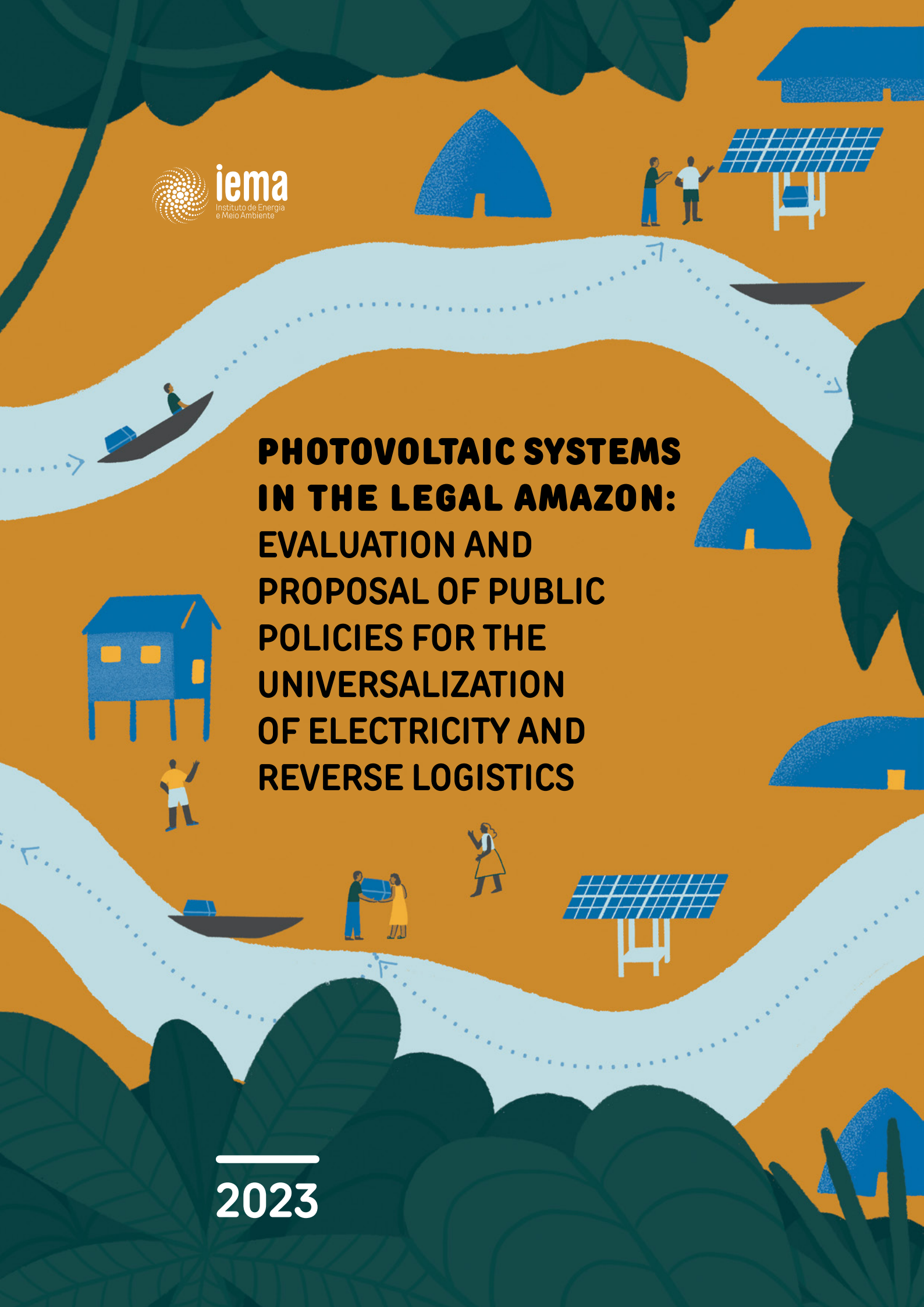

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PHOTOVOLTAIC SYSTEMS IN THE LEGAL AMAZON: EVALUATION AND PROPOSAL OF PUBLIC POLICIES FOR THE UNIVERSALIZATION OF ELECTRICITY AND REVERSE LOGISTICS

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Instituto de Energia e Meio Ambiente (IEMA)

Photovoltaic Systems in the Legal Amazon: evaluation and Proposal of public policies for the universalization of electricity and reverse logistics

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EXECUTIVE SUMMARY

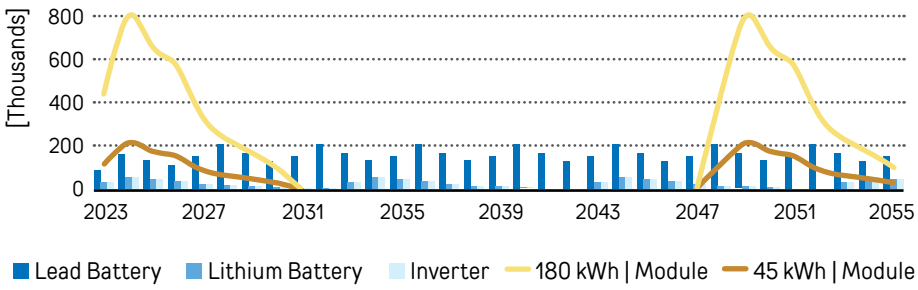
- The National Program for Universal Access to and Use of Electric Energy in the Legal Amazon – *Mais Luz para a Amazônia* (MLA) – chooses the implementation of off-grid photovoltaic systems (autonomous, not connected to the grid) combined with energy storage systems for batteries to meet the demand of people who lack access to the public energy supply service, in remote locations in the Legal Amazon.

- **Prioritizing service to consumer units exclusively through renewable sources, as proposed in the MLA program, is a suitable decision by the State**, as it seeks to achieve access to electricity in a sustainable manner. Considering that these areas are generally difficult to access and have a sensitive ecosystem, this work aims to identify and analyze the degree of development of the supply chain and decommissioning of photovoltaic and battery storage systems in Brazil. **The objective is to elucidate the possible challenges to be faced and, thus, guarantee the implementation of systems, from the outset, in the most socio-environmentally appropriate manner possible**.

Components		TOTAL
PV MODULE	**45 kWh/month**	**1.753.770**
	180 kWh/month	**6.576.637**
INVERTER		**784.811**
LEAD-ACID BATTERY		**5.435.991**
LITHIUM-ION BATTERY		**784.811**

- To meet the MLA's universalization goals, **more than three million pieces of equipment would be needed over the lifetime of the systems**, if we apply the scenario of energy supply using the Individual Electric Power Generation System with an Intermittent Source **(SIGFI, the acronym in Portuguese) of 45 kWh/month, with a lithium-ion battery, and 12 million pieces of equipment for the 180 kWh/month SIGFI scenario, with a lead-acid battery**.

- Regarding the electric power generation system, the photovoltaic module is responsible for the largest number of components. However, with the advantage that its operating life only allows for **replacement in two consecutive periods over the 32 years of operation** considered in the analysis scenarios. In other words, it is predominant until 2026, for SIGFI 45, and until 2030, for SIGFI 180, with **input peaks that exceed 200 and 800 thousand components in the year**, respectively, occurring in the second year of the analyzed scenario. In both cases, **the replacement of photovoltaic modules is repeated starting in 2048, coinciding with the end of the operating life of the first units implemented**.



- About the batteries to store the electrical energy generated by the photovoltaic modules, the **lead-acid** type requires constant replacement — every three years. **Throughout the analyzed scenario, its input would be over 100 thousand components per year, reaching 200 thousand units. The lithium-ion battery and the solar inverter**, equipment that transforms direct current into alternating current, **require four replacements, without exceeding 100,000 components in each replacement**.

- **In 2030, the installed capacity of the MLA program will reach 363 MWp (Megawatt-peak), considering the SIGFI 45 standard. In the SIGFI 180 standard, the capacity will be 1,381 MWp**. This value is greater than the current residential photovoltaic powered distributed generation (PVDG) installed capacity of each Brazilian State. Currently, São Paulo appears in first place, with 1,282 MWp, followed by the state of Rio Grande do Sul, with 922.2 MWp.

- If all 219,221 consumer units via the MLA program are supplied by individual systems, this number would be equivalent to **16% of the number of residential systems currently installed across the country**, in addition to being higher than the photovoltaic powered distributed generation (PVDG) installed capacity in the Mid-West and North regions of the country, the scope of the MLA.

- **Lead-acid batteries have a lower price** compared to other types of batteries, low implementation complexity, eliminate the need to control the operating temperature and have a mature logistics and recycling chain, characteristics that contrast with lithium-ion batteries. On the other hand, **the lithium-ion battery has more durability,** shorter recharge time and longer discharging and charging times, reducing the need for replacements and maintenance throughout the operating life of the system.

- **Lead-acid batteries dominate energy storage systems, while lithium-ion batteries are limited to Research and**

Development (R&D) projects. Unlike the solar chain, there is no database and structured information on the number, power, and distribution of batteries installed with the function of storing electric energy in hybrid electric generation systems in Brazil.

- Currently, the photovoltaic solar grid has focused on large centralized systems and on distributed generation connected to the electrical grid (on-grid) and not on off-grid systems, in remote regions. **Its equipment production chain is concentrated in the South and Southeast regions**, in places with transport infrastructure and access to import hubs (ports) and to manufacturers of equipment, components, and national installation structures. The number of integrating companies installed in the North Region is reduced. This regional imbalance is also reflected in the training and availability of collaborators specialized in the photovoltaic solar network.

- **There is no data available on areas related to installed and operating off-grid systems in Brazil**. Such lack of information results in challenges such as, for example, the exact mapping of communities and consumer units that lack access to electricity and the number of trained workers that would be needed to install these systems. The structuring and availability of data and information represent a significant bottleneck for monitoring, enforcement, and proposing suggestions, evaluations, and improvements to energy access programs.

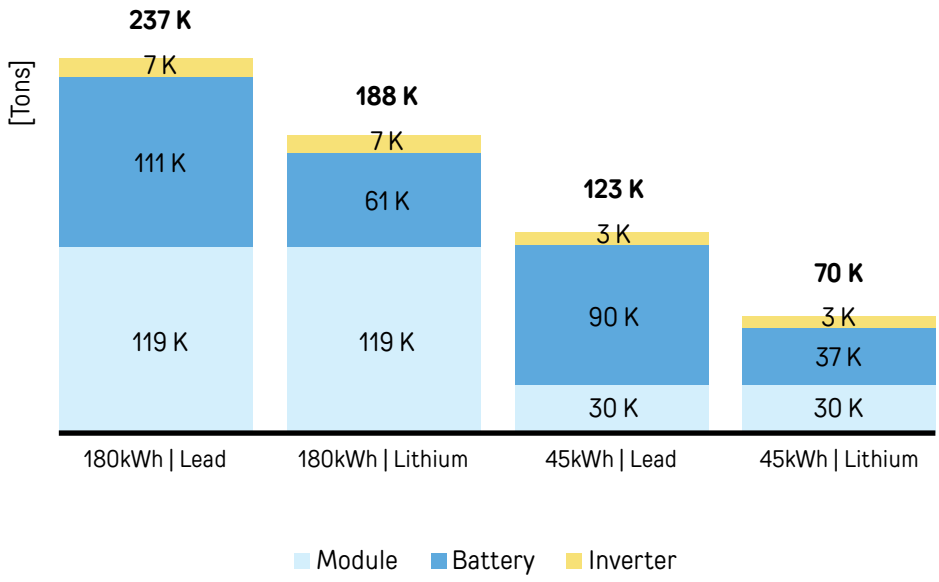
- **This deficiency occurs in the MLA program, which lacks information on places that do not have access to energy supply or on the systems implemented**, despite the requirement of making this available. There is no tabulated or georeferenced database for monitoring the connections and characteristics of the systems installed via the program.

- There is a growing discussion about the use of second-life lithium-ion batteries, whose quick recharge capacity

is exhausted, but which may still be useful for stationary (immobile) applications. However, their use in isolated and remote systems in the Amazon generates uncertainties as they have a shorter operating life than new batteries and may present technical problems in the short term. Furthermore, their cost is high when compared to traditional vehicle batteries (lead-acid) and the photovoltaic generation system, with the aggravating factor of disposing of waste (used batteries) from a chain to serve a region that lacks waste treatment services, such as the Amazon.

- **At the end of the operating life of the systems installed via MLA, between 71 thousand and 237 thousand tons of waste would be produced.** The SIGFI 180 with a lead-acid battery generates around 7 thousand tons/year, corresponding to almost twice the amount of electronic waste collected in Brazil in 2021. The SIGFI 45, with a lithium-ion battery, correspond to 54% of the mass of such equipment.

- **Throughout the MLA program, a total of 119,356 tons of waste from photovoltaic modules can be generated by the**



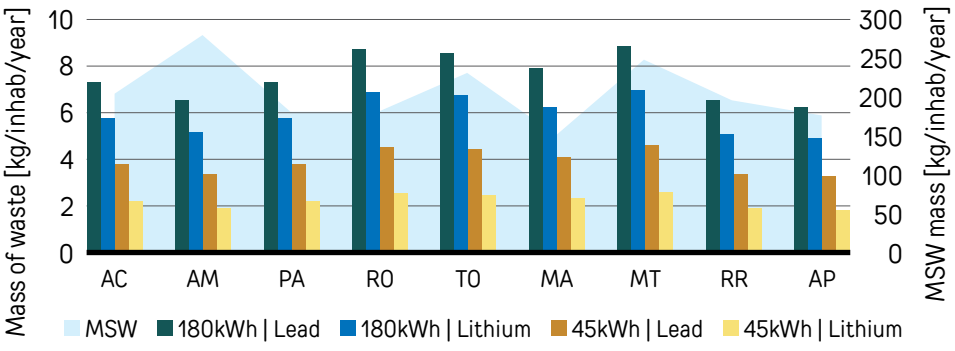
180 kWh systems, and 31,854 tons by the 45 kWh systems. Glass and aluminum frames account for 88% of the material.

- Considering the total amount of waste generated during the MLA program, divided linearly over the 32 years analyzed, the states of **Acre, Amapá and Amazonas would produce the lowest annual amount of waste per inhabitant. Mato Grosso, Rondônia and Tocantins, in turn, would be the largest generators of waste per inhabitant**.

- Pará, which has the largest number of consumer units to be supplied by the MLA program, would have 2.2 kg/inhabitant/year of waste with SIGFI 45 systems powered by a lithium-ion battery. For the SIGFI 180 system with a lead-acid battery, this value would increase to 7.3 kg/inhabitant/year.

- On the other hand, Mato Grosso, which has the lowest supply target within the program, has the highest amount of waste generated annually per inhabitant, as it registers the lowest number of inhabitants per consumer unit. It is estimated the generation of 2.7 kg/inhabitant/year in SIGFI 45 with lithium-ion battery and 8.9 kg/inhabitant/year in SIGFI 180 with lead-acid battery. In 2019, the state of Mato Grosso generated 246 kg/inhabitant/year of urban solid waste (MSW).

- It is worth noting that **these waste generation values under the MLA program are underestimated** because they disregard other components. Even so, they will exceed the



annual collection of electrical and electronic equipment throughout the country, most of which is carried out in the Mid-South region.

- **Waste from lithium-ion batteries, to supply MLA program consumer units, can reach between 37,000 and 61,000 tons. When looking at lead-acid batteries, the value can reach more than 90 thousand tons, for the 45 kWh system, and more than 110 thousand tons, for the 180 kWh system**. Most of its components are recyclable. However, the decommissioning and reverse logistics chain and the recycling market must meet this demand.

- **Waste generation is expected to grow starting in 2047, almost tripling the annual mass of waste in 2049** due to the end of the operating life of most photovoltaic modules. More than half of the waste would occur between 2047 and 2055 for SIGFI 180. Before that period, the waste generated would result from damage and premature degradation of photovoltaic modules and replacement of solar inverters and batteries, ranging from 42% to 47% of the mass total, depending on the storage system.

- **Ensuring the effective management of waste from these storage systems in remote regions requires a structured decommissioning chain**, which must bear the waste generated in order to reduce its risk of environmental and human exposure, in addition to guaranteeing the replacement of secondary source resources needed to manufacture lead batteries.

- According to the **National Solid Waste Policy, instituted by Law No. 12,305/2010**, manufacturers, importers, distributors, and traders of various products such as automotive batteries – exclusively the lead-acid type, also used in photovoltaic systems – are required to structure and implement reverse logistics systems. However, **the text leaves out lithium-ion batteries, demonstrating that there is still a lack of regulatory regimen in the country for this type of technology**.

- Unfortunately, **reverse logistics for these components is practically non-existent in the Legal Amazon**. Of the 5,570 Brazilian municipalities, only 400 (7% of the total) have reverse logistics services and, among these, **only 58 of the 808 municipalities in the Legal Amazon**. In Tocantins, there are only two municipalities out of 14, and Roraima has only one municipality out of 14 that offer this service. These data demonstrate that Brazil does not have the structure and tools to comply with its laws and reduce the possible negative impact of waste generated on the environment and the health of the population.

- **The number of municipalities in the North Region that have recycling pickup services is negligible — only 40 municipalities (12% of the total)**. Of these, 26 (8% of the total) have door-to-door recycling pickup services, demonstrating that there is a lack of this type of public service in the region.

- Regarding the final destination of waste in the region, 30 municipalities have sanitary landfills and 71 have controlled landfills. **The majority, 444 municipalities, dispose of their waste in landfills, and another 319 do not provide information on the final disposal of their waste**.

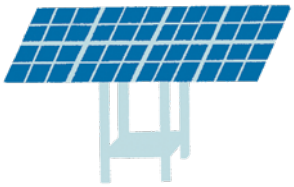
- It is also prohibited to import hazardous solid waste and rejects that cause damage to the environment, public and animal health and plant health, including second-life batteries. These no longer meet the load of their specific use, but, theoretically, could be used in the stationary storage of off-grid or distributed generation systems.

- **Gaps remain to be filled in order to adequately face two important challenges**: (1) the planning and execution of the installation of thousands of off-grid systems in remote areas, spread over a vast territory with little logistical infrastructure for transport and communication; and (2) the planning and execution of the removal and recycling of waste to be generated (photovoltaic modules, batteries and components) on a scale and in a distributed manner.

- **This work presents inherent recommendations** such as the need to: build a consolidated database and georeferenced information on the socioeconomic characteristics of remote communities in the Legal Amazon and make it publicly available; reproduce the existing database of the photovoltaic solar chain of systems connected to the electrical grid for the off-grid solar chain; create regional hubs in the Legal Amazon for the distribution of systems and components and to decentralize the workforce for supporting and operating the program; make the process of bidding, quotation and hiring of services and equipment under the MLA program public.

- **The importance of including new participants in this chain is also highlighted, increasing the competitiveness and efficiency of the implementation of the systems and ensuring the anticipation of the goal of completing the MLA program, scheduled for 2030**. Project standards must be defined according to the installation site in order to reduce the risk and the technical and economic barriers of the business model. **The State and companies must prepare for the generation of waste on a large scale and develop mechanisms to encourage and capitalize on opportunities in this segment**. It is also necessary to promote continuous innovation and the training and technical and scientific training of professionals, using existing public policy instruments, such as the strategic calls of the Research and Development Program (R&D) and the Energy Efficiency Program (PEE, the acronym in Portuguese) led by the Brazilian Electricity Regulatory Agency (Aneel).

CONCLUSIONS AND RECOMMENDATIONS



The ***Mais Luz para a Amazônia*** **(MLA) program entails access** to electricity in the Legal Amazon **region solely through renewable sources of energy generation. This requirement is a coherent decision,** as it seeks to provide access to electricity in the region in a sustainable manner, especially as it **supplies consumer units excluded from the public access service. Thus, the implementation of photovoltaic solar technology as a possible alternative is quite suitable.**

Supplying more than 219,000 consumer units – as anticipated under the MLA program – using SIGFI should change the level of photovoltaic electricity generation in the North of the country, raising it to a prominent position in the ranking of capacity and number of systems installed nationally. Depending on the level of consumption to be met**, fair universal access to electricity for remote communities in the Amazon can result in the acquisition of up to six million photovoltaic modules and more than five million stationary batteries** over the operational life of the systems.

Bearing in mind the number of equipment and components needed to implement the systems, the amount of resources to be contributed throughout the program, and the institutional participation of distributors and other agents in the electricity sector**, it would be naturally appealing to companies that participate in the solar and energy storage supply chain.**

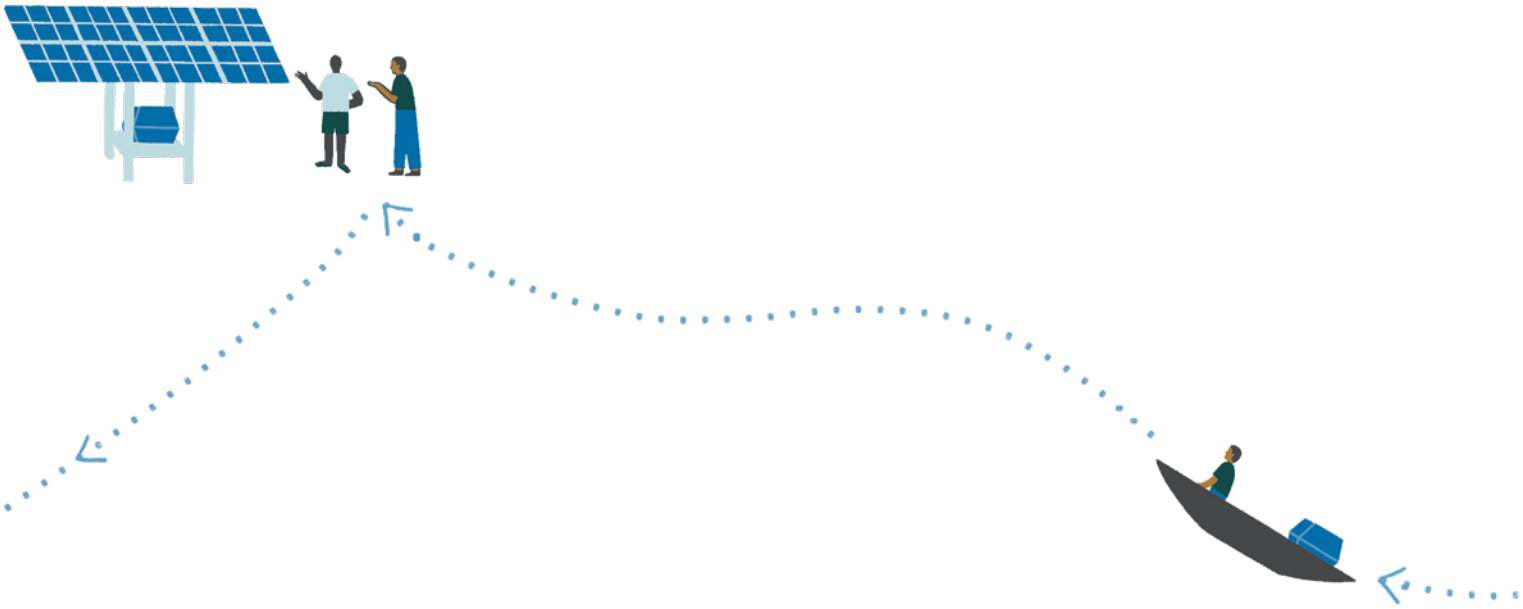
However, there are still gaps to be filled in order to adequately face two important challenges: **(1) the planning and execution of the installation of thousands of off-grid systems in remote areas**, distributed over a vast territory with little logistical infrastructure for transport and communication; and **(2) the planning and execution of the removal and recycling of the waste** to be generated (PV modules, batteries and components), on a scale and in a distributed manner.

The universalization of access to energy supply in remote regions of the Legal Amazon is a matter of regional development and requires a robust program. This discussion must involve diffe-

rent actors linked to different public policies, agents from the State, from the solar photovoltaic and storage chain, and civil society organizations. In order to implement a complete service cycle, these actors will have to deal with the complexity of the demands of the MLA program and a structured system of decommissioning and final disposal of energy generation and storage components.

Thus, we present proposals that pool **suggestions for improving the solar photovoltaic and storage chain** for the supply of off grid systems in the Legal Amazon as well as recommendations regarding the **implementation of reverse logistics and recycling systems** for photovoltaic systems and batteries, used in the implementation of the *Mais Luz para a Amazônia* program.

These suggestions address the themes of: (i) development of monitoring and systematization of data and socioeconomic information on the populations supplied and the systems implemented in the program; (ii) expansion and transparency in contracting equipment and services for the implementation of generation and storage systems; (iii) redefinition of the program's service standards, considering final uses, consumption patterns and repressed demand for energy from consumer units; (iv) development of waste management and reverse logistics mechanisms designed for the region; and (v) establishment of research and development processes, regulatory and institutional structure to work and expand access to electricity and establish an effective policy for waste and reverse logistics for the region.



IMPROVEMENT OF THE SOLAR PHOTOVOLTAIC AND STORAGE CHAIN TO SUPPLY OFF-GRID SYSTEMS IN THE LEGAL AMAZON

Although Brazil has shown exponential growth in the installed capacity of centralized and distributed photovoltaic systems over the last few years, its equipment production chain, in addition to being insufficient to serve the national market and, therefore, heavily dependent on imports[1], is concentrated in the regions South and Southeast, in places with transport infrastructure and access to import points (ports) and to manufacturers of equipment, components and national installation structures. The number of integrator companies installed in the North of the country is reduced, and there are no manufacturing units, except for a battery assembly unit in the Manaus Free Trade Zone. This regional imbalance is also reflected in the training and availability of workers specialized in the photovoltaic solar chain.

The current status of the photovoltaic solar chain demonstrates that its focus is the development and implementation of large centralized systems and PVDG connected to the electrical grid, and not off-grid systems in remote regions.

The focus on PVDG connected to the electricity grid is also shared by regulatory and supervisory agents, considering the deficit of information available on off-grid systems installed and operating in the country. This is not the case with systems connected to the electrical grid, which have ample sources of information, whether from state bodies or professional associations. This lack of information results in challenges. Among them, the exact mapping of communities and consumer units that need access and the demand for qualified workers in sufficient quantity to implement thousands of peak and micro capacity systems to supply thousands of consumer units. Therefore, the structuring and provision of data and information represent a significant bottleneck for monitoring, supervising, and proposing suggestions, evaluations, and improvements to programs for access to electricity, as in the case of the *Mais Luz para a Amazônia* Program (MLA). Measuring and monitoring this information is essential for preparing a plan that includes the establishment of management

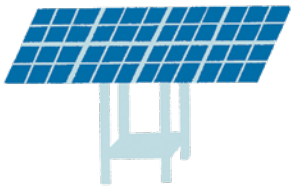
1. The photovoltaic solar chain is incorporated nationally predominantly based on the provision of equipment import and distribution services; sale of solar kits, using mainly imported technology and financed with public and subsidized credit and installation services; and O&M of systems mainly by integrator companies.

mechanisms, goals, and resource allocations, to ensure the long-term sustainability of electrification projects.

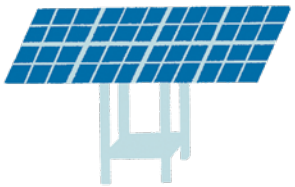
This deficiency occurs in the MLA program, which does not have accessible information[2] about places that lack access to electricity or about the systems implemented, despite the requirement to make this available. We also highlight the absence of a tabulated or georeferenced database for monitoring the connections and characteristics of the systems implemented in the program.

As a suggestion of recommendations to improve the access and content of this data, we suggest:

- **Building and PUBLICLY providing a consolidated database** and georeferenced information on the socioeconomic characteristics of remote communities in the Legal Amazon, preferably linked to the CadÚnico system, to integrate information on the access to electricity program with other social assistance and redistribution of income programs. IBGE (Brazilian Institute of Geography and Statistics) needs to expand the tool for mapping and providing information on people from remote regions, including info on location, as data on remote and isolated communities in the Amazon region end up being integrated with data at the municipal level, making it difficult to evaluate and focus public policies on this specific target-audience.



- **Increased public transparency** of information on universalization programs through periodic, updated, and georeferenced demonstrations on the Aneel (the Brazilian Electricity Regulatory Agency) platform. This must also include economic transfers per distributor, through the Chamber for the Commercialization of Electric Energy (CCEE), and the evolution of installed units and their respective technical characteristics, with monitoring of annual targets, including segmentation



2. In an attempt to verify the evolution of the program's service, Rede Energia & Comunidades requested the Brazilian Ministry of Mines and Energy (MME), through Information Request No. 405/2022, access to data and information on connections and program service targets in July 2022. However, the requested information and data were not provided, signaling the lack of a systematized information structure on the part of the entities responsible for the MLA Program. In addition, the study Universalization of access to electricity in Brazil: evaluation of SIGFIs and MIGDIs, produced by IEI (2022), found that the list of SIGFI and MIGDI systems implemented by distributors are incomplete on the Aneel portal, indicating that the distributors do not follow the requirements established in the MLA program and in its operational manual.

by distributor. This is the only way to monitor the evolution of the program and measure the efficiency of resource allocation concomitantly with technically founded and data-based suggestions for improvements.

- **Replicate, for the off-grid solar chain, the already existing database of the photovoltaic solar chain of systems connected to the electrical grid**, contemplating regionalized data on: cost of equipment and services; technical characteristics of the installations; type and structure of the companies participating in this chain (number of companies, number of employees, type of skills required); origin and destinations of equipment; development of a price bank for equipment and services considering local specificities. Based on this, it is possible to start a process of opening the off-grid market and the North Region and rethink the mechanism for purchasing and maintaining equipment locally.

Therefore, the definition of project standards adapted to the implantation site becomes important in order to reduce the risk and the technical and economic barriers of the business model. Thus, the transparency of information about the implemented systems; the standard and periodicity of maintenance with a description of the main failures and interruptions; the decommissioning process and costs; and the final destination, as well as the processes used, of waste from off-grid systems throughout their life cycle are essential.

Consequently, addressing these issues, combined with the possibility of disclosing and expanding bids for the purchase of equipment and spare parts, contracting system implementation services, and developing and training workers, are solutions that depend on regulation, but also the improvement of public policies. These, in turn, should expand the options for contracting services for the implementation of generation systems and transparency regarding the number, location, and technical characteristics of the systems implemented and expenditures incurred.

Thus, the inclusion of new participants should be stimulated, increasing the competitiveness and efficiency of the implantation of the systems or, at least, guaranteeing the anticipation of the goal of concluding the program — foreseen for 2030. Recommendations for supplying the solar photovoltaic and storage chain to the demand for off-grid systems in the Legal Amazon region are focused on:

- **Creating regional centers for the distribution of systems and components**, in addition to providing training for workers in the regions where the program is carried out and where the systems are implemented, i.e., **decentralizing the workforce for the supply and operation of the program**.

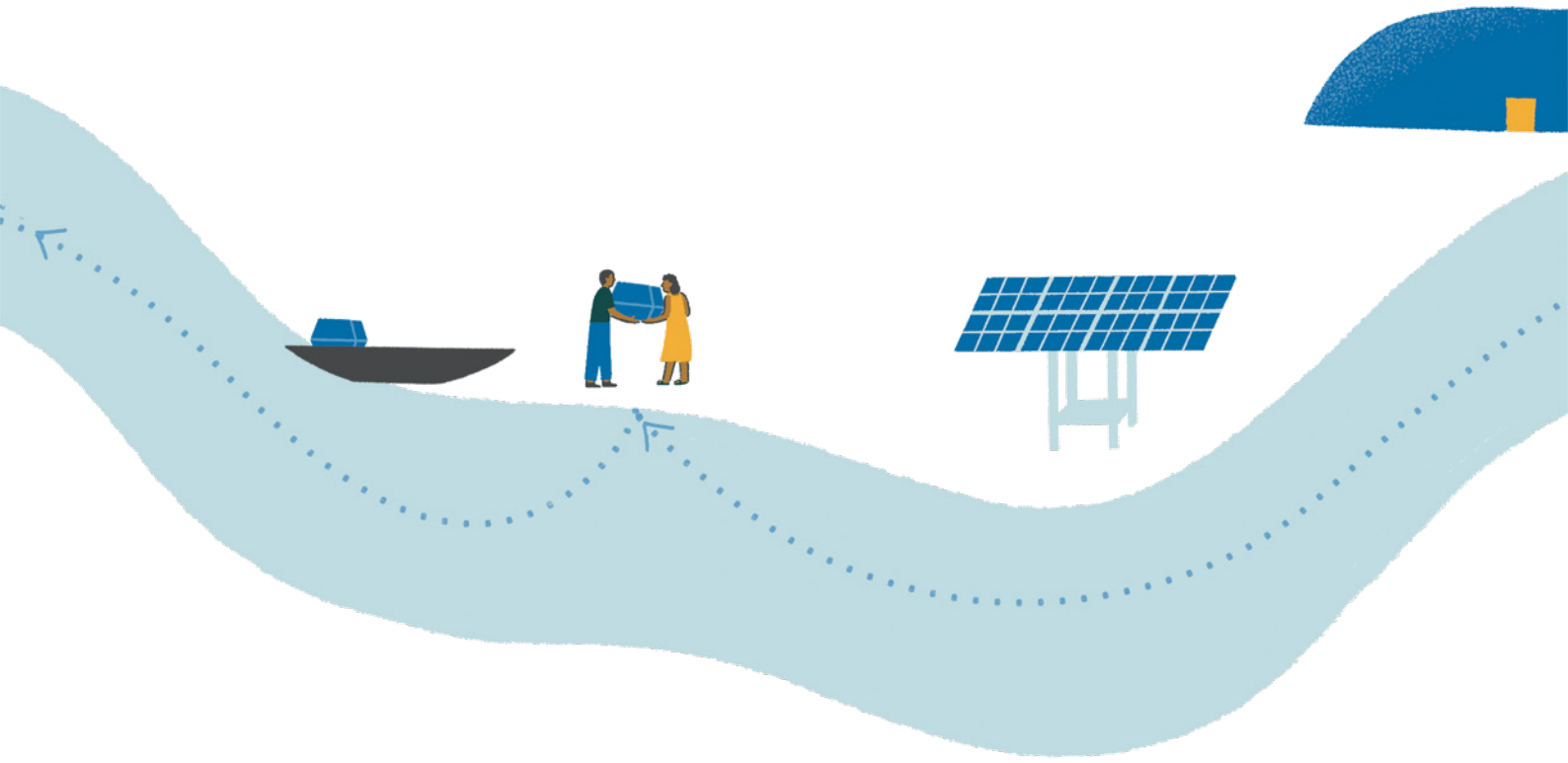
- **Requiring and publicly disseminating the process of bidding, quotation and contracting of services and equipment**, as well as the electricity contracting auctions carried out by the CCEE, **under the MLA program**. In addition to being transparent, this process allows the participation of the various agents in the chain, increasing competition and reducing the cost of the systems.

- Prioritizing the use of equipment produced by national manufacturing units, which can help the development of domestic production of equipment for the solar storage chain. However, this development policy must be analyzed together with other State actors. The objective is to guarantee that the systems acquired or contracted by the program do not have excessive costs or a shorter operational life when compared with the equipment offered in the market of imported origin and that the goal of the universalization period of the program is not compromised.

- Standardizing the hiring of preventive maintenance services for generation and remote storage systems, employing people from the local community (who must be trained to perform the services based on the implementation of training programs for workers), with service benchmarking goals and annual renewal for companies that perform this type of service. The distributors would have the role of managing and informing the inspection agent of the performance indexes of the systems and the quality of the energy supply per block of the concession area. This policy aims to guarantee the provision of a universal service, admitting workers from local communities and ensuring their quality over time.

- Focusing on the implementation of power generation in remote communities above economic consumption (the user's ability to have electronic equipment to consume electricity) and payment capacity, as families who receive access

to electricity can consume less energy than the monthly minimum and are required to pay the minimum amount for monthly generation[3]. Currently, there is no option to dispose of the excess energy generated and stored. This energy surplus could be consumed in productive activities or by including new loads common to local communities, providing energy for collective use. However, due to the lack of socioeconomic data and surveys of consumption habits, there are uncertainties regarding the production load and repressed demand of families.



3. The SIGFI 45 standard pays for the consumption of 45 kWh/month and the SIGFI 180, for the consumption of 180 kWh/month.

EFFECTIVE IMPLEMENTATION OF REVERSE LOGISTICS AND RECYCLING FOR COMPONENTS OF OFF-GRID SYSTEMS TO BE INSTALLED IN THE LEGAL AMAZON

The waste generation scenarios of the electricity generation systems to meet the MLA program show that up to 119 thousand tons of photovoltaic module waste and 110 thousand tons of lead-acid battery waste could be generated over the course of the operational life of the systems, in a region with little structure to deal with this liability.

Brazil's National Policy on Solid Waste (PNRS, the acronym in Portuguese) defines that the accountability for the waste generated shall be shared between the producer and the consumer and assigns to the manufacturer and importer the responsibility for structuring reverse logistics systems for lead-acid batteries and large household appliances, which include other photovoltaic components. The policy does not define specifications for lithium-ion batteries.

However, it should be noted that Decree No. 10,240/20 — which regulates reverse logistics — does not favor it in isolated and remote locations, since the criteria and parameters established for defining the stations for receiving waste foster services in urban regions with higher demographic density, better service infrastructure, and more developed economic activities[4]. Thus, the reverse logistics system, recycling, and final disposal of electrical and electronic waste in the Legal Amazon may not be able to deal with the waste generated under the MLA program, since only 7% of the Amazonian municipalities have reverse logistics systems, concentrated in urban regions, mainly in state capitals, and do not include recycling pickup services, processing, and proper destination for this waste. Disposal takes place primarily in dumps, where there is widespread contamination of water, land, and air, deteriorating the environment and the health of local populations.

As the MLA Manual and the Development Plan of the distributors do not present a plan regarding the decommissioning of these systems, the municipalities will be responsible for processing the additional volume of waste generated from the universalization program.

Therefore, in the coming years, policy makers and stakeholders in the photovoltaic and storage solar chain will have to prepare for the generation of waste at scale and develop mechanisms to

4. Among the criteria and parameters mentioned are: number of households with electricity; estimate of the amount of electrical and electronic products sold and discarded in the domestic market; distance for consumers to travel to the pickup stations; and demonstration of the ability to finance the reverse logistics operation.

foster and capitalize on the opportunities of this segment. In this regard, we recommend:

- Planning the implementation of photovoltaic and off-grid storage systems within the scope of the MLA program, with the establishment of a complete process of decommissioning the systems and final disposal of their waste in its operational manual.

- Stimulating investment and public and private funding for the end-of-life management of equipment used in the MLA program, overcoming funding barriers, usually facilitated to large agents, and ensuring the support of all interested parties, such as local, regional cooperatives, small-scale distributors, and waste processors.

- Promoting continuous innovation and training and technical and scientific capacity-building of professionals, using existing public policy instruments, such as the strategic calls of the Research and Development Program (R&D) and the Energy Efficiency Program (PEE, the acronym in Portuguese) from the Brazilian Electricity Regulatory Agency (Aneel), to:

  a. Support the creation of value and the use of end-of-life photovoltaic modules and second-life batteries of strictly national origin, to avoid importing waste from other countries;

  b. Elaborate technical and regulatory subsidies to add value to the chain of management, collection, recycling and final destination of equipment used in universalization programs, and to boost the capacity of recycling centers, especially in sensitive places such as the Legal Amazon;

  c. Invest in R&D, education, and training projects to support end-of-life equipment management and the development of local recycling industries. The increase in waste flows will provide local opportunities for the energy and waste sectors, with new markets and trade flows, which must be coordinated with local technical capacity building policies. The investment must also consider the priority of hiring representatives of local communities for the implementation, operation and maintenance (O&M), and the final disposal of the equipment of the energy generation and storage systems;

d. Stimulate technological innovations in order to create recycling processes for rare and potentially dangerous materials contained in equipment. For this, in addition to stimulating innovation, it will be necessary to encourage professional training, with gains that go beyond legal requirements and provide environmental and socioeconomic benefits.

- Adding regulations covering solar chain waste to the existing solid waste law, creating specific rules for photovoltaic waste. We also recommend that a public organization or one designated by it be responsible for disclosing data and information on waste disposal from the on-grid and off-grid solar chain.

- Assigning the mapping of markets that receive photovoltaic material, by the distributors operating in the region or a designated entity, including volume measurement and composition of short-term end-of-life PV modules. Likewise, mapping the availability of technologies, services, and distributed and scalable infrastructure for the recovery, recycling, and final destination of this equipment.

- Including a monitoring and reporting system — assigning responsibility to local distributors that implement the systems — that covers waste streams in national and regional regulations in order to improve decision-making and planning. These statistical data must be systematized and made publicly available in order to subsidize the improvement of waste flow forecasts, increase understanding about the causes of failure of equipment and services, and support the adaptation of the regulatory structure considering regional characteristics from the country.

- Expanding the infrastructure and waste management instruments adapted to the conditions of each region of the Amazon, with coordination mechanisms between the different sectors of the economy present in these regions, mainly energy and waste. In this sense, manufacturers, importers, and other actors participating in the solar photovoltaic and storage chain must ensure periodic training and skill-building of workers involved in the dismantling and reverse logistics chain. This task could be assigned to a new entity structured by the actors participating in the chain or use the physical and teaching structure of existing technical training institutes.

- Developing a specific reverse logistics adaptation policy for photovoltaic and storage systems in the Amazon, in order to include them in Brazil's National Policy on Solid Waste (PNRS). For this, it is necessary to segregate centralized, distributed, and off-grid PV reverse logistics, considering specifications of process and inspection chains for centralized generation, service levels for distributed generation, and technological and information requirements on the implementation of off-grid systems, given that:

  a. Linked to large electricity generating companies, centralized generation favors reverse logistics, as these groups have a well-defined process, inspection and O&M chains;

  b. Photovoltaic generation equipment is classified as electronics. However, the ideal scenario would be to create a distinct categorization for it, since distributed generation also requires distributed reverse logistics, with a level of service and goals different from the reverse logistics of centralized systems[5];

  c. Off-grid generation includes the use of a storage system, which requires information on the place of implantation and the type of technology used in these systems to deal with future toxic waste in regions with a high degree of environmental sensitivity and lacking in sanitation services.

- Establishing a mechanism that guarantees the dismantling, distribution of pickup stations, and orderly recycling of photovoltaic and end-of-life storage systems, avoiding the accumulation of waste in landfills or other places with undue impacts on health public and the environment.

5. In the case of photovoltaic systems, reverse logistics must distinguish between centralized and distributed systems. In addition, the photovoltaic industry needs to be treated separately, as happens with electrical and electronic equipment and batteries, where there is segregation between automotive batteries and other types.

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