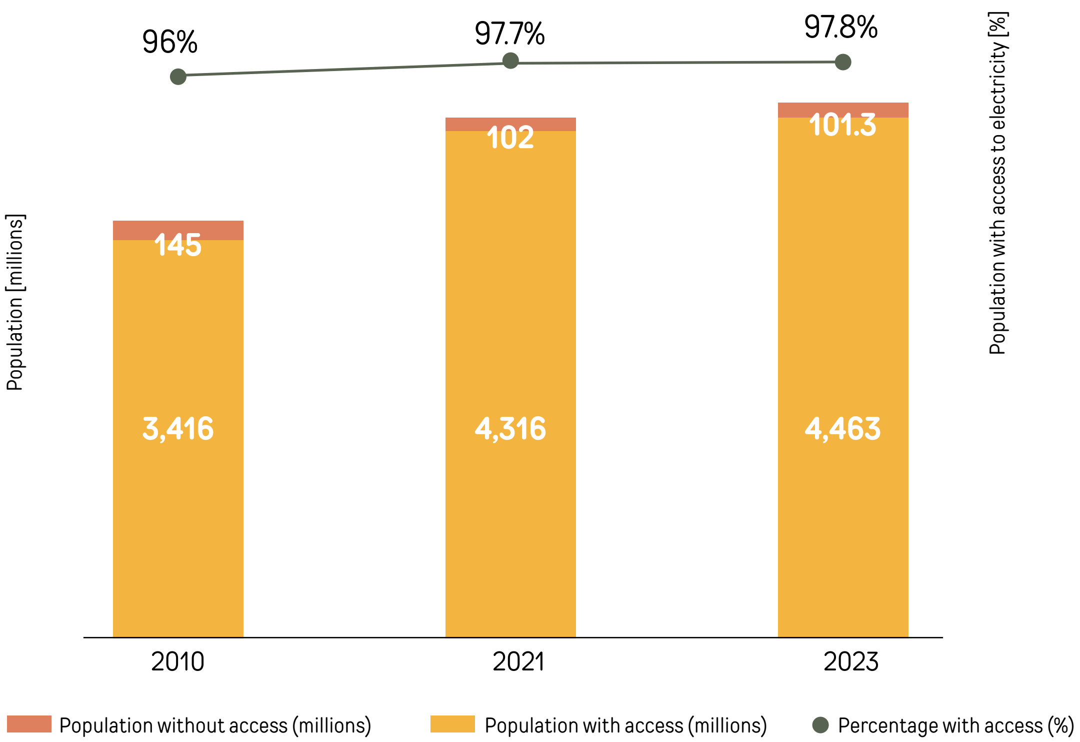


Figure 5. Global population with and without access to electric energy in urban area, 2010–2023.
Source: Data from The World Bank (2025c) and IEA (2025).

In the rural environment, the advance was from 73% to 84% in the same period, as shown in **Figure 6**. In absolute terms, in the period considered, the urban population with access grew by one billion, while the rural population with access increased by 480 million, resulting in the decrease of rural electricity exclusion from 886 million to 550 million people from 2010 to 2023.

[1] Provided that treated as an entry point and supplemented by metrics of density, accessibility, dispersion and centrality, including temporal accessibility (time to essential services/markets) and distance to infrastructure (substations, navigable waterways, connection points) and adding indicators of socioeconomic vulnerability and service coverage (electrification, internet, water). Furthermore, in the Amazon context, considering environmental and seasonal barriers (flood/ebb, navigability) that reconfigure the effective spatialization. This type of treatment avoids dichotomous biases and improves the explanatory power for the design and prioritization of public policies, such as electrification, connectivity, drinking water, health, among others.

RURAL AREA

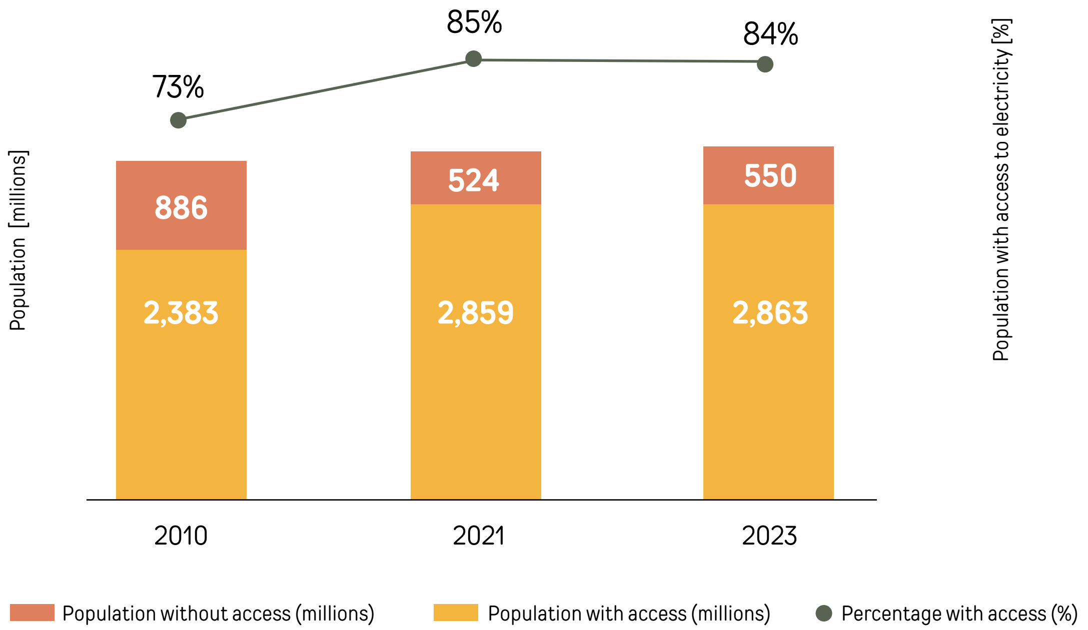


Figure 6. Global population with and without access to electric energy in rural area, 2010–2023.
Source: Data from The World Bank (2025c) and IEA (2025).

Even so, in Sub-Saharan Africa rural exclusion grew from 376 million to 451 million in the period, while, in Central and South Asia, rural exclusion fell abruptly from 383 million to 25.6 million. In the urban environment, global exclusion reduced from 145 million to 101 million between 2010 and 2023, even in the face of the growth of rural–urban migration, that is, it reduced both the previously existing exclusion and the potential exclusion associated with urban population increase. This strong contribution was marked in Central and South Asia, which reduced its urban exclusion from 31 million to one million.

When observing exclusion by countries, the contrasts become even more marked. In 2023, 18 of the 20 countries with the largest absolute access deficits were located in Sub-Saharan Africa; the remaining two were Pakistan and Myanmar, situated in South and Southeast Asia, respectively, presented in **Figure 7**.

Figure 7. Twenty countries with the largest number of people without access to electric energy.
Source: Data from The World Bank (2025c) and IEA (2025).

Only three countries – Nigeria (86.9 million), Democratic Republic of the Congo (79.6 million) and Ethiopia (56.4 million) – concentrated one third of global exclusion. In relative terms, some countries present rates higher than 80% of the population without access to electricity, such as Malawi (84.4%), Chad (88%) and Burundi (88.4%). The most extreme case is that of South Sudan, where 94.6% of the population remains without access, configuring the highest rate of energy exclusion in the world, as demonstrated in **Table 3**.

2.2 ELECTRICITY EXCLUSION IN LATIN AMERICA AND THE PAN-AMAZON REGION

In Latin America and the Caribbean (LAC), significant advances in access to electricity have been registered since the beginning of the 2000s. The proportion of households with access went from 87.7% in 2000 to 97.1% in 2023, as demonstrated in **Figure 8** (IEA 2025a; The World Bank 2025c).

Table 3. Countries with largest absolute number of people without access to electric energy.

Region	Country	Population without access [Million]	% of global total	Accumulated % of global total	% Population without access to electric energy
Africa	Nigeria	86.9	13.0%	13.0%	38.8
Africa	DRC	79.6	11.9%	25.0%	77.9
Africa	Ethiopia	56.3	8.5%	33.4%	44.6
Africa	Tanzania	34.9	5.2%	38.7%	51.7
Africa	Uganda	23.5	3.5%	42.2%	48.5
Africa	Niger	21.7	3.3%	45.5%	79.9
Africa	Mozambique	21.7	3.3%	48.7%	64.4
Africa	Madagascar	18.4	2.8%	51.5%	60.6
Africa	Burkina Faso	18.2	2.7%	54.2%	78.3
Africa	Angola	17.9	2.7%	56.9%	48.9
Africa	Malawi	17.7	2.7%	59.6%	84.4
Africa	Sudan	16.4	2.5%	62.0%	34.0
Africa	Chad	16.1	2.4%	64.4%	88.0
Africa	Kenya	13.1	2.0%	66.4%	23.8
Asia	Myanmar	12.7	1.9%	68.3%	23.2
Africa	Burundi	11.7	1.8%	70.1%	88.4
Asia	Pakistan	10.7	1.6%	71.7%	4.5
Africa	Mali	10.6	1.6%	73.3%	45.5
Africa	South Sudan	10.5	1.6%	74.8%	94.6
Africa	Zambia	10.0	1.5%	76.3%	48.9
	Rest of the World	**157.6**	**23.7%**	**100.0%**	**2.0**

Source: Data from The World Bank (2025c) and IEA (2025).

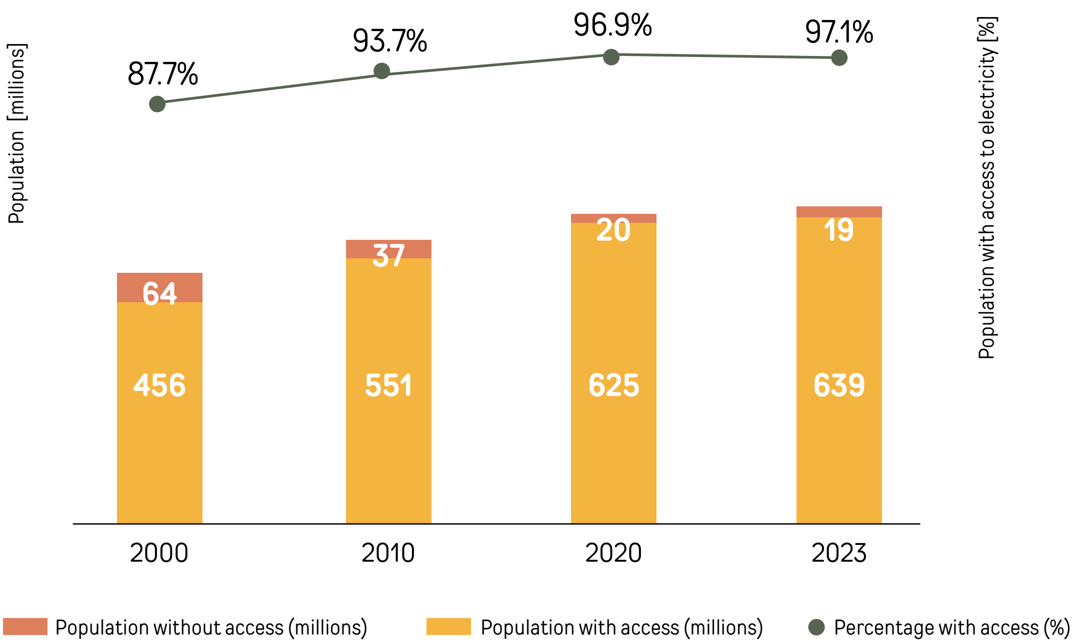


Figure 8. People with and without access to electric energy in the LAC, 2010-2023.
Source: Data from The World Bank (2025c) and IEA (2025).

However, aggregate data may hide significant disparities between sub-regions and countries, as well as between different social groups. Geographical factors, income and ethnic origin configure determining factors of inequalities in access to electric energy.

From a territorial point of view, LAC countries present marked contrasts in access to electric energy. Chile and Cuba have already reached universalization, with 100% of the population served. Venezuela, Brazil, Argentina, Uruguay, Paraguay and Costa Rica register the lowest electricity exclusion rates, varying between 0.1% and 0.4% of the population. In contrast, in part of LAC, the situation is considerably more challenging. In 2023, approximately 10.4% of the population of Guatemala, 12.8% of Honduras and 52.1% of Haiti still remained without access to electricity, as demonstrated in **Figure 9** (IEA 2025a; The World Bank 2025c).

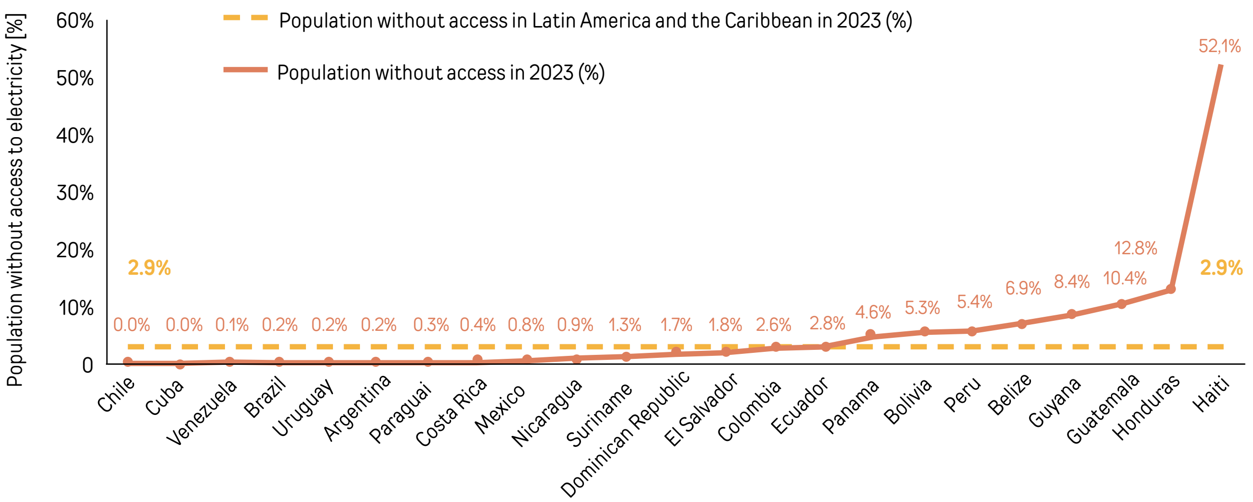


Figure 9. Electricity exclusion indicator in LAC countries in 2023. Source: Data from The World Bank (2025c) and IEA (2025).

Regarding inequalities according to geographical area in the urban-rural cleavage, it is observed, as indicated in **Figure 10**, that the evolution of access to electricity in urban areas demonstrates consistent advances between 2000 and 2023. In 2000, the electricity access rate in urban areas of LAC was 97.2%, corresponding to 386 million people served and 11 million still without access. In 2010, the contingent of people with access rose to

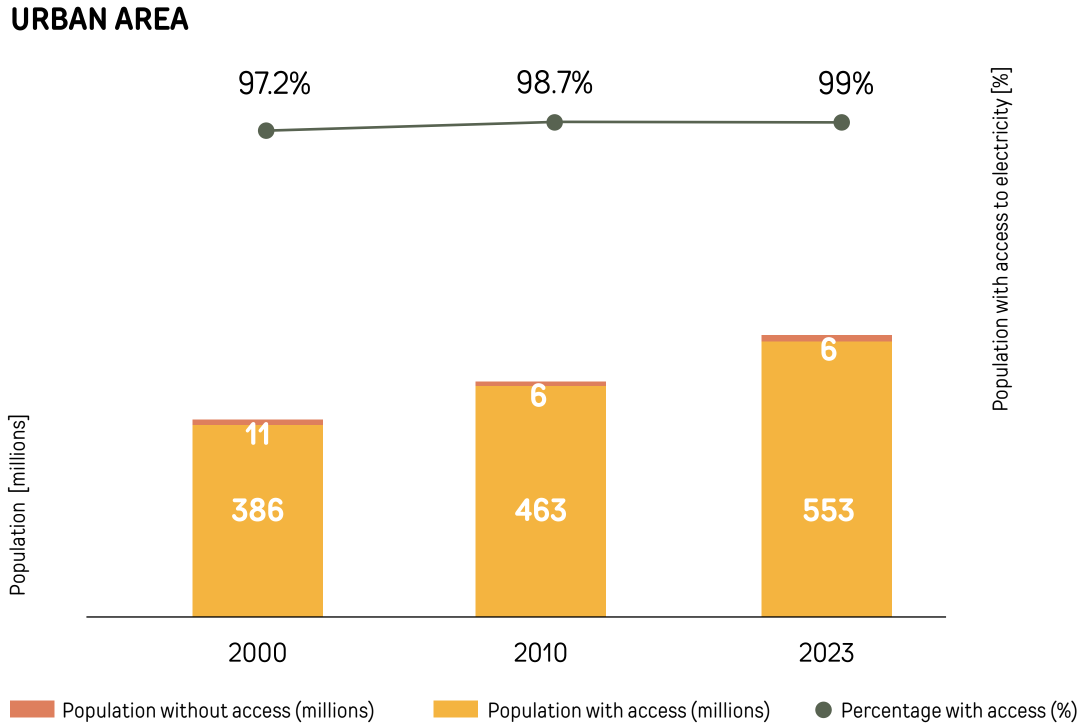


Figure 10. LAC population with and without access to electric energy in urban area, 2000-2023.
Source: CEPALSTAT – Portal de Datos y Publicaciones Estadísticas of the Economic Commission for Latin America and the Caribbean (2025).

463 million, while exclusion fell to 6 million urban inhabitants, raising the coverage rate to 98.7%. In 2023, the indicators pointed to new advances, with 553 million people in urban areas having access to electricity and only 6 million remaining excluded. As a result, the coverage rate reached 99%, practically universalizing the service in the urban environment.

In the case of rural areas, exclusion in the analyzed period is relatively higher than in urban areas, as demonstrated in **Figure 11**. In 2000, the electricity access rate in rural areas was 66.5%, which corresponded to 43 million people without access. In 2010, a significant improvement was observed, the coverage rate rose to 81.8%, evidencing an expressive advance in the period with 105 million rural people having access, but 23 million remaining excluded. In 2023, the coverage rate reached 89.8%, consolidating the positive trend of expansion, although without reaching universalization, since 13 million people still remained without service.

RURAL AREA

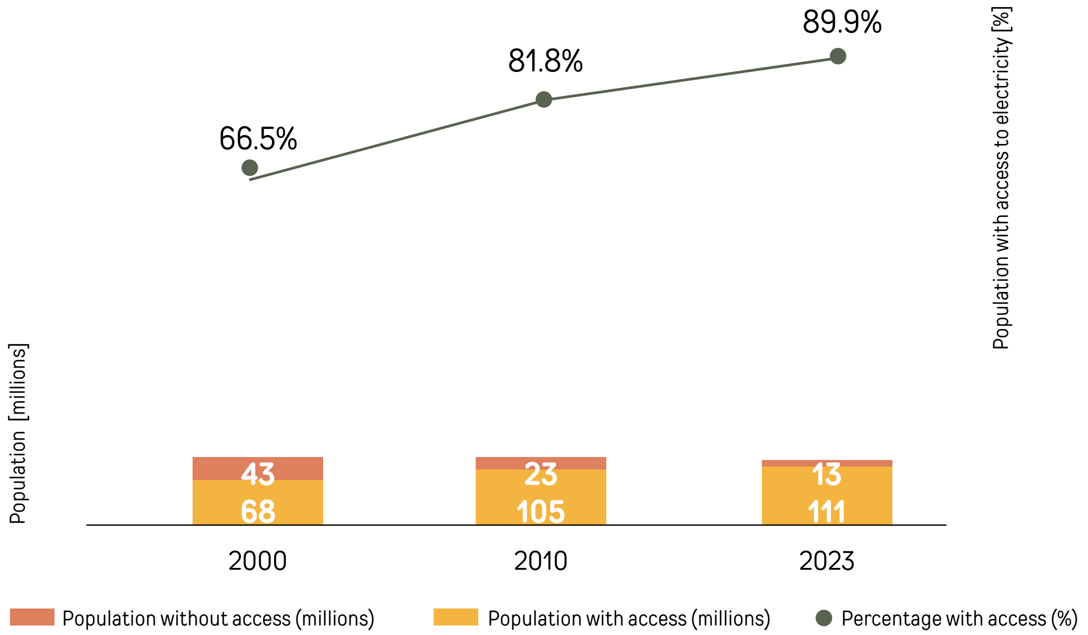


Figure 11. LAC population with and without access to electric energy in rural area, 2000–2023.
Source: CEPALSTAT (2025).

These numbers evidence that, while the universalization of access to electricity in urban areas of LAC is practically consolidated, with rates exceeding 99% in 2023 and 6 million people still excluded, in the rural environment exclusion remains more accentuated, with approximately 13 million people without access, about 10 pp below that observed in urban areas. This disparity confirms that electricity exclusion in the region assumes a predominantly rural character and reinforces the need for specific strategies for isolated communities, where conventional grid expansion tends not to be the most cost-effective solution.

When analyzing access inequalities by population groups[2], the data presented in **Figure 12** indicate significant advances in the 2000–2023 period, although relevant inequalities persist in some groups. Among Indigenous peoples, the proportion of the population without access reduced from 28.6% in 2000 to 10.5% in 2023, an annual reduction rate of 4%. Despite the consistent reduction, this group continues to present the highest levels of relative energy exclusion.

Among the Afro-descendant population, exclusion was reduced from 11.1% in 2000 to 2.4% in 2023, which represents one of the most expressive advances in the period – the highest annual reduction rate, 6% per year (p.a.), among the analyzed groups –, with strong reduction of inequalities in relation to the regional average.

In the other population groups, exclusion went from 10.1% in 2000 to 2.8% in 2023. Considering the population as a whole, electricity exclusion reduced from 13.2% in 2000 to 4.0% in 2023. These results confirm the trend of reduction of energy exclusion in the region, but also evidence the permanence of structural inequalities, especially among Indigenous peoples, who remain the most vulnerable group in terms of universal access to electric energy.

[2] Only ten countries in the region include, in their household surveys, source of data for this indicator, a specific question on ethnic origin. This methodological limitation must be considered in the interpretation of the results, since some groups may vary considerably in the region.

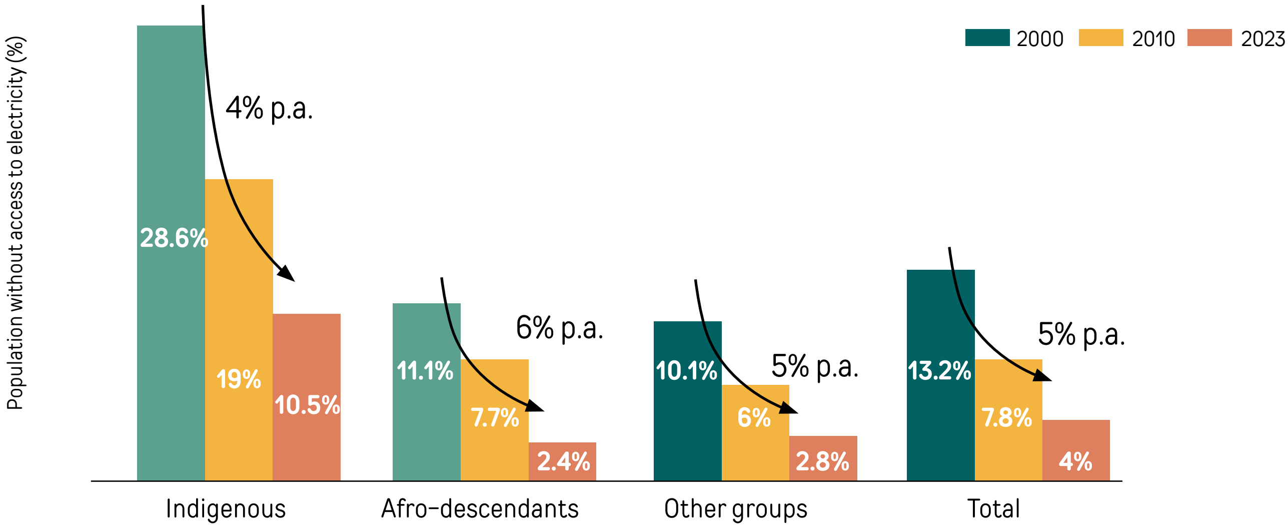


Figure 12. Proportion of the Indigenous, Afro-descendant population, other groups and total population without access to in the LAC, 2000-2023. Source: CEPALSTAT (ECLAC 2025).

The analysis of electricity exclusion by income ranges evidences the persistence of structural inequalities, even though the advances between 2000 and 2023 have been significant, as demonstrated in **Figure 13**. In 2000, exclusion affected 29.3% of the bottom 20% / poorest 20% (Range 1), while, among the 20% richest (Range 5), exclusion was 1.7%. In the period, all ranges registered expressive reductions, from 5% to 3% p.a., with more accentuated falls in the lower income layers. In 2023, exclusion among the poorest receded to 8.2%, that is, a reduction superior to 20 pp in relation to the beginning of the series. In the intermediate ranges, exclusion reduced to 4.4% (Range 2) and 2.6% (Range 3). Whereas among the higher income groups, the indicators approached universalization: 1.6% in Range 4 and 0.8% in Range 5.

These results confirm a general trend of reduction of electricity exclusion in all income ranges, but demonstrate that inequality persists more accentuatedly among the poorest segments of the population. In 2023, the electricity exclusion of the bottom 20% / poorest 20% was still ten times higher than that observed among the 20% richest, evidencing the strong correlation between income and access to electric energy.

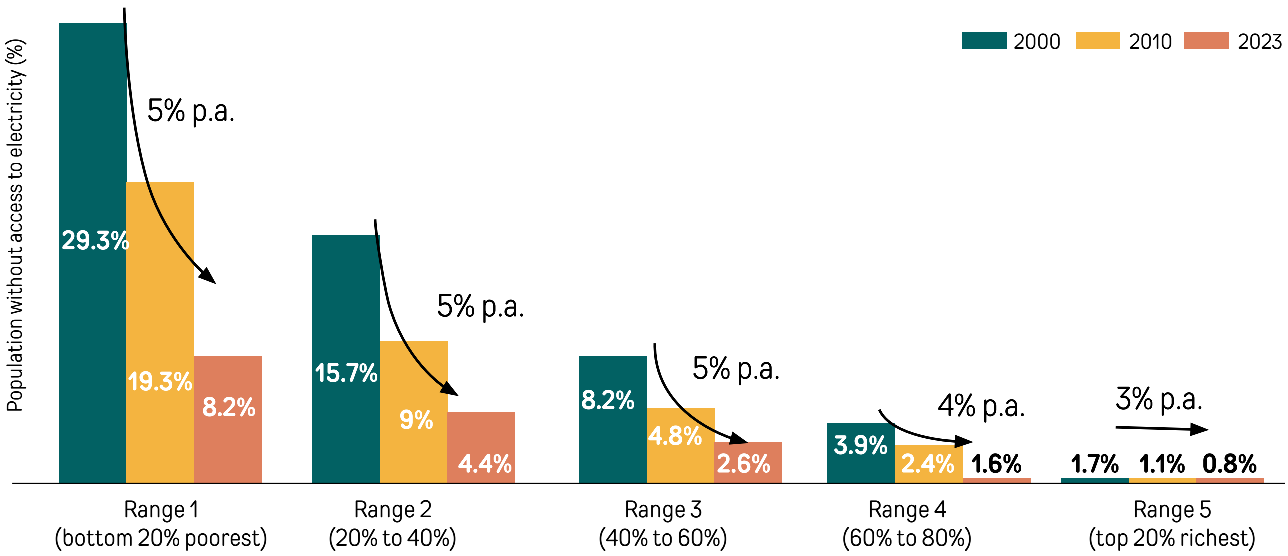


Figure 13. Proportion of the population by income range without access to in the LAC, 2000-2023. Source: CEPALSTAT (ECLAC 2025).

In the Pan-Amazon countries, although electricity coverage rates vary between 91.6% and 99.9% – mostly at the global rate of 91.7%, with the exception of Guyana (91.6%) –, significant disparities still persist, as illustrated in **Figure 14**. It is estimated that approximately five million people remain without access to electric energy in the region. (ECLAC 2025).

In relative terms, Guyana, Peru and Bolivia present the lowest electrification rates among Pan-Amazonian countries, with 91.6%, 94.6% and 94.7%, respectively, which represents approximately 2.6 million people without access to electricity. In absolute values, the largest contingents of exclusion are concentrated in Peru and Colombia, with 1.8 million and 1.4 million people without access to electric energy, as demonstrated in **Table 4**. In Brazil, although the official coverage rate is 99.8% – corresponding to about 400,000 people (ECLAC 2025), six times greater than the total of Guyana –, it is estimated that approximately one million people still do not have access to public electricity services (IEMA 2020).

The integrated analysis of electricity access indicators evidences that energy exclusion in LAC is heterogeneous and is distributed unequally according to territorial, socioeconomic and ethnic dimensions.

From a spatial, geographical point of view, urban areas reached levels close to universalization, with coverage of 99% in 2023, remaining about 6 million people without access. Whereas in the rural environment, although significant advances occurred, coverage went from 66.5% in 2000 to 89.8% in 2023, still persisting approximately 13 million excluded people, confirming that inequality in energy access is predominantly rural.

From the socioeconomic perspective, the analysis of income ranges, by quintiles, demonstrates that, in 2023, exclusion among the 20% poorest (Range 1) was still ten times higher than that observed among the 20% richest (Range 5), 8.2% against 0.8%. Despite the reduction superior to 20 pp between 2000 and 2023 in Range 1, income remains a determining factor of access, reproducing historical social asymmetries.

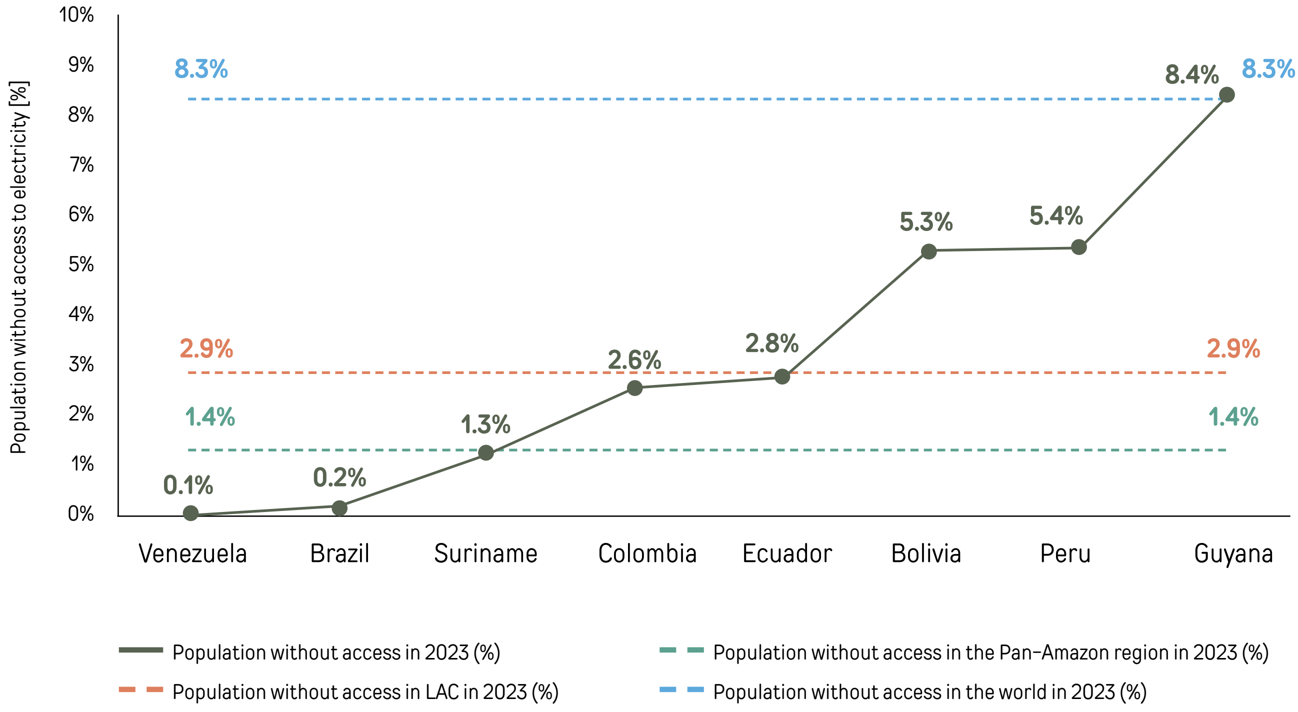


Figure 14. Exclusion rate of access to electric energy in Pan-Amazon countries in 2023.
Source: CEPALSTAT (ECLAC 2025) and World Bank (2025c).

Table 4. Population and electricity access data in Pan-Amazonian Countries in 2023.

Country	Population [millions]	Population without electricity access [millions]	Electricity access rate [%]
Venezuela	28,301	0,028	99.9%
Brazil	211,141	0,422	99.8%
Suriname	0,629	0,008	98.7%
Colombia	52,321	1,360	97.4%
Ecuador	17,980	0,503	97.2%
Bolivia	12,244	0,649	94.7%
Peru	33,846	1,828	94.6%
Guyana	0,826	0,069	91.6%
Total	**357,288**	**4,869**	**98.6%**

Source: The World Bank (2025c).

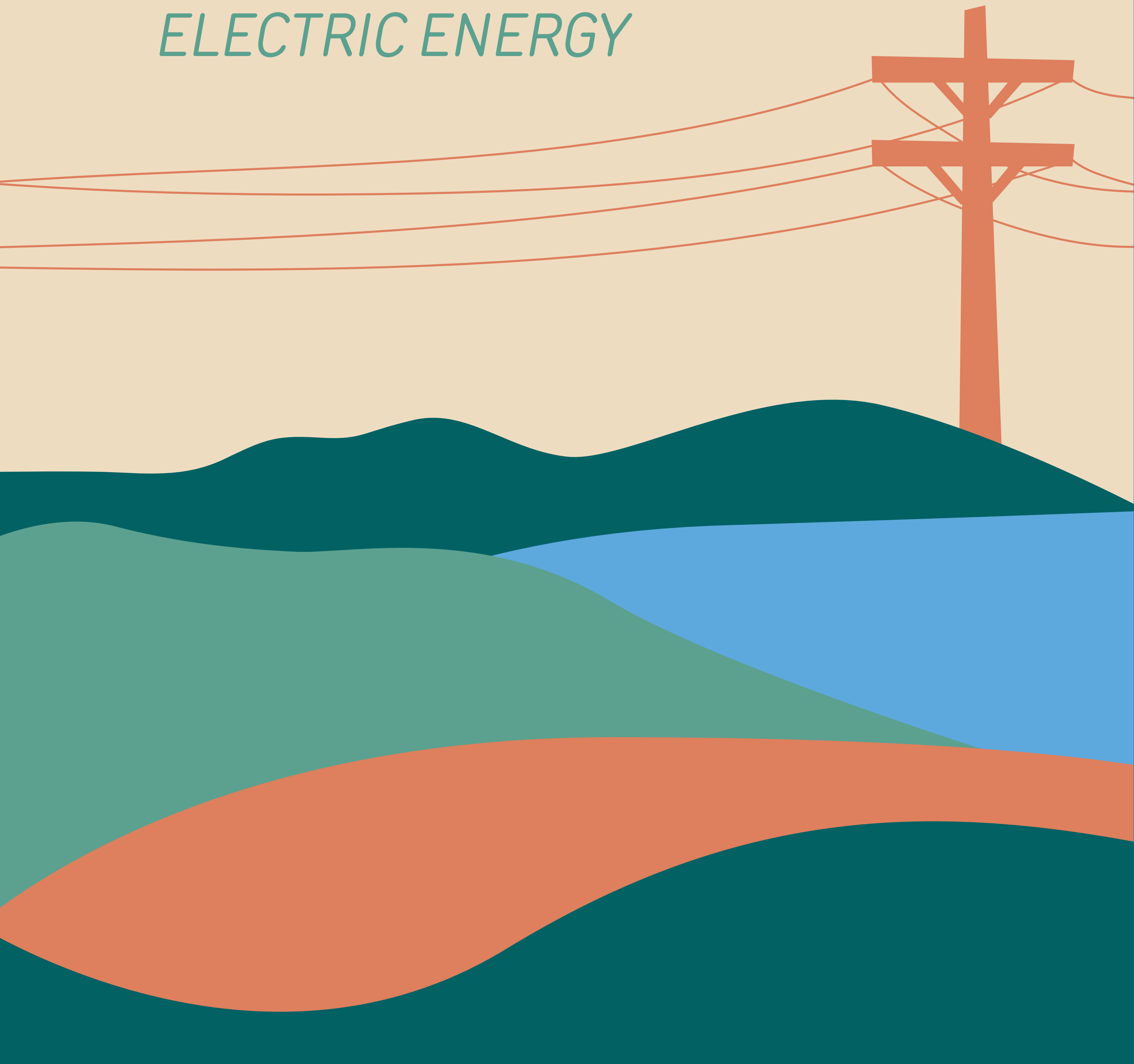
From the ethnic point of view, exclusion also presents unequal patterns. Among the population that identifies as Indigenous, 10.5% remained without access in 2023, against only 2.4% among Afro-descendants and 2.8% in the other groups, evidencing the persistent vulnerability of Indigenous and traditional populations, which adds to the structural challenges of geographical location and lower per capita income.

Therefore, inequality in access to electricity in the region stems from a set of overlapping factors: residing in remote rural areas, belonging to the lower income layers and integrating Indigenous populations significantly increases the probability of energy exclusion. These results reinforce the need for integrated public policies that articulate territorial, social and cultural strategies to overcome the multiple determinants of electricity exclusion.

Thus, even in countries that present high coverage rates and are close to universalization, critical pockets of electricity exclusion persist, evidencing the need for focused policies to overcome historical inequalities and ensure effective universal access.

3

PROJECT INITIATIVES AND PUBLIC POLICIES FOR ACCESS TO ELECTRIC ENERGY



As already addressed, access to energy must provide an energy service capable of guaranteeing all social energy demands - individual and community - and economic ones in the household, productive and community spheres (ESMAP 2014).

In this context, the implementation of State public policies is fundamental to face energy exclusion, especially in low-income countries and regions or with low Human Development Index (HDI), where structural challenges and institutional restrictions hinder universalization of access. These policies must be structured in the long term, with governance and administrative continuity, ensuring predictability and regulatory coherence.

Cooperation initiatives with multilateral and international institutions, such as the World Bank, Inter-American Development Bank (IDB), International Energy Agency (IEA), International Renewable Energy Agency (IRENA) and UN agencies, also assume a central role.

These entities technically and financially support electrification projects in vulnerable territories, through concessional and even non-reimbursable credit lines, risk guarantees, technical assistance and governance arrangements for decentralized execution (IADB 2018; The World Bank 2025b), reducing regional asymmetries and aligning local efforts with the SDG 7 goals, with the combination of national public policies and international support, accelerating the universalization of access, while simultaneously reducing regional inequalities (ESMAP 2022c).

Public policies for energy access can be classified into different stages of instrumentalization, from first access programs, aimed at connecting still excluded

Table 5. Characteristics of the technical instruments of access to electric energy.

TYPE OF SYSTEM	CHARACTERISTICS OF THE TECHNICAL INSTRUMENTS OF ACCESS
Grid electrification	Expansion of the conventional electric grid to connect new households or communities, ensuring continuous supply through centralized infrastructure of generation, transmission and distribution.
Microgrid electrification	Implementation of local generation and distribution systems, generally from renewable sources, serving isolated communities or those distant from the main grid, with capacity to operate autonomously.
Off-grid systems	Individual decentralized solutions, such as home solar systems, designed to provide basic electricity services in remote areas where grid or microgrid expansion is economically unviable.
Cross-border generation and transmission	Generation projects and transmission lines connecting neighboring countries, allowing the exchange of electric energy, increasing system reliability and optimizing the utilization of regional energy resources.
Transmission and distribution	Strengthening and modernization of electricity transport and distribution infrastructure, reducing technical and commercial losses, expanding reliability and enabling new connections.
Rural feeder segregation	Technical separation between energy feeders destined for rural and urban areas, enabling greater control of supply quality, load prioritization and reduction of losses in agricultural regions.
Energy efficiency	Set of measures and technologies to reduce energy consumption while maintaining service level, including equipment modernization, demand management systems and use of more efficient technologies.
Market regulation and reform	Improvement of the regulatory framework and restructuring of the electricity market to encourage investments, promote competition, ensure transparency and ensure the inclusion of decentralized solutions in the electricity sector.

Source: based on the work of Silva et al. (2022; 2021, 2024), IEMA (2023), IEI (2022), Ribeiro et. al (2024), ESMAP (2014) and Bhatia and Angelou (2015).

populations, to policies and projects oriented towards full access, which ensure continuity, quality and reliability of supply.

The instruments, systematized in **Table 5**, include: (i) reinforcement and expansion of existing generation, transmission and distribution; (ii) the expansion of distribution networks, prioritizing peri-urban and denser rural regions; (iii) the implementation of community microgrids – such as the Isolated Microsystems of Electric Energy Generation and Distribution (MIGDI) – in isolated areas; and (iv) the dissemination of individual generation systems – such as the Individual Generation Systems with Intermittent Sources (SIGFI) – serving each consumer unit individually; and (v) indirect access instruments based on energy efficiency programs and market regulation.

The diversity of models seeks to adapt to the territorial and socioeconomic characteristics of the communities, combining lower cost solutions with decentralized renewable sources, ensuring equity and efficiency in the execution of electrification policies (Ferreira and Silva 2021).

Table 6. Impacts of technical instruments on access to electric energy.

Access	Type of system	Connection to electric grid	Legality	Peak capacity (W)	Availability (h)	Night supply	Quality (V)	Reliability (interruptions)	Economic affordability
1st Access	Grid electrification								
	Microgrid electrification								
	Off-grid systems and solar lanterns								
Expansion of Access	Cross-border generation and transmission								
	Transmission and distribution								
	Rural feeder segregation								
Indirect	Energy efficiency								
	Market regulation and reform								

Source: Authors' assessment based on the work of Silva et al. (2022; 2021, 2024), IEMA (2023), WWF (2022), IEI (2022), Ribeiro et. al (2024), ESMAP (2014) and Bhatia and Angelou (2015), REC (2025b, 2025a)

These policies, in addition to expanding access, strengthen local production, improve public services and promote integration with broader social policies of education, health and productive development (IEMA 2023; Silva et al. 2024). The impact of the different instruments of access to electric energy is systematized in **Table 6**, in which the color orange indicates null impact, light green represents low impact and dark green high impact.

3.1 INTERNATIONAL INITIATIVES OF ELECTRIC ENERGY ACCESS PROJECTS

3.1.1 International programs and initiatives for access to electric energy

Several international programs have played a central role in the universalization of energy access. The *Integrated Electrification Strategies and Planning* (IESP), coordinated by the *Energy Sector Management Assistance Program* (ESMAP)[3], provides technical and operational assistance to governments for the preparation of national least-cost electrification plans, utilizing geospatial models to integrate conventional distribution grid solutions, microgrids and off-grid systems (*off-grid*), implementation schedules, execution modalities and structured financing plans. The goal is for at least 50 countries to officially adopt these strategies by 2030, in a context where 63 countries still have more than half a million people without access to electricity (ESMAP 2022c).

The IESP is structured on five pillars: (i) technical-operational support for geospatial planning and microgrid portfolios; (ii) improvement of the *Global Electrification Platform*; (iii) definition of data standards for planning; (iv) training of governments, academia and sector actors; and (v) geospatial analyses aimed at public health emergencies, such as COVID-19 (ESMAP 2022c).

In parallel, the Off-Grid Solar/Lighting Global program expands decentralized solar solutions to remote regions, using solar lanterns and home systems. The program seeks to ensure affordable prices by promoting favorable regulatory environments, establishing quality standards, developing subsidy models, stimulating private sector involvement and disseminating financing mechanisms such as *pay-as-you-go* (PAYG) – prepaid models in which the consumer buys usage quotas, in contrast to the traditional post-consumption billing model (ESMAP 2022b).

Among the experiences stand out: the *Africa Regional Geospatial Planning Support Facility*, which supported Angola, Benin, Burkina Faso, Somalia and Tanzania; the *Access to Distributed Electricity and Lighting ADELE Project*, in Ethiopia, the World Bank's largest intervention in decentralized electrification (US$ 375 million, 700 microgrids and 5 million beneficiaries); and the *Liberia Electricity Sector Strengthening and Access Project (LESSAP)*, in Liberia, which seeks to universalize access by 2030, serving more than one million households, with one third via microgrids and solar systems (ESMAP 2022c).

In addition, the IESP operates in countries such as Pakistan and Nigeria, reducing implementation times and supporting rural electrification of health centers. Other projects were financed in countries such as Chad, Mauritania, Republic of the Congo, Malawi, Somalia, Somaliland, Zambia, Botswana, Mozambique, Sierra Leone and Uganda (ESMAP 2022c).

3.1.2 Indicators and metrics of international initiatives for access to electric energy

The traditional – binary – access metric, based only on the presence or absence of grid connection, does not capture its multidimensional nature. Deficiencies in supply reduce the utility of electricity, create economic barriers that limit its use and allow the establishment of illegal connections, generating losses and risks to people's health and well-being. Therefore, access must also include off-grid solutions, such as autonomous systems (*off-grid*) and microgrids, accounted for according to the quantity and quality of the energy supplied.

In this context, ESMAP (2014) developed the multi-tier approach, which expands the traditional metric by evaluating access from successive levels, as illustrated in **Figure 15** and systematized in **Table 7**, defined by

[3] The *Energy Sector Management Assistance Program* (ESMAP), in partnership with the World Bank and more than 20 institutions, supports developing countries through technical assistance and financing to accelerate the energy transition and ensure the achievement of SDG 7 (ESMAP 2022a).

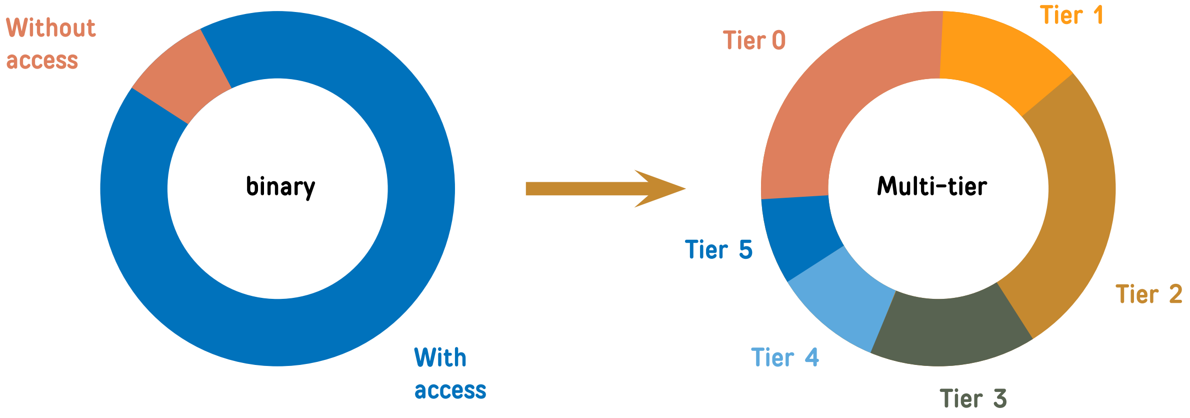


Figure 15. Structure of the understanding and classification of access to electric energy.
Source: adapted from (ESMAP 2014).

Table 7. Multi-tier matrix to measure access to electric energy supply.[4]

Attributes	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	No energy	1-50 W	50-500 W	500-2,000 W	>2,000W	
Availability (duration)	<4h	4-8h		8-16h	16-22h	>22h
Reliability	Unscheduled interruptions				No unscheduled interruptions	
Quality	Low quality			High quality		
Affordability	Not economically affordable		Economically affordable			
Legality	Not legal / in irregular situation			Legal / in regulatory compliance		
Health and Safety	Not convenient				Convenient	

Source: adapted from ESMAP (2014).

[4] Complete table in **ANNEX 1**.

attributes of supply: capacity; availability (duration); reliability; quality; economic affordability; legality; health and safety. This approach overcomes the limitations of traditional metrics and guides policies and investments aimed at meeting the SDG 7 goal.

A multi-tier framework to measure access to electricity services complements the supply matrix by evaluating the equipment and appliances available in the household. This approach evidences that the same household can present distinct levels of supply and services, such as the presence of appliances even in precarious supply conditions or, conversely, their absence in contexts of adequate supply. Complementarily, it also considers electricity consumption, in direct relation to the levels of services received, defined by annual and daily levels based on indicative hours of use of home appliances, as demonstrated in **Table 8**.

The multi-tier approach, therefore, allows assessing access to electricity comprehensively, considering supply, services and consumption. This perspective evidences that households may have distinct classifications in each dimension, offering a more complete view than the binary metric. **Table 9** presents the analysis and limitations of the application of the multi-tier approach.

Generation, transmission and distribution projects play a central role in raising access levels. By correcting quality deficits and expanding availability, they allow households to advance from low tiers (1 to 3) to higher tiers (3 to 5). Investments in transmission and distribution reinforce reliability, reduce losses and enable new connections, sustaining demand growth. This enables unconnected units (tiers 0 to 2) to join the grid and those already connected to obtain greater reliability and economic affordability, according to the tiers demonstrated in **Table 7** and **Table 8**.

Table 8. Multi-tier matrix to measure access to services and household electricity consumption.

Attributes	**Tier 0**	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4**	**Tier 5**
Tier criterion	No Energy	Basic lighting and cell phone charging	General lighting, cell phone charging, television and fan (if necessary)	Tier 2 and any medium power appliances	Tier 3 and any high power appliances	Tier 2 and any very high power appliances
Annual consumption level, in kWh		≥4.5	≥73	≥365	≥1,250	≥3,000
Daily consumption level, in Wh		≥12	≥200	≥1,000	≥3,425	≥8,219

Source: adapted from Bhatia and Angelou (2015).

Table 9. Analysis framework and limitations of the multi-tier approach.

Aspect	Analysis	Alternatives
Methodological approach	Complexity of the methodology, with definition of tier limits considered subjective; independent attributes do not always evolve simultaneously.	Adopt clearer limits calibrated based on empirical evidence; combine attributes gradually according to previous experiences.
Data collection	Requires extensive data collection, which can be financially unviable; some relevant aspects are not covered in the standard instrument.	Incorporate specific additional modules into surveys; apply different levels of detail of the matrix according to available resources.
Mathematical formulation of indices	Conversion of ordinal values (tiers) into cardinal access values may not be mathematically robust.	Improve calculation methodology; test hybrid or weighted metrics; validate statistical robustness in different contexts.

Access to energy for productive uses is defined as those that increase income or productivity, characterizing value-added activities. The diversity of activities, scales and degrees of mechanization hinders the definition of a common metric, as each activity demands specific energy applications from different sources. In general, these applications include: lighting, information and communication, motive power, space heating, product heating and water heating. Specific indices can also be elaborated for agriculture, small businesses and craft activities.

Access to energy in community facilities is equally paramount for socioeconomic development. Public lighting favors mobility, security and social dynamism. In health units, it guarantees care, equipment operation and cold chain. In schools, it extends study time and improves learning. In government buildings, it enables e-governance and communications. In community, religious or cultural centers, it allows night use and provision of collective services. Measurement must consider coverage, light intensity and diversity of services, in addition to financial sustainability, understood as the capacity of institutions to bear costs of energy, fuels, parts and maintenance.

Finally, **Table 10** systematizes the application of the multi-tier approach for different accesses to electric energy – household, productive and community –, evidencing its utility for public policies and integrated planning.

Table 10. Comparison framework of the application of electric energy access multi-tiers.

Application context	Evaluation basis	Main limitations	Index calculation
Electricity supply	Performance of electricity supply (capacity, duration, reliability, quality, affordability, legality, health and safety).	Formal connection may exist without adequate or continuous supply.	Multi-tier classification by supply attributes.
Electricity consumption	Annual consumption tiers estimated from indicative hours of appliance use.	Does not reflect real diversity of appliances and does not adequately incorporate energy efficiency.	Multi-tier classification by annual consumption ranges; distinct from supply and services.
Household services	Type and availability of equipment and appliances used in the household.	Households may have equipment even with precarious supply or, conversely, lack equipment despite adequate supply.	Multi-tier classification parallel to supply, defined by types of equipment available.
Productive uses	Energy applications in productive activities (lighting, ICTs, motive power, space, product and water heating).	Diversity of uses, scales of operation and informal sector hinder standardi-zation.	Index calculated by the average of tiers obtained for each productive application; lowest tier among applications defines global access.
Community facilities	Community services (health, education, public lighting, governance and community centers).	Great variety of community services and different attributes to measure (coverage, intensity, financial sustainability).	Index based on multi-tier assessment of attributes per community facility; lowest tier among attributes defines global access.

3.1.3 Results of international initiatives for access to electric energy

International programs have resulted in significant advances, mainly in African countries, which concentrate the largest shares of the population still excluded from basic access to electric energy. In 2023, about 561 million people were benefited by decentralized renewable solutions, responsible for more than half of new connections in Sub-Saharan Africa between 2020 and 2022 (IEA et al. 2025).

Off-grid solar energy is considered the lowest cost solution for 41% of the population that will still remain without access in 2030 (IEA et al. 2025), especially in productive uses such as pumping, refrigeration and cold storage, which expand income and the capacity to pay for the electric energy service.

However, data from the *Multi-Tier Framework* (MTF) demonstrate vulnerabilities, since the majority of beneficiaries of solar photovoltaic (PV) systems above 200 W (Tier 2) receive less than 8h of electricity per day, and users in Tier 3 or higher (PV>800W), who receive 8 to 16h of electricity per day, are almost nonexistent (ESMAP 2025), reflecting supply quality and reliability problems and the demand for public policies that progressively raise the level of access.

The social dimension of exclusion is also central. In African and South Asian countries, female-headed households present lower probability of *off-grid* access, with economic affordability as the main barrier. Between 2021 and 2023, access exclusion in *least developing countries* (LDCs)[5] fell from 481 to 476 million, on the other hand, in countries in contexts of fragility, conflict and violence – *Fragile and conflict-affected countries* (FCV)[6] – increased from 422 to 427 million (IEA et al. 2025).

Figure 16 presents the evolution of the number of people served by international programs. The total grew from 219 million in 2021 to 326 million in 2022 and 385 million in 2023. In this period, Tier 1 went from 172 million to 253 million (more than 81 million, 47% growth), while Tier 2 advanced from 47 million to 132 million (more than 85 million, 181% growth). These results indicate relevant quantitative gains, but also highlight the need to progressively raise the quality and reliability of access.

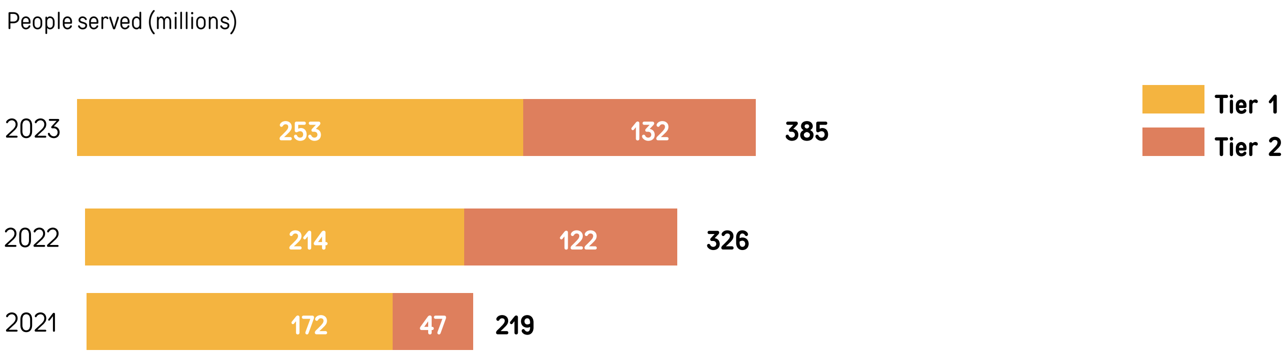


Figure 16. Number of people who received access to electric energy by type of supply level.
Source: adapted from IEA/IRENA/UNSD/World Bank/WHO (2025).

[5] According to UN classification, currently, there are 44 countries classified as LDCs, these are countries with: (i) low per capita income (measured by GDP per capita); (ii) weak institutional and human capacities (education, health, nutrition); and (iii) high economic and environmental vulnerability (external shocks, political instability, natural disasters). These countries have the largest deficit of access to electricity and clean energies, requiring international financing flows, concessional subsidies and technical cooperation to advance in the SDGs (IEA et al. 2025; UNFCCC 2020).

[6] Characteristics of FCV countries and regions: (i) low state institutional capacity to provide basic services (including energy, health, education); (ii) armed conflict or political instability, such as civil wars, insurgencies, territorial disputes; and (iii) generalized violence, physical insecurity affecting populations, infrastructure and investments. Currently, there are 21 countries in conflict and 17 countries in a situation of institutional and social fragility, only Haiti and Venezuela are in Latin America (The World Bank 2025a).

In summary, the data reveal that, although coverage has expanded, the greatest challenges lie in service quality, serving vulnerable populations, mainly in least developed countries and those in armed conflict, and in the sustainability of solutions. The combination of grids, microgrids and off-grid systems, associated with public financing and social inclusion policies and knowledge about the end consumer – needs, demographic profiles, payment capacity and decision processes –, remains essential to ensure the achievement of SDG 7.

3.2 PUBLIC POLICIES IN SOUTH AMERICA AND THE PAN-AMAZON REGION

The analysis of public policies and initiatives for universalization of access to electric energy in South American countries reveals heterogeneous advances and varied institutional strategies, reflecting the socioterritorial contexts and state capacities of each country.

Based on the systematization of technical documents, case studies and specialized scientific literature, it was observed that Argentina, Brazil, Chile, Colombia, Peru and Venezuela possess structured programs for rural and remote electrification, with different levels of emphasis on renewable and decentralized solutions.

3.2.1 Project for Renewable Energy in Rural Markets (PERMER) – Argentina

Argentina has been operating with the *Proyecto de Energías Renovables en Mercados Rurales* (PERMER), aimed at expanding access through decentralized systems based on renewable sources.

In 1999, the country had already reached an electrification rate of 95%, but about 25% of the rural population remained without access. PERMER, established in 2000, financed by the World Bank and the *Global Environment Facility* (GEF), was structured to electrify 35,000 remote households, 1,750 public facilities (hospitals and schools) and 500 commercial enterprises, using *off-grid* concessions supervised by provincial regulatory agencies (Bazilian et al. 2012; PERMER 2015).

The model provided that technology choice was the responsibility of the concessionaire, while costs were divided: 30–40% from the concessionaire, 10% from the user and 50–60% in subsidies, paid in two phases, upon acquisition and installation. Regulatory agencies evaluated service quality, installations and user satisfaction (Bazilian et al. 2012).

One of the most advanced cases was that of *Empresa Jujeña de Sistemas Eléctricos Dispersos Sociedad Anónima* (EJSEDSA), concessionaire of Jujuy, which started in 1996 and, in five years, electrified 4,000 rural households with hybrid microgrids (micro-hydro, solar-photovoltaic, wind-diesel) and home solar systems (Bazilian et al., 2012).

PERMER was established in 2000 as a new component of the *Programa de Abastecimiento Eléctrico a la Población Rural de Argentina* (PAEPRA), launched in 1995. PAEPRA created a national and provincial fund to subsidize rural electrification projects, granting subsidies to private concessionaires selected by bidding, who assumed the commitment to supply electricity at the lowest possible cost, including through *off-grid* solutions, receiving the regional monopoly, with the obligation to attend new connections and maintain service continuity throughout the concession.

While PAEPRA prioritized rural electrification in general, PERMER concentrated on individual systems (*stand-alone*) for dispersed settlements and community facilities, distributed in two phases: (i) 2000–2012; and (ii) 2015–2020, as systematized in **Table 11** (IEA 2024c).

Consumers bore the installation costs and a fixed monthly tariff that covered about 40% of the initial investment over 15 years, in addition to maintenance expenses and batteries. Additional subsidies were allocated to the poorest families, gradually reduced during the term of the concession. The first phase of PERMER lasted six years, until 2007, with extension until 2012, and the second started in 2015, lasting five years, and consolidating itself as one of the main decentralized electrification programs in Latin America (IEA 2024c).

Table 11. Systematization of the two phases of PERMER.

Aspect	PERMER I (2000–2012)	PERMER II (2015–2020)
Objective	Bring electricity to dispersed rural communities without expectation of grid access in the short/medium term; improve quality of life and promote population fixation.	Expand PERMER I coverage, meeting new demands in dispersed rural areas.
Energy sources	Photovoltaic (residential and institutional), home wind, micro-hydro, hybrid plants (diesel/renewables), solar thermal (water, heating, cooking).	Residential photovoltaic, systems for schools, public services, water pumping, productive activities and microgrids.
Financing	US$ 30 million (IBRD) + US$ 9.5 million (GEF) + US$ 50 million additional (IBRD).	US$ 200 million (IBRD) + counterpart of US$ 40 million (US$ 11 million federal government, US$ 6 million provinces, US$ 23 million private sector).
Managing institutions	National Energy Secretariat (Coordinating Unit and Provincial Executing Units); public and private concessions.	Same as PERMER I, expanded with greater intergovernmental articulation and private participation.
Scope	Installation of PV systems (residential), systems in schools, hospitals, public buildings, national parks, water pumping, vaccine refrigeration etc.	Installation of 18,500 residential SHS, repowering in 700 schools, public services, microgrids and support for productive uses.
Beneficiaries	Thousands of rural households and hundreds of schools and hospitals in various provinces.	~118,000 people benefited in 12 provinces (Catamarca, Chaco, Entre Ríos, Jujuy, La Pampa, La Rioja, Neuquén, Rio Negro, Salta, San Juan, Santiago del Estero, Tucumán).
User and tariff	Costs defined per province: calculation of full tariff, definition of subsidy and amount paid by the user.	Same logic as PERMER I, with varying subsidies according to province.

Source: elaborated based on PERMER (2015).

3.2.2 Light for All Program (LPT) – Brazil

Brazil stands out for the Light for All Program (LPT), with national scope and robust financing mechanisms aimed at rural and remote electrification. In addition to incorporating education actions for rational energy use and energy efficiency, integrating low-income communities, Indigenous peoples, Quilombola communities, Riverine communities, rural settlements and populations in conservation areas (MME 2024).

Although the majority of initial beneficiaries were served by grid extension, the program started to include strategies based on Distributed Energy Resources (DER) for isolated regions, with low population density and environmentally sensitive (BRASIL 2020).

The first guidelines for renewable solutions appeared in 2009. Between 2011 and 2014, two alternatives stood out: the Individual Generation Systems with Intermittent Sources (SIGFI) and the Isolated Microsystems of Electric Energy Generation and Distribution (MIGDI). Both aimed to ensure lighting, refrigeration and communication in residential and community uses. The standards provided for minimum autonomy of 48 hours, interruption limit of up to 216h/month and availability of 45 kWh/month per consumer unit (Ferreira et al. 2023). MIGDI is recommended for demands greater than 900 kWh/month, limited to 100 kWp of installed capacity (Silva et al. 2024).

The institutional structure follows a multi-agent model. The Ministry of Mines and Energy (MME) coordinates the program and defines priorities. ANEEL regulates distribution activities, defines O&M tariffs, inspects performance reports and supervises commissioning protocols. ENBPar, a state-owned company resulting from the unbundling of Eletrobras during the privatization process, evaluates the technical-economic viability of projects. Execution is the responsibility of the Regional Distribution Concessionaire (RUC) – private companies and rural electrification cooperatives – responsible for demand collection, project execution and O&M, being able to outsource tasks to local companies (Ferreira et al. 2023).

Financing is mostly guaranteed by the Energy Development Account (CDE), which covers 90% of direct investment costs, with funds paid by consumers of the National Interconnected System (SIN). The counterpart includes participation of Regional Concessionaires and cooperatives (MME 2024).

Operation and maintenance costs are covered by tariffs paid by users, with discount from the Social Tariff for Electric Energy, since 2010, destined for low-income families, elderly, people with disabilities and Indigenous and Quilombola populations enrolled in the Single Registry. The tariff offers discounts of 100% for consumption up to 80 kWh/month for families with per capita monthly income of up to half a minimum wage (Rede Energia & Comunidades et al. 2025). **Table 12** systematizes the structure and characteristics of the LPT.

3.2.3 Rural and Social Electrification Program – Chile

Chile adopts a mixed strategy to universalize access to electric energy, prioritizing grid extension in interconnectable areas and the implementation of decentralized solutions in isolated rural communities. In the last three decades, national electricity coverage went from just over 50% of the rural population to 96.5%, reaching almost 100% in the total country (IEA et al. 2025). The current challenge lies less in grid expansion and more in service quality and inclusion of isolated communities, with plans to meet the residual deficit through individual photovoltaic systems (up to 10 kWp), hybrid renewable microgrids and community thermal and electrical energy solutions (IEA 2025f; Ministerio de Energía 2024)

The regulatory framework is led by the Ministry of Energy, in coordination with the ministries of Housing and Urbanism and the Environment, aligning energy policies with the reduction of energy poverty and the fulfillment of SDG 7. Governance is centralized in the Ministry of Energy, which defines guidelines, supervises programs and articulates intersectoral coordination, while execution is decentralized, with participation of

Table 12. Characteristics of the Light for All Program.

ASPECT	DESCRIPTION
Creation year	2003 (first guidelines for decentralized solutions in 2009; inclusion of SIGFI and MIGDI in 2011).
Objective	Universalize access to electric energy in rural and remote areas, focusing on traditional populations, remote communities, Indigenous peoples, Quilombola communities, Riverine communities, settlements and conservation areas.
Strategies	Extension of distribution networks; decentralized renewable energy systems (SIGFI – Individual Generation Systems with Intermittent Sources; MIGDI – Isolated Microsystems of Electric Energy Generation and Distribution).
Technical parameters	SIGFI: 80 kWh/month per UC, 48h autonomy, interruption limit of 216h/month. - MIGDI: up to 100 kW installed, recommended for demands > 900 kWh/month. - Priority use: lighting, refrigeration, communication and community services.
Institutional structure	-MME (Ministry of Mines and Energy): coordination and final decision. -ANEEL: regulation, tariff definition, inspection and audit. -ENBPar: technical viability to MME. -Regional concessionaires/cooperatives: execution, O&M and meeting local demands.
Financing	- Energy Development Account (CDE): covers 80–100% of direct investment costs. - 10% counterpart from concessionaires.
Tariffs and subsidies	2010 until August 2025, tiered discounts (65% for 0–30 kWh; 40% for 31–100 kWh; 10% for 101–220 kWh). For Indigenous and Quilombola peoples: full subsidy up to 50 kWh/month. After August 2025: 100% discount for monthly consumption up to 80 kWh and exemption from CDE payment for consumption up to 120 kWh for families with per capita income of up to half a minimum wage.
Target audience	Low-income rural families, Indigenous communities, Quilombola communities, Riverine communities, rural settlements, populations in conservation areas and in regions of difficult access.
Main results	3.5 million households connected to the grid and 65 thousand served by SIGFI and MIGDI in isolated areas, ensuring basic electricity access, social inclusion and support for productive activities for more than 17.5 million people.

Source: elaborated based on IEMA (2023) and MME (2023, 2024).

sectoral ministries, local governments, distribution concessionaires and social organizations (Ministerio de Energía 2021).

Complementarily, the government implements tariff protection mechanisms, such as the *Energy Emergency and Stabilisation Fund*, which freezes or limits adjustments in electricity prices for households and small businesses. The *Fondo de Acceso a la Energía* (FAE) institutionalizes citizen participation, allowing community entities to present projects and ensuring transparency, integration with social and territorial development policies. These mechanisms also encourage energy efficiency actions, substitution of firewood with cleaner sources, improvement of thermal insulation of homes and energy education programs (IEA 2022, 2024a).

Monitoring is conducted by the Ministry of Energy in partnership with regulatory bodies and external audits, monitoring indicators of coverage, reliability, energy efficiency and social impacts of solutions on energy poverty reduction, productive use of energy and improvement of habitability conditions. Plans and funds, such as FAE and the *Energy Emergency and Stabilisation Fund*, have periodic execution reports, ensuring transparency and socioeconomic responsibility (IEA 2024a; Ministerio de Energía 2024).

Financed projects include: (i) photovoltaic systems with or without batteries, up to 10 kWp, for communities and small establishments; (ii) thermal solar systems with accumulation capacity of up to 1,500 liters for residences and community centers; (iii) renewable microgrids for medium-sized communities; and (iv) residential energy efficiency programs, such as the *Programa con Buena Energía*, which distributes kits of domestic solutions and trains residents (Ministerio de Energía 2021, 2024).

Financing relies on multiple instruments: (i) the FAE, with public budget resources for community projects; (ii) housing subsidies for energy efficiency and solar thermal solutions; (iii) specific programs of the Ministry of Energy and the Environment, such as heating system replacement; and (iv) extraordinary mechanisms, such as the *Energy Emergency and Stabilisation Fund*, for tariff protection. In addition, the policy mobilizes international cooperation contributions and public-private partnerships to expand scale and financial sustainability of projects (IEA 2022, 2024a). **Table 13** systematizes the characteristics of the electric energy access programs of Chile.

3.2.4 National Rural Electrification Plan (PNER) – Colombia

Colombia adopts mixed strategies to expand access to electricity in rural and vulnerable areas, combining the extension of networks of the National Interconnected System (SIN) with autonomous systems and decentralized microgrids. In 2023, national electrical coverage reached 97.4%, but there were still 1.36 million people without access, concentrated in dispersed and vulnerable areas. The National Rural Electrification Plan (PNER) projects universalization by 2031, with intermediate milestones between 2023 and 2027, aligning with rural reform policies, the Peace Agreement and the achievement of SDG 7, with priority for municipalities and Indigenous and Afro-descendant communities (Minergia 2018, 2023).

The institutional arrangement is coordinated by the *Ministerio de Minas y Energía* (MEM). Expansion plans are prepared by Network Operators (OR), evaluated by the *Unidad de Planeación Minero Energética* (UPME) and submitted to the regulation of the *Comisión de Regulación de Energía y Gas* (CREG), with execution by regional concessionaires. The *Instituto de Planificación y Promoción de Soluciones Energéticas* (IPSE) operates in non-interconnected areas, while financing comes from sectoral funds, *Obras por Impuestos* (OXI) programs and international support (Minergia 2023, 2025a).

To achieve the objectives, three central public policy instruments were structured: FAER, FAZNI and FOES. The *Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas* (FAER), created by Law 788/2002 and regulated by Decree 1122/2008, finances the expansion and modernization of electrical infrastructure in interconnected rural areas (IEA 2024b; Minergia 2025a). The *Fondo de Apoyo Financiero para la Energización de las Zonas No Interconectadas* (FAZNI), instituted by Law 633/2000 and updated by Decree

Table 13. Characteristics of the electric energy access program of Chile.

Dimension	Description	Policies and Instruments
Universalization strategy	Mixed strategy: extension of networks in interconnectable areas and decentralized solutions in isolated communities.	Programs such as *Ruta de la Luz* and *Programa de Electrificación Rural y Social*; use of individual photovoltaic systems (up to 10 kWp), hybrid microgrids and community thermal and electric energy solutions.
Achieved results	Rural electrical coverage went from just over 50% to 96.5% in 30 years, reaching almost 100% in the country.	National coverage data (IEA, Ministerio de Energía).
Governance	Normative and guideline centralization in the Ministry of Energy; decentralized execution with sectoral ministries, local governments, concessionaires and social organizations.	Ministerio de Energía (central coordination); Ministries of Housing and Urbanism and the Environment (intersectoral coordination).
Protection and participation instruments	Mechanisms to reduce tariff vulnerability and institutionalize social participation.	*Energy Emergency and Stabilisation Fund* (tariff protection); *Fondo de Acceso a la Energía* (FAE) (community projects, citizen participation).
Complementary actions	Energy efficiency, substitution of firewood with clean sources, improvement of thermal insulation and energy education programs.	Programs of the Ministry of Energy and the Environment.
Monitoring and evaluation	Monitoring of indicators of coverage, reliability, energy efficiency and social impacts; periodic reports.	Ministry of Energy; regulatory bodies; external audits; reports from FAE and *Energy Emergency and Stabilisation Fund*.
Financed projects	Project typologies for communities, residences and establishments.	(i) Photovoltaic systems up to 10 kWp with or without batteries; (ii) Thermal solar systems up to 1,500 liters; (iii) Renewable microgrids; (iv) *Programa con Buena Energía* (domestic kits and training).
Financing	Multiple instruments: public budget, subsidies, emergency funds, international cooperation and PPPs.	(i) FAE; (ii) Housing subsidies (efficiency and thermal solar); (iii) Specific programs of the Ministry of Energy and Environment; (iv) *Energy Emergency and Stabilisation Fund*; (v) International cooperation and public-private partnerships.

1124/2008, supports the construction, replacement and rehabilitation of electrical infrastructure in areas not connected to the SIN, with resources from sectoral contributions, national budget and international cooperation (IEA 2025d; Minergia 2025b). Whereas the *Fondo de Energía Social* (FOES) ensures economic affordability through focused tariff subsidies, financially compensating operators who pass on discounts directly to the invoices of low-income consumers (IEA 2025g).

Combined, FAER, FAZNI and FOES structure the basis of the Colombian universalization policy – the PNER –, articulating expansion of interconnected networks, service to isolated zones and social subsidies, as systematized in **Table 14**.

The PNER strategy includes: (i) extension of SIN networks in areas of higher density and lower cost; (ii) renewable microgrids (solar, hydro, hybrid with storage) in isolated localities; (iii) individual photovoltaic systems of up to 0.5 kWp per household in dispersed areas, with a goal of benefiting 84,445 new users by 2031; and (iv) community and productive solutions integrated into households, agricultural uses and collective services (schools, health posts and community centers) (Minergia 2023).

The regulatory framework is defined by Decree 1623/2015, which establishes criteria for planning and expansion, prioritizing economic efficiency, cost reduction, productive uses and financial sustainability. Citizen participation occurs through simplified sociotechnical diagnoses in community assemblies (PDET, PNIS), allowing identification of demands and validation of solutions. Subsequent socialization ensures local understanding and appropriation (Minergia 2023).

Finally, monitoring and evaluation mechanisms contemplate indicators from 2018 to 2031, with specific matrices for municipalities. Monitoring is carried out by UPME and IPSE, ensuring articulation between funds and programs and strengthening the sustainability of implemented solutions (Minergia 2018, 2023). **Table 15** systematizes the general characteristics of the public policy for access to electric energy in Colombia.

Table 14. Systematization of the financial instruments of the public policy for access to electric energy of Colombia.

Fund	Full name	Objective	Financing sources	Target audience	Expected results
FAER	*Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas*	Finance expansion and modernization of electrical infrastructure in interconnected rural areas	Sectoral contributions, public resources and regulated tariffs (Law 788/2002)	Rural communities interconnected to the SIN	Expand coverage, ensure tariff efficiency and integrate territorial electrification plans
FAZNI	*Fondo de Apoyo Financiero para la Energización de las Zonas No Interconectadas*	Finance construction, replacement and rehabilitation of electrical infrastructure in non-interconnected areas	Sectoral contributions, national budget and international cooperation (Law 633/2000)	Communities in isolated zones and not interconnected to the SIN	Expand electrical coverage in isolated zones with financial sustainability
FOES	*Fondo de Energía Social*	Guarantee economic affordability of energy for rural areas and vulnerable populations	Financial compensations via invoices, passed on by energy operators	Low-income families, rural areas and vulnerable populations	Reduce access inequalities and ensure service continuity

Table 15. Characteristics of the electric energy access program of Colombia.

ASPECT	DESCRIPTION
Goal and current exclusion (2023)	– Serve 431 thousand people by 2031, with universalization of access to electricity. – 97.4% of the population with access; still 1.36 million people without electricity, concentrated in dispersed and vulnerable rural areas.
Regulatory framework	Decree 1623/2015 which establishes criteria for planning, economic efficiency, cost reduction, sustainability and prioritization of productive uses.
Governance	– Coordination: MEM *Ministerio de Minas y Energía*. – Planning, evaluation and monitoring: UPME *Unidad de Planeación Minero Energética*. – Tariff regulation and inspection: CREG *Comisión de Regulación de Energía y Gas*. – Execution in non-interconnected zones: IPSE *Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas* (execution in NIA). – Execution and local operation: Regional concessionaires.
Implementation strategy	Mixed model: (i) network extension of the National Interconnected System (SIN); (ii) renewable microgrids (solar, hydro, hybrid with storage) in isolated localities; (iii) individual photovoltaic systems (up to 0.5 kWp per household) for dispersed areas; (iv) integrated community and productive solutions (agriculture, health, education).
Financial instruments and financing	– Works for Taxes Programs (OXI). – Sectoral funds: (i) FAER for infrastructure expansion in interconnected areas; (ii) FAZNI for construction, replacement and rehabilitation in isolated, unconnected areas; and (iii) FOES to ensure economic affordability for vulnerable populations. – International resources: cooperation, IDB etc. – Estimate ~USD 380 million just via FAER (2024–2031).
Citizen participation	Simplified sociotechnical diagnoses in community assemblies, local validation of solutions and socialization of impacts.
Monitoring and evaluation	– National and specific indicators for municipalities. – Monitoring by UPME and IPSE, with periodic reports on coverage, installed capacity and sustainability of solutions.

3.2.5 Fund for Rural and Urban-Marginal Electrification (FERUM) – Ecuador

Ecuador structured the National Rural Electrification Plan (PNER) as a fundamental instrument for universalization of access to electric energy and national policies of productive and territorial development (IEA 2025c). The strategy adopts a mixed model, prioritizing network extension in interconnectable areas and applying decentralized systems in isolated zones, defined based on territorial diagnoses, demand studies and cost-effectiveness criteria (IEA 2025b) and use of integrated technological solutions of renewable sources, such as solar photovoltaic, micro-hydro, and hybrid diesel-renewable systems.

The regulatory framework is coordinated by the Ministry of Energy and Mines (MEM), which establishes criteria for economic efficiency, social and environmental sustainability, and prioritization of vulnerable territories. The plan projects to universalize access by 2030, with intermediate connection goals and coverage expansion. It is estimated that grid extension will meet most of the demand, while Non-Interconnected Areas (NIA) will be covered by individual solar systems of 0.5 to 1 kWp per household and community microgrids, benefiting tens of thousands of new users (MEM 2023a).

Implementation incorporates participatory processes, with community consultations, local workshops and use of simplified questionnaires to identify energy demands and productive uses. This process ensures that communities understand impacts and responsibilities in operation and maintenance. For monitoring, the PNER adopts indicators of coverage, installed capacity, reliability and financial

Table 16. Characteristics of the electric energy access program of Ecuador.

ASPECT	DESCRIPTION
Coverage Goal	Universalization of access by 2030; intermediate goal of 97% in 2014; coverage reached 96.77% in 2013.
Access strategies	Mixed model: grid extension in interconnectable areas; decentralized systems in isolated zones.
Project Modalities	– Extension of conventional networks; – Hybrid renewable microgrids (solar, hydro, diesel-renewable); – Individual solar photovoltaic systems (0.5–1 kWp/household).
Financing	*Fondo de Electrificación Rural y Urbano Marginal* (FERUM), sectoral contributions from distributors, public budget and international cooperation (mainly IDB).
Investments	1999–2006: USD 259 million; 2007–2014: USD 440 million; 2013: USD 34.72 million in 582 grid projects and 24 isolated projects.
Governances	*Ministry of Energy and Mines* (MEM) coordinates; regional distributors execute; ARCONEL regulates and supervises; IDB as financial partner.
Community Participation	Community consultations, participatory workshops and simplified questionnaires; communities act in basic operation and rational use of energy.

sustainability, with periodic reports from MEM and the regulator ARCONEL, in addition to technical and financial audits that allow goal adjustments.

Projects follow three main modalities: (i) extension of conventional grids for higher density localities, (ii) hybrid renewable microgrids in medium and isolated villages, and (iii) individual solar photovoltaic systems for dispersed households. Each modality is parameterized in terms of power, minimum reliability and basic services such as lighting, refrigeration, communication and productive uses (MEM 2015).

Financing is guaranteed by the *Fondo de Electrificación Rural y Urbano Marginal* (FERUM), fed by mandatory sectoral contributions from distributors, public budget resources and international cooperation, mainly from the Inter-American Development Bank (IDB). The model combines cross-subsidies, government contributions and limited user participation, ensuring economic affordability and sustainability. Between 1999 and 2006, FERUM invested USD 259 million and, in the period 2007–2014, the amount was expanded to USD 440 million. In 2013, electricity coverage reached 96.77%, and the goal for 2014 was 97.04 (MEM 2015). Currently, 582 electricity network projects and 24 unconventional isolated system projects remain in execution, totaling USD 34.72 million in investments (IDB 2025).

The central objective of FERUM is to expand and improve access to electric service in rural and marginal urban areas, reducing historical inequalities. Among its specific objectives are: (i) strengthen the institutional capacity of distributors for selection, execution and monitoring of projects and (ii) ensure the sustainability of solutions, especially in hard-to-reach zones. The institutional arrangement involves MEM as coordinator, regional distributors as executors and ARCONEL as regulator, with community participation in basic operation activities and rational use of energy (IDB 2025).

Complementarily, Ecuador develops energy planning and efficiency initiatives, such as the *Development of Energy Foresight and Planning*, aimed at the elaboration of national energy and energy efficiency plans, and the *Network for the Improvement of Electric Power Distribution Systems*, which aims to modernize and systematize sector information to improve electricity distribution quality (IEA 2025c). These initiatives reinforce the integrated character of the policy, articulating electrification, efficiency and long-term planning (MEM 2023a). **Table 16** systematizes the general characteristics of the public policy for access to electric energy in Ecuador.

3.2.6 National Rural Electrification Plan (PNER) – Peru

Peru develops grid extension strategy through the *Programa Nacional de Electrificación Rural* (PNER). PNER is the main Peruvian public policy for universalization of access to electric energy in dispersed and vulnerable rural areas and communities. Elaborated by the *Ministerio de Energía y Minas* (MEM), through the *Dirección General de Electrificación Rural* (DGER), the plan complies with the General Law of Rural Electrification (Law 28749) and its regulation (DS No. 018-2020-EM), in line with the national infrastructure policy and SDG 7 (IEA 2025e).

The PNER 2024–2033 establishes the goal of connecting 507 thousand households, reaching 96% coverage by 2026. The strategy is based on geospatial planning and adopts a hybrid model of solutions: (i) extension of conventional networks in larger communities and close to existing lines; (ii) renewable microgrids (solar, hydro and hybrid) in medium and isolated populated centers; and (iii) individual photovoltaic systems for dispersed households in difficult access zones (MEM 2023b).

The institutional model centralizes coordination in MEM/DGER, with execution by regional distributors and regulatory supervision of the *Organismo Supervisor de la Inversíon em Energía y Minería* (OSINERGMIN). Communities participate in basic operation and rational use of energy, while advanced maintenance is the responsibility of concessionaires.

Between 2013 and 2022, the previous plan allocated USD 1.28 billion to rural systems, USD 53 million to small hydroelectric plants, USD 294 million to photovoltaic modules and USD 42.5 million to wind power plants, establishing the use of renewables as a selection criterion with a weight of 10% (IEA 2025e).

Financing is articulated by the *Fondo de Inclusión Social Energético* (FISE), created in 2012 to combat energy poverty. By 2019, FISE benefited 2.9 million households with tariff subsidies, promoted vehicular conversion to LPG and natural gas and enabled the installation of 177,609 solar panels, mainly in residences, but also in schools and health posts, ensuring basic services in vulnerable communities. The program used digital vouchers, SMS and mobile banking, reducing administrative costs and accelerating implementation (IEA 2023).

With the new plan, PNER provides for the electrification of more than 500 thousand households by 2033, prioritizing schools, health posts and drinking water systems in regions of greater vulnerability. Thus, PNER consolidates itself as a central instrument to universalize electrical access in Peru, by combining geospatial planning, social subsidies, decentralized renewables and community participation, promoting social inclusion, reduction of regional inequalities and greater energy resilience in the rural territory (MEM 2023b).

3.2.7 Sowing Light Program (SL) – Venezuela

Venezuela implemented the national program *Sembrando Luz* – SL –, aimed at decentralized access to energy and drinking water, to serve more than 300 thousand people in isolated Indigenous and border communities. The central objective was to improve quality of life, strengthen productive activities. The target population comprised communities of up to 500 inhabitants, organized in community councils and located more than 10 km from transmission lines (MPPEE 2013).

The main strategy was based on decentralized renewable energy systems, adjusted to the availability of local resources and the profile of beneficiaries. In the 1st phase (2005), photovoltaic systems (PV) of 1,200 and 3,840 Wp were installed in schools, health centers and community services; the 2nd phase (2007) smaller systems (300 and 600 Wp) for residential demands, served residences, covering lighting, communication and refrigeration; whereas in the 3rd phase (2009), hybrid microgrids (solar, wind, diesel and batteries) were implemented, with supply of up to 2 kWh/day per household, 3.7 kWh/day for health and up to 7.7 kWh/day for schools (Leduchowicz-Municio et al. 2022).

The program was centralized in the Ministry of Popular Power for Electric Energy (MPPEE), responsible for financing, mostly from oil income. The initial photovoltaic technology was supplied by Cuba in exchange for oil, within the scope of the 2000 bilateral agreement. The Foundation for the Development of the Electric Service (FUNDELEC) coordinated the design, execution and realization of sociotechnical diagnoses to verify social and technical viability before approval (López-González, Ferrer-Martí, and Domenech 2019).

Management incorporated direct community participation. Community operators, designated by the Councils, were trained by FUNDELEC to operate and maintain microgrids, financed by local tariffs. Individual systems had basic maintenance performed by the users themselves, trained at implementation, while complex repairs remained under the responsibility of FUNDELEC. The program also included regional mobile workshops and continuous training on efficient and rational use of energy (López-González et al. 2019). **Table 17** systematizes the general characteristics of the public policy for access to electric energy in Venezuela.

3.3 RESULTS OF ANALYSES AND LESSONS LEARNED FROM REGIONAL PUBLIC POLICIES

Although universalization programs have provided expressive advances in the expansion of electricity coverage in rural and remote areas, universal access to energy still faces critical challenges, especially in regions with low Human Development Index (HDI), in conflict areas, in tropical forest zones and in territories occupied by Indigenous peoples, Quilombola communities, Riverine communities and other traditional populations.

Evaluations evidence recurrent limitations, such as low continuity of services, fragility in financial and operational sustainability of implemented systems, vulnerability of community management models and insufficiency of technological adaptation to socioterritorial contexts. In addition, some countries with presence of the Amazon biome, such as Ecuador, Bolivia and Suriname, still do not have consolidated public policies for systemic tackling of energy exclusion, which reinforces the need for robust regulatory frameworks, financing mechanisms

Table 17. Characteristics of the Venezuelan electric energy access program.

Phase / Year	Technology	Installed Capacity	Target Audience	Application
1st Phase (2005–2006)	Community Photovoltaic Systems (PV).	1,200 Wp and 3,840 Wp.	Schools, health centers, community houses, cafeterias, military posts, nature reserves.	Essential public services; community infrastructure.
2nd Phase (2007)	Residential PV.	300 Wp and 600 Wp.	Households (up to 500 inhabitants per community).	Lighting, communication, refrigeration.
3rd Phase Stage 1 (2009)	Hybrid Microgrids (wind + solar + diesel + batteries).	Up to 2 kWh/day/household; 3.7 kWh/day (health); 3.8–7.7 kWh/day (schools); Max. power 450 VA.	Isolated communities.	Serve multiple community and household uses.
3rd Phase Stage 2 (2012)	Autonomous wind systems.	1.5 kWp.	Residences.	Basic household supply (lighting, communication, refrigeration).

Source: elaborated by the author based on MPPEE (2013), Leduchowicz-Mucio et al. (2022) and López-González et al. (2019).

adjusted to local realities and participatory strategies that ensure community protagonism and respect for sociocultural diversity.

In general, results point out that universalization requires: (i) specific legislation for decentralized technologies, elaborated with social participation; (ii) valorization of local sources and strengthening of national markets of Distributed Energy Resources (DER); (iii) financial incentives that balance implementation and maintenance costs in low HDI contexts; (iv) participatory management models and community training; and (v) integration of energy policies with broader objectives of food security, productive inclusion, health and education.

Lessons derived from the analyzed programs offer relevant subsidies for future universalization processes in "*last-mile*" contexts, both in the Pan-Amazon region and in regions of Africa and Asia, strengthening the perspective of universal, perennial, just and quality access, as established by SDG 7.

In this sense, the analysis of different programs and public policy initiatives allowed identifying key dimensions that synthesize the main lessons learned. Results confirm that the last mile of universalization requires the integration of renewable DER, such as individual photovoltaic systems with battery storage, hybrid microgrids and community solutions. Experiences such as PERMER (Argentina), PNER (Colombia and Peru), FERUM (Ecuador) and LPT (Brazil) show that the combination of network extension, microgrids and off-grid systems ensures greater territorial coverage.

The use of integrated geospatial planning methodologies (IESP/ESMAP) allows composing least-cost portfolios that reconcile different technological solutions with schedules, quality goals and associated financing plans. Multi-tier indicators (MTF/ESMAP) demonstrate that simple connection does not guarantee energy sufficiency, reinforcing the need for minimum standards (Tier 3) for productive uses and food security.

Below, the main results of public policy evaluations are systematized in eight dimensions established by Municio et al. (2022) Udaeta et al (1997, 2012; 2015, 2016), complemented by **Table 18**, which consolidates the findings of the analyses within each dimension.

3.3.1 Dimensions of analysis and lessons learned

Decision strategies

Processes conducted by private companies prioritized profitability, while public decisions ensured greater equity. In PERMER, technology decision was the responsibility of the concessionaire, regulated by provinces, or the company that operationalizes the initiative, as in the case of ESMAP. Whereas in LPT (Brazil), PNER (Colombia) and SL (Venezuela), decisions centralized in ministries and regulators favored social criteria.

Public governance showed greater capacity to reduce inequalities, especially in low-density areas. International experience indicates that the adoption of PAYG models, with certified technical standards and technical assistance, can increase reliability and economic affordability, reducing inequality in the decision-making process, on the other hand, countries with programs designed specifically to subsidize the payment of the electricity tariff for low-income consumers proved effective in mitigating energy poverty.

Development of energy sovereignty

Models with strong private participation stimulated national renewable markets, as in Chile, with incentives for the solar and thermal industry. Public programs, such as LPT and SL (Venezuela), prioritized local sovereignty and, in the case of SL, community autonomy, albeit with less market dynamism. Both arrangements evidence trade-offs between industrial strengthening and consolidation of local capacities, demonstrating the importance of valuing local renewable resources and nationally developed technologies, strengthening internal markets and encouraging technology transfer in cooperation projects. This strategy balances industrial strengthening with the consolidation of community capacities.

Legal and institutional frameworks

Distributed and multi-agent executions, as in the Colombian PNER, with FAER, FAZNI and FOES, and in Chile, with FAE and tariff funds, fostered new policy instruments, while centralized models dependent on exclusive income, such as SL (Venezuela) dependent on oil export surplus, limited long-term sustainability, despite immediate social gains.

Clear regulatory frameworks, such as Decree 1623/2015 in Colombia and LPT technical parameters – defined in the operationalization manual –, ensured greater predictability. The standardization of technical protocols by context, with minimum power, autonomy and interruption limits, proved effective to facilitate acquisition, commissioning and maintenance.

Management models
Standardized technical protocols and participatory management models, accompanied by institutional support, reinforced community autonomy. SL (Venezuela) trained community operators for O&M, while PERMER operated with private concessions regulated by provincial agencies. LPT structured multi-agent management (MME, ANEEL, ENBPar and concessionaires).

These experiences demonstrate that hybrid management models – community with regulated technical support –, with government training and multi-agent arrangements that strengthen verifiable participation and operation indicators, increase reliability and local appropriation.

Economic structure and financing
Stable financing sources were decisive: CDE in Brazil, FERUM in Ecuador, FISE in Peru and the Energy Emergency and Stabilisation Fund in Chile ensured long-term financial sustainability, while programs based on financial resources from funds exclusive to oil income (SL – Venezuela) or unstable subsidies demonstrated greater vulnerability. Furthermore, tariff subsidy instruments (Social Tariff in Brazil, FOES in Colombia) guaranteed accessibility to low-income families.

The use of dedicated and stable funds, with clear rules for eligibility and disbursement by performance (CAPEX and O&M), is essential. Therefore, recommended financial structures include public budget, sectoral funds, international cooperation, *de-risking*[7] instruments and payment guarantee or exemption models of the electric energy tariff according to the income of beneficiary families.

Technological strategies
Standardization of technological models by sociospatial context increased efficiency and equity: Brazilian LPT defined minimum parameters (80 kWh/month per UC in SIGFI and up to 100 kWp in MIGDI); Peruvian PNER established minimum power in PV systems and prioritized renewable microgrids in medium villages; Venezuelan SL applied differentiated solutions by phase (individual PV, community PV, hybrid), but without national standardization, which hindered maintenance.

It became evident that it is fundamental to adopt reference specifications by territory, ensuring homogeneity in operation and performance. However, bottlenecks persist, such as low *off-grid* reliability, high cost of microgrids and data fragmentation, demanding georeferenced registries and independent audits.

Socioeconomic benefits
While LPT (Brazil) prioritized mainly household electric energy access, SL (Venezuela) and PERMER (Argentina) emphasized community infrastructure, such as schools, health units and water pumping systems.

Energy sufficiency proved essential to enable socioeconomic transformation, with multi-tier indicators (MTF/ESMAP) confirming that Tier 3 represents the minimum threshold necessary to ensure productive uses, food security and community services.

[7] *De-risking* instruments are financial and institutional mechanisms created to reduce perceived or real risks in investment projects, especially in sectors such as renewable energy, infrastructure and universalization of access to electricity, created with the aim of attracting private capital to contexts where risk is considered very high (for example, projects in remote regions, with low population density or regulatory uncertainties), covering borrower default, technical or execution failures and risks of expropriation, war, abrupt legal changes and mitigating legal and regulatory insecurity. Examples are: (i) World Bank/ESMAP with partial risk guarantees for off-grid solar projects in African countries; (ii) IDB with first-loss funds in microgrids in Latin America; and (iii) Brazil with CDE acting indirectly as de-risking by covering non-recoverable costs of universalization.

In addition, the integration of electrification with health, education, water and agriculture policies, allied with instruments aimed at productive uses with greater income impact, such as pumping, refrigeration and cold chain, expands the positive effects of access.

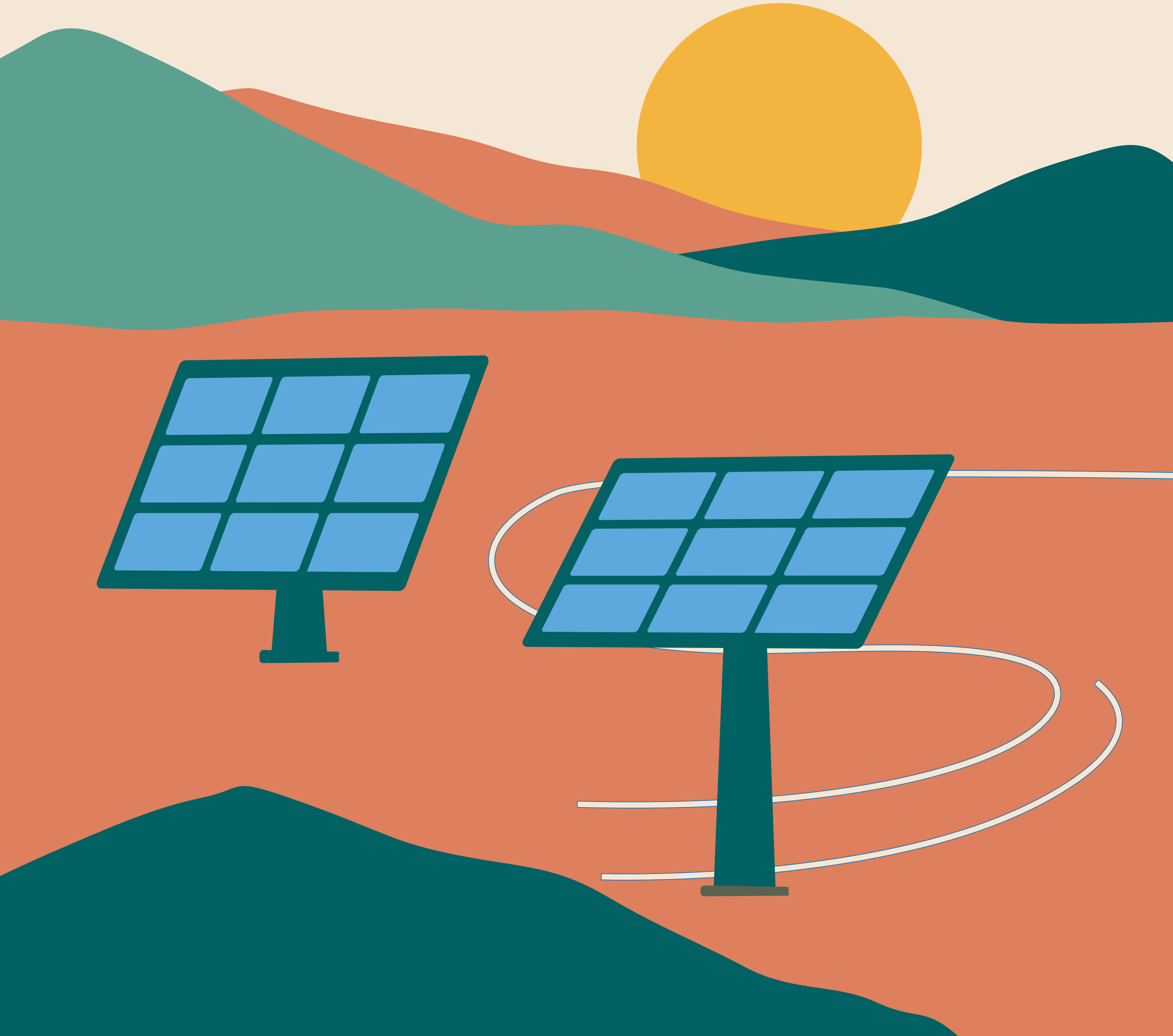
In this sense, energy efficiency and educational programs, such as the Programa con Buena Energía in Chile, reinforce that universalization of electricity must be articulated with sustainable territorial development.

Table 18. Systematization of the analyzed dimensions.

Dimension	Indicators	Governance	Financing	Technologies	Benefits
Rural coverage	REI, MTF (Tier 3 minimum); territorial coverage; % of UC served.	Ministerial coordination; decentralized execution (concessionaires, communities).	Sectoral funds, public budget, international cooperation.	PV systems, hybrid microgrids, community PV; grid + off-grid integration.	Expansion of electrical coverage in dispersed rural areas.
Decision strategies	Social criteria vs. profitability; inclusion of isolated populations.	Private processes (PERMER) vs. public (LPT, PNER).	Public decision guarantees social subsidies; private depends on PPPs.	Technological choice regulated by concessionaires (PERMER) vs. public standards (LPT).	Reduction of access inequalities; inclusion of vulnerable populations.
Energy sovereignty	Renewable market share; strengthening of local autonomy.	Chile: renewable market; LPT/SL: state; PNER: multi-agent funds.	National market (Chile); state funds (SL, LPT, PNER).	National DER; local technologies; incentive to industry.	Strengthening of local sovereignty and/or renewable market.
Legal and institutional frameworks	Existence of decrees and standards, parameters (SIGFI/MIGDI).	Multi-agent models (Colombia); centralized (SL); hybrid (Brazil).	FAER, FAZNI, FOES (Colombia); FERUM (Ecuador); CDE (Brazil).	Technical protocols (SIGFI/MIGDI); regulatory standards.	Greater long-term sustainability; regulatory predictability.
Management models	Technical protocols; community participation indicators; O&M performed locally.	Community management (SL), private concessions (PERMER), multi-agent (LPT).	Hybrid models: public subsidies + community support.	Community management with training; private concessions; decentralized public management.	Community autonomy; greater reliability and local appropriation.
Economic structure and financing	Stable sources (CDE, FAER, FERUM, FISE); tariff subsidies (FOES, Social Tariff).	Sectoral funds; regulatory agencies; external audits.	Stable sources: CDE, FERUM, FISE; O&M subsidies and social tariffs.	Individual PV systems, hybrid; integration with storage; collective solutions.	Continuity of actions; affordability for low-income families.
Technological strategies	Technological standardization; minimum power per UC; typology of systems (PV, microgrids, hybrid).	Central planning; local execution; national technical regulation.	Public Capex, international cooperation, PPP support.	Technological standardization by sociospatial context; minimum power requirements.	Territorial equity in service; efficiency in expansion.
Socioeconomic benefits	TIER indicators; access to health, education, productive uses; community infrastructure served.	Intersectoral integration: health, education, agriculture, water.	Social subsidies, intersectoral funds, international cooperation.	Home PV; solutions for schools, health and pumping; domestic energy efficiency.	Socioeconomic transformation; food security; guaranteed collective services.

4

SCIENTIFIC LITERATURE REVIEW



4.1 ACCESS TO ELECTRIC ENERGY: A BIBLIOMETRIC AND SYSTEMATIC REVIEW

For the literature review presented in this chapter, the Web of Science platform was used to collect references of works carried out around the theme of access to electric energy through pilot projects or case studies, geographically limited by the Pan-Amazon region.

The Web of Science platform (WOS 2020) gathers articles from scientific journals, books and work reports in a database with publications originating from various countries in distinct areas of knowledge. The tool provides identification of the most relevant indexed publications in an area of knowledge and current scientific trends.

The selection of keywords respected the mentioned criteria. **Table 19** presents the selection of the combination of keywords used in the search and the number of article records.

The processing of information from the selected records proceeded in order to identify duplicate records and those with missing information, such as title, abstract and DOI number. 103 duplicate records and 28 with missing information were identified. After filtering the selected values, 140 records remained.

The final phase of screening aimed to identify titles and abstracts of the articles that had adherence to the theme. The identification of adherence followed the classification

Table 19. Consolidation of keywords and records found.

Keywords	Results
energy access OR electricity access OR renewable energy AND off-grid OR stand-alone system OR remote energy system AND case stud* OR pilot project* AND Amazon	10
power system OR isolated system OR energy system AND remote communit* OR isolat* area OR isolat* communit* AND case stud* OR pilot project* OR field experiment* OR demonstration project OR real-world application OR implementation OR practical experienc* OR decentralized energy project AND Amazon	68
energy access OR electricity access OR renewable energy AND case stud* OR pilot project* OR field experiment* OR demonstration project OR real-world application OR implementation OR practical experienc* OR decentralized energy project AND remote communit* OR isolated area OR rural communit* OR isolat* communit* AND Amazon	37
solar energy OR biomass energy OR micro hydro OR renewable energy AND off-grid OR microgrid OR isolated system AND Case stud* OR pilot project AND Amazon OR Amazon region OR Amazon rainforest	16
solar energy OR biomass energy OR micro hydro OR renewable energy OR power system OR isolated system OR energy system AND off-grid OR microgrid OR isolated system AND case stud* OR pilot project* OR field experiment* OR demonstration project OR real-world application OR implementation OR practical experienc* OR decentralized energy project AND Amazon OR Amazon region OR Amazon rainforest	138
Energy access AND Community training AND Amazon	11
Total	**280**

scale that scores with 0 the records with little or no adherence, with 1 the records with medium adherence and with 2 the records totally adherent to the research theme. Thus, 95 records had little or no adherence, 28 had medium adherence and 25 records were classified as totally adherent. The analysis of the bibliography concentrated only on the records totally adherent to the research theme.

The systematic analysis of the selected literature allowed identifying the geographic distribution of publication, the temporal distribution, the distinction of approaches, the renewability and the energy sources used in the case studies, the number of energy sources used in the systems, the type of energy storage, the purpose of energy use and the main conclusions and contributions of scientific publications to access to electric energy in the Pan-Amazon region.

Regarding the geographic distribution of the proposed energy solutions, the majority was concentrated in Brazil. **Figure 17** shows the geographic distribution of the pilot projects determined in the scientific literature review.

Just over 54% of the publications were conducted and tested in the Brazilian portion of the Amazon. Of the 24 of the 25 publications selected that contained geographic information, 14 were conducted in Brazil. Peru and Ecuador had four publications identified, followed by Colombia, with three, and Bolivia, with only one publication in its territory.

Among 25 scientific publications, only 10 made available approximate geographic coordinates of the energy systems. The majority of the located energy systems are in Brazil: eight systems, distributed in the states of Pará (Brazilian state) (three), Amazonas (two), Tocantins (Brazilian state) (two) and Roraima (Brazilian state) (one). The other two systems are in Ecuador, in the departments of Zamora and Orellana. **Figure 18** reveals the temporal distribution of the number of selected records.

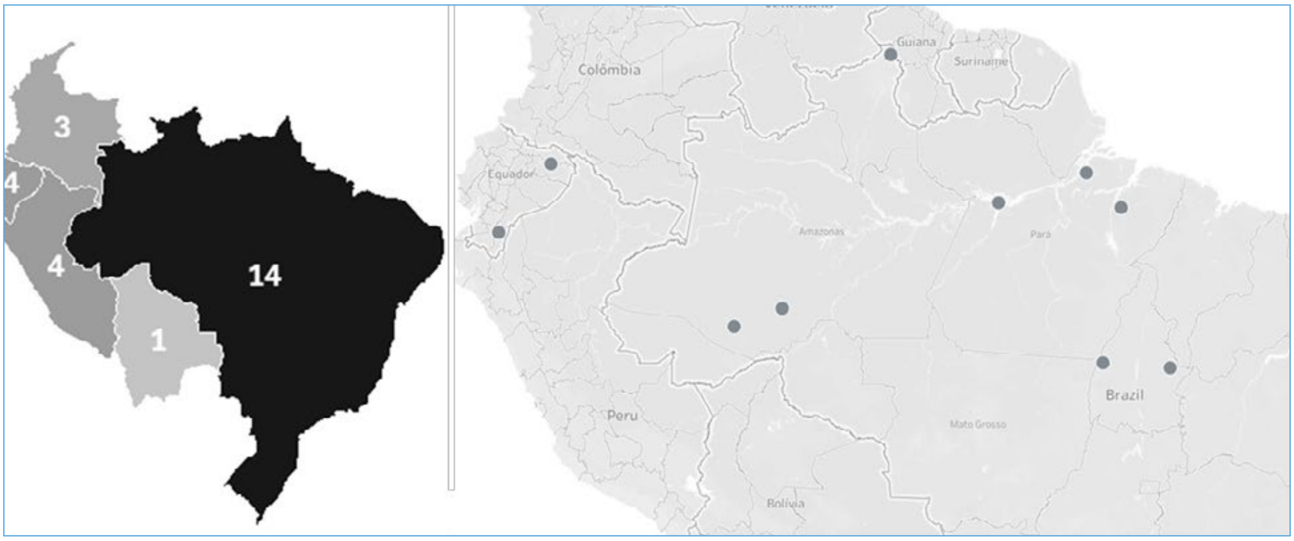


Figure 17. Geographic distribution of the pilot projects from the scientific literature review.

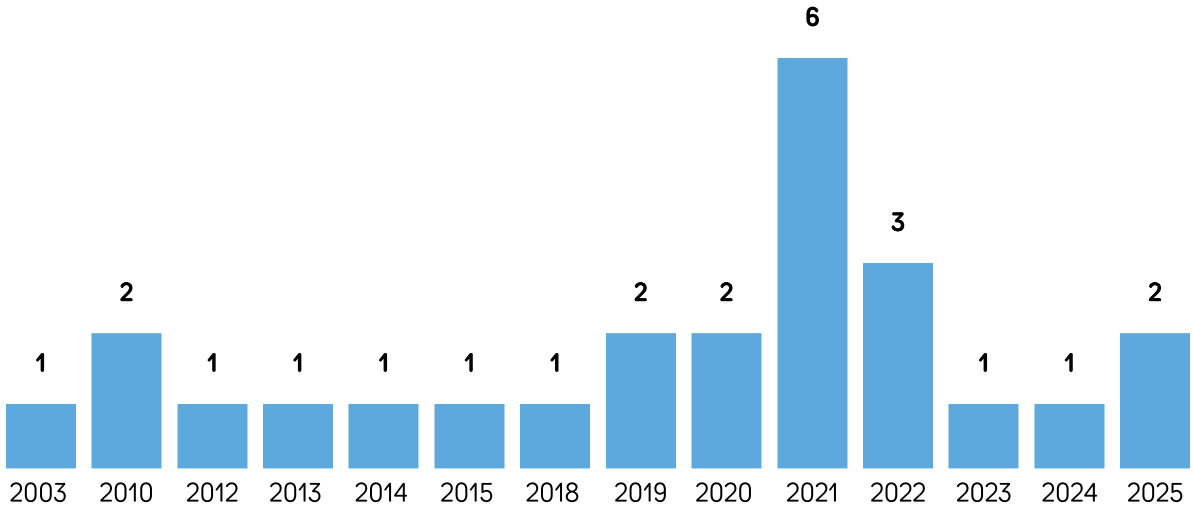


Figure 18. Number of records by year of publication.

The records have a temporal variation of 22 years, between 2003 and 2025. The highest occurrence of records is observed in the year 2021, with six records, followed by the following year, 2022, with three records. The years 2019, 2020 and 2025 counted with two records, as well as the year 2010. In the last 5 years there were more publications adherent to the research theme than in the rest of the temporal records, indicating a growing trend towards the study of pilot projects or case studies with renewable energy in the Amazon. **Figure 19** reveals the occurrence of the different approaches identified in the selected records.

Scientific publications present a technocratic tendency in the evaluation of pilot projects or case studies involving energy solutions for access to electric energy in the Pan-Amazon region. The solely technical approach, that is, which focuses strictly on the technical functioning aspects of the systems employed, was the most identified approach among the records, appearing seven times. Next, technical approaches combined with economic ones, with five occurrences, and technical, economic, environmental and social (Brandão et al. 2021; Duarte et al. 2010; Espinoza, Jara-Alvear, and Flores 2018; Fonseca et al. 2021), as well as technical and social (Del-Río-Carazo et al. 2021; Lembi

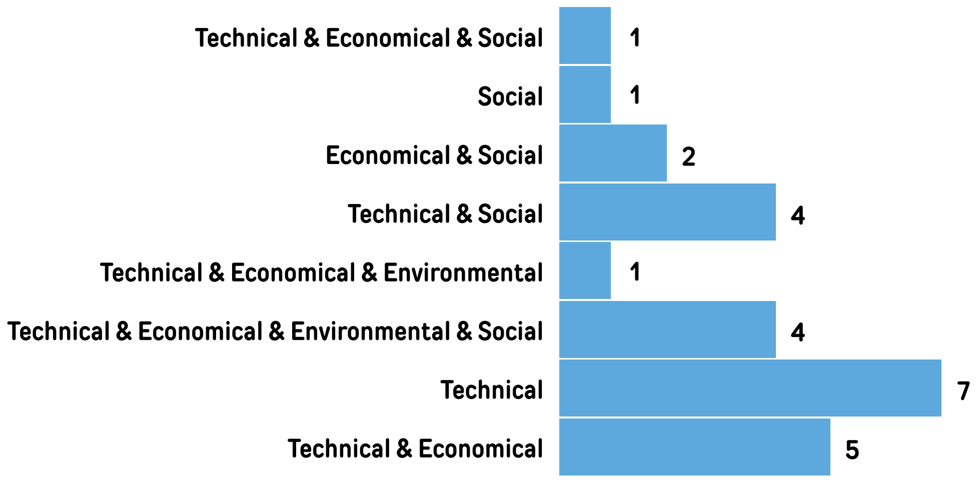


Figure 19. Approach of analysis of the selected records.

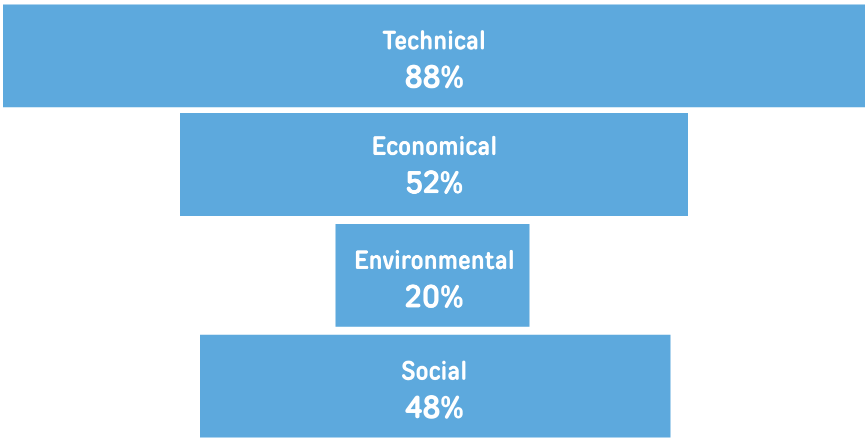


Figure 20. Consolidation of the proportion of approach of the selected records.

et al. 2025; Lillo, Ferrer-Martí, and Juanpera 2021; Mazzone 2020), both with four occurrences, close the list of the three combinations that most occurred among the selected articles. Besides the technical approach, It was possible to Identify only one record with solely social focus among all evaluated approaches (Lillo et al. 2015). **Figure 20** presents the proportion of occurrences of the approaches.

The predominance of the technical approach, identified in 88% of the times, can be explained by the almost omnipresence in the records. Only three publications did not have a focus on evaluating the technical functioning of the systems (Lillo et al. 2015; Mazzone 2019; Valer et al. 2014). The economic and social approaches presented themselves similarly, with 52% and 48%, respectively. The environmental approach occurred in only 20% of the records, although all publications dealt with energy systems utilizing renewable sources of energy. **Figure 21** reveals the proportion of utilization of energy sources used in the energy systems.

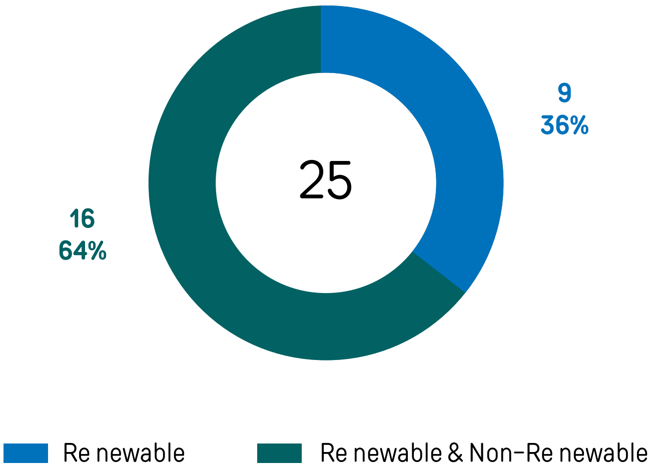


Figure 21. Distribution of types of sources, renewable and fossil, used in the pilot projects.

All energy systems described in the publications took advantage of the use of renewable energy sources. However, more than 60% of the pilot projects or case studies used diesel as fossil fuel, either complementarily or as security in case of system failures. **Figure 22** details the occurrence of diesel and other technological options in the observed publications.

Diesel was used in 11 of the 25 energy solutions evaluated, being the third most frequent source. The solar photovoltaic source, in turn, was present in 20 of the 25 publications, indicating that access to decentralized electric energy in the Pan-Amazon region can be facilitated by the utilization of the solar source of energy, due to the isolation that the biome imposes on certain communities and the aptitude for harnessing solar resources in the Amazon region.

In conformity with solar harnessing is the use of energy storage technologies, which proved to be fundamental in autonomous systems for 20 solutions of the 25 investigated energy solutions. In smaller proportion are the use of hydroelectric / Hydro source (Clairand et al. 2022; Guignard et al. 2022; Lembi et al. 2025; Lillo et al. 2015; da Luz, Vila, and Ferreira 2023), biomass (Brandão et al. 2021; Duarte et al. 2010; Fonseca et al. 2021; Pinheiro et al. 2012), wind (energy) (Clairand et al. 2022; Lillo et al. 2015; da Luz et al. 2023), hydrogen (Fonseca et al. 2021; Rezk et al. 2020; Silva, Severino, and de Oliveira 2013) and biofuel (Rodrigues et al. 2021), varying between one and five occurrences.

In addition to energy sources and their utilization technologies, it was possible to identify the energy storage technology employed in the energy systems. **Figure 23** reveals the distribution of energy storage technologies.

The use of lead-acid batteries was more frequent among the identified technologies. Eight energy systems opted to use lead-acid to store energy in publications from the year 2003 to the year 2025, while it was not possible to identify the technology on seven occasions.

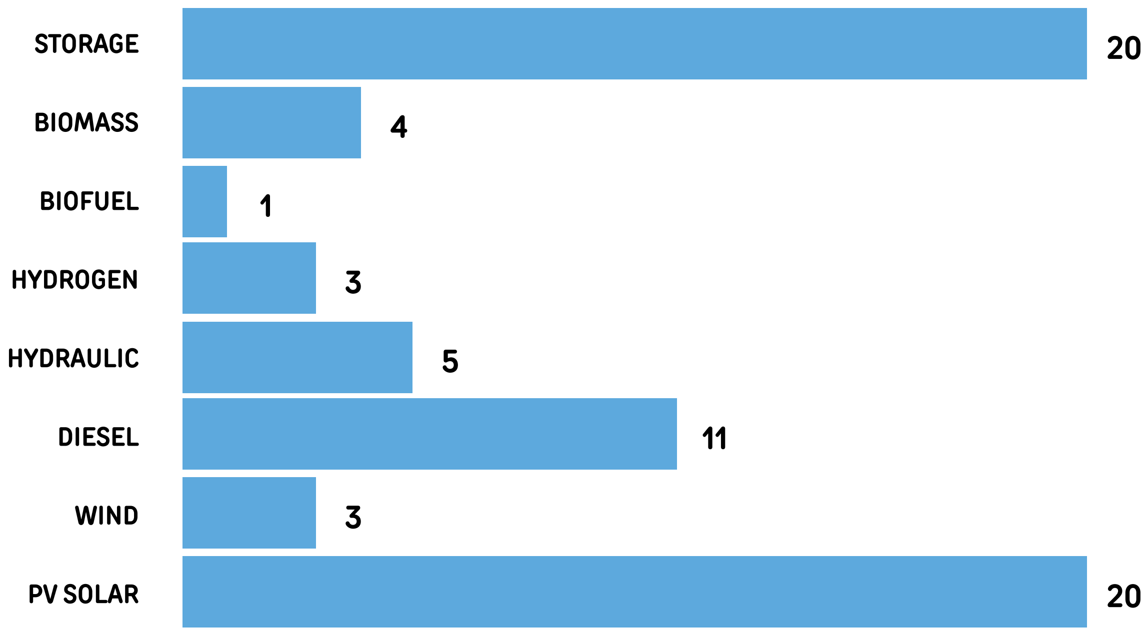


Figure 22. Occurrences by type of technology solution in the selected pilot projects.

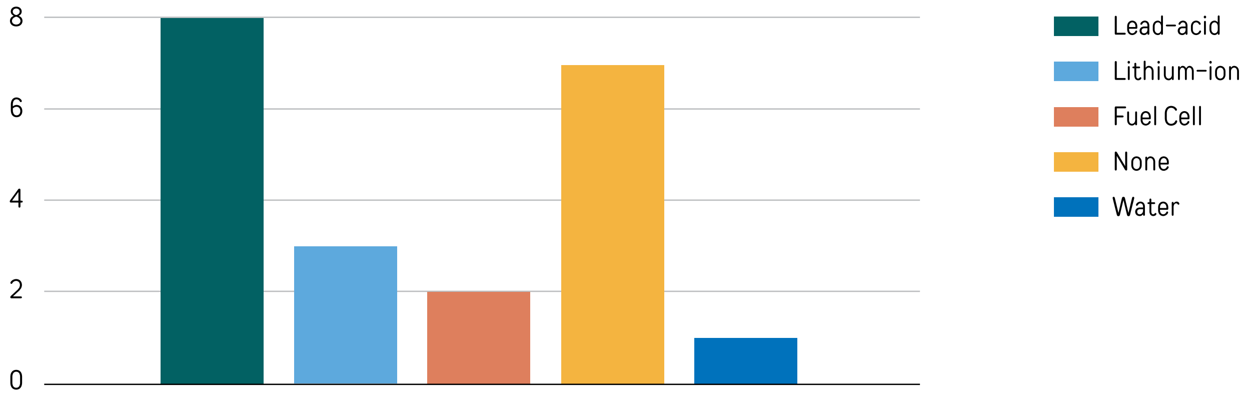


Figure 23. Occurrences of types of storage technology in the pilot projects.

Lithium-ion batteries were identified on three occasions in works published from 2022 onwards (Domenech et al. 2022; da Luz et al. 2023; Rodriguez, Arcos-Aviles, and Guinjoan 2024). Storage using *fuel cells*, which is electrochemical conversion used in projects for hydrogen energy utilization, occurred in two publications (Fonseca et al. 2021; Rezk et al. 2020).

Finally, a publication explored the use of water storage in a reservoir in order to use it to move a turbine and, thus, generate electricity when the photovoltaic system is not able to convert solar energy into electricity (Guignard et al. 2022).

The combination of different technologies for utilization of energy sources was observed in the evaluated energy systems, as detailed in **Figure 24**.

The combination of sources and technologies for energy utilization proved common among scientific publications. Only two records evaluated energy systems with only one source: biomass (Rodrigues et al. 2021) and biofuel (Pinheiro et al. 2012).

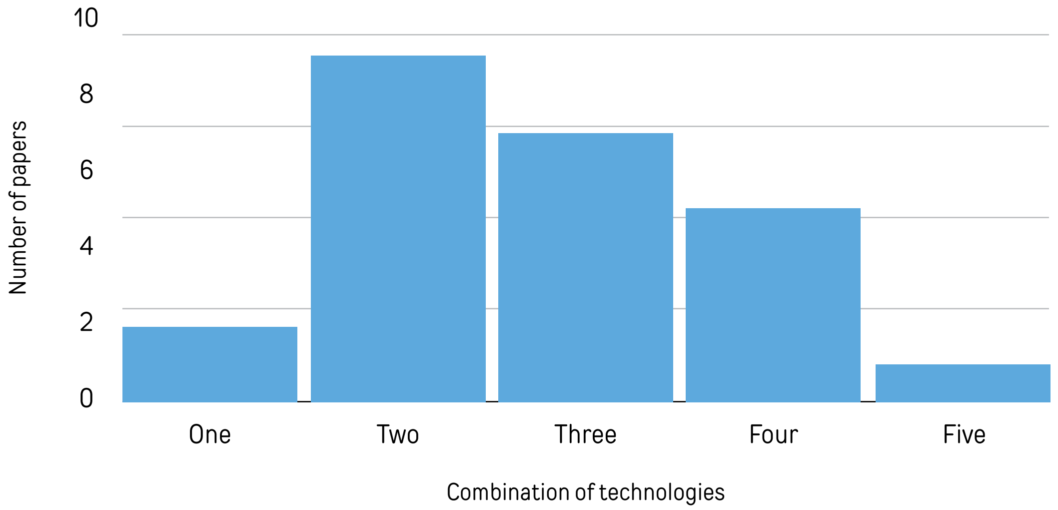


Figure 24. Occurrence of technological combinations in the pilot projects.

The combination of two technologies was observed in the majority of publications, with nine occurrences, closely followed by the combination of three, with seven occurrences, and four, with five occurrences. The combination of five technologies in an energy system happened once, which considered an energy system that utilized solar, hydroelectric / Hydro, wind (energy), diesel energy and used a storage system with lithium-ion batteries (da Luz et al. 2023). Furthermore, the combination of energy utilization requires designing a distribution system for the generated electricity. **Figure 25** presents the occurrence of electric typologies found in the analyzed records.

Most pilot projects or case studies of access to electric energy conducted in the Pan-Amazon region used a distribution system in microgrids. 67% of the publications developed systems that used microgrids for load utilization.

Only 29%, or 7 publications, had autonomous off-grid systems, that is, systems that generate electricity to satisfy the consumer unit directly. There was only one publication that compared impacts of access to electricity through *off-grid* and *on-grid* systems, which explains the presence of the *on-grid* record in the accounting of bibliometric results (Valer et al. 2014). A large part of the energy systems were designed to provide electrification to the communities or residences where they were inserted, as demonstrated in **Figure 26**.

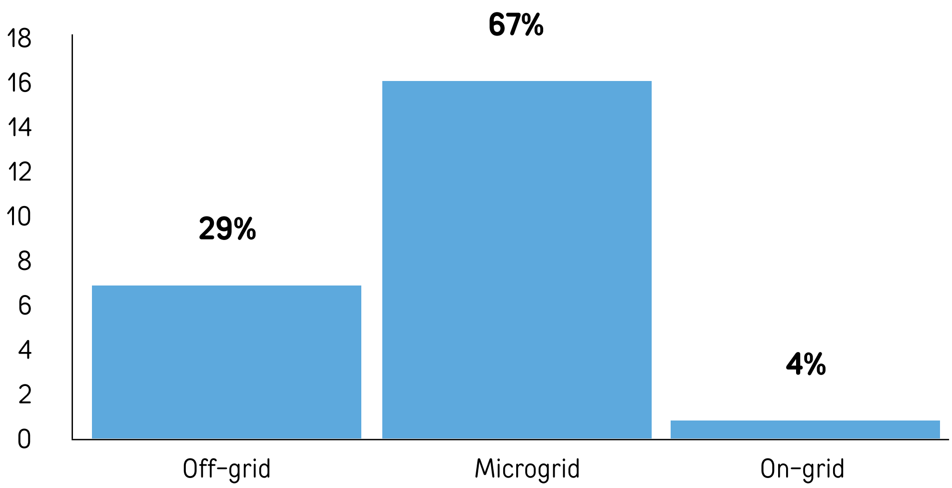


Figure 25. Occurrences of types of topologies of the service solutions of the pilot projects.

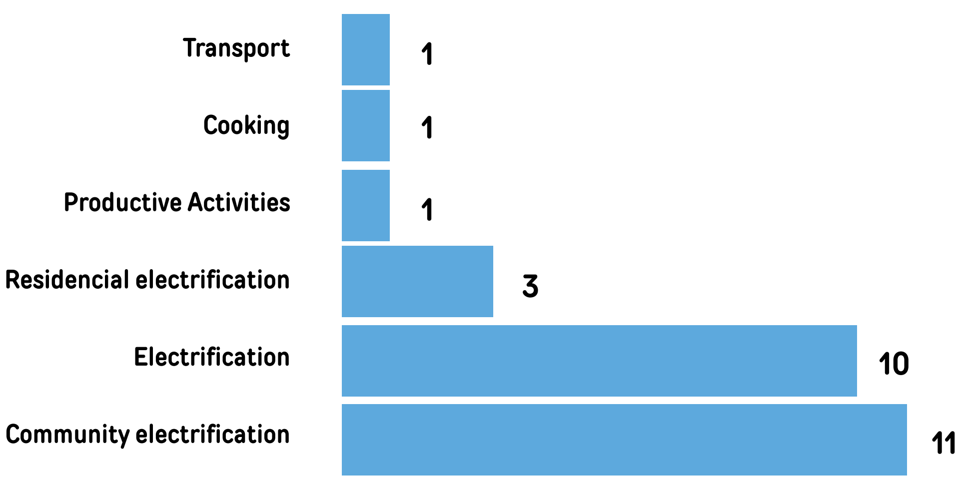


Figure 26. Types of consumer units served by the pilot projects.

The most identified purpose of the systems was community electrification and electrification in general (without specifying the consumer unit). 11 publications had community electrification as the main purpose of the energy system, which was followed by electrification in general sense and use, with 10 occurrences, and by residential electrification, with only three records. It was observed that the energy systems also served purposes of transportation, cooking and productive activities. On two occasions the energy systems served more than one purpose, which explains why the sum of purpose occurrences is greater than the number of selected publications.

4.2 ACCESS TO ELECTRIC ENERGY: RESULTS OF THE BIBLIOMETRIC AND SYSTEMATIC REVIEW

The systematic literature review showed that 88%, or 22 of 25 publications adherent to the theme of this study had a focus on revealing the technical functioning of the proposed energy solutions. And seven of them had this as the sole objective. The massive presence of the technical approach in scientific publications about pilot projects or case studies regarding access to electric energy in the Pan-Amazon region may portray a tendency towards a utilitarian view of the situation of energy vulnerability of the communities.

Lillo et al. (2015), who evaluated management models of off-grid systems implemented in isolated communities in Peru, had already warned about the limitations of the impact of energy solutions on the lives of community members when purely technocratic projects were developed outside the community context without considering the demands, needs, culture, barriers and customs of the communities. In addition, the author warned about the lack of community involvement in the crucial phases of project development. For Pena et al (2025), not involving those who receive the energy solution prevents technology and knowledge transfer to both actors in this relationship, in addition to compromising the sustainability of the initiative.

The observation of limited knowledge and technology transfer can be perceived by counting the projects that involved the community in the implementation of solutions in order to provide community training and capacity building. Of the 25 selected projects, only seven included or cited community involvement in a way to allow technology and knowledge transfer. Of the seven, only one publication reported the number of community members involved in technology and knowledge transfer and made the gender distinction of those involved. Of the six remaining publications, one took advantage of community labor without promoting training or capacity building, while the other five publications reported training or capacity building without counting those involved.

Lembi et al (2025)[8] designed *off-grid* energy solutions of solar and hydraulic utilization in the Brazilian Amazon with co-participation of the served communities. About 70 community members were involved in all phases of project implementation, among which three were women. According to the author, community participation in the integral development of the initiative is a necessary action to make the community self-sufficient in relation to the energy solution and ensure project sustainability. The author also reports that the planning of the hydraulic energy harnessing technology occurred at river points indicated by the community based on traditional knowledge. Despite the challenges of managing the community engagement process, it was possible to stimulate technology and knowledge transfer to achieve gains on both sides of the process.

It is noteworthy that of the seven publications that reported some degree of community involvement, five were exclusively renewable, none had a strictly technical approach and three proposed energy distribution with microgrids.

Obviously, the restricted number of adherent projects found and the combined filters do not allow making any conclusion. However, it is known that technology and knowledge transfer confers a notion of ownership of the systems to those who receive them (Fressoli et al. 2013), and that community systems further increase the notion of technological appropriation. Now, if trainings and community involvement are more frequent in community systems, the diffusion of community choice seems

[8] The authors of this scientific publication are from *Michigan State University* (MSU) and report the same pilot project present in the assessment of energy solutions developed by organizations with Mott Foundation support. Therefore, in the present study, this project appears both in the scientific literature review and in the quantitative and qualitative assessment of pilot projects incentivized by Mott Foundation.

coherent, since community systems increase the degree of reliability and involvement of the community in system management.

A large part of the publications revealed the use of microgrids for the distribution of energy generated in the community by the case study energy solutions. About 67% of the publications reported the adoption of microgrids. The reasons for this may contain a tendency to optimize this distribution, since the generation of electric energy is centralized at one point in the community and its distribution is facilitated through simple infrastructure. Half of the publications that mentioned the distribution system in microgrids had community electrification as their purpose. This reinforces the hypothesis for the preference for the use of microgrids in remote systems.

Rodriguez et al. (2024) proposed an energy management model to optimize the management of microgrids in isolated communities in the Ecuadorian Amazon. Results showed an annual reduction of 2.4% of wasted energy and 1.5% of fossil energy consumption. For the author, interconnected distribution systems in isolated communities have improved functioning compared to isolated ones, and, furthermore, interconnected microgrids are better than separate microgrids.

Of the 16 studies that included the use of microgrids for energy solutions in isolated localities in the Amazon, 12 combine three or more generation and energy storage technologies, only three publications study the combination of two technologies and none cite a single technological option. This reinforces the characteristic of expanding technological uses to harness the potential of energy sources in isolated localities in the Amazon.

The benefits of using microgrids in isolated systems in the Amazon are highlighted by Da Luz et al. (2023) when considering the possibility of combining multiple electric energy generation technologies to provide system reliability and efficiency compared to individual systems. The study tested the combination of five energy harnessing technologies for electricity generation, concluding that the use of a hybrid system with diesel generator, photovoltaic system and battery is the best configuration when water resources cannot be harnessed. For the author who conducted a study on different approaches to microgrid design in the Amazon, these simplified energy distribution systems in isolated localities are adherent to the challenges of rural electrification.

Pena et al (2025) designed a photovoltaic system to meet productive demands of açaí processing in Riverine communities of the Brazilian Amazon. The system was able to deal with daily variations in demand from activities in the açaí chain and other economic activities, in addition to meeting domestic electric energy demands. Furthermore, the use of microgrids may allow increasing system capacity if there is variation and potential increase in electric energy demand in the future, with economic activities being included in some cases for socioeconomic development of communities, provided that systems are designed considering consumer needs (Mazzone 2020).

Regarding future demand growth, Mazzone (2019) warns that demographic growth, migration and increase in income-generating activities may cause pressure on energy systems and that demand increase may be better adapted in communities that still maintain the use of fossil fuel, although the author highlights the gains of harnessing renewable energy for electricity generation.

As previously pointed out, system sustainability is achieved with greater community participation in all stages of energy solution implementation. In addition, the increase in income-generating activity can be boosted by access to electric energy. However, for Duarte et al. (2010), who evaluated scenarios of adding different amounts of vegetable oils to the fuel used to generate electric energy in a community in the Brazilian Amazon, it is necessary, more than engaging, to create occupation modalities in the community. The author's proposal was to stimulate the use of palm oil as primary energy to reduce diesel consumption in electric energy generation, an activity that required cultivation and created jobs for the community. For the author, access to electric energy only effectively boosts community economic development when the energy source depends on community labor.

However, it is necessary to reflect on this stimulus, since the primary source of energy to be used by the systems will depend on the availability of resources in each region. The use of palm oil, for example, did not replace the use and dependence on diesel in the community evaluated by Duarte, et al. On the other hand, fossil fuel substitution was observed only when projecting the implementation of energy storage technologies, as was the case of the study published by Viteri et al. (2019), which showed that the best technological combination scenario for energy harnessing was the use of photovoltaic systems with energy storage in communities in the Colombian Amazon, thus completely avoiding the use of fossil fuel.

The main environmental, social and economic impacts found in the literature review are listed in **Table 20**.

Most of the social impacts are related to access to electric energy, which, obviously, is present in all publications. However, technology and knowledge transfer and increased use of appliances (Lembi et al, 2025), creation of jobs, permanent and temporary (Brandão et al. 2021), community lighting and extension of school operating hours (Valer et al. 2014), increased employability with agriculture and productive processes in the community (Duarte et al 2010), electricity consumption above international minimum standards (Mazzone 2020), increased time for educational activities (Del-Río-Carazo et al. 2021) and improvement in the community's quality of life (Lillo et al. 2015) were also observed.

Regarding the main economic and environmental impacts observed, the reduction of diesel and other fossil fuel consumption was the main reason for estimating them, and stood out in the majority of publications. Brandão et al (2021), who projected the use of biomass as an energy source for a future isolated system plant in the Brazilian Amazon, estimated an annual reduction of more than 200 thousand dollars compared to the fossil fuel utilization scenario, which, consequently, would avoid water consumption and emission of 131 kg CO_2 and particulate matter. Fonseca et al (2021) detailed a case study of an energy solution with different renewable sources estimated reduction of water consumption and sequestration of 854 tons of CO_2 per year, in addition to the reduction of fossil fuel consumption.

Another publication that estimated economic gain quantitatively was carried out by Del-Rio-Carazo et al (2021), with savings of more than 50 thousand euros per year due to an electrification initiative of 51 communities in Peru. Pena et al (2025), in turn, reported gains in yield improvement and açaí processing with the arrival of electricity for productive purposes in the community.

Finally, it is worth highlighting what was not possible to observe in the literature review. Gender differentiation in the perceived impact of energy solutions was not observed. Only one publication accounted for such differentiation. In addition, little was reported about financing sources and economic sustainability of pilot projects, having only considerations about the impact of community involvement and beneficiary training on project sustainability. Operation and maintenance was addressed only in project cost simulations, not being deepened, with the exception of publications that reported capacity building and training, the form of system operation. The inclusion of these topics in scientific article investigations would attenuate the technocratic perception of scientific works published in international journals.

Table 20. Systematization of the environmental, social and economic impacts of the literature review.

Reference	Country	Sources & technologies	Positive impact		
			Economic	Environmental	Social
Lembi et al. (2025)	Brazil	Solar, diesel, hydraulic, Storage	–	Reduced fossil fuel consumption	Acesso à energia, transferência de tecnologia, transferência de conhecimento, uso de eletrodomésticos
Brandao et al. (2021)	Brazil	Diesel, biomass	Annual operating cost savings of $261,663	131.56 kg CO_2 avoided, particulate emissions reduced, and 43,500 L/year diesel saved	8 permanent and 22 temporary jobs created
Valer et al. (2014)	Brazil	Solar, storage	Lower lighting expenses, more productive hours (e.g., night fishing), improved productive activities	Reduced diesel consumption	Access to appliances, lighting, and evening education
Duarte et al. (2010)	Brazil	Diesel, biomass	Savings from reduced diesel use	Reduced fossil-fuel use and CO_2 emissions	Employment increased for 6.5 % of the community in agriculture and production
da Luz et al. (2023)	Brazil	Solar, wind, Diesel, hydraulic, Storage	Savings from reduced diesel use	Reduced fossil-fuel use and CO_2 emissions	Access to electricity
Mazzone, A. (2019)	Brazil	Solar, diesel, storage	Reduced monthly expenses	–	Energy sufficient to meet the IEA minimum annual consumption
Pena et al. (2025)	Brazil	Solar, storage	Improved açaí processing chain	–	Knowledge gains from involvement in system construction
Fonseca et al. (2021)	Colombia	Solar, H2, biomass, storage	Annual cost reduction	854 kg CO_2/year sequestered, decreased CO_2 and water use	–
Del-Río-Carazo et al. (2021)	Peru	Solar, storage	Annual savings of €53,365	–	Electricity access, increased study time, and training-based knowledge transfer
Lillo et al. (2015)	Peru	Solar, wind, hydraulic, storage	–	–	Enhanced community living standards

5

QUANTITATIVE AND QUALITATIVE ASSESSMENT OF PILOT PROJECTS IMPLEMENTED IN THE PAN-AMAZON REGION

The pilot projects assessed in this chapter correspond exclusively to initiatives funded by the **Charles Stewart Mott Foundation** between 2016 and 2025, within the scope of its efforts to expand access to electricity in remote Amazonian territories. This analytical focus was adopted to enable learning from philanthropy-funded pilot projects, while acknowledging that it does not encompass the full universe of philanthropic initiatives in the sector. The projects analyzed constitute a consistent empirical base, comprising hundreds of interventions implemented across different Pan-Amazonian countries and encompassing a wide diversity of socio-territorial contexts, technological arrangements, governance models, and scales of service provision. The selection of these projects is grounded in the availability of systematized data and longitudinal monitoring, allowing for an integrated assessment of technical, economic, social, environmental, and institutional impacts. Accordingly, the quantitative and qualitative evaluation presented seeks to extract lessons learned, identify recurring patterns, and inform recommendations aimed at improving, scaling up, and replicating sustainable electrification public policies for traditional and isolated Amazonian communities.

5.1 CHARACTERIZATION OF PILOT PROJECTS

The analyzed projects were implemented in six countries of the Pan-Amazon region, covering 223 communities and approximately 90 households. Seven organizations supported by philanthropic resources of the Mott Foundation were identified – Health and Joy Project (PSA), Kara Solar, WWF, Socio-Environmental Institute, *Michigan State University* (MSU), *Derecho, Ambiente y Recursos Naturales* (DAR) and *Amazon Conservation Team* (ACT) – which acted with different governance arrangements, scales of intervention and objectives.

Most initiatives used solar photovoltaic energy as the main source, in some cases combined with battery storage systems. Specific projects introduced differentiated technological solutions, such as the use of hydrokinetic turbines in river transport and small-scale wind generation experiences.

The purpose of the interventions varied between basic household service, electrification of community infrastructure (schools, health posts and community centers) and support for productive activities (refrigeration, water pumping and agro-extractive processing). This diversity reflects both the socioterritorial heterogeneity of the beneficiary communities and the search for solutions adjusted to the environmental and cultural specificities of the Amazon region.

5.1.1 Previous data of pilot projects

Previous information made available by partner organizations was essential to guide the elaboration of the questionnaires. The data came in diverse formats (spreadsheets, PDF tables and emails) and covered interventions by the Health and Joy Project (PSA), Kara Solar, *Michigan State University* (MSU), *Derecho, Ambiente y Recursos Naturales* (DAR) *and World Wildlife Fund* (WWF). Although only PSA is Brazilian, organizations like WWF and Kara Solar operated in multiple Amazonian countries.

The projects mostly used photovoltaic systems, implemented in Indigenous communities, Riverine communities and Extractive reserves, with diverse purposes, including household electrification, community infrastructure and productive activities. The diversity of territories, nationalities and objectives reinforced the need for standardized and comparable collection instruments, capable of capturing the complexity of Amazonian contexts.

5.2 METHODOLOGY OF QUANTITATIVE AND QUALITATIVE ASSESSMENT OF PILOT PROJECTS

5.2.1 Survey, systematization and structuring of indicators

The formulation of the evaluation methodology was based on internal metrics of the Mott Foundation, built from previous data of pilot projects, and on indicators from scientific and technical literature.

References from national and international studies on environmental, economic and social impacts of access to electric energy were used, highlighting Barreto et al. (2020), IFAD (2020), Acevedo et al. (2021), UNDP (2019), UN WOMEN (2022) and CIF (2017). In the Amazon context, indicators applied in the Xingu Solar project (IEMA, 2019), which evaluated the installation of photovoltaic systems in Indigenous communities, were incorporated.

Additionally, methodologies from development and investment institutions such as IADB (2018), ESMAP (2024) and BNDES (2022a, 2022b), as well as additional documents from IEA et al. (2025a; 2025) and The World

Bank (2025b, 2025c; 2014), consolidated the basis of international best practices.

These references consolidate international best practices and served as the methodological basis for the formulation of the quantitative and qualitative questionnaires.

5.2.2 Structure of indicator survey and questionnaires

The structuring of indicators resulted in the elaboration of two complementary instruments: the quantitative questionnaire and the qualitative questionnaire. Both were formulated based on scientific studies, pilot project data and international evaluation references, ensuring a balance between statistical comparability and capture of local sociotechnical experiences.

5.2.2.1 Elaboration of the quantitative questionnaire – multidimensional

The quantitative questionnaire was structured to collect standardized and comparable information on pilot projects in Amazonian communities. Indicators were organized into six thematic areas:

1. Organizational: identifies the responsible institution, details financing and execution terms, financial coverage degree and general project description;

2. Geographic: locates the project, specifying country, state, municipality, territory, community and its geographic coordinates;

3. Technical: characterizes the implemented energy system, including purpose, type of renewable source, installed capacity, generated energy, lifespan, storage and installation standards;

4. Economic: evaluates costs and viability, considering total investment, operation and maintenance expenses, financial return, tariffs, avoided costs with fossil fuels and cost per beneficiary;

5. Environmental: analyzes environmental impacts, such as substitution and reduction of use of fossil fuels, waste management, changes in land use, removal and replanting of vegetation; and

6. Social: measures social benefits, such as number of beneficiaries, technical training (including gender), impacts on income, expanded access to health, education and communication, reduction of manual labor and changes in local productive activities.

This structure ensures the collection of comparable and comprehensive data, allowing for a systematic evaluation of the technical, economic, social and environmental impacts of the projects. The complete instrument - quantitative questionnaire - is available in **ANNEX 2**.

5.2.2.2 Elaboration of the qualitative questionnaire – sociotechnical

The qualitative questionnaire – sociotechnical questionnaire - was conceived to document in a descriptive way the community experiences of access to electric energy, allowing the capture of local perceptions, management practices and lessons learned. The instrument is structured around ten thematic axes.

1. Diagnosis, motivation and institutional framework
2. Participatory planning and co-conception (*co-design*)
3. Energy justice and social inclusion
4. Technology and technical implementation
5. Operation, maintenance and training
6. Financing and economic sustainability
7. Results and impacts
8. Environmental sustainability
9. Governance and community management
10. Learnings and recommendations for public policies

The questions are open-ended, with descriptive textual responses to be filled out by technical teams of the executing organizations. In addition to sociotechnical aspects, they incorporate indicators sensitive to gender and social inclusion, addressing women's access to energy, participation in leadership, financing with gender perspective and mitigation of gender-based violence. The complete instrument – sociotechnical questionnaire - can be found in **ANNEX 3**.

5.2.3 Elaboration and application of questionnaire

The indicators were converted into questions structured in spreadsheets, with filling instructions in different languages, according to the nationality of the organizations. Each row corresponds to a served community, ensuring detail by locality in technical, social, economic and environmental terms. The questionnaires were sent by institutional email to all organizations involved in the pilot projects supported by the Mott Foundation over the last decade.

5.2.4 Systematization and analysis of questionnaire data

The data received underwent joint validation with the executing organizations, ensuring consistency and completeness. Then, they were consolidated into a single database, which served as a reference for quantitative and qualitative analyses. The analyses were performed with the support of *Microsoft Excel, Tableau and Qgis*, enabling integration between statistics, graphical representations and georeferencing.

5.3 RESULTS BY DIMENSION OF QUANTITATIVE ANALYSIS

5.3.1 Characteristics of pilot projects by organization

Michigan State University (MSU)

Implemented pilot projects designed together with beneficiaries, with solar photovoltaic technology and one case with hydrokinetic turbine, for community electrification, groundwater pumping, communication and connectivity and income-generating activities in Riverine communities, Quilombola communities and in Extractive reserves, in the Pará municipalities of Oriximiná and Santarém in 2024.

Kara Solar

Implemented pilot projects for the electrification of solar hubs, responsible for supplying energy to boats with electric motors powered by stationary battery systems and to communication and connectivity equipment, in addition to training beneficiaries between 2021 and 2023 across the Brazilian, Ecuadorian, Peruvian, and Surinamese Amazon.

World Wild Fund (WWF)

The **WWF-Brazil** implemented projects in Extractive reserves, with the installation of photovoltaic systems enabled through the donation of equipment from the Ministry of Mines and Energy and logistical support from the Chico Mendes Institute for Biodiversity Conservation (ICMBio) and the Lábrea Municipal Administration (AM). Among the initiatives, the implementation of the solar microgrid of Vila Limeira stands out, designed to fully meet community demand. **WWF-Bolivia** carried out the installation of an energy system from solar source, using photovoltaic and thermal technologies, destined for an açaí processing unit. This was the only project aimed at a consumer unit connected to the public energy distribution service. **WWF-Guianas** implemented, in 2023, a photovoltaic system in an Indigenous community located in Suriname. Whereas **WWF-Colombia** promoted, in 2024, the replacement of a gasoline generation system with a photovoltaic solution in a hotel situated in the Colombian Amazon.

Socio-Environmental Institute (ISA)

Between 2017 and 2022, installed dozens of photovoltaic systems in the Xingu Indigenous Territory and in the Raposa do Sol community, in the Brazilian states of Mato Grosso and Roraima, respectively, with the purpose of electrifying villages and providing water pumping, in some cases, in addition to training residents to install and perform maintenance of energy systems.

Health and Joy Project (PSA)

With Mott support since 2016, implements photovoltaic systems in Indigenous territory and Extractive reserves to expand access to electricity, sanitation, health, communication and connectivity and income-generating activities in the municipalities of Santarém, Itaituba and Jacareacanga in the state of Pará.

Amazon Conservation Team (ACT)

Since 2017, installed photovoltaic systems to serve health posts and an Indigenous community center for communication and connectivity. It also installed residential lighting kits based on a small photovoltaic module, lamp and batteries in dozens of residences in isolated areas of the Colombian and Peruvian Amazon.

Derecho, Ambiente y Recursos Naturales (DAR)

Implemented photovoltaic systems between the years 2018 and 2024 in public infrastructures of conservation areas and in isolated communities of the Peruvian department of Loreto to ensure productive uses, income generation, forest surveillance and protection of natural resources.

5.3.2 Analysis of the economic dimension of pilot projects

Most pilot projects received financial support through grants from the Mott Foundation. In 64% of cases, the energy solutions were fully funded by the foundation, including projects from ACT, DAR and PSA. WWF relied on partial financing from Mott in initiatives in Bolivia, Colombia, Suriname and part of the projects in Brazil, as well as ISA. MSU and Kara Solar complemented their projects with resources from other organizations.

Figure 27 presents the investments made by the organizations. ISA was the largest investor, allocating more than US$ 2 million to the electrification of 100 Indigenous communities in the states of Mato Grosso and Roraima. PSA appears in second place, with US$ 1.4 million applied in 46 communities in western Pará, focusing on communication, education, community electrification, health and sanitation. Kara Solar invested approximately US$ 1.4 million in projects for the electrification of solar centers for charging electric boats and other uses in nine communities in Brazil, Colombia, Ecuador and Suriname. WWF also contributed resources in communication, community electrification, income generation, sanitation and tourism projects. MSU and DAR invested amounts lower than US$ 100 thousand, while no information was obtained on the costs of ACT projects.

The analysis of economic, social and technical variables shows relevant relationships between total investment, number of beneficiaries and annual energy generated, as exemplified in **Figure 28.a**. An increasing logarithmic relationship was verified, but of low intensity, between amount invested and number of direct beneficiaries ($R^2 = 0.3519$). This means that only 35% of the variation is explained by investment. The result, however, is statistically significant (p-value = 0.0001), ruling out the hypothesis of chance. The dispersion of points, represented by circles whose size indicates energy generated and color represents territory type, suggests that variables such as purpose and territorial context also influence the number of direct beneficiaries.

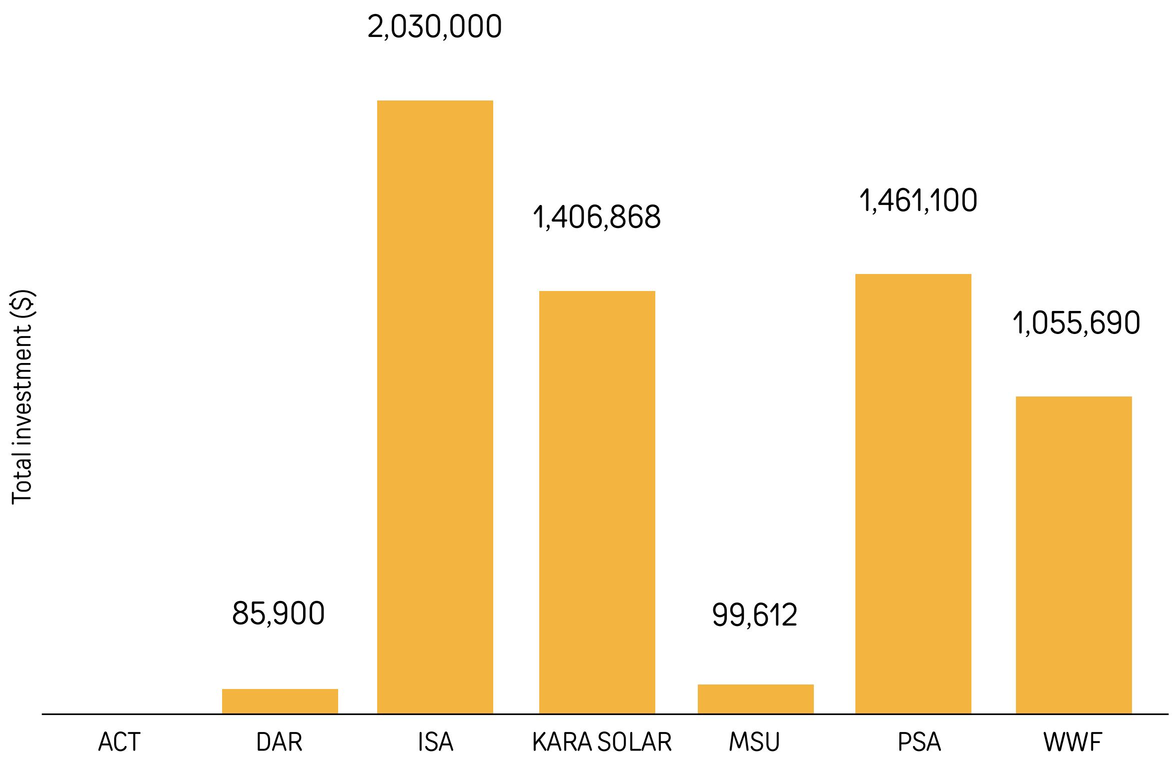
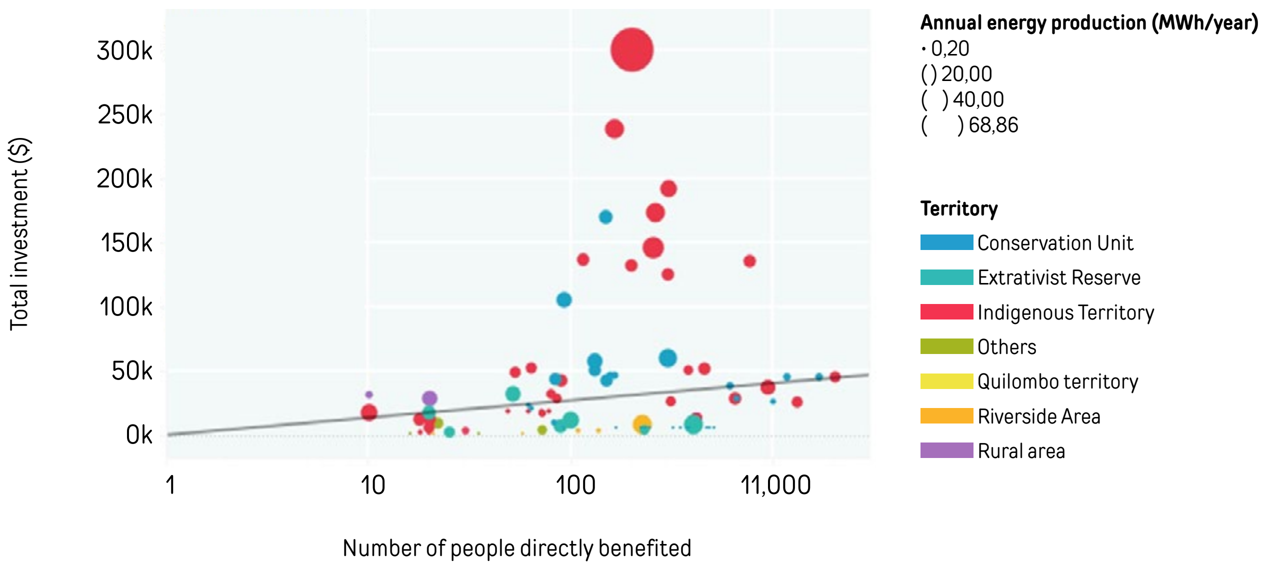


Figure 27. Total investment by organization.

The second distribution **(Figure 28.b)** referring to indirect beneficiaries, presented similar behavior ($R^2 \approx 0.35$), but with a larger angular coefficient (10,338.1 against 5,854.7 for direct beneficiaries). This indicates that, for each increment in investment, the number of indirect beneficiaries grows more intensely, suggesting greater community reach, albeit with lower individual impact. The larger circles are concentrated between 10 and 1,000 indirect beneficiaries, in projects with investments between US$ 50 thousand and US$ 200 thousand, mainly in Indigenous territories (red) – with 95% of cases –, Conservation units (blue) and Extractive reserves (green).



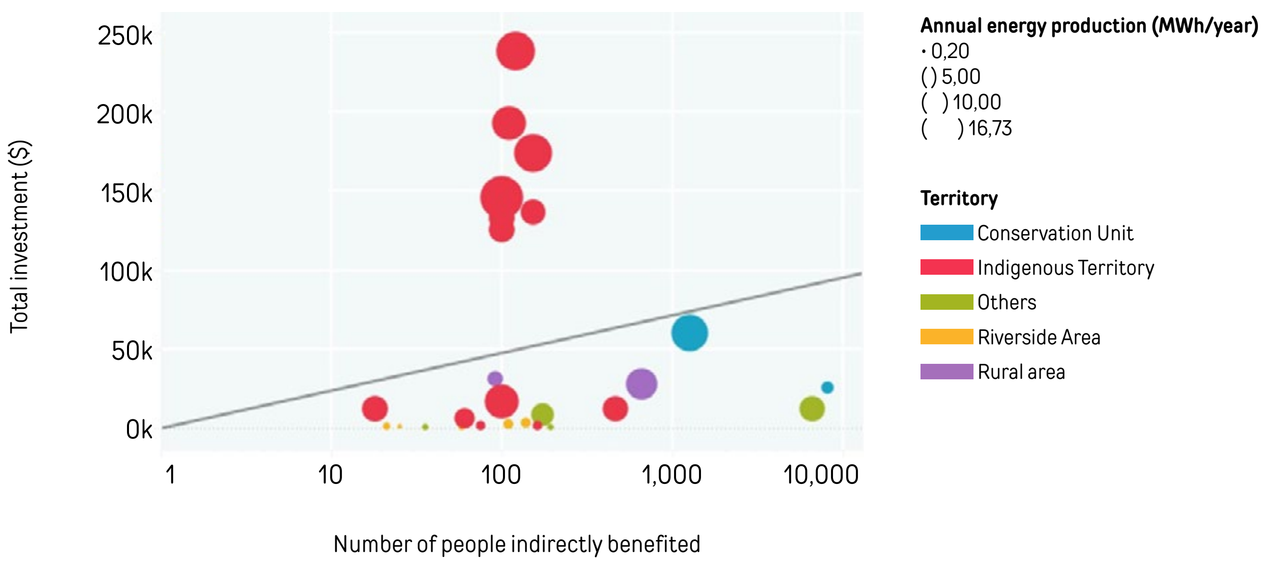


Figure 28. Total investment by number of people: (a) directly and (b) indirectly benefited from the communities.

In addition to total investment, the cost per beneficiary was analyzed. **Figure 29** details the cost per beneficiary. Communication and connectivity projects presented costs exceeding US$ 8 thousand per person, while those with sanitary purpose exceeded US$ 3 thousand. Combined, these two types represented 90% of the highest costs. The other purposes — education, tourism, community electrification and income generation — registered lower average costs, with community electrification being the most efficient in terms of scale of beneficiaries.

Finally, the impact on beneficiary income was investigated, as presented in **Figure 30**. Community electrification projects registered the greatest effect, with average increment exceeding US$ 361 per month per family, mainly in communities with subsistence activities (farming, fishing and hunting). Income generation and tourism projects also presented significant impacts, while the purposes of communication and connectivity and residential electrification showed modest results, varying between US$ 7 and US$ 9. Whereas education projects practically did not present direct impact on income.

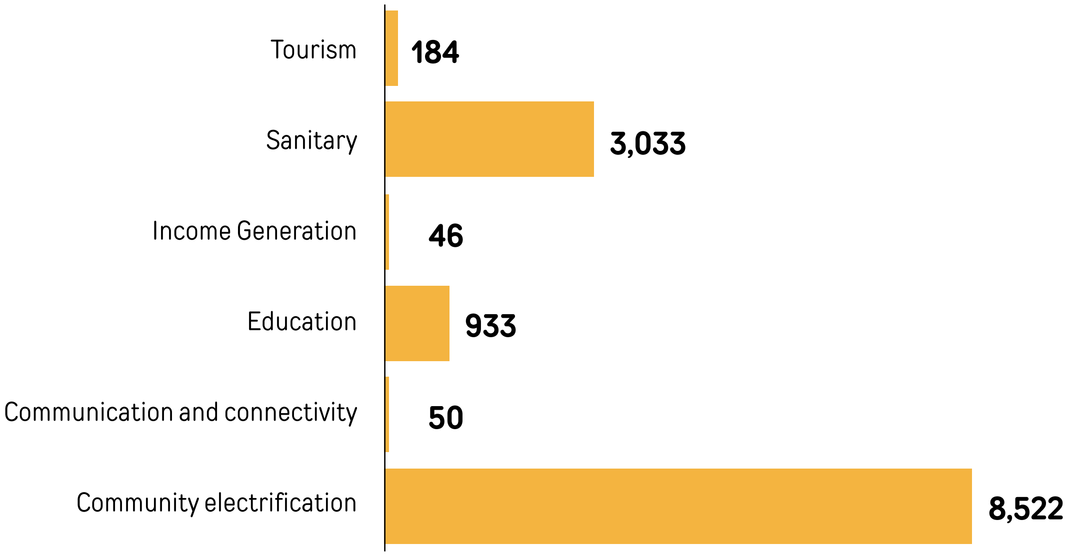


Figure 29. Cost per beneficiary ($) by project purpose.

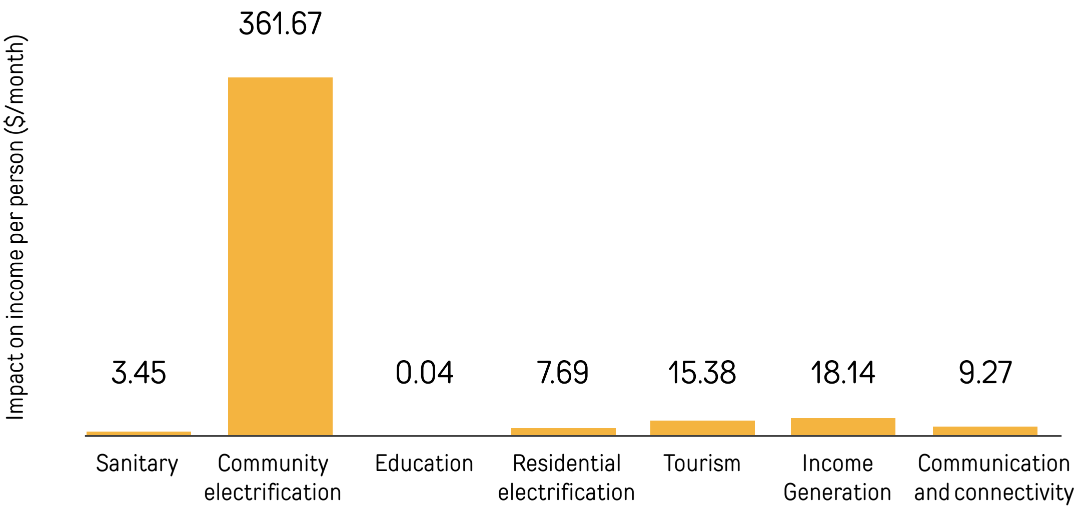


Figure 30. Impact on monthly income per benefited person ($/month).

5.3.3 Spatial analysis of pilot projects

Figure 31 presents the spatial distribution of the pilot projects analyzed.

Of the total, 191 communities were served in Brazil, 94 in Colombia, 21 in Peru, 4 in Ecuador, 2 in Suriname and 1 in Bolivia. In Brazil, projects covered the states of Amazonas, Maranhão, Mato Grosso, Pará, Rondônia and Roraima. In Colombia, services occurred in the departments of Amazonas, Caquetá, Guaviare and Putumayo; in Peru, in the departments of Amazonas and Loreto; in Bolivia, in Pando; in Ecuador, in Morona Santiago and Pastaza; and in Suriname, in Sipaliwini and Marowijne. In all cases, solutions were directed to remote Amazonian areas devoid of public infrastructure, which justifies the implementation of pilot projects based on renewable sources. **Figure 32** shows the quantity of communities served by territory type.

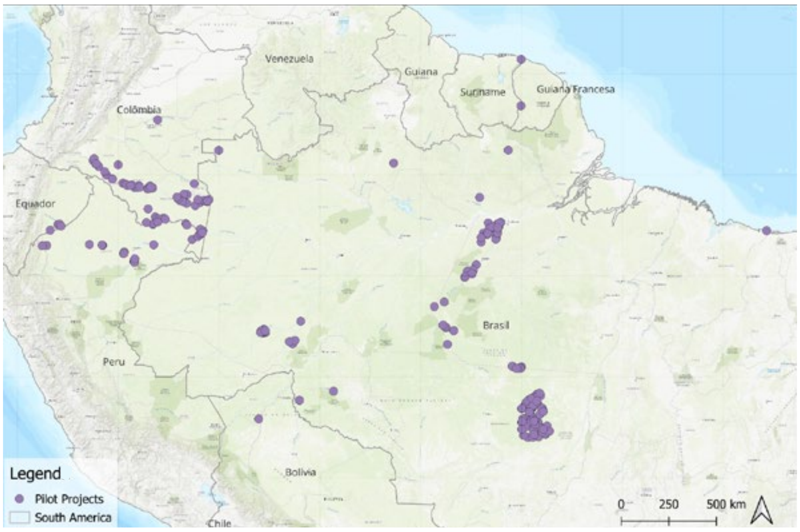


Figure 31. Location of the pilot projects financed by the Mott Foundation.

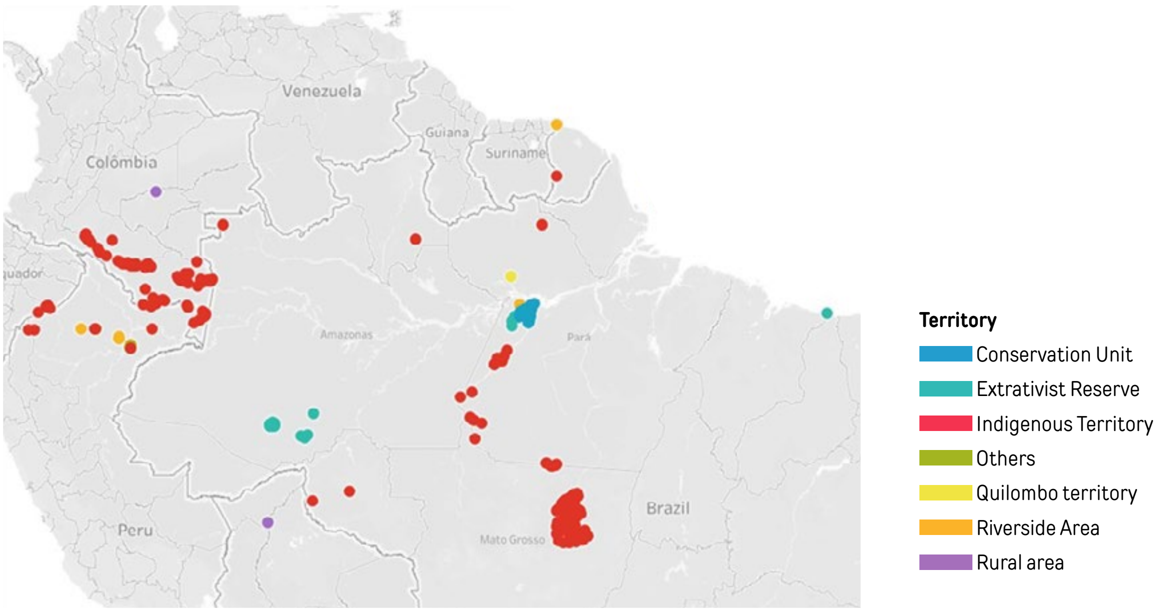


Figure 32. Communities and households served by territory type.

Most projects concentrated on Indigenous territories, which gathered 141 communities and 90 households. Among these, stand out 100 communities in the Xingu Indigenous Territory (Brazil), served by ISA, and 6 communities and 90 households in Indigenous territories along the Caquetá river (Colombia), benefited by ACT, as demonstrated in **Figure 33**.

Extractive territories represented 11% of services, with 36 communities contemplated, 7 by MSU and 29 by WWF. Conservation units corresponded to 10% of the total, with 30 communities served exclusively by PSA. Riverine, rural, Quilombola and other typologies represented 5% of the benefited communities and households.

5.3.4 Analysis of the technical dimension of pilot projects

Regional differences demanded distinct approaches for the implementation of pilot projects supported by the Mott Foundation over ten years of operation in Amazonian countries. Multiple energy use purposes were identified, as **Figure 34** shows. In 24 of the 223 communities and 90 households there was more than one purpose, which explains why the sum of occurrences is greater than the total number of localities served.

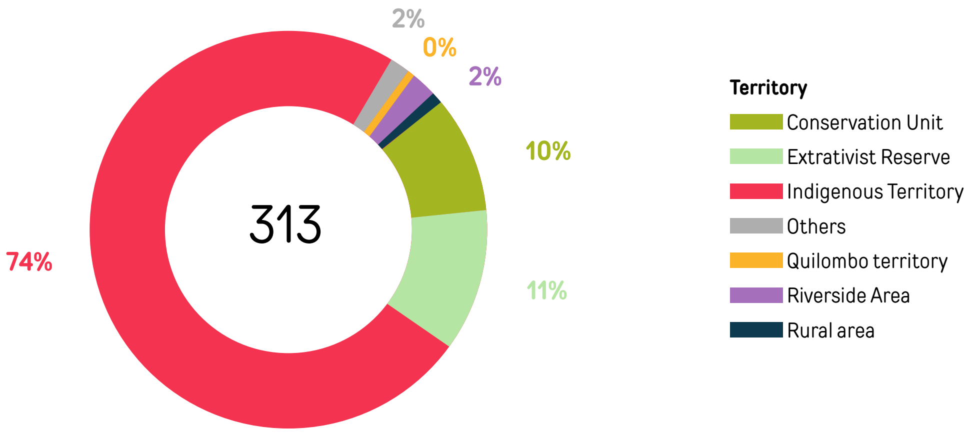


Figure 33. Proportion of service by territory type.

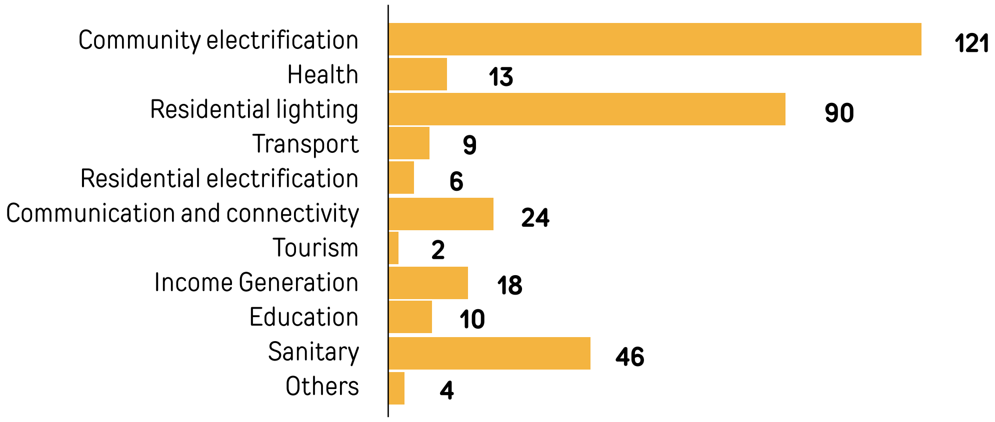


Figure 34. Purposes of the pilot projects.

Community electrification was the most frequent purpose, with 121 occurrences (35%). Residential lighting accounted for 90 occurrences (26%), corresponding to 100% of the analyzed households. This category was treated separately from residential electrification because it corresponds to small-scale systems, implemented by ACT, aimed exclusively at night lighting. The sanitary purpose, associated with water pumping projects, represented 46 records (13%). The other purposes, which totaled 25% of the whole, involved communication and connectivity, health, transport, education, income generation, residential electrification, tourism and other unspecified uses.

Despite the diversity of purposes, the technological matrix was homogeneous: all energy solutions used the solar photovoltaic source, as demonstrated in **Figure 35**. Among them, 98 hybrid systems incorporated fossil fuels as complement. In 86% of communities, energy storage systems were installed, divided almost equally between lithium-ion and lead-acid batteries. There were also two cases of diversification: the installation of a wind turbine in an Indigenous village in Roraima and a hydrokinetic turbine in an Extractive Reserve in Pará.

The comparison between installed capacity and annual energy generated by purpose, as presented in **Figure 36**, evidences different demand levels. The transport sector, served exclusively by Kara Solar, was the most demanding, with generation exceeding 9 MWh/year and installed capacity of 8 kWp per community. Activities classified as "other uses" – registered in four communities – were the second largest energy demand. Whereas the purposes of residential electrification and health presented similar values, with annual generation of 3.11 and 3.06 MWh and installed capacity of 3.48 and 2.9 kWp, respectively. On the other hand, exclusive residential lighting systems, implemented by ACT, had the lowest energy requirements, limited to providing night light with simplified solar systems.

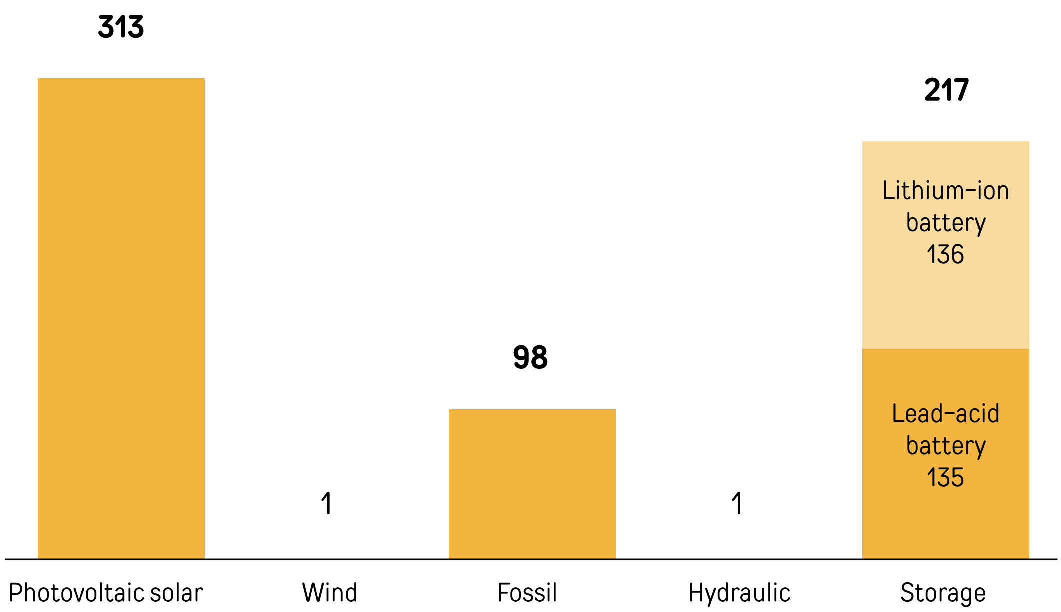


Figure 35. Participation of energy sources.

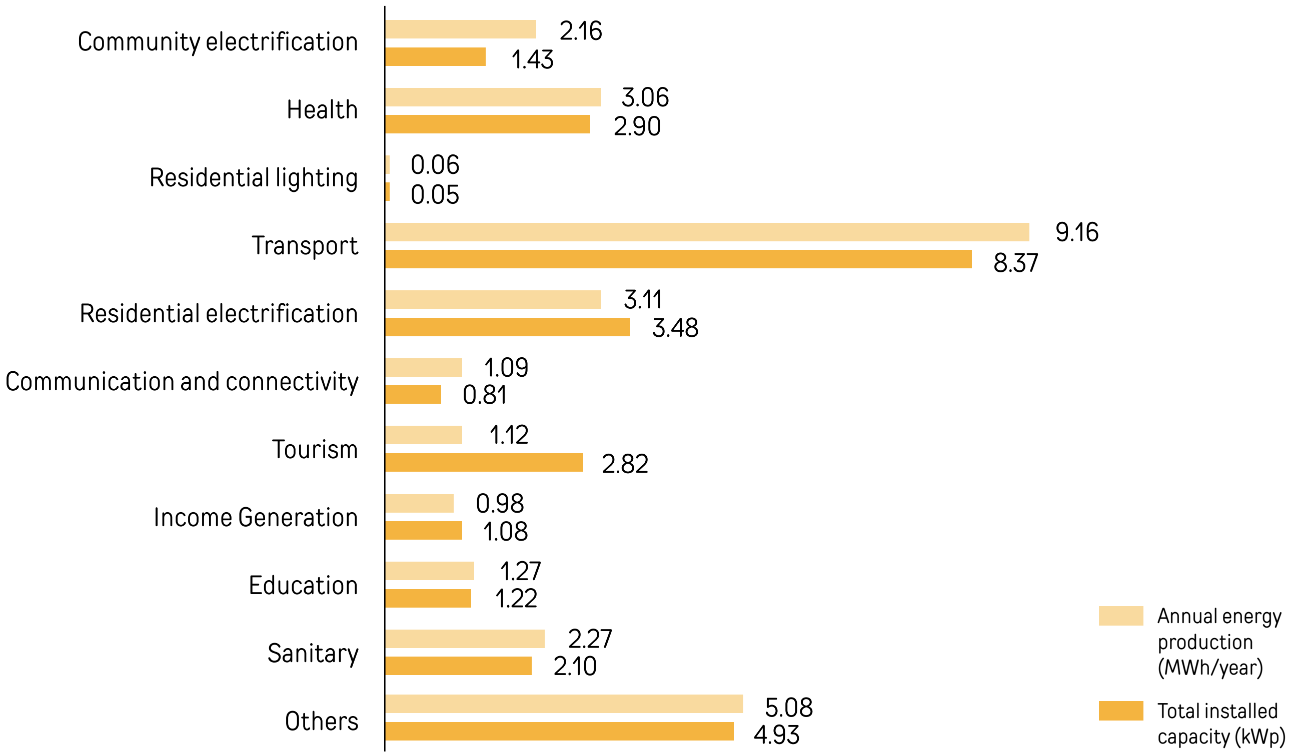


Figure 36. Annual energy generation and installed capacity by occurrences of project purpose.

5.3.5 Analysis of the social dimension of pilot projects

Pilot projects supported by the Mott Foundation benefited more than 70 thousand people in the Amazon over 10 years of work in access to renewable energies. **Figure 37** presents the percentage distribution of direct and indirect beneficiaries by organization.

The total of 43,614 direct beneficiaries corresponds to 60% of the served universe. This number was leveraged by projects implemented in Indigenous villages by ISA, which reached 20,570 people. PSA, the organization that benefited the most people, exceeded 26 thousand served, of which 16 thousand were direct. Combined, these two organizations concentrated 88% of direct beneficiaries. On a smaller scale appear Kara Solar, ACT, DAR, MSU and WWF, which together registered just over 6 thousand direct beneficiaries.

Some organizations presented a predominance of indirect beneficiaries. DAR reached 8.6 thousand people, of whom 94% indirectly. ACT registered 8.2 thousand total beneficiaries, being 85% indirect, while WWF served 3.4 thousand people, with 75% indirect.

Table 21 shows access to communication, education and health services enabled by pilot projects. More than 4 thousand people had expanded access to communication and connectivity in conservation units, corresponding to 64% of the total for this service compared to other territories. In Indigenous territories, more than 2 thousand people obtained this benefit, in addition to records in Extractive reserves and Riverine areas.

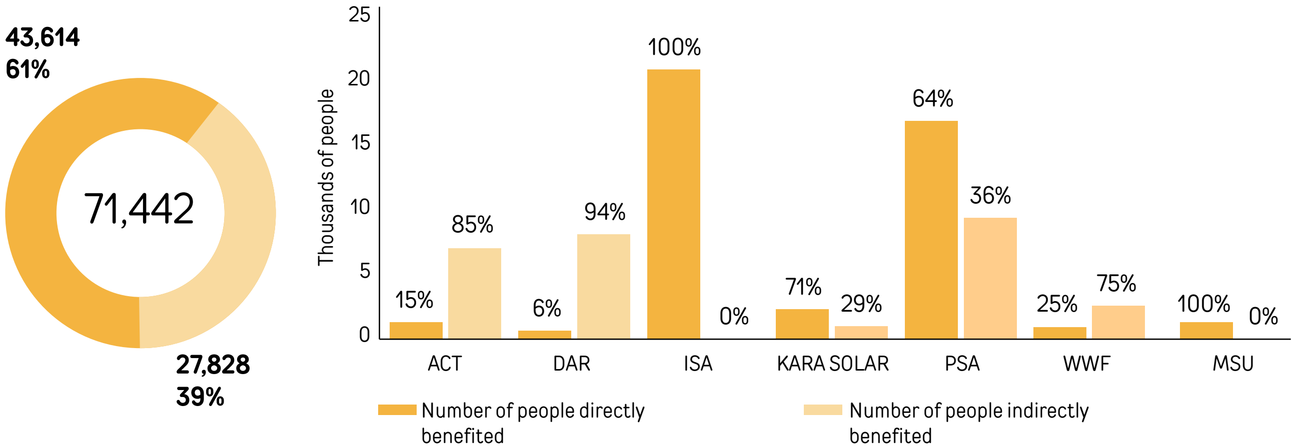


Figure 37. Number of people directly and indirectly benefited by organization.

Table 21. Access to communication and connectivity, education and health services by territory type.

Territory	Number of people who gained access to communication services due to the project	Number of people who gained access to education due to the project	Number of people who gained access to healthcare due to the project
Conservation Unit	4,056	370	5,111
Extrativist Reserve	210	86	260
Indigenous Territory	2,264	300	9,293
Quilombo Territory		13	
Riverside Area	145	36	244

Access to education was also more expressive in conservation units, followed closely by Indigenous territories. In Quilombos, 13 people had access exclusively to educational services. Health services were more representative among Indigenous people: 62% of the total, or more than 9 thousand beneficiaries, this being the service most demanded by this group, as shown in **Figure 38**.

In conservation units, more than 5 thousand people accessed health, representing 34% of the total and 53% compared to other services. In Extractive reserves, access to health was equivalent to that observed in communication, while in Riverine communities there was greater predominance of health over other services.

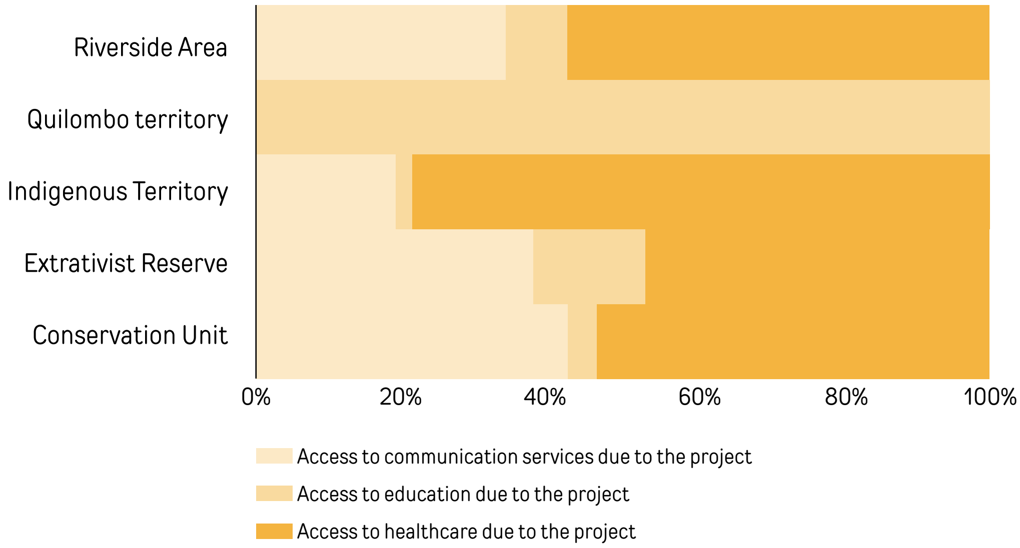


Figure 38. Percentage distribution of access to communication and connectivity, education and health services by territory type.

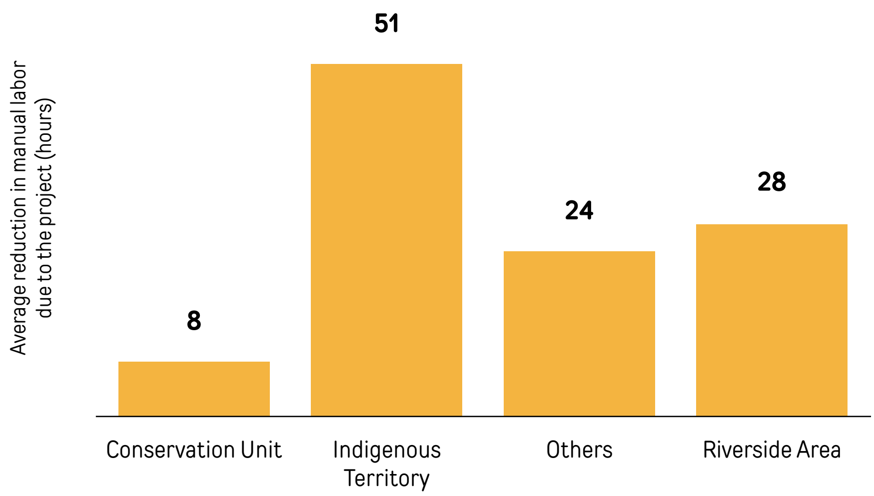


Figure 39. Average reduction in manual labor due to the implementation of the pilot project (hours).

Another relevant impact was the reduction of manual labor due to electrification, as presented in **Figure 39**. In Indigenous territories, the reduction exceeded 50 hours per week per resident. Among Riverine people, the average was 28 hours per week, followed by the category "others" with 24 hours. In conservation units, the reduction was the lowest registered, and there were no responses for this variable in other types of territories.

The number of women trained to install, operate, and maintain the systems accounted for 15% of the 583 individuals involved in training activities. **Figure 40** shows their distribution by territory.

Conservation Units had the highest absolute number of women participating in training for the implementation of energy solutions, with 24 women out of 72 total

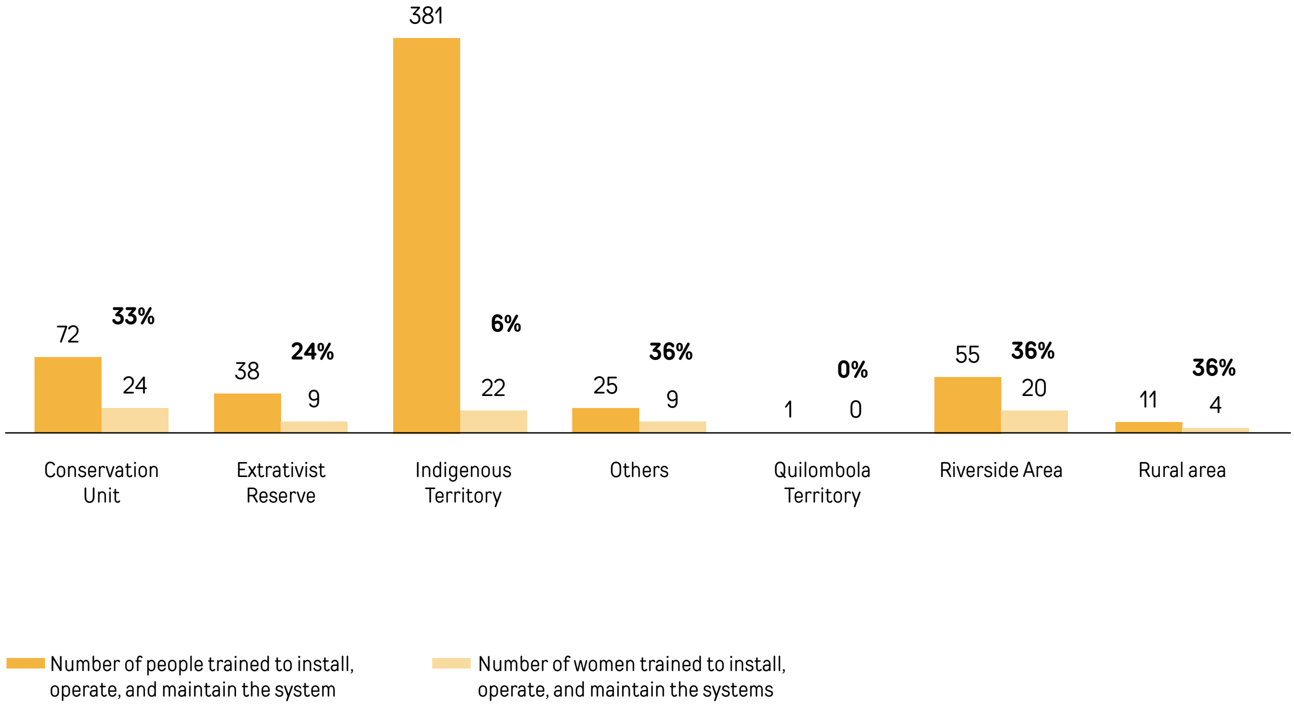


Figura 40. People trained to install, operate, and maintain the systems

trainees. However, riverside areas, rural areas, and territories classified as "other" exhibited the highest percentage of female participation, each with 36%. These were followed by extractive reserves, with 24%, and Indigenous territories, with only 6%. The latter is particularly noteworthy, given that over 400 individuals were involved in training activities in Indigenous territories, but only 22 were women. No data was reported on female training for installation, operation, or maintenance of energy systems in quilombola territories.

A similar pattern was observed in project implementation participation. Women represented 15%, equivalent to 114 women of the 781 individuals involved in the installation, operation, and maintenance of the systems as shown in **Table 22**.

Projects implemented in rural areas demonstrated significant female participation in installation, operation, and maintenance activities, with women representing 70% of the 10 individuals involved in these functions, despite only four women having participated in training in these areas. In riverside areas, women accounted for 32% of participants in implementation activities, followed by "other" territories at 26%, Conservation Units at 22%, and extractive reserves at 17%. In Indigenous territories, the same percentage of female participation observed in training (6%) was reflected in operational activities, with only 6% of the 469 individuals involved in system implementation being women.

Finally, the number of women engaged in leadership roles within the pilot projects exceeded the number of

Table 22 . People included in project installation, operation and maintenance

Territory	Number of beneficiaries included in project installation, operation, and maintenance	Number of women included in project installation, operation, and maintenance	% of women included in project installation, operation, and maintenance
Conservation Unit	104	23	22%
Extrativist Reserve	42	7	17%
Indigenous Territory	469	30	6%
Others	54	14	26%
Quilombola Territory	0	0	0%
Riverside Area	102	33	32%
Rural area	10	7	70%
Total	**781**	**114**	**15%**

women involved in operational activities.
A total of 121 women held leadership positions, compared to 88 who received technical training and 114 who were involved in installation, operation, and maintenance.

5.3.6 Analysis of the environmental dimension of pilot projects

The variables of the environmental dimension were selected to evaluate the substitution and avoided use of fossil fuels, the implementation of solid waste management mechanisms and the alteration of land use. Low adherence of responses was observed in variables not related to the use of fuels and waste, restricting the analysis to these two main axes. **Figure 41** presents the substitution of fossil fuel use due to the implementation of pilot projects. In 99.7% of communities there was reduction in diesel consumption; in 32% of cases full substitution occurred and, in more than two thirds, the reduction was partial.

Figure 42 presents the volume of fossil fuel avoided by purpose. Kara Solar's solutions, focused on river transportation and the electrification of charging centers for communication and connectivity, accounted for more than 200 thousand liters of fossil fuel avoided, equivalent to more than 200 residential water tanks of 1,000 liters each. These projects represented 90% of the total avoided consumption, while the remaining ones accounted for just over 30 thousand liters.[9]

The reduction of fossil fuel use has direct correlation with avoided CO_2 emission. Using the emission factor of 2.6 $kgCO_2/l$ (IPCC 2006), the volume of avoided emissions was estimated as a function of energy produced, as demonstrated in **Figure 43**. Statistical analysis revealed a coefficient of determination (R^2) of 0.4412, indicating that

[9] The methodology adopted by Kara Solar to estimate avoided fossil fuel consumption incorporates, in addition to direct use, the consumption associated with its logistics of transportation to remote areas. This approach is particularly important in the Amazon context, where fuel supply can require volumes equivalent to those of the end-use activity itself.

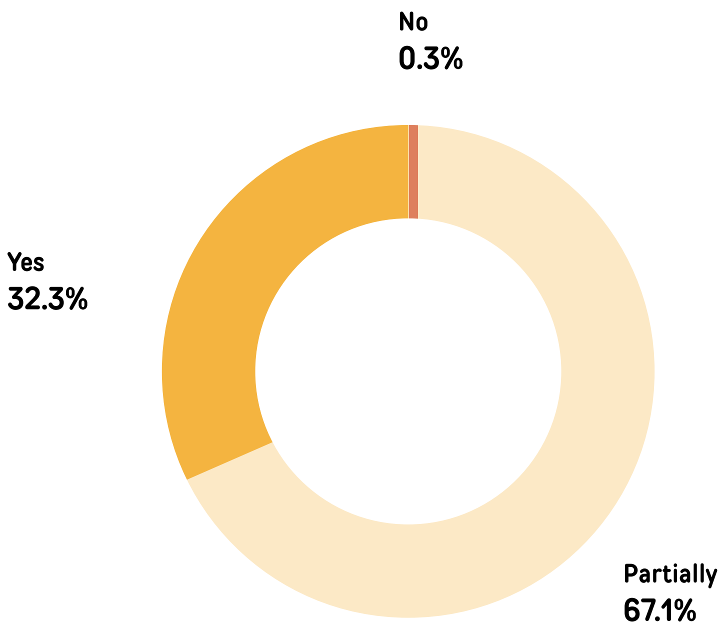


Figura 41. Proportion of substitution of fossil energy use.

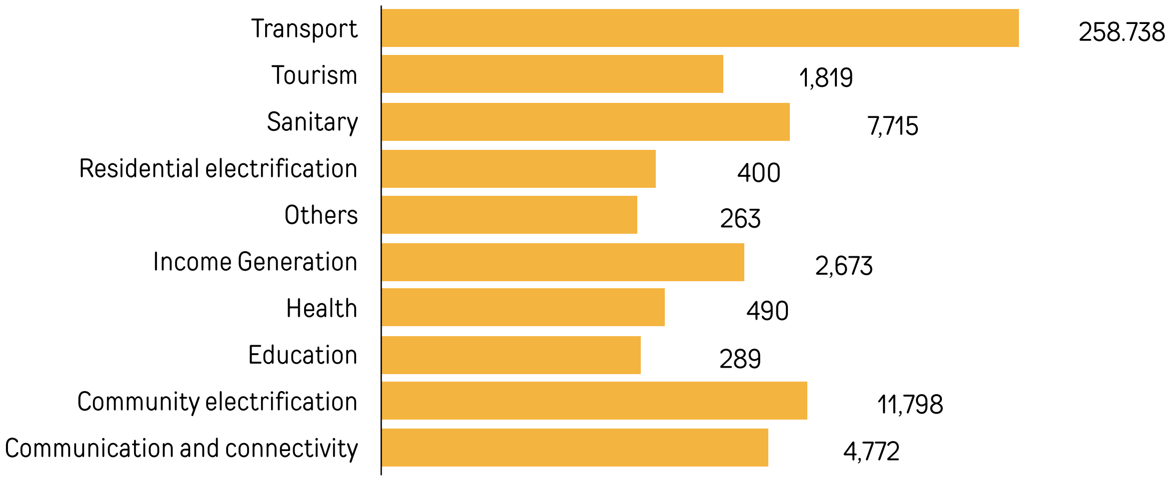


Figura 42. Avoided consumption of fossil fuel by purpose in logarithmic base (liters).

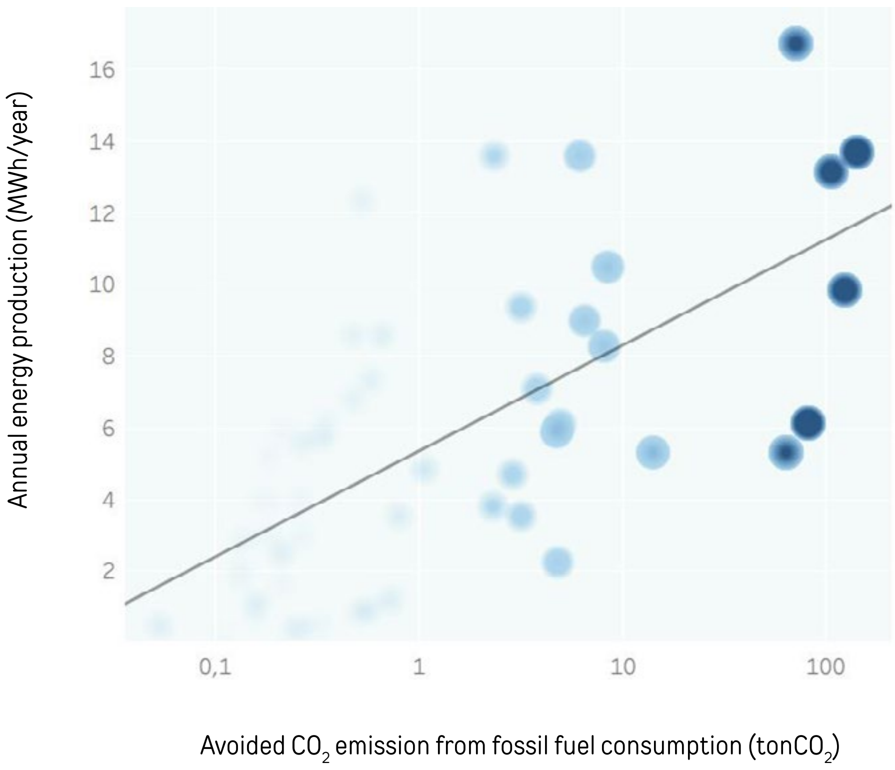


Figure 43. Energy generation (MWh/year) by avoided emission ($tonCO_2$) in logarithmic base.

44% of the variation of avoided CO_2 emission is explained by energy generation. The relationship is moderately strong and statistically significant ($p = 0.0001$), ruling out the chance hypothesis.

The most intense points of the graph, concentrated on the right, correspond to transport projects, in which color intensity reflects larger volumes of avoided emission. In some cases, these projects were not the ones that generated the most energy, but presented greater fossil fuel substitution, occurring because renewable transport, even if it does not demand large amounts of electric energy, requires integral substitution of fossil fuel to enable its operation.

Thus, results demonstrate that transport activities are strategic to expand the participation of renewable sources in the Amazon, representing the axis of greatest potential to reduce emissions of CO_2 and other greenhouse gases through pilot projects.

5.4 RESULTS OF THE SOCIOTECHNICAL QUESTIONNAIRE

The following are the main information obtained through the application of the sociotechnical questionnaire. The sequence of tables represents the summaries of responses for each axis of the questionnaire, which is followed by a brief evaluation of the collected information.

5.4.1 Diagnosis, motivation and institutional framework

The questions aiming to diagnose the motivation and institutional framework of the implementation of pilot projects in the Pan-Amazon region are based on seven questions, which can be analyzed in the content of **ANNEX 3**.

Before project implementation, energy access was precarious and intermittent. Almost all communities lived in non-interconnected zones, depending on small diesel or gasoline generators that provided electricity for only a few hours at night. In many cases, the use of candles and kerosene was the only option, resulting in high monthly expenses and respiratory problems. Essential services, such as schools and health posts, were compromised: food was not refrigerated, vaccines were not stored properly and community meetings were limited by lack of lighting and high fuel cost.

Projects emerged to respond to interconnected social, economic and environmental needs. In the social field, they sought to ensure continuous and safe electricity for education, health and community safety, in addition to alleviating the domestic burden on women and the risks of cooking with firewood or kerosene. In the economic aspect, they intended to reduce high costs with fossil fuels, enable productive activities, such as açaí processing, fish refrigeration and tourism, and diversify family income sources. From an environmental point of view, the need to reduce greenhouse gas emissions and dependence on firewood, including for cooking, stands out.

All organizations emphasized the importance of community participation from diagnosis to implementation. Field surveys, meetings and assemblies were held with local leaders, traditional authorities and residents, ensuring that system design reflected specific needs, such as water pumping, refrigeration and public lighting. This involvement strengthened the sense of belonging and responsibility of communities in system operation and maintenance.

The legal and institutional environment proved heterogeneous. In countries like Colombia, Peru, Ecuador and Brazil, there are laws that favor renewable energies in isolated areas, such as the Constitution of Ecuador, the Rural Electrification Law of Peru and ANEEL resolutions in Brazil. However, most regulations still favor large grid-connected projects, without clear guidelines for microgrids and community systems. Additional barriers include delays in distributed generation approval, difficulties in importing equipment and absence of long-term financing and maintenance mechanisms, especially for battery replacement.

Articulation with public authorities varied according to context. In Brazil, there were partnerships with municipal secretariats of health, education and water supply, which integrated solar systems into schools, health posts and pumping systems. In Peru, regional and district governments offered logistical support and training. Whereas in some cases in Ecuador and Colombia, initial action took place almost exclusively between NGOs, Indigenous federations and the communities themselves, with little government participation.

Almost all projects waived formal environmental licensing, given the low impact of small-scale solar installations. Financing was mostly philanthropic. Few initiatives accessed government credits or carbon markets, highlighting an opportunity to strengthen financial sustainability through incentives for avoided emissions.

Recommendations presented by organizations converge towards the creation of specific funds for isolated systems, adequate tariffs and subsidies for microgrids, maintenance and battery replacement mechanisms, in addition to training programs and strengthening of local governance. They also suggest integrating energy access into health, education, water supply and economic development policies, recognizing electricity as an essential service.

Together, evidence demonstrates that renewable energy systems managed by the communities themselves are technically viable and socially transformative. Solar photovoltaic energy showed greater adaptability. Projects reduced fossil fuel consumption, decreased family costs, improved educational and health services. In addition, they strengthened autonomy and capacity for monitoring and surveillance against deforestation and resource exploitation.

Lessons learned about diagnosis, motivation and institutional framework of the different pilot projects are systematized in **Table 23**.

Table 23. Systematization of learning about diagnosis, motivation and institutional framework of the pilot projects.

Country	Organization	Prior Energy Access	Initiative Goals/ Needs	Community Participation	Legal / Regulatory Framework	Public Authority Support	Env. License / Financial Procedure	Recommended Improvements for Community Projects
Bolivia	WWF	High electricity tariffs	Energy security, local governance, lower costs, less fossil fuel & firewood use	Community planning and oversight	National framework on energy matrix change	Protected Area Authority	No	Existing regulations already favorable
Brazil	ISA	Partially electrified, fossil-fuel use	Household & community electrification, public lighting, sanitation, health, communication	Demand assessment and energy system design	ILO 169	Partially to a territory	No	Apply Social Tariff to productive uses
	PSA	Partially electrified, fossil-fuel use	Household/ community electrification, drinking water, education, productivity, health	Collected community data and main demands	SIGFI regulation	Santarém Municipality	No	Simplify rules for community systems within universalization programs
	MSU	Diesel-based, ~3 hrs/day electricity	Reduce isolation, cut diesel costs, lower air pollution	100% co-design and participation	NBR 5410, 16690, 5419, 16274; NR-10, NR-35	Santarém Municipality	No	Incentives for utilities/consumers to deploy community energy systems
	WWF	Fully reliant on fossil fuels for power, transport, water, education	Food, education, drinking water, domestic use, security	Leaders involved in planning; residents (by gender/age) in implementation	ANEEL Res. 482/2012, 687/2015	ICMBio, Lábrea Municipality	No	Strengthen ANEEL's National Energy Efficiency Program for remote community systems
Colombia	ACT	Off-grid, poor lighting	Public lighting, productive activities, education, health	Community assembly participation	Constitution, ILO 169, Law 1715/2014, rural energy policy	ESE Hospital San Rafael de Leticia; Indigenous EPS Mallamas; Dept. Health Secretariat	No	Create ZNI funding access, battery maintenance/ replacement guidelines, formalize community management
	WWF	Limited gasoline-based supply	Tourism	Community approval and discussion	–	No	No	Improve tax incentives for community energy
Ecuador	Kara Solar	Unreliable electricity	Transportation, reduce fossil-fuel dependence	Participatory needs assessment	2008 Constitution; Organic Electricity Law; Distributed Generation Reg.	Municipal/ provincial government	Customs clearance & financial compliance required	Enact specific laws and state financing for clean, subsidized energy in remote areas
Peru	ACT	Off-grid, poor lighting	Public lighting, productive activities, education, health	Community assembly participation	Constitution (Art. 89); ILO 169; Prior Consultation Law; Rural Electrification Law	Provincial Municipality; Caballococha Parish	No	Provide ZNI public funding access, battery maintenance/replacement guidelines, formalize community management
	DAR	Isolated microgrid, 3-4 hrs/day	Electricity as basic right; security, health, education; clean cooking	Community consultation and demand mapping	Climate Change Framework Law; National Energy Policy 2010-2040; Regional Ordinance 018-2017-GRL-CR; DL 1002	District Municipality; Loreto Regional Gov.	No	Adapt laws for isolated systems; special tariff for renewable microgrids; fund for storage replacement
Suriname	WWF	Dependent on diesel, small PV	Renewable access, biodiversity monitoring, ecotourism, safe water	Community consulted	Electricity Act 2016	Energy Authority, Ministry of Natural Resources	–	–

5.4.2 Participatory planning and co-conception (co-design)

Information collection on planning was divided into seven questions, which can be analyzed in the content of **ANNEX 3**.

Community electrification experiences in different regions of the Pan-Amazon region reveal a **consistent pattern: active community participation is a determining factor for the success and sustainability of renewable energy projects in remote areas**. The analysis of reports shows that community involvement not only occurred, but was structured in a way to strengthen local autonomy, value traditional knowledge and ensure that energy solutions met collective priorities.

In practically all cases, the process began with a participatory diagnosis. Meetings, assemblies, interviews and questionnaires were used to survey energy needs and understand the reality of each location. These stages allowed identifying priorities such as lighting for homes and public spaces, communication through internet or telephony, health, education and transport. Community participation helped define which spaces would be benefited, which equipment would be most useful and how systems should be distributed to best serve families and collective areas.

In addition to diagnosis, it was common to hold workshops, trainings and participatory mapping, in which residents themselves could learn about system operation, understand their limitations and participate in the construction of solutions. In many cases, these activities resulted in formal agreements for use and maintenance of equipment, in addition to strengthening local capacities in renewable energies. In some localities, cultural and traditional gatherings were integrated into the process, serving as spaces for knowledge exchange, consensus building and reinforcement of social cohesion.

A central aspect identified in all projects was the valorization of local knowledge, although it was not present in all projects. The choice of locations for installation of turbines, solar panels or power grids took into account traditional knowledge about geography, flood and drought cycles of rivers, and best times for material transport. Residents indicated suitable wood species for supports and poles, suggested safe locations for water pumps and defined routes for distribution lines. In river transport systems with solar energy, the design of vessels was inspired by traditional models, adapting motors and navigation techniques according to local experience. This integration between modern technology and ancestral practices ensured greater efficiency, reduced costs and increased acceptance of solutions.

Priorities defined by communities were clearly reflected in technical projects. Domestic and public lighting, communication, water supply, refrigeration of medicines and food, in addition to support for productive activities, were recurring demands. In some localities, the installation of solar systems enabled the functioning of schools and health posts, as well as storage of agricultural and fishing products in cold rooms. In others, the creation of transport systems moved by solar energy significantly reduced costs with fossil fuel, expanding access to health services and markets for production flow.

The collective decision process was another common and essential element. In meetings and assemblies, residents defined rules of use, maintenance fees and management mechanisms for the systems. Many communities created funds for battery replacement, calculating monthly contributions per family based on equipment cost and life expectancy. Although not all families could always contribute regularly, the practice strengthened governance and increased awareness about the importance of financial sustainability. In some cases, committees or associations responsible for energy management were created, reinforcing community autonomy.

Autonomy to propose adjustments and expansions was also reported in different contexts. Communities can request location changes, capacity expansions or inclusion of new equipment, provided there is technical viability and available resources. During implementation, adaptation suggestions were discussed with technical teams and, in many cases, incorporated immediately.

After installation, responsibility for operation and maintenance passed entirely to communities, who decided independently on future modifications. Another relevant point was integration with productive activities and essential services. Water pumping systems by solar energy were widely used, reducing manual effort, expanding agricultural production and strengthening production chains, such as açaí and cassava flour. Electric energy also allowed the functioning of workshops, carpenter's shops and small home industries, expanding income generation opportunities. Public lighting contributed to community safety and to the expansion of nighttime activities, such as study, fishing and collective meetings.

Despite advances, long-term sustainability of systems still presents challenges. Battery replacement and periodic maintenance require financial resources that are not always readily available. Although some communities have structured funds or received support from institutional partners, in other cases replacement depends on new projects, donations or specific collections. **In areas of conservation units, access to credit and insurance is limited, since residents do not possess formal land title, which hinders obtaining traditional financing.**

Social benefits of the initiatives were expressive. The arrival of electricity reduced time dedicated to manual activities, improved health and education conditions and strengthened social cohesion. There was time gain for educational activities, greater domestic comfort and reduction of expenses with fossil fuels, such as diesel. In various communities, fuel savings allowed redirecting resources to food, education and improvements in local infrastructure.

From an environmental point of view, renewable energy solutions reduced fossil fuel use and greenhouse gas emissions. In many cases, diesel substitution was partial, but significant; in others, it reached completion. Transport systems by solar energy avoided burning thousands of liters of fuel, decreasing river and air pollution, in addition to contributing to climate change mitigation.

Analysis of these experiences demonstrates that the combination of appropriate technology, social participation and respect for traditional knowledge is fundamental for the success of electrification projects in isolated regions. Community involvement from diagnosis to daily management ensures that energy solutions not only provide electricity, but also strengthen autonomy, generate income, improve quality of life and encourage environmental preservation.

These projects also show that collective learning is cumulative and inspiring. In some cases, the installation of pilot systems led to replications in neighboring communities, supported by governments or other organizations. The sharing of experiences, whether through workshops or simple demonstrations, generated a multiplier effect, amplifying the impact of original initiatives. Lessons learned with participatory planning and co-conception of pilot projects are systematized in **Table 24**.

5.4.3 Energy justice and social inclusion

Information collection on energy justice and social inclusion in pilot projects was divided into five questions, which can be analyzed in the content of **ANNEX 3**.

The analysis of electrification initiatives from the perspective of reducing energy access inequalities showed that interventions sought to ensure that clean, safe and continuous energy supply was treated as a basic right, not restricted to urban areas. In some cases, it was recognized that completely eliminating these inequalities is still a challenge, but implemented actions represent significant advances towards energy justice. Proposals valued the use of renewable sources, mainly solar, as an alternative to fossil fuels, reinforcing the idea that energy should be a collective good accessible to rural, Indigenous, Riverine and border communities.

Served populations were selected considering vulnerability and isolation criteria. Indigenous peoples, Riverine communities, Extractivists, Peasant women / Rural women and Afro-descendants stand out, as well as groups strongly dependent on rivers for transport and subsistence. In various territories, the choice of

Table 24. Systematization of the learnings with participatory planning and co-conception of the pilot projects.

Country	Organization	Participation in planning and design	Workshops and mappings and results	Co-conception tools and methodologies	Integration of local knowledge	Prioritization of local demands	Decision on tariffs, management and maintenance	Autonomy to propose changes and expansions
Bolivia	WWF	Project presented and accepted by community; support for implementation	Diffusion of experience generated expansion by other institutions	Interviews, meetings, questionnaires, observation of energy use	United local knowledge, interest of authority and university students	Support for productive enterprise	Agreements in community meetings for implementation and maintenance	Community owner/manager has freedom for changes
Brazil	ISA	Demand indication; meetings, assemblies, seminars	Records in reports, maps and minutes with community priorities	Maps, questionnaires, group dynamics	Installation site defined by local knowledge	Community services: school, health post, internet, radio, community kitchen	Management and maintenance decided together; technical training program; debate on maintenance fee	Communities can propose alterations considering technical and budgetary limitations
	PSA	Meetings and social and technical diagnoses since conception; technical training	Workshops and social and technical diagnoses	Community workshops, prior consultation, demand identification, donation term	Wooden supports for solar panel, use of local labor, community leadership for operation	Lighting, health, education, water supply, income generation	Assemblies define rules and management models for collective systems	Communities/families can alter systems after donation
	MSU	Meetings, workshops, questionnaires and trainings	Workshops and participatory dynamics; list of energy priorities	Questionnaires, workshops, participant observation, trainings	Communities define locations, materials (wood), routes and installation times; financial management	Internet, public lighting, water pumping, reduction of diesel use	Fund for battery exchange with monthly contribution per family	Total autonomy, although additional cost for expansions is a challenge
	WWF	In-person meetings for all project phases; communities defined uses and locations; IOM training	Workshops and visits helped dimension systems and align expectations	Identification of previous needs, semi-structured interviews, energy expectations workshops	Local techniques for making wooden structures for system equipment: alternative to use of metal, cement and brick	Water pumping, lighting, refrigeration, internet, carpentry, irrigation, leisure	In Vila Limeira: assembly defined tariffs and maintenance; others, specific quotes	Communities can propose, but cost and lack of credit hinder
Colombia	ACT	Meetings and assemblies defined criteria, strategic spaces and system use	Training, usage agreements, field verification	Participatory diagnosis	Knowledge applied in use and management of systems	Domestic lighting, communication, health, governance	Community agreements for use, security, maintenance and battery replacement	Communities can propose changes, expansions only with technical support
	WWF	Participation in diagnosis visit, prioritization, installation and training	Workshops and visits helped dimension systems and align expectations	Identification of previous needs, semi-structured interviews, energy expectations workshops	No	Tourism	–	Can propose alterations during design; autonomy after installation
Ecuador	Kara Solar	Prior consultation and dialogue; joint decision with technical team	Workshops and participatory mappings generated project appropriation	Participatory maps, diagnoses, questionnaires, "wayusa" morning meetings	Design of canoes and motors adapted to Achuar model of traditional navigation	Transportation, lighting, communication, health	Agreements with communities for management and maintenance	Communities can propose alterations during installation, but mechanisms to change after installation is under definition
Peru	ACT	Meetings and assemblies defined criteria, strategic spaces and system use	Training meetings with practical demonstrations	Participatory diagnosis	Knowledge applied in use and management of systems	Domestic lighting, communication, health, governance	Community agreements for use, security, maintenance and battery replacement	Communities can propose changes, expansions only with technical support
	DAR	Diagnosis, interviews, consultations, solution design and management agreements	Workshops and meetings enabled building priorities and governance agreements	Participatory diagnoses, interviews, consumption surveys	Traditional cooking practices, location for PV panel implantation, productive practices, safety	Lighting, communication, health, education, production	Communities discuss symbolic tariffs; creation of energy committees	Can suggest expansions and adjustments in coordination
Suriname	WWF	Community meetings and household questionnaires	Community workshops	Questionnaires	Based on previous community experience	Lighting and communication in multifunctional building	Tariff proposed by traditional authority (STIDUNAL)	System donated to community organization with total autonomy

localities took into account the relationship of trust already established, difficulty accessing essential public services and strategic importance of community spaces, such as health posts, organizational centers and schools. Prioritization also covered rural producer associations, reinforcing concern with the inclusion of different social segments that traditionally remain on the margins of electrification programs.

Responses evidence that many communities had previously received low-quality equipment, without technical monitoring or with strong dependence on diesel generators. To face these deficiencies, new projects invested in more reliable photovoltaic systems adapted to local context, in addition to developing trainings and educational materials for operation and maintenance. In some cases, teams reviewed previous installations and planned reactivation of disabled systems, while others highlighted that there were no previous experiences to correct. Strategies were also incorporated to ensure financial sustainability, such as access to public funds and scaling mechanisms for productive associations, strengthening the autonomy of beneficiary communities.

Community management of renewable energy systems resulted in strengthening local identity and organizational capacity. Stable electricity supply enabled expansion of productive activities, such as crafts, and enabled the use of living spaces, meetings and health and education services at extended times. In some regions, solar technology boosted cultural practices, such as traditional ceremonies, and inspired youth to engage in initiatives linked to innovation and environmental conservation. Knowledge acquired in technical trainings contributed to increasing community autonomy, allowing system maintenance and management to be done collectively and with participation of women and youth.

Effects on local power distribution were varied and, in most cases, discreet. In some communities, individuals responsible for operating energy systems assumed leadership roles or gained greater social visibility, while in others governance structures remained unchanged. Electrification contributed to dynamizing collective spaces and expanding participation of different groups in community decisions, but did not cause significant reconfigurations in existing hierarchies. In certain territories, economic strengthening was observed, with business opportunities and reduction of operating costs, which increased interest of local actors, although without substantially altering already consolidated traditional authority. Learnings about energy justice and social inclusion are systematized in **Table 25**.

5.4.4 Technology and technical implementation

Information collection on technology and topology of electric energy generation and storage and technical implementation of energy systems was structured in five questions, which can be analyzed in the content of **ANNEX 3**.

Organizations' experience presents a range of technological choices, with predominance of solar photovoltaic energy due to its feasibility in remote regions, ease of transport and low maintenance cost. Consistent solar irradiation in Amazonian and rural areas, added to simplicity of operation and safety, favored the adoption of this generation source. In some cases, solar energy was combined with hybrid systems with diesel to ensure supply in periods of low insolation, or tested in conjunction with technologies such as hydrokinetic turbines, with the aim of expanding energy autonomy and reducing dependence on fossil fuels. Previous studies of energy potential and cost-benefit analyses supported these decisions, also considering adaptation to specific environmental and logistical conditions of each locality.

Adaptation of systems to local conditions was a central aspect of the implementation process. Several projects took into account factors such as tropical climate, rainfall seasonality, flood risk, labor availability and access difficulties. In some cases, installation was planned for dry periods, when river navigation or land transport were safer. System structures, such as panel supports and inverter protection cabinets, were reinforced or adjusted to resist humidity and

Table 25. Systematization of learnings about energy justice and social inclusion of pilot projects.

Country	Organization	Correction of historical inequalities	Prioritized groups	Correction of previous failures	Strengthening of identity, organization and autonomy	Changes in power distribution
Bolivia	WWF	Implemented energy projects that resulted in community participation and appropriation of energy solutions	Organizations of Amazonian fruit producers (men and women)	There was no need	Strengthened identity, participation and community organization	Economic empowerment for actors who did not have it
Brazil	ISA	Enabled fulfillment of energy demands in excluded Indigenous lands	Indigenous communities	Yes, incorporated learnings and improvements in processes	Reinforced community management and valorization of training, especially of women and youth	Yes, although difficult to measure
	PSA	Brought solar energy to areas historically without electric grid	Indigenous peoples, Extractivists and Riverine communities	Improved solutions that started in 1999 by the organization, with training for maintenance and greater autonomy	Reinforced community organization and self-management	No evidence of changes directly linked to the project
	MSU	Reduced inequality costs, but does not eliminate structural difference	Riverine populations	Few previous experiences	Strengthened organization and autonomy through system control	Occasional cases of new leadership; majority without significant change
	WWF	Energy for conservation units in areas of electricity exclusion	Associations of Riverine extractivists	Followed socioenvironmental safeguards to guarantee rights	Renewable energy became part of identity and ecotourism services	No
Colombia	ACT	Focusing communities in Non-Interconnected Zones to guarantee clean and safe access	Indigenous peoples and isolated rural communities (Colombia and Peru)	Reactivated old solar systems; regained local trust; created maintenance booklets	Greater organization capacity and collective resource management; energy solution allowed collective management activities	Better organization and community engagement, without major power changes
	WWF	Brought energy to Non-Interconnected Zones	Rural and Afro-descendant communities	-	Renewable energy became part of identity and ecotourism services	No
Ecuador	Kara Solar	Combats historical exclusion with clean energy and solar transport	Achuar and Amazonian Riverine communities	Corrected failures of previous solar projects with training and local maintenance; built local trust	Strengthened cultural identity, autonomy and community management; inspired youth	Expanding access and inclusion to energy and transport helped distribute power in the life of Achuar communities
Peru	ACT	Focusing communities in Non-Interconnected Zones to guarantee clean and safe access	Indigenous peoples and isolated rural communities (Colombia and Peru)	Reactivated old solar systems; regained local trust; created maintenance booklets	Greater organization capacity and collective resource management; energy solution allowed collective management activities	Better organization and community engagement, without major power changes
	DAR	Combated energy inequality in native and rural communities of Loreto	Indigenous, rural and Riverine communities	Prioritized renewable energy instead of fossil, adapted project to local reality and implemented financial sustainability mechanisms	Strengthened organization, autonomy and cultural identity using local knowledge in projects	Access to energy allowed empowerment of local leaders, increased community participation and created new community positions with division of responsibilities
Suriname	WWF	Yes	Coastal Indigenous community	Yes	Yes, with greater organizational capacity	No

high temperatures. Logistics, sometimes complex, required well-coordinated river routes, use of adapted vessels and detailed planning for displacement of heavy equipment to difficult access communities. In various situations, local teams were trained for work execution, integrating electricians, masons and helpers from the community itself or nearby localities.

Community participation in selection and understanding of technologies was significant. In some projects, the choice for solar energy or hybrid systems resulted from assemblies, meetings and comparisons between alternatives, in which costs, sustainability and ease of operation were discussed. There were cases where, although the final technical decision was conducted by specialists, residents were consulted regarding usage priorities and installation positioning. In almost all initiatives, community training was useful to teach about operation, maintenance and care of equipment, production of guidance booklets in accessible language and even structured programs to train local "solar electricians". This training effort sought to ensure technological appropriation and autonomy for system management and maintenance.

Technical challenges faced were diverse and demanded creative solutions. Transport logistics was a recurrent difficulty, mainly in areas with difficult navigation rivers or impassable roads during the rainy season. To overcome these obstacles, some teams organized community river transport or chartered vessels equipped with internet antennas for real-time communication. In certain contexts, lack of adequate tools in early installations was circumvented with duplicate equipment acquisition to allow simultaneous work by different teams. Absence of precise environmental data, such as solar radiation or river current speed, motivated development of remote monitoring systems to evaluate performance and adjust operations. Scarcity of technical labor also required specific training, including classes intended for women, in order to strengthen local maintenance capacity. Issues related to energy storage, such as limited lifespan of lead-acid batteries, were resolved with replacement by lithium batteries, more durable and efficient.

Regarding possibility of expansion or integration with other technologies, responses indicate distinct scenarios. In several cases, systems were designed to meet basic lighting and communication demands, without provision for significant expansion. However, some projects possess infrastructure that would allow incorporating new sources, if technical studies and financial resources are viable. There are mentions of biomass generation potential, use of cattle manure for gas production and integration with larger government systems, although in many places these alternatives are limited by logistical or community appropriation challenges. In other situations, existing hybrid systems, such as solar grids associated with diesel generators, already offer flexibility for moderate expansions or capacity adjustments.

Learnings with technical implementation of different energy generation and storage technologies and topologies of energy systems are systematized in **Table 26**.

5.4.5 Operation, maintenance and training

Information collection on operation and maintenance (O&M) and technical training of community energy agents (ACE) was structured in four questions, which can be analyzed in the content of **ANNEX 3**.

Experiences of operation, maintenance and training of renewable energy systems present patterns reflecting the diversity of community contexts and institutional arrangements in the Amazon. Generally, daily responsibility for operation and maintenance is assumed mainly by the communities themselves, with variations in external support level and internal organization form. In many cases, each family is responsible for household systems, while collective equipment, such as health posts and community centers, remain under the management of locally designated persons or groups. In some initiatives, community or technical organizations formed specifically for this purpose conduct operation, relying on occasional support from partner entities. There are also cases where local associations or chosen guardians take care of the system, being able to resort to technicians from the city or support institutions when necessary.

Table 26. Systematization of learning with technologies and technical implementation of energy systems of the pilot projects.

Country	Organization	Reason for technology choice	Adaptation to local conditions	Community participation and understanding	Technical difficulties and solutions	Possibility of expansion
Bolivia	WWF	-	-	-	-	-
Brazil	ISA	Studies indicated potential for hybrid systems (solar, wind, diesel and biomass) in Roraima; option for solar/diesel due to feasibility and costs in Mato Grosso	Installation planned according to dry and rainy seasons; technical training and local labor	Communities participated in assemblies, defined sources and had technical training	Logistical difficulties and rapid evolution of technological standards; resolved with electrician training program and updated equipment acquisition	Potential for biomass, run-of-river turbines or gas from cattle manure, although some options are not priority
	PSA	Solar photovoltaic for logistical feasibility and simple maintenance; option of integration with diesel in water pumping	Projects adjusted to climate, logistics and social context; local labor still limited	Communities participate in all stages, from diagnosis to post-installation management	Difficulties in equipment purchase and technical labor; resolved with external suppliers, "Electricians of the Sun" course and planning for dry periods	Possible, subject to feasibility assessment and available resources
	MSU	Solar, solar-diesel hybrid and hydrokinetic to test feasibility in the Amazon	Installations adapted to context: batteries and controls next to generator; turbine on floating platform with modified rotor	Communities chose micro-systems and participated in trainings	Lack of tools, internet and environmental data; solved with equipment purchase, internet antenna on boat and monitoring development	Possible, but requires additional studies; example of turbine and hybrid system in independent networks
	WWF	Modular solar, easy installation; hybrid solar/diesel microgrid in Vila Limeira to ensure supply in bad weather	Systems adapted to local realities	Communities participated and understood functioning	Few difficulties; previous experience helped foresee problems	No, except Vila Limeira hybrid system
Colombia	ACT	Solar photovoltaic for feasibility in remote areas, low maintenance and facilitated energy supply	Systems chosen according to climate, logistics and possibility of local maintenance	Communities participated in decision and received training and intercultural booklets	Equipment transport to difficult access areas and battery replacement	Cannot expand in residential; expansion in health posts/schools is possible, but not considered so far
	WWF	Solar energy after cost-benefit analysis	Standard equipment; adaptation in installation and protection of inverters; community labor in installation	Did not participate in the choice; received operational training	No relevant difficulty	Yes
Ecuador	Kara Solar	Solar systems reliable, safe and suitable for river transport in Ecuador	Projects adapted to tropical climate, solar radiation and river depth	Co-designed processes; training in operation and maintenance	Challenges of river logistics, transport and climate; overcome with local partnerships, planning and continuous maintenance	Potential for river micro-turbines, but climate change affects river current prediction
Peru	ACT	Solar photovoltaic for feasibility in remote areas, low maintenance and facilitated energy supply	Systems chosen according to climate, logistics and possibility of local maintenance	Communities participated in decision and received training and intercultural booklets	Equipment transport to difficult access areas and battery replacement	Cannot expand in residential; expansion in health posts/schools is possible, but not considered so far
	DAR	Solar photovoltaic chosen for constant radiation, favorable river logistics, legal framework and sustainability	Projects planned for Amazon climate, flood risk and logistics; prioritization of local purchases	Participatory selection with solar vs. diesel comparison; training in maintenance and use	Expensive river transport and short-life batteries; resolved with community logistics and adoption of lithium batteries	Studying hybridization and river turbine potential, still in early phase
Suriname	WWF	Community already familiar with solar energy and government project underway	Yes, adapted to climate and local logistics	Yes, participation and understanding	None	Possibility of expansion or integration into government project

Technical training is a recurring element, planned to strengthen community autonomy. Several initiatives promoted theoretical and practical trainings, from basic training on system use and panel cleaning to structured intermediate and advanced level programs. Some projects developed permanent workshops and specialized courses, training local electricians and technicians, including encouragement for women and youth participation. Methodologies combine face-to-face classes, illustrated booklets and continuous monitoring, and in certain cases include partnerships with universities, technical education institutes and private companies to ensure certification and higher quality of trainings.

Regarding performance, most systems operate stably, providing energy according to defined objectives. Reported failures concentrate on natural wear problems, such as battery lifespan, and environmental factors, such as humidity, connection corrosion and sediment accumulation in water pumps. Overload situations resulting from unplanned use were also cited, such as connection of equipment exceeding system capacity, in addition to logistical difficulties linked to parts transport and distance from assistance centers. In general, solutions include battery replacement, component adjustments and development of remote monitoring mechanisms for early failure detection.

The level of community technical autonomy varies according to system complexity. In localities where individual or smaller installations predominate, received training allows residents to perform preventive maintenance and small repairs, such as panel cleaning, cable checking and simple component changes. Whereas in more sophisticated systems, such as microgrids or hybrid structures, the need for specialized support is still significant, requiring the presence of external technicians for complex interventions or replacement of higher cost and sensitivity equipment.

Generally, projects demonstrate that the combination of practical training, technical monitoring and community participation is essential for the sustainability of renewable energy systems in isolated areas. Joint action of trained residents, local leaders and external partners, when well coordinated, ensures regular functioning and adaptation of solutions to cultural, environmental and logistical realities of the Amazon region.

Learnings with operation and maintenance (O&M) and technical training of community energy agents (ACE) are systematized in **Table 27**.

5.4.6 Financing and economic sustainability

Information collection on financing models and economic sustainability of energy systems implemented in different Amazonian communities was structured in five questions, which can be analyzed in the content of **ANNEX 3**.

Regarding financing and economic sustainability, analyzed electrification projects reveal a diversity of arrangements and financial maturity levels. Largely, initial resources came from philanthropic donations or international cooperation, frequently with complements from local counterparts and logistical support. Private funds, such as Mott Foundation's, were recurrent, while some initiatives also relied on public financing, partnerships with companies, support from universities or governmental institutions. In some cases, such as in certain Brazilian communities, there was additionally the donation of equipment from federal programs already closed or contributions from public bodies for transport and infrastructure.

Long-term economic sustainability presents different perspectives. Several projects consider their model viable, mainly because installed systems possess relatively low operation costs and can be managed locally. However, the need for replacement of components with limited lifespan, such as batteries and controllers, imposes challenges to financial autonomy. Some groups work with the creation of community funds aimed at these replacements, while others recognize the importance of maintaining external support or partnerships with public policies to ensure continuous maintenance and technical assistance. There are also initiatives planning to migrate to revenue generation models, such as leasing programs and moderate tariffs, in order to gradually reduce dependence on donations.

Table 27. Systematization of the learnings with operation, maintenance and training of community team for operation of the pilot projects.

Country	Organization	Current responsible for operation and maintenance	Local technical training	Functioning and failures	Autonomous technical capacity
Bolivia	WWF	-	-	-	-
Brazil	ISA	Communities or indicated local technicians; occasional support from ISA; strategic poles operated by health professionals or ATIX	Training programs with federal institutes, universities and companies, training dozens of electricians (including women)	Individual systems maintained by local technicians; microgrids require ISA support; failures linked to lifespan, electrical discharges and intense use	Autonomy for maintenance of individual systems; microgrids require external support
	PSA	At least two reference persons in each community	Initial training during installation and workshops "Electricians of the Sun" (theory and practice)	Stable systems; occasional failures linked to cleaning, connections or overload; repairs done by trained community members	Autonomy for preventive maintenance; dependence on external technicians for complex failures
	MSU	Elected person or group in each community; cases of autocratic leadership caused problems	Yes, with trainings and remote monitoring	General functioning stable; failure in pumping system due to oversi-zed pump and misuse in another community; resolved with new intake and guidance	Members trained for problem detection; remote monitoring under development
	WWF	Designated "Guardian" in each community; possible replacement by trained electricians	Initial theoretical and practical training; participants started installing systems alone	Regular functioning; failures in batteries and pumps due to sediments, solved with exchanges	Autonomous capacity for maintenance and equipment replacement
Colombia	ACT	Household systems: families; collective systems: Indigenous organizations and hospital coordination	Practical days in each community for use and maintenance, with illustrated booklets adapted to cultural context	Regular functioning; failures in batteries, controllers and parts, resolved with replacement and technical assistance	Basic autonomy for simple maintenance; external dependence for complex repairs
	WWF	Person responsible for ecotourism center (Guaviare); other projects not defined	Training after system definition and with manuals	System working; overload due to new equipment installation, without resources for immediate repair	Basic knowledge for maintenance; repairs depend on specialized technicians
Ecuador	Kara Solar	Achuar technicians from the communities themselves, with external support	Training at basic, interme-diate and advanced levels, with practical sessions and continuous support	Reliable operation; occasional stops in solar boats due to motor fra-gility, resolved with local maintenance and parts replacement	Communities trained to operate, maintain and repair systems routinely
Peru	ACT	Household systems: families; collective systems: Indigenous organizations and hospital coordination	Practical days in each community for use and maintenance, with illustrated booklets adapted to cultural context	Regular functioning; failures in batteries, controllers and parts, resolved with replacement and technical assistance	Basic autonomy for simple maintenance; external dependence for complex repairs
	DAR	Communities and leaders trained, with support from allies and DAR team	Practical workshops in community, with local coordination and culturally adapted material	Systems generally regular; failures in batteries, corrosion and overload; solutions with lithium batteries, connection protection and usage guidance	Partial capacity for basic maintenance; external dependence for complex repairs or battery replacement
Suriname	WWF	Community organization	Member training (including 3 women and 3 men) in maintenance and problem solving	Stable functioning; projector failure, resolved by safety device tripping	Capacity for simple maintenance and small repairs

Establishment of tariffs or community contributions also varies widely. In collective use systems, it is common to define fees in local assemblies, with collection and management by committees or associations of the community itself. These resources are directed to preventive maintenance, equipment replacement and, in some cases, to remuneration of local operators. In residential or small-scale contexts, many experiences opted not to charge for energy use, adopting only voluntary contributions or informal agreements. In communities that established tariffs, values were calculated to be lower than costs previously paid for the use of fossil fuels, facilitating adherence and encouraging financial discipline.

Management of default and maintenance costs is treated in a way adapted to each reality. In communities where there is regular charging, dialogue and installment renegotiation strategies are common, while others resort to adjustments in contribution value to compensate for non-payment by some residents. In several cases, local associations directly administer funds and monitor consumption, ensuring transparency and avoiding public embarrassment. This community governance reinforces co-responsibility and system sustainability, although there is still dependence on external support in situations requiring complex repairs or replacement of expensive components.

Some initiatives have begun exploring or are already implementing more structured organization models, such as energy communities, registered associations or cooperatives. These experiences strengthen local management, allowing greater collective participation and favoring expansion of access to energy. In other localities, debate on creation of funds or cooperative models is still ongoing, with the perspective of consolidating practices that ensure continuity and efficiency of implemented systems, aligning community self-management with long-term financing mechanisms.

Learnings with financing models and economic sustainability of pilot projects implemented in communities are systematized in **Table 28**.

5.4.7 Results and impacts

Information collection on results and impacts of pilot project implementation on the life and structure of Amazonian communities was structured in five questions, which can be analyzed in the content of **ANNEX 3**.

Analyzed electrification projects demonstrated broad impacts on essential public services and daily life of served communities. In terms of services, significant improvement was observed in health, with energy for operation of basic medical equipment, medicine conservation and health post operation at extended hours. In education, lighting in homes and schools expanded study hours, enabled use of computers and printers and enabled night pedagogical activities. Communication also benefited significantly, through cell phone charging, satellite internet installation and greater use of community radios. In some cases, sanitation was reinforced, especially with water pumping systems, and transport began to include clean mobility solutions, such as solar boats.

Renewable energy systems also opened space for new economic activities and income increase, albeit heterogeneously. In various localities, electrification reduced production costs and allowed economic diversification. There were advances in community-based tourism, handicraft production and value addition to local products, such as fruit pulps and fish derivatives. Refrigeration enabled food processing and storage, reducing post-harvest and post-fishing losses, in addition to enabling bakery ventures with native inputs. In some contexts, transport systems moved by solar energy improved access to markets, reinforcing production chains linked to agriculture, fishing and bioeconomy. In others, energy served mainly for domestic needs, with more indirect economic impacts.

Effects on the lives of women, youth and vulnerable groups were consistent. Electricity availability reduced time dedicated to domestic tasks, such as fetching and transporting water, washing clothes and food conservation, allowing greater involvement in productive and educational activities. Women began to have more

Table 28. Systematization of the learnings of financing and economic sustainability of the pilot projects.

Country	Organization	Financing sources	Model sustainability	Tariffs and local contributions	Default management and maintenance costs	Cooperative or community models
Bolivia	WWF	–	–	–	–	–
Brazil	ISA	International donations, partnerships with companies, universities and public funds (Amazon Fund, Climate Fund)	Sustainable when integrated with public policies; in self-management requires local partnerships	No tariffs, but debate on creating battery fund	–	–
	PSA	Public, private resources and donations	Community self-management viable for collective systems	Tariffs only in collective systems, defined by management committees	Internal rules for default; part of productive income covers maintenance	Self-management model, not cooperative
	MSU	National Science Foundation (USA) and Mott Foundation	Sustainable if there is community fund for replacement of batteries and other components	Monthly fund per family to exchange batteries; values between R$72 and R$78	Treated in assemblies; leadership redefines quotas in case of default	No
	WWF	Mott Foundation, PRODEEM (equipment), ICMBio support, Lábrea Municipality and UEA	Vila Limeira: sustainable; schools depend on public support	Vila Limeira: tariff of R$1/kWh, managed by association	Community fund covers maintenance; dialogue in cases of default	Vila Limeira operates as energy community
Colombia	ACT	Mott Foundation and ACT counterpart	Viable in medium term; depends on parts replacement and technical assistance	Voluntary contributions or internal agreements defined in some communities	Without formal charging, there is no structured default management	Did not adopt cooperatives/consortia
	WWF	Mott Foundation	Community created replacement fund with fuel savings	No tariffs	Maintenance costs covered with fuel savings	Communities act as registered associations
Ecuador	Kara Solar	Private philanthropy, donations, IDB support	Depends on philanthropic support; plans transition to sustainable lending model and small fees	No energy charge; some communities pay Starlink	No energy charge; maintenance covered by organization	Community associations and study of cooperative model
Peru	ACT	Mott Foundation and ACT counterpart	Viable in medium term; depends on parts replacement and technical assistance	Voluntary contributions or internal agreements defined in some communities	Without formal charging, there is no structured default management	Did not adopt cooperatives/consortia
	DAR	International technical cooperation donations, non-monetary support from allies and community contributions	Partial sustainability; battery replacement not yet covered	Some associations created symbolic tariffs defined in assemblies	Community governance with DAR support; default still under adjustment	Explores community models and water savings for maintenance
Suriname	WWF	Donors: Mott and WWF network	*Sustainable if remaining off-grid*	Tariffs do not apply, only suggestions	Not applicable	No

income generation opportunities, leadership in local enterprises and participation in technical courses, while young people expanded their study time, including in distance learning, and engaged in productive initiatives. In some regions, specific technical training for women sought to reduce gender barriers in functions linked to system operation and maintenance.

Regarding reduction of economic vulnerabilities, projects contributed in different ways. Substitution of candles, kerosene, batteries and diesel generators resulted in lower spending on fossil fuels, stabilizing family and community budget. In localities with cold chains, food and fish losses decreased, strengthening food security and economic resilience. In some cases, possibility to process and conserve products raised family economic autonomy, especially for women, and reduced dependence on extractive activities or volatile markets.

Finally, strengthening of production chains varied according to context. Projects linked to agriculture, fishing, bioeconomy and tourism benefited from reliable access to energy, expanding production capacity and product marketing. Even in communities where productive integration is still incipient, electrification already provides better conditions for communication, storage and management, creating bases for future more complex economic initiatives.

Learnings with results and impacts on people's lives and community structure with implementation of energy systems of pilot projects are systematized in **Table 29**.

5.4.8 Environmental sustainability

Information collection on environmental sustainability of implementation, operation and decommissioning of energy systems was structured in three questions, which can be analyzed in the content of **ANNEX 3**.

In terms of waste management, some organizations have not yet needed to perform disposals, as photovoltaic systems remain within their useful life. However, several already plan or implement specific procedures. There are cases of community guidance and partnerships with reverse logistics companies for future battery replacements, while others already perform collection and recycling of lead-acid batteries or reuse of damaged panels in educational or decorative activities. Some institutions also opt for components with longer durability, such as lithium batteries, to reduce waste generation in the short term.

Reported environmental impacts were predominantly positive. Substitution of diesel generators, candles and batteries with solar energy reduced greenhouse gas emissions, noise pollution and contamination risks from fossil fuels. In certain projects, renewable energy also contributed to avoiding deforestation by reducing the need for motorized transport. Negative effects were minimal or potential, such as possibility of improper battery disposal or increase in plastic waste associated with new productive activities.

Regarding monitoring, some organizations already calculate or estimate avoided CO_2 emissions, applying recognized methodologies, while others maintain partial records or develop specific studies to improve measurement. In general, increasing concern with emission mitigation and creation of structured reverse logistics processes is observed, pointing to gradual advances in consolidation of project environmental sustainability.

Learnings with environmental sustainability of implementation, operation and decommissioning of pilot projects are systematized in **Table 30**.

5.4.9 Governance and community management

Information collection on governance structure and community management of energy systems implemented in different communities was structured in four questions, which can be analyzed in the content of **ANNEX 3**.

Governance and community management models of energy systems present diversity, but maintain common elements of participation and co-responsibility. In some contexts, the form of management varies according to solution type: in domestic systems responsibility is individual, while in collective facilities, such as health posts or community headquarters, administration is conducted by locally

Table 29. Systematization of the results and impacts on people's lives and community structure with the implementation of pilot projects.

Country	Organization	Benefited public services	New economic activities / production or income increase	Influence on life of women, youth or vulnerable groups	Reduction of economic vulnerabilities	Strengthening of production chains
Bolivia	WWF	Fruit processing	Production cost reduction	Productive activities; women's participation in technical courses on photovoltaic system maintenance	Reducing electricity costs in remote areas to benefit producers	Strengthening the açaí and almond supply chain
Brazil	ISA	Health, education, drinking water, communication	Small activities like product refrigeration, motorcycle and bicycle workshops, handicrafts	Night study and handicraft production by youth and women	Reduced spending on batteries; greater possibility of online commerce	Potential for greater future integration; support to fishing and agriculture (lighting and communication)
	PSA	Health, education, communication and sanitation	Community tourism, irrigation, fruit processing; production cost reduction	Reduced time in domestic tasks and greater participation of women and youth in productive activities; technical courses for women	Expansion of energy access for productive uses, strengthening economic autonomy	Integration with tourism, fish feed factory, fruit pulp processing
	MSU	Education (lighting and internet in schools), health (food refrigeration and drinking water), communication (Starlink), sanitation (water pumping)	Start of agroforestry projects and support for local trade via internet	Reduction of domestic work; use of washing machines; children with fresh school meals	Decrease in electricity costs in remote areas	In initial phase of productive integration
	WWF	Lighting, health, education, communication, water, refrigeration, extractive production, leisure	Forest restoration with açaí seedling nursery, greater agility in cassava flour production, açaí processing	Women with more free time, use of appliances, possibility of distance learning	Elimination of fuel costs for water pumping and production	Strengthening of cassava and açaí chains
Colombia	ACT	Health (basic equipment, medicine conservation), communication (cell phone charging, radios), indirect education (home lighting)	Craft production during night hours	More time for income generation and support for children's education; youth with better study conditions	Reduced spending on candles, kerosene and batteries, but without structural poverty changes	No relevant integration with agriculture, fishing or tourism; domestic impact only
	WWF	Lighting, education, entertainment, refrigeration	Did not create new activities, but reduced spending on fuel and extended service time	Reduced travel to obtain food and drinks thanks to refrigeration	Reduction of cost with fossil fuel	Strengthening of tourist activity and reduction of noise pollution
Ecuador	Kara Solar	Clean river transport, health, education (student transport), communication	Tourism, handicrafts, better access to agricultural and fishing markets	Reduction of domestic tasks, more time for handicrafts; children study at night; support for people with disabilities	Less dependence on fossil fuels and energy costs; strengthening of tourism and handicrafts	Integration with agriculture, fishing, bioeconomy and ecotourism
Peru	ACT	Health (basic equipment, medicine conservation), communication (cell phone charging, radios), indirect education (home lighting)	Craft production during night hours	More time for income generation and support for children's education; youth with better study conditions	Reduced spending on candles, kerosene and batteries, but without structural poverty changes	No relevant integration with agriculture, fishing or tourism; domestic impact only
	DAR	Health, education, communication; support for local economy with cold chain	Bakery with native inputs, fish and meat processing, native fruit drinks, handicrafts	Reduction of domestic time; greater female economic autonomy; youth with access to study and local work	Income diversification, reduction of post-harvest/fishing losses, greater food security and community resilience	Strengthening of agriculture (native fruits), fishing (processing), bioeconomy (handicrafts and drinks)
Suriname	WWF	Communication and education	–	Three women trained in basic solar system maintenance	–	Tourism

chosen representatives. In other localities, management also alternates between individual responsibility or committees, with technical rules previously passed on and suggested funds for maintenance.

There are experiences prioritizing more formal collective structures, adopting community self-management and training of residents to operate, monitor and maintain systems, which ensures autonomy and local strengthening. In some communities, formal associations assume full management, while in others operation is more informal. In certain cases, specific community entities received detailed financial calculations to plan reinvestments and monitor long-term costs. In others, administration is integrated into existing associations, with active resident participation.

Decisions on technical issues or modifications to systems are usually made in open meetings or assemblies, often complemented by local cultural practices of deliberation. In some situations, a designated electrician or technician answers to community leadership and population, with decisions validated in collective meetings. In certain places, responsibility is incorporated into productive associations and surveillance committees, still in process of defining clear norms adapted to cultural reality.

Generally, rules of use, maintenance, tariffs and conflict resolution are debated and agreed upon collectively, strengthening the sense of ownership and co-responsibility. Most communities demonstrate a feeling of responsibility and autonomy, although in some cases there are limitations related to technical complexity and equipment cost.

Learnings with technical implementation of different energy generation and storage technologies and topologies of energy systems are systematized in **Table 31**.

5.4.10 Learnings and recommendations for public policies

Information collection on technology and topology of electric energy generation and storage and technical implementation of energy systems was structured in five questions, which can be analyzed in the content of **ANNEX 3**.

The set of analyzed experiences reveals a wide spectrum of lessons learned in electrification initiatives with renewable sources in Amazonian communities and other remote contexts. Despite different territorial and institutional realities, reports converge in pointing out significant logistical challenges, the need for participatory implementation strategies, the importance of local training and the relevance of regulatory and financial adjustments for expansion and sustainability of these projects.

One of the most recurring obstacles is complex logistics. Transport of equipment to difficult access regions requires detailed planning, high costs and, in many cases, creative solutions to overcome geographic and climatic barriers. Riverine or dense forest communities reported that movement of materials depends on river and road conditions, which can delay schedules and increase expenses. In some places, adverse climate imposed navigation restrictions, while in others presence of hostile groups raised operational risk. Distance from suppliers and scarcity of local technicians for specialized maintenance amplify the challenge, making essential logistic planning that considers seasonal and cultural particularities of each territory.

To deal with these limitations, several strategies proved effective. Formation of alliances with community leaders, local associations, municipal governments and research institutions was widely used to legitimize actions, facilitate logistics and create a continuous support network. Previous work of approach and dialogue with communities proved decisive to build trust relationships, ensure participation in all stages and avoid conflicts. In many cases, selection of quality equipment and training of residents to perform basic maintenance reduced dependence on external support and prolonged system lifespan.

Community training, in turn, emerged as central element. Practical workshops, accessible pedagogical

Table 30. Systematization of the learnings with the environmental sustainability of the pilot projects.

Country	Organization	Waste management	Environmental impacts	Monitoring / Avoided emissions
Bolivia	WWF	Guidance to associations on proper waste disposal and coordination with local governments. It is anticipated that waste will be generated over the long term	Positive: lower fossil dependence	No formal monitoring; emission reduction inferred due to fossil fuel exchange
Brazil	ISA	Waste removed during works; partnership with reverse logistics company for future battery replacement	Positive: reduction of smoke and noise; limited visual impact	Estimates possible, but without formal calculation; in one pole there was 75% reduction in diesel consumption
Brazil	PSA	Management addressed in installations and training; disposal of lead-acid batteries at authorized points; lithium batteries with reverse logistics in partnership with manufacturer; damaged equipment donated to laboratory or stored	Positive: lower GHG emission and lower fossil dependence; challenge: lack of complete reverse logistics for all components	No continuous system; performs specific estimates and develops study with UFOPA
Brazil	MSU	Still no need for disposal; educational video production to guide communities; first battery exchange scheduled	Positive: emission reduction with replacement of diesel generators; no negative impact observed	Estimated calculation of 44,669.82 kg of CO_2 avoided until Aug/2025
Brazil	WWF	Battery exchange done by electrician and sent to manufacturers; damaged panels reused or recycled; defective donations disposed for recycling, although municipal collection is precarious	Positive: reduction of GHG, elimination of noise and fuel disposal in soil; no negative impacts	No
Colombia	ACT	Systems still in useful life; procedure for battery and component disposal under elaboration with authorities and managers	Positive: substitution of candles, batteries, gasoline and diesel; no negative occurrence	No formal monitoring; emission reduction inferred due to fossil fuel exchange
Colombia	WWF	Communities guided for proper disposal, but without formal process; waste expected only in long term	Positive: lower GHG emission and noise; potential risk of future improper disposal	Online monitoring in jaguar corridor, includes renewable energy use
Ecuador	Kara Solar	Collection of used batteries for recycling; minimization and storage of other waste; logistics under development	Positive: reduction of air and water pollution, lower emissions	Monitors fuel displacement, calculates CO_2 avoided and deforestation prevented with construction of land roads
Peru	ACT	Systems still in useful life; procedure for battery and component disposal under elaboration with authorities and managers	Positive: substitution of candles, batteries, gasoline and diesel; no negative occurrence	No formal monitoring; emission reduction inferred due to fossil fuel exchange
Peru	DAR	Still without management program; prefers longer life equipment (lithium batteries) to reduce waste	Positive: reduction of fossils and deforestation; food conservation; valorization of forest products; potential risks of improper battery disposal, increase in plastics and solid waste	Maintains database since 2018 with CO_2 calculations avoided according to IPCC standards
Suriname	WWF	-	-	-

materials and training of community energy agents strengthened technical autonomy and co-responsibility. In some projects, participation of women was prioritized, promoting gender equity and expanding knowledge dissemination. This approach not only ensures daily operation, but also reinforces local governance, allowing decisions on maintenance, tariffs and energy use to be made collectively, with greater transparency and commitment.

Another important lesson is the need to integrate energy solutions into existing social and productive processes. Electrification of schools, for example, was highlighted as strategic starting point, as it extends benefits to the whole community, enabling everything from food conservation in community freezers to internet access. In regions where local economy depends on activities like fishing, agriculture and bioeconomy, availability of reliable energy boosts production chains and reduces losses, becoming driver of sustainable development. In some cases, electricity was incorporated into local value chains, such as bakery, fish processing and handicrafts, expanding economic opportunities.

Initiatives also evidence relevance of decentralized energy generation. Opposed to centralized model, which often does not reach isolated areas, distributed generation proved viable and efficient when adapted to context. Solar-diesel hybrid system projects, community microgrids and autonomous solutions were cited as reliable alternatives, especially in localities distant from national grids. Energy autonomy, besides ensuring access to basic services, reinforces territorial sovereignty and reduces need for road or transmission line expansion, which can generate environmental and social impacts.

From regulatory and financial point of view, experiences point to bottlenecks limiting scalability of these initiatives. Many projects operated parallel to existing public programs, without direct articulation with national electrification policies. In some cases, there was dialogue with energy access programs, but integration was partial or insufficient. Absence of adequate financing mechanisms for small community projects is another obstacle: implementation in remote areas raises logistical costs and demands specific subsidy models, often non-existent. Dependence on external resources for long-term maintenance was also identified as weakness, reinforcing need for public policies contemplating not only installation but continuous support.

Among recommendations derived from these experiences, stands out creation of policies recognizing and supporting collective use systems with community management. This includes definition of legal frameworks facilitating operation of microgrids, isolated micro-generation and hybrid arrangements, as well as clear norms for reverse logistics and equipment disposal, especially batteries and electronic components. Financial incentives, such as specific credit lines, subsidies for isolated communities and payment mechanisms for environmental services, are also considered essential to enable system expansion and maintenance. Some initiatives also suggest incorporation of intercultural and territorial criteria in electrification programs, so as to respect diversity of ways of life and ensure just energy transition.

Participation in experience exchange networks appears as opportunity to strengthen local capacities and influence policies. Some organizations reported involvement in regional and international forums on renewable energy and electrification of remote areas, which enables practice sharing, access to innovation and construction of partnerships for climate finance. These exchange spaces allow communities to learn from each other, expand their technical repertoire and become protagonists in formulating sustainable energy solutions.

Another relevant finding is that economic viability of systems cannot be evaluated only by number of beneficiaries. In many cases, population density is low, but social and environmental impact is high, justifying public and private investments. Lessons learned show success does not depend exclusively on technology, but on how it is implemented: with effective participation, continuous training, integration to productive activities and post-installation monitoring.

Table 31. Systematization of the learnings of governance and community management of the pilot projects.

Country	Organization	Adopted management model	Rules of use, tariffs, maintenance and conflict resolution (community participation)	Decisions regarding problems or changes	Community responsibility and autonomy
Bolivia	WWF	Management through a producer's association	Use, maintenance, and dispute resolution as defined in coordination meetings and formalized in agreements with the producers' association	The producers' association assembly decides on the measures that need to be taken and how to implement them	The responsibility lies with the producers' associations
Brazil	ISA	Indicated electrician answers to leadership and community	Rules agreed previously; conflicts discussed in periodic meetings	Local leadership decides on daily basis, confirmed by community in meetings	Community feels responsible, but faces technical and cost limitations
	PSA	Community self-management for collective use systems	Rules debated and agreed in workshops and meetings, ensuring understanding and acceptance	Decisions made in meetings or assemblies, with PSA technical support when necessary	High level of autonomy and sense of belonging, strengthened by continuous training
	MSU	Individual or committee, depending on community	Technical rules passed on; tariffs suggested by team and accepted or not by community	Varies by community; local leadership decides, team intervenes only if requested	Communities feel responsible and autonomous
	WWF	Management via association (e.g., Apavil in Vila Limeira); in other cases, informal community management	In Vila Limeira, rules defined collectively; in others no detailed data	Association assembly defines actions when necessary	Communities, especially Vila Limeira, demonstrate responsibility and autonomy
Colombia	ACT	Varies: individual (families), community organization (health posts) or designated representatives	Rules defined in participatory spaces, with clear and accepted community agreements	Community tries to solve with trained people; if necessary, activates ACT	Communities are responsible and autonomous; changes are made according to technical capacity and resources
	WWF	Management via association	Basic commitments defined in community agreement, without formal conflict rules	Community decides and informs organization in case of anomalies	Communities feel responsible and autonomous
Ecuador	Kara Solar	Community management with active participation of local members and organization support	Rules defined in assemblies and formal agreements, socialized and approved by community	Decisions in assemblies and traditional ceremonies, with technical support from team	Communities see themselves as main managers of systems
Peru	ACT	Varies: individual (families), community organization (health posts) or designated representatives	Rules defined in participatory spaces, with clear and accepted community agreements	Community tries to solve with trained people; if necessary, activates ACT	Communities are responsible and autonomous; changes are made according to technical capacity and resources
	DAR	Community and productive, integrated into existing associations or surveillance committees	Process underway for participatory definition of clear and culturally adapted norms	Collective decisions in coordination with DAR or partner institutions	High degree of co-responsibility; process of strengthening internal governance underway
Suriname	WWF	Community association (Stidunal)	Rules and financial analysis presented and discussed with community; reinvestment forecast	Trained community informs association for problem solution	Communities feel responsible and autonomous

Several projects reinforce that clear communication is indispensable. It is necessary to explain to beneficiaries system functioning, load capacity and usage limitations, avoiding unrealistic expectations and preventing conflicts, such as unauthorized use compromising energy efficiency. Construction of usage and maintenance rules, as well as tariff definition when applicable, must be done participatively to ensure understanding and adherence of all users.

In terms of replicability, participatory processes of diagnosis and decision, local technical training, flexibility to adapt solutions to needs of each community and strengthening of internal governance are characteristics that stand out. Community self-management experiences demonstrate that, when residents are protagonists, technical and social sustainability is greater. Direct community involvement in installation, maintenance and monitoring stages creates sense of belonging and increases commitment to proper system functioning.

Finally, contribution of energy solution initiatives enabled by philanthropic support to public policies for access to electric energy in the Pan-Amazon region is clear. Experience shows it is possible to ensure access to electricity sustainably and conciliatory with local knowledge, even if context is challenging. Replication of gains obtained by mentioned experiences will depend on integration between appropriate technologies, community participation, continuous training and support to territory organizations.

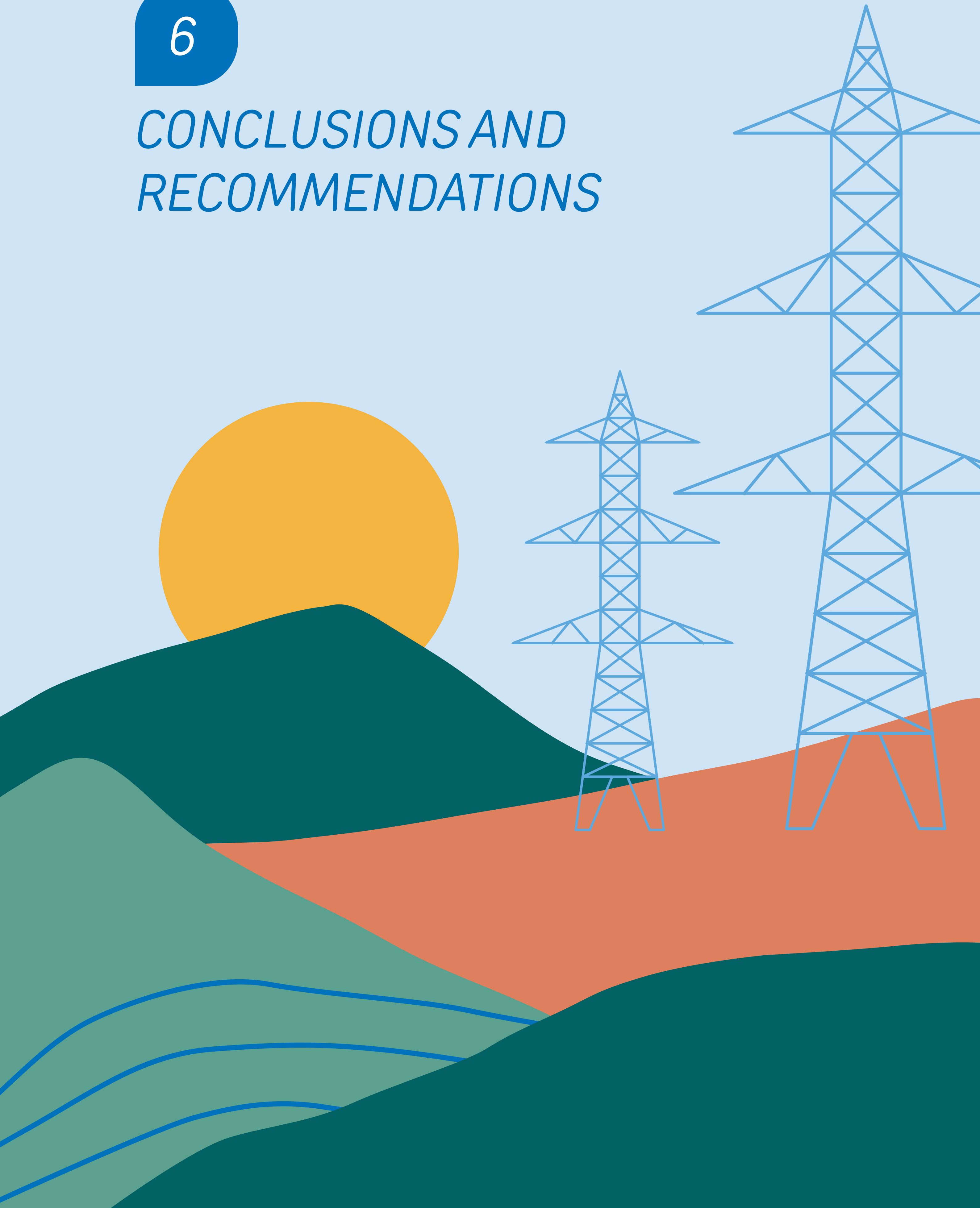
Learnings and recommendations for implementation and perennity of projects implemented with aim to guarantee access to sustainable, quality electric energy with community consultation and participation, respecting rights of traditional populations are systematized in **Table 32**.

Table 32. Systematization of the learnings and recommendations for public policies.

Country	Organization	Main Challenges	Effective Strategies	Lessons for Public Policies	Replicable Elements	Dialogue with Public Programs	Necessary Legal and Financial Adjustments	Exchange Networks
Bolivia	WWF	Responsibility for maintaining systems and strengthening organizational management	Partnerships with government programs, universities, and producer associations to improve equipment maintenance	Promote renewable energy expansion through government initiatives by supporting producers with technical oversight and post-installation assistance	Ongoing technical training, management agreements with beneficiaries and local governments	Dialogue and coordination among different levels of government	Fund national policies to support Amazon projects and engage multilateral institutions in their implementation	Share experiences at national events and exchange lessons learned with WWF Colombia
Brazil	ISA	High logistical and governance costs, growing demand.	Community involvement and partnerships with research institutions, climate adaptation.	Policies must contemplate generation for productive activities and battery renewal.	Technical training, installation by task forces, management pacts.	Dialogue with Light For All Program.	Regulatory adjustments for low-cost energy supply for productive uses.	Exchange limited to nearby communities.
	PSA	Logistics in remote areas, need for continuous training, waste management, financial sustainability and limited integration to public policies.	Practical training of local agents, community self-management, partnerships with universities, planned logistics, gradual dialogue with public bodies.	Incentivize self-management models and create norms for equipment reverse logistics; permanent community training.	Community self-management, continuous trainings, integration between technical and local knowledge.	Independent action, but influenced inclusion of solar energy in Cisterns Program.	Recognition of collective systems in federal programs; creation of promotion lines and subsidies for isolated areas.	Energy and Communities Network and exchange meetings.
	MSU	Cultural, logistical and operational challenges; need for equipment advancement by suppliers.	Reliable local commercial partnerships.	MIGDIs are viable if there is community ownership sense; the more reliable the system, the more community engages in caring for it; priority for school electrification.	System co-design, MIGDIs in concentrated communities, resident training (encouraging female participation).	Action in areas outside scope of electric energy access universalization programs.	Legal incentives for MIGDIs and stimulus for use of clean sources instead of fossils.	Energy and Communities Network and contacts with other projects.
	WWF	Technical language adaptation, maintaining communication with dynamic communities, energy use conflicts.	Detailed project design, intense dialogue with leaders and public bodies, flexible suppliers.	Need for differentiated approach for remote regions, avoid standardizing energy solutions without considering local context, integration between executor, planner and consumer	Prior dialogue, clear communication on energy use and maintenance instruction.	Connection with Light for All and participation in debates and state law formulation.	Studies on microgrid use, maintenance of tariff exemption for low income.	National Council of Extractivist Populations, Energy and Communities Network.
Colombia	ACT	Difficult access, logistical and climatic limitations, few suppliers and technicians;	Previous relationship, participatory planning with leaders, use of quality equipment, resident training for maintenance.	Success depends on community processes, technical monitoring and respect for local structures. PP must prioritize local capacities and quality equipment with post-installation technical support.	Participatory process, maintenance training, articulation with community processes.	No formal dialogue.	Flexible norms for small-scale community projects and clear rules for waste management; financial support for high logistical costs.	Did not participate
	WWF	Costs higher than expected and consumption increase with more service hours.	Constant dialogue with community and technical team.	Incentivize small projects and energy communities, creating differentiated financial incentives.	Characterization methodology, online monitoring, community agreements.	No formal dialogue.	Support for project structuring and adequate financing.	Does not participate in networks.
Ecuador	Kara Solar	Road expansion, lack of long-term financing, scarcity of local technical capacity.	Community technical training, strategic alliances with governments and associations, use of local ties to overcome barriers.	Proves viability and effectiveness of decentralized generation and community energy autonomy.	No replication restrictions: most important is having methodology adapted to local context; solar systems in river transport with recharge system.	Dialogue with multimodal port plan of Pastaza Province.	Policies to finance solar mobility technologies in the Amazon; multilateral institution support.	Participation in clean energy events and networks in the Amazon.
Peru	ACT	In some places, presence of hostile groups. Difficult access, logistical and climatic limitations, few suppliers and technicians;	Previous relationship, participatory planning with leaders, use of quality equipment, resident training for maintenance.	Success depends on community processes, technical monitoring and respect for local structures. PP must prioritize local capacities and quality equipment with post-installation technical support.	Participatory process, maintenance training, articulation with community processes.	No formal dialogue.	Flexible norms for small-scale community projects and clear rules for waste management; financial support for high logistical costs.	Did not participate
	DAR	Logistics in remote areas, need to integrate technical and local knowledge, organizational strengthening.	Alliances with governments and local committees, participatory design with broad social inclusion.	Policies must recognize community models and create differentiated financial mechanisms for the Amazon.	Integration to production chains, use of renewable energies in bioeconomy, participatory methodology.	Articulation with management plan of Pucacuro Reserve and regional clean energy norms.	Inclusion of decentralized renewables in legislation, creation of funds and climate incentives.	Amazonian, national and international networks of community energies.
Suriname	WWF	Adverse climate and remote access; difficult transport.	Transport planning avoiding bad weather times.	Projects must be adapted to local needs to ensure autonomy.	Analysis of bottlenecks and barriers before installation.	Link to "Suriname Villages Micro-grid Solar Project Phase II".	-	Participation in national dialogues on renewable energies and remote area electrification.

6

CONCLUSIONS AND RECOMMENDATIONS



6.1 MAIN CONCLUSIONS

The Pan-Amazon region presents persistent pockets of electricity exclusion in remote areas of low population density, without infrastructure and with subsistence economies, even in the face of national coverage rates exceeding 91%.

Access to energy must be treated as a fundamental right and an enabling condition for health, education, food security and productive inclusion, especially in Indigenous territories, Quilombola communities, Riverine communities and Extractivists.

On a global scale, the advance until 2023 (91.7%) is insufficient for SDG 7 (Sustainable Development Goal 7), with deceleration of the expansion pace and deficit concentrated in remote rural areas and low-income populations.

Universalization requires hybrid portfolios of solutions (solar, wind, biomass, battery storage) articulated with different topology models (grid extension, microgrids and off-grid systems), ensuring at least Tier 3 for implementation of energy systems to enable productive uses and essential services.

Experiences such as PERMER (Argentina), LPT (Brazil), PNER (Colombia and Peru) and FERUM (Ecuador) evidence that multi-agent and decentralized arrangements, supported by clear regulatory frameworks and stable funds (FAER/FAZNI/FOES, FERUM, CDE, FISE), ensure greater sustainability, while centralized models, such as SL in Venezuela, showed vulnerabilities.

Technical-contextual standardization (SIGFI/MIGDI in Brazil, minimum requirements in Peru) increased reliability and facilitated O&M. Even so, bottlenecks persist related to the cost of microgrids, low reliability of part of the off-grid systems and data fragmentation, evidencing the need for georeferenced registries and independent audits.

Scientific literature shows predominance of technical analyses (88%), with low integration of social, economic, environmental and gender dimensions. Solar PV systems with storage predominate, many still complemented by diesel (60%). Reports highlight reduction of operational costs, substitution of fossils (generating more than USD 200 thousand per year in savings for the community and up to 854 tCO_2/year avoided) and socioeconomic gains (expansion of study time, use of appliances, strengthening of production chains), but also gaps in financing, O&M, technological transfer and community participation.

The quantitative analysis of pilot projects funded by the Mott Foundation between 2016 and 2025 showed service to 223 communities and 90 households in six countries, benefiting more than 70 thousand people (42,372 direct and 28,248 indirect). Solar PV technology predominated (86% with batteries), with purposes of community electrification (35%), residential lighting (26%), sanitation/pumping (13%) and others (education, health, communication, transport). Socioeconomic impacts include income increase (up to US$ 361/month in community electrification projects), improvement of public services and reduction of manual labor (up to 50 hours per week in Indigenous territories). From an environmental point of view, 99.7% of communities reduced diesel use, with 32% having total elimination. Solar transport projects accounted for more than 200,000 liters of avoided fuel.

The qualitative assessment evidenced the importance of integral community participation - from diagnosis to system management - as a factor for strengthening governance and local appropriation. Solutions adapted to traditional knowledge expanded efficiency and acceptance. However, challenges persist in O&M (batteries, specialized maintenance, long-term financing). Gender inclusion remains limited, only 15% of those trained were women, with even lower participation in Indigenous territories, although there is greater female involvement in Riverine and rural areas, mainly in system management and governance. Good practices include reverse logistics and monitoring of avoided emissions.

The conclusions reinforce the strategic value of pilot projects as public policy laboratories, demonstrating the technical and social viability of decentralized electrification, even if on a limited scale. These learnings offer fundamental subsidies for the design of inclusive, economically viable and environmentally sustainable policies adjusted to local contexts.

6.2 STRATEGIC RECOMMENDATIONS

Based on the results and conclusions obtained in the different analyzed axes, it is essential that public policy frameworks and programs for access to electric energy explicitly incorporate the territorial and cultural heterogeneity of the Pan-Amazon region and other regions.

In this sense, to guide this process, seven axes of strategic recommendations aimed at improving policies for access to electric energy are proposed. The adoption of these recommendations is fundamental so that the transition to renewable systems ensures not only the expansion of access, but also the promotion of social equity, environmental conservation, the guarantee of territorial rights and the sustainable development of the region.

Axis 1. State public policy

- Institutionalize universalization as State policy, with regulatory predictability, multi-year goals and integration into territorial planning.
- Structure *least-cost* hybrid portfolios (grid, microgrids, off-grid), guaranteeing Tier 4 as minimum threshold.
- Consolidate decentralized multi-agent governance, with national coordination, local execution and independent audits.

Axis 2. Regulation and instruments

- Create specific frameworks for microgrids and isolated systems, including technical standards, commissioning, social pricing and O&M protocols.
- Establish contextual standardization (SIGFI/MIGDI and similar), with catalogs of solutions adapted by territorial typology.
- Make beneficiary participation mandatory in all phases, with free, prior and informed consultation (FPIC) in Indigenous territories and other traditional territories.

Axis 3. Financing and economic affordability

- Create stable CAPEX + O&M funds, with rules for disbursement by performance and lines dedicated to battery replacement.
- Adopt *de-risking* instruments (guarantees, *blending*, *concessional finance*) to attract private capital without compromising the social function of electrification.
- Structure differentiated social tariffs for isolated communities and stimulate energy cooperatives and community funds.

Axis 4. Operation, maintenance and training

- Implement life cycle plans for systems, foreseeing expansion, maintenance and replacement.
- Ensure continuous technical training for local residents, focusing on women and youth, ensuring certification of community technicians.
- Prioritize technologies with greater reliability and lower Life Cycle Cost (LCC), such as lithium batteries.

Axis 5. Data, monitoring and oversight

- Create georeferenced registries and public dashboards with technical, social, economic and environmental indicators.
- Implement *ex-ante*, intermediate and ex-post evaluations, with metrics of energy justice and gender.
- Ensure independent audits to strengthen transparency and learning.

Axis 6. Social and gender inclusion

- Define clear goals for female participation in technical and leadership functions.
- Create training programs and specific scholarships for women and youth in isolated territories.
- Adapt tariff and service design to socioeconomic realities of vulnerable groups.

Axis 7. Multilateralism and philanthropy

- Align international cooperation with national energy plans, prioritizing innovation, institutional strengthening and monitoring.
- Direct philanthropy as a laboratory for public policies, to test solutions, generate evidence and support replication at scale.

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ANNEX 1

Table 33. Complete multi-tier matrix to measure access to electric energy supply.

<table>
<tr><th>Attributes</th><th></th><th>Tier 0</th><th>Tier 1</th><th>Tier 2</th><th>Tier 3</th><th>Tier 4</th><th>Tier 5</th></tr>
<tr><td rowspan="3">1. Peak capacity</td><td rowspan="2">Power capacity rating (in W or Wh/day)</td><td rowspan="3">No energy</td><td>Min. 3 W</td><td>Min. 50 W</td><td>Min. 200 W</td><td>Min. 800 W</td><td>Min. 2 kW</td></tr>
<tr><td>Min. 12 Wh</td><td>Min. 200 Wh</td><td>Min. 1.0 kWh</td><td>Min. 3.4 kWh</td><td>Min. 8.2 kWh</td></tr>
<tr><td>Or Services:</td><td>Lighting of 1,000 lumen-hours/day (lmh/day)</td><td>Lighting, ventilation, television and cell phone charging available</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">2. Availability (duration)</td><td>Hours per day</td><td rowspan="2"><4h</td><td>Min. 4 h</td><td>Min. 4 h</td><td>Min. 8 h</td><td>Min. 16 h</td><td>Min. 23 h</td></tr>
<tr><td>Hours per evening</td><td>Min. 1 h</td><td>Min. 2 h</td><td>Min. 3 h</td><td>Min. 4 h</td><td>Min. 4 h</td></tr>
<tr><td>3. Reliability</td><td></td><td colspan="4">Unscheduled interruptions</td><td>Max. 14 interruptions per week</td><td>Max. 3 interruptions per week with total duration less than 2h</td></tr>
<tr><td>4. Quality</td><td></td><td colspan="4">Low quality</td><td colspan="2">voltage problems do not affect the use of desired appliances</td></tr>
<tr><td>5. Economic affordability</td><td></td><td colspan="3">Not economically affordable</td><td colspan="3">Cost of a standard consumption package of 365 kWh/year less than 5% of family income</td></tr>
<tr><td>6. Legality</td><td></td><td colspan="4">Not legal / in irregular situation</td><td colspan="2">Bill paid to utility, to prepaid card seller or to authorized representative</td></tr>
<tr><td>7. Health and Safety</td><td></td><td colspan="4">Not convenient</td><td colspan="2">Absence of past accidents and perception of low future risk</td></tr>
</table>

Source: adapted from ESMAP (2014) and Bhatia and Angelou (2015).

ANNEX 2

The collection of quantitative data from pilot projects for access to electric energy developed in the Pan-Amazon region by civil society organizations was structured in six axes: environmental, economic, geographic, organizational, social and technical. The structure was adapted for the use of spreadsheets and organized as illustrated in **Figure 44**.

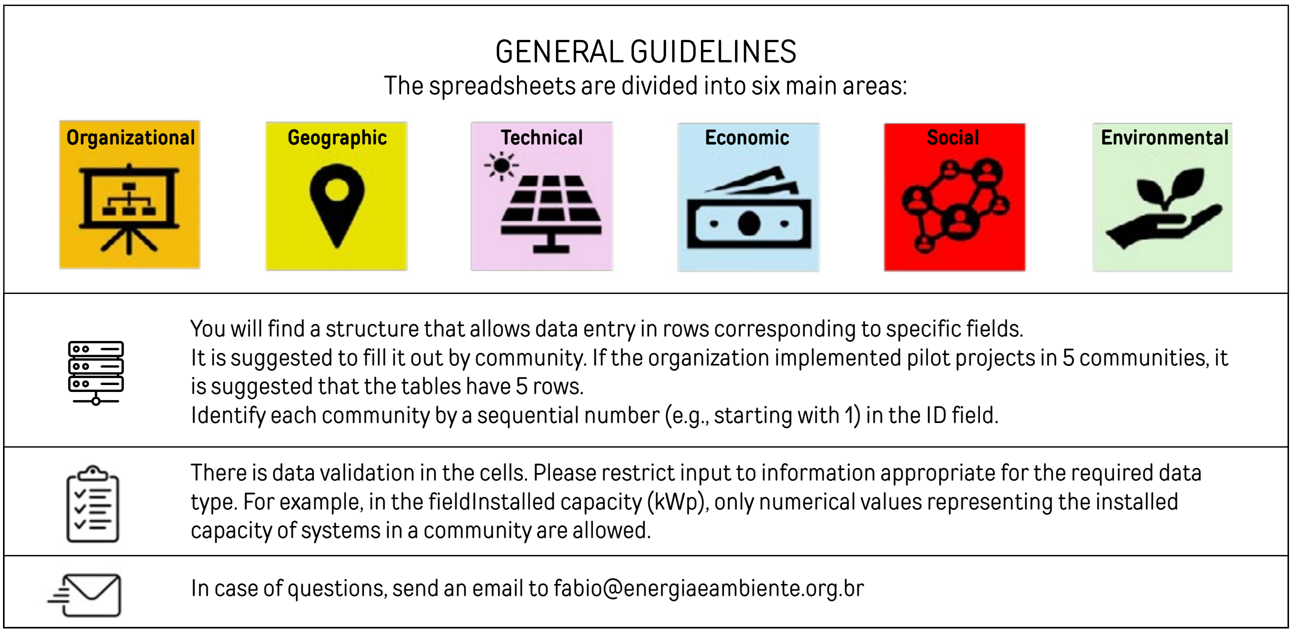

Figure 44. Guidance page of the quantitative questionnaire.

Below, the questions used in each dimension are presented in topic structures.

Environmental

- Was there substitution of a fossil energy source?
- What type of fossil fuel is still used?
- Avoided use of fossil fuels (Liters)?
- Was there implementation of a solid waste management mechanism generated by the intervention?
- Was there guidance to beneficiaries on solid waste management?
- Land use area altered for the implementation of the intervention (m²)?
- Was there removal of native vegetation?
- If yes, was there replanting?
- Replanted area (m²)?

Economic

- Total investment ($)?
- Operation and maintenance expenses ($)?
- Investment payback time (years)?
- Levelized Cost of Energy ($/MWh)?
- System transport cost ($)?
- Cost with labor hiring ($)?
- Is there a charge for the use of installed electric energy?
- Who receives the tariff payment?
- Value of residential/community energy tariff ($/month)?
- Avoided cost estimate with fossil alternatives ($)?
- Cost per beneficiary ($)?

Geographic

- Name of community/village?
- Territory name?
- Territory type?
- Municipality?
- State/Province?
- Country?
- Longitude?

ANNEX 2

Organizational
- Organization name?
- Financing start date?
- Financing end date?
- Pilot Project execution year?
- Duration of Pilot Project execution (in months)?
- Project fully funded by the Mott Foundation?
- Brief description of the project?

Social
- Number of people directly benefited?
- Number of people indirectly benefited?
- Quantity of people trained to install, operate and perform system maintenance?
- Quantity of women trained to install, operate and perform project maintenance?
- Quantity of beneficiaries included in installation, operation and maintenance of the project?
- Quantity of women included in installation, operation and maintenance of the project?
- Quantity of women with responsibility function over the project?
- Impact of intervention on beneficiary income ($/month)?
- Number of people who accessed education due to the project?
- Number of people who accessed health services due to the project?
- Number of people who accessed communication services due to the project?
- Average time of manual labor reduction due to the project (hours)?
- What is the main income generation activity in the community?
- Describe the subsistence productive activities developed in the community?
- Describe the electric-powered appliances acquired after the project?

Technical
- Project purpose
- More than one purpose? Describe
- Energy source
- More than one source? Describe
- System type?
- Total installed capacity (kWp)?
- Annually produced energy (MWh/year)?
- Average system lifespan (years)?
- Uses energy storage system?
- Storage system type?
- If followed technical installation standards, describe?

ANNEX 3

PRESENTATION OF THE SOCIOTECHNICAL QUESTIONNAIRE – ENGLISH VERSION

This questionnaire aims to gather detailed and systematized information on experiences of access to electric energy in rural, traditional and isolated communities of the Legal Amazon. It is **directed to organizations that implemented pilot projects or permanent initiatives** using solutions based on renewable energy sources.

The questionnaire structure is organized into **10 thematic axes**, in order to capture the diverse technical-operational, social, environmental and institutional aspects that make up the complexity of energy system implementation in Amazonian territories.

1. **Diagnosis, motivation and institutional framework**
2. **Participatory planning and co-conception (co-design)**
3. **Energy justice and social inclusion**
4. **Technology and technical implementation**
5. **Operation, maintenance and training**
6. **Financing and economic sustainability**
7. **Results and impacts**
8. **Environmental sustainability**
9. **Governance and community management**
10. **Learnings and recommendations for public policies**

The **questions are open-ended and filling is textual** can be done by technical team of the executing organizations and provides for **open and descriptive responses**, focusing on documentation of best practices, lessons learned, difficulties faced, solutions found and future recommendations.

Note: At the end of this complete questionnaire, a simplified questionnaire is included aimed at key actors, focusing on collecting suggestions for governance, local training, technological options and improvement of public policies for energy access in remote areas. Filling out the simplified questionnaire is optional.

1. Diagnosis, Motivation and Institutional Framework
1.1 What was the situation of communities before the projects regarding access to energy?
1.2 What social, economic or environmental needs motivated the initiatives?
1.3 Who participated in the initial diagnoses? Were the communities consulted?
1.4 What laws, norms or rules influenced the projects (positively or negatively)?
1.5 Was there support or articulation with public bodies? Which ones?
1.6 Were there licensing and financing processes? If yes, what obstacles were faced?
1.7 Does the country's current regulation favor community projects? What should change?

2. Participatory Planning and Co-conception (Co-design)
2.1 Did communities participate in planning and system design? How?
2.2 Were workshops, mappings or participatory dynamics held? What results did they bring?
2.3 What co-conception tools were used (maps, questionnaires etc.)?
2.4 Were local knowledges incorporated into technical projects? Illustrate some examples of how these knowledges were considered and incorporated.
2.5 Were local priorities incorporated into technical projects (lighting, communication, health, education, transport etc.)? Illustrate some examples of how these prioritizations were met.
2.6 Were decisions on tariffs, management and maintenance made in a participatory way?
2.7 Do communities have autonomy to suggest changes or expand systems?

3 Energy Justice and Social Inclusion
3.1 Did projects seek to correct historical inequalities of access to energy?
3.2 Which social groups were prioritized (e.g.: Indigenous, Quilombola, Riverine)?
3.3 Did initiatives contribute to repair failures of previous experiences?
3.4 Did projects strengthen identity, organization or autonomy of involved communities?
3.5 Were there changes in local power distribution after access to energy?

ANNEX 3

4. Technology and Technical Implementation
4.1 Why were the used technologies (solar, wind, hydro, hybrid) chosen?
4.2 Were systems adapted to local contexts (climate, logistics, labor)?
4.3 Did communities participate in the choice or understand the functioning of technologies?
4.4 What technical difficulties were faced and how were they resolved?
4.5 Is there possibility of system expansion with other technologies (biomass, river turbine etc.)?

5. Operation, Maintenance and Training
5.1 Who is currently responsible for operation and maintenance of systems?
5.2 Was there local technical training? How was it carried out?
5.3 Have systems functioned regularly? What failures occurred and how were they solved?
5.4 Do communities have autonomous technical capacity to maintain systems?

6. Financing and Economic Sustainability
6.1 What financing sources were used (public, private, donations, tariffs)?
6.2 Is the adopted economic model sustainable in the long term?
6.3 Are there local tariffs or community contributions? How are they defined? How are they paid? How are they managed?
6.4 How are default (when there is charging) and maintenance costs treated (how are they paid)?
6.5 Did experiences use models such as cooperatives, consortia or energy communities?

7. Results and Impacts
7.1 Which public services were benefited (health, education, communication, sanitation, transport, other)?
7.2 Did systems contribute to creation of new economic activities? Was there increase in production, income or added value? In which sectors?
7.3 Did energy influence the daily life of women, youth or vulnerable groups? Was there reduction of time dedicated to manual and domestic tasks?
7.4 Did projects contribute to reducing economic vulnerabilities?
7.5 Did projects strengthen local production chains? Was there integration with agriculture, fishing, bioeconomy or tourism?

8. Environmental Sustainability
8.1 Did projects adopt waste management practices (batteries, panels, packaging)? 8.2 What is the process and final destination of this waste?
8.3 Were there significant environmental impacts (positive or negative)?
8.4 Are there environmental monitoring or avoided emission mechanisms?

9. Governance and Community Management
9.1 What is the management model adopted for systems (individual, committee, association, cooperative)?
9.2 Were usage rules, tariffs, maintenance and conflict resolution defined with community participation? Are they clear?
9.3 How are decisions made in case of problems or need for changes?
Do communities feel responsible and with autonomy over systems?

10. Learnings and Recommendations for Public Policies
10.1 What were the main challenges faced in project implementation?
10.2 What strategies were effective to overcome technical, logistical or institutional limitations?
10.3 What lessons do projects offer for formulation of energy public policies?
10.4 What elements of experiences can be replicated in other communities?
10.5 Did projects dialogue with existing public programs in the country or region? If there are national or subnational public policies related to energy access, inform name and, if possible, access link.
10.6 What legal or financial adjustments would be necessary to expand this type of initiative?
Do involved organizations participate in experience exchange networks with other initiatives?

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