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Towards Systems-Oriented Energy Solutions: A Multilevel Analysis of a Low-Income Energy Efficiency Program in Brazil

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Abstract: There is a consensus among scholars and practitioners that energy solutions, such as electricity services and related products and systems, are paramount to the ability of nations to overcome environmental and social issues. As a result, policymakers and problem solvers in emerging economies have shown a keen interest in the transition to sustainable energy systems. Nevertheless, the design of sustainable energy solutions in low-income markets presents many challenges, such as those related to limited financial resources and poor infrastructure. In low-income markets, the adoption of a systems-oriented approach to product–service combinations may represent a promising alternative to traditional design approaches and result in a more socially and environmentally sound path to economic development. Building on design theory grounded in systems theory, this paper analyzes multiple aggregation levels of the sociotechnical system of a low-income energy efficiency program in Brazil. In this study, the authors examined findings from the literature, carried out field observations, and had discussions with practitioners and experts. The study identifies constraints that hinder energy solutions that could achieve higher levels of socioeconomic and environmental benefits in low-income energy markets. Based on the findings, the paper provides insights into sustainable energy transitions and concludes that low-income energy efficiency programs can be improved through design-led policy and stakeholder collaboration.

Keywords: energy solution; low-income market; multilevel perspective; sociotechnical system; sustainable product–service systems; systems design approach; systems thinking

1. Introduction

Energy is essential for the achievement of sustainable development as it plays a central role in both socioeconomic development and environmental challenges [1,2]. Energy solutions are pivotal in enabling emerging economies to overcome social issues, such as lack of access to safe water, lack of opportunities for income-generating activities, poor education services, and inadequate health care and sanitation [1]. The term "energy solution" adopted in this paper refers to electricity services and related products and comprises energy's technical and financial aspects, as well as societal aspects (e.g., stakeholders, user practices, cultural norms).

Daily activities that depend on energy solutions, such as lighting, cooking, heating, refrigeration, transportation, and communication, are essential for human development and the fulfilment of human needs [3,4]. Nevertheless, in emerging economies, low-income households often have either no connection with the national grid or, in cases where they are connected, receive poor quality services with an intermittent and unreliable electricity supply. Global awareness of the importance of energy to poverty alleviation and environmental issues has raised severe concerns among governments, energy utilities, and civil society. These energy challenges have increased the pressure on problem solvers to reduce the environmental impacts and improve the socioeconomic benefits of the generation, distribution, and consumption of electricity in low-income markets. Consensus exists that without access to sustainable electricity services and related products, sustainable energy systems cannot be created and sustainable development cannot be achieved [5,6].

Therefore, it is of the utmost importance to gain a better understanding of low-income energy markets, and thereby develop more sustainable energy solutions. Moreover, opportunities are recognized for investments in infrastructure, product, and service development that can lead to energy solutions that do not repeat the environmental mistakes made by developed economies in recent decades (e.g., fossil fuel dependency and high energy consumption). Energy solutions for low-income markets present a favorable opportunity to satisfy demand in alignment with sustainable development goals [4]. However, sustainable energy solutions in low-income markets face many constraints, such as limited financial resources and poor infrastructure. Therefore, better design and systems practices are required, in addition to the ability to deal with increased complexity [7–9].

This paper presents a systems-oriented approach based on a multilevel analysis [10,11] of an energy efficiency low-income program in Brazil. A considerable amount of literature has been published that focuses on low-income energy markets and systems-oriented approaches like the ones explored here [12–19]. These studies contend that the dematerialization of products can lead to decoupling of economic growth from resource consumption and increasing the incentive for energy efficiency. Similarly, other relevant studies [15,20] have concluded that a considerable number of sustainable technologies already exist. However, the short and long-term effectiveness of energy solutions largely relies on the link between products and related services, the interaction with users and its surroundings, and the way in which they are offered to the market.

In this context, the findings from the current study can advance a better understanding of the interplay between societal and technical factors in low-income energy efficiency programs and identify constraints imposed by their complexity. Based on the results, the paper proposes recommendations to the improvement of Brazilian low-income energy efficiency programs through design-led policy and stakeholder collaboration.

In the following section, the increasing complexity of energy challenges in low-income markets is discussed, with emphasis on the integration of systems thinking into design. Next, the multilevel model is explained, examples are provided, and the methodology is described. Then, based on the multilevel analysis, the findings are presented. Following the presentation of the main results, the paper offers insights into decision-making and problem-solving aimed at improving energy solutions for low-income energy efficiency programs in Brazil. Finally, concluding remarks are presented.

2. Energy Solutions in Low-Income Markets

In the literature, a path towards tackling energy challenges and improving living conditions in low-income contexts refers to the access to modern sources of energy, the promotion of energy efficiency, and improvements in affordability [21,22]. Moreover, increasing the use of renewable energy sources is especially important in emerging economies since they will experience the most significant increase in energy demand and carbon dioxide emissions as they continue to develop [23,24]. To address these energy challenges, the United Nations (UN), within its Sustainable Energy for All initiative, established three primary global energy goals: (I) ensure universal access to modern sources of energy; (II) double the global rate of improvement in energy efficiency; and (III) double the share of renewable energy in the global energy matrix by 2030 [25].

In Brazil, the combination of poor electricity services and the increase in electricity demand and consumption results in major energy challenges. For instance, low-income households struggle with issues such as penalties imposed due to electricity theft [26], dependency on economic instruments (e.g., subsidies), use of energy-inefficient household appliances [27], lack of awareness and information [28], and an unreliable electricity supply (e.g., blackouts and shortage of electricity) [29]. In past decades, the Brazilian Electricity Regulatory Agency (ANEEL) has taken measures to develop a new regulatory framework to address the most significant national energy challenges [30]. New energy policies have been developed and introduced [31,32]. In particular, to tackle energy challenges faced by the Brazilian low-income population, ANNEL established obligations to energy utilities to promote energy efficiency R&D and consumer-oriented energy efficiency programs.

Among the national energy programs relevant to the low-income sector, the Brazilian Energy Efficiency Program (PEE) has gained prominence. PEE is an incentive program that promotes the efficient use of electric power. The PEE program has 14 project typologies, of which two (i.e., low-income and pilot project) are suitable to tackle energy challenges faced by the Brazilian low-income energy market.

The "pilot project" typology supports innovative projects (e.g., unprecedented projects, new technologies, and new methodologies) that allow replication and future upscaling. The "low-income" typology comprises projects with investments in low-income communities and consumer units benefiting from the social tariff (more information about social tariff is given in the results section). Low-income projects consist mainly of demand-side management (DSM) focusing on changing consumer demand for electricity. Common activities adopted in the PEE low-income typology include: replacement of inefficient household appliances; educational actions; regularization of illegal connections; improvements in residential electrical installation (e.g., home wiring and electric power meter upgrade); and the use of incentivized renewable energy sources, such as solar water heating and solar home systems. In low-income contexts, the effective implementation of DSM strategies must overcome a number of constraints (see Table 1).

Table 1. Overview of the complexity associated with low-income energy markets.

Sociotechnical Systems Components	Low-Income Market Constraints	Examples of Constraints
Market and user practices (e.g., user preferences, electricity consumption patterns)	User	High illiteracy rate among stakeholders
Culture and its symbolic meanings (e.g., ways of living, individual and collective habits)		
Maintenance and distribution network (e.g., maintenance services, repair shops, local electrician, hardware stores)	Technical	Unskilled technical personnel, lack of energy-saving features, poor heating and insulation standards (dwelling)
Infrastructure (e.g., electrical grid, housing conditions, shared products and facilities)		
Knowledge production and transfer (e.g., universities, research institutions, R&D, capacity building)	Institutional	Lack of trust between stakeholders (e.g., between low-income population and state-owned utilities)
Stakeholder relationships (e.g., hierarchy, economic classes, political position)	Socioethical	Electricity access as a campaign tool to attract votes from minorities.
Regulatory and economic instruments (e.g., policies, energy efficiency and electrification programs, subsidy, social tariff)	Economic	High dependency on subsidies.
	Regulatory	Lack of policies relevant to energy poverty
Resources (e.g., fossil fuel, renewables)	Environmental	Lack of environmental awareness

Source: Based on [33,34].

These constraints constitute barriers to problem solvers and affect the development and implementation of energy solutions in ways vastly different from constraints experienced in middle-/high-income contexts [34]. Consequently, sustainable energy solutions must integrate a range of comprehensive products, services, and systems to overcome constraints and provide access to affordable, reliable, and clean energy solutions in low-income markets.

In the literature, the integration of products, services, supporting networks, and infrastructures as a commercial solution is called a product–service system (PSS) [35]. The PSS concept is potentially suitable to address the issues in low-income energy markets as it provides a higher level of wellbeing at a lower cost as a result of its higher system efficiency [36]. An example that illustrates an energy PSS is the IndiGo solar power system technology developed by Eight19 in Kenya (Africa). IndiGo is a pay-as-you-go off-grid application that addresses the lack of home lighting and the increasing necessity to charge mobile phones in rural areas and remote low-income communities. The system allows users to buy electricity using mobile phones. It comprises a 3, 10, 40, or 80 watt solar panel; battery; two LED lamps; a phone charging unit and module. The equipment costs 10 dollars and users are charged a fixed fee of one dollar a week to use it. Customers add credit to their solar power device using scratch cards validated on a standard mobile phone via text message. The received passcode entered into the IndiGo unit causes it to operate, typically for a week. The power generated is sufficient to charge a mobile phone and provide eight hours of light for two small rooms. In Kenya, people tend to spend around two dollars per week on kerosene to light their houses and one dollar on power for mobile phones. Using the IndiGo system results in energy savings and eliminates harmful emissions caused by burning kerosene and problems associated with smoke inhalation [37].

Several authors [36,38,39] agree that integrated product–service offerings such as "IndiGo" can stimulate significant change in current production and consumption patterns for an environmentally sound path to socioeconomic development. Notably, the requirements for creating a sustainable transition in low-income energy markets may only be possible with significant changes in existing energy systems [4]. As a result, studies that consider PSS at a systems-oriented level have emerged [40–44]. Although several authors acknowledge that PSS has an inherent holistic perspective [45–49], consensus exists over the need for further development of its systems orientation [50,51]. For instance, despite the successful implementation of the IndiGo solar power system in the example above, unanticipated challenges were reported by the company, which illustrate the complexity of energy supply in low-income markets. In particular, distribution has proven very costly in this case because many areas served by the energy company were remote villages with low population density. Ultimately, the constraints associated with distribution became a major barrier and limited the processes of introducing and scaling up the energy solution.

The IndiGo solar power system example illustrates some limitations of a PSS solution at the current level. However promising, at this level PSS lacks a comprehensive approach to encompass all the different technical and societal factors involved in the design process. From the unanticipated challenges experienced by the company to introduce, and scale up, the PSS solution, the lack of a holistic approach is observed. To tackle this issue, it is necessary to gain a better understanding of the complexity of the technical and societal factors that influence a given system. One way to do so is to approach problem-solving and stakeholder values using tenets, methodologies, tools, and techniques that are associated with systems thinking. Adopting a design approach toward PSS that considers the parts of the system as intertwined components, rather than as independent entities, is fundamental for a proper conceptualization and in-depth understanding of the system in place [50,52]. Moreover, the integration of systems thinking on PSS is fundamental because it enables upscaling and embedding solutions into the sociotechnical system to achieve radical improvements [40].

In order to contribute towards filling this gap, this study adopted a systems-oriented approach based on a multilevel perspective that builds upon the work of Elzen et al., [10] and Geels [11] to analyze multiple aggregation levels of the sociotechnical system of an energy PSS. The study examined energy PSSs in low-income energy efficiency programs in Brazil to contemplate the complexity of societal and technical factors involved in solutions for low-income energy markets. The multilevel model helps to identify misalignments between those factors and to propose recommendations for the improvement of energy solutions through design-led policy and active collaboration among stakeholders.

3. A Multilevel Perspective on Energy Product–Service Systems

At the crossroads of energy and design, sustainable energy solutions can be developed by deploying new technologies to generate sustainable energy and promoting changes in lifestyle to save energy [20]. According to Reinders et al. [20], as complexity, functionality, and user interaction increase, energy solutions have to be integrated into a system of products and services that closely interacts with stakeholders and the surroundings (Figure 1).

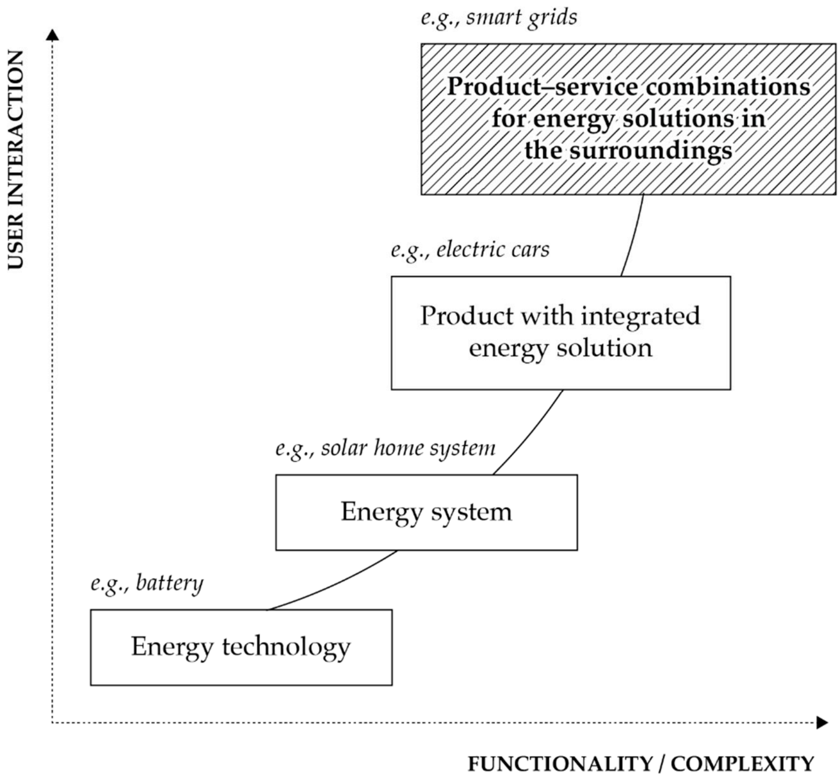

Figure 1. Energy solutions in relation to an increased degree of integration with products, services, stakeholders, or environments [20].

It is likely that the transition from one existing pattern of production and consumption to another demands solutions that go beyond product-centered innovation approaches [53]. Given the complexity of energy challenges in low-income markets, it is clear that improvements on the product technology level, although fundamental, are not enough to create the radical improvements necessary for sustainable transitions. Moreover, complex systems, such as a sustainable energy system, cannot be conceived by technological solutions alone. In such a complex system, the social and organizational practices are complex, unstructured, and messy, and technologies are appropriated and incorporated into everyday practice rather than integrated in a rational way [54]. Furthermore, energy systems in low-income markets often involve multiple stakeholders, including private companies, government, energy utilities, end-consumers, knowledge producers, community representatives, and nongovernmental organizations that influence each other. For these reasons, sustainable energy solutions for low-income markets require a holistic approach and a multilevel perspective, which entails complex relations and interconnections between components of the sociotechnical system [55].

A multilevel perspective employs the notion that an energy solution can be designed at different system levels or different aggregation levels of the societal and technical components of the system. This study contends that to achieve higher levels of sustainability and innovation, the value creation should occur across multiple system levels. Moreover, it should acknowledge the interconnections amongst components of the sociotechnical system within the whole system. To support problem solvers to do so, this study explored a multilevel model that builds on innovation theories, such as technological transition [56] and system innovation, and the transition to sustainability [10,11]. Additionally, it considered design studies such as those exploring the design for system innovations and transitions [43,57,58] and the integration of product–service systems to system innovation and transition theories [41,59–63].

The multilevel model allows for the analysis of a sociotechnical system regarding alignments between components across multiple system levels and their implications for product–service development (energy solutions). The multilevel analysis was adopted to consider three primary aggregation levels as follows: the micro level, which focuses on product technology interventions and behavior change; the meso level devotes attention to product–service arrangements, infrastructure, and organizational change; and, the macro level puts emphasis on design visions, policy-making, and societal change. Table 2 illustrates how design interventions can take place across different systems levels based on the multilevel model.

Table 2. How design intervention manifests at different sociotechnical aggregation levels.

Description	MICRO	MESO	MACRO
Core Idea/Focus	Improving existing or developing new technologies, products, services and behaviors.	Improving existing or developing new integrated product–service combinations, infrastructure, and new business models.	Promoting change on how societal needs are fulfilled, to support the transition to a new sociotechnical system.
Primary agent fostering the change	Individuals, households, and communities.	Organizations, institutions, and companies.	Governments and world Organizations.
Scale of change	Behavior, surroundings, and technological change.	Infrastructure and Organizational change.	Societal change.
Types of interventions	Product technology and services.	Product–service systems.	Systems-oriented PSSs, designs, visions and future scenarios

The three aggregation levels are not meant to offer an optimal description of reality, rather they are a heuristic tool for reflection, analysis, and synthesis. Moreover, by describing a sociotechnical system using the multilevel model, the authors do not intend to suppose that overlap between the levels does not exist. Similar phenomena can manifest across levels in different ways. For instance, at the macro level, "economic factors" can be described as economic instruments created by the government to support new energy policies that generate opportunities for investments in low-income energy efficiency programs. At the meso level, such factors might represent budget allocation introduced by energy utilities to realize investment in voluntary actions against energy poverty. Finally, at the micro level, economic factors can manifest as economic constraints for product–service development created by the low purchasing power of end-consumers.

In addition to being used to analyze how design interventions can affect different levels in a single case, the model can be used to compare solutions of sociotechnical systems that emphasize different levels (Figure 2).

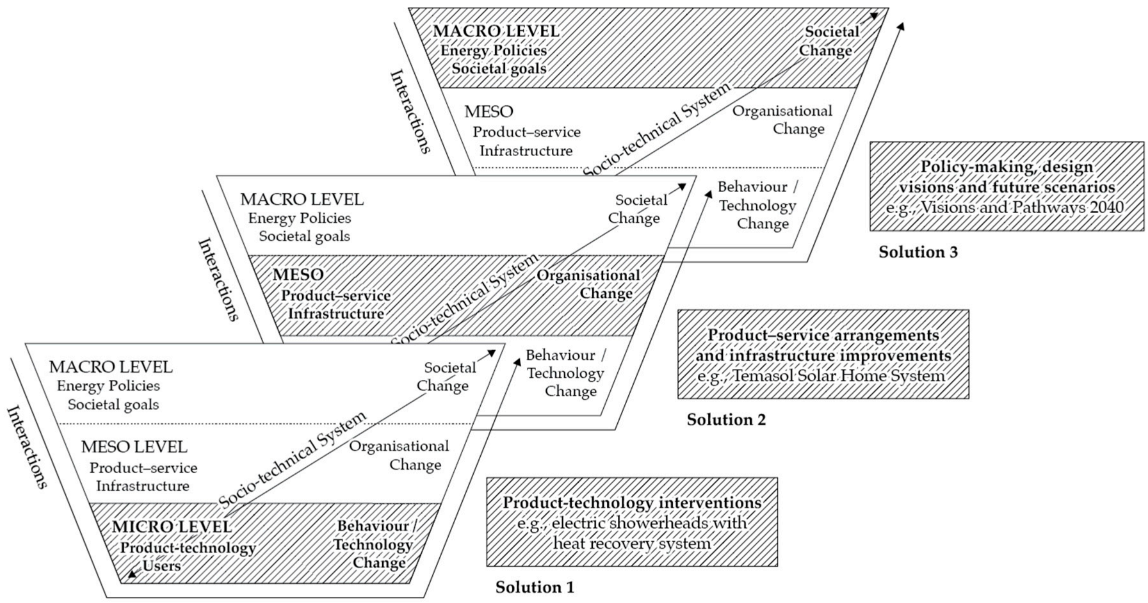

Figure 2. Visual representation of a multilevel analysis of three energy solutions using the multilevel model [10,11,56].

In the next sections, each aggregation level is described in greater detail. Examples are presented to demonstrate how an energy solution (design intervention) introduces changes in the system dynamics from the level of user behavior and infrastructure development to the level of regulatory instruments and system transitions. The examples demonstrate that it is unlikely that energy solutions implemented at the micro and meso levels (e.g., new energy technologies and infrastructure improvements) will be able to replace existing systems with sustainable energy systems without changes at the macro level (e.g., regulatory frameworks, policy revisions, and future planning). Therefore, the capacity to analyze a complex system at different aggregation levels is of paramount importance to create the potential to achieve radical improvements in existing and future systems [62,64].

3.1. Micro Level: Solution 1—Electric Showerhead With Heat Recovery

A design intervention at the micro level focuses on improving existing or developing new technologies, products, services, and behaviors. Energy solutions fulfil a primary function and are usually characterized by a dominant product technology. At this aggregation level, energy solutions aim at improving existing, or developing new, products and services. New technological developments (e.g., renewable energy technology, energy efficient products) and energy practices (e.g., more efficient consumption patterns) emerge to satisfy the immediate needs of the system. An example is electric showers with a water heat recovery system adopted in low-income energy efficiency programs in Brazil.

Electric resistance showerheads are an alternative to water heating and are widely adopted by Brazilian low-income households. Although electric showerheads are low-cost devices, they account for 20% of the residential energy consumption in a household [65], which therefore accounts for a considerable part of the household expenditure on electricity. Moreover, these devices present a significant peak load problem for energy utilities because they account for 43% of the consumption peak between 6 and 9 pm [66]. For these reasons, in low-income households, a heat recovery system for electric showerheads has been proposed as a solution for increasing energy efficiency and decreasing the negative consequences of high peak demand on the quality of the electricity supply at peak time. The heat recovery system absorbs the heat of the water that goes down the drain and transfers part of the thermal energy to the water that will go into the shower, which reduces electricity usage.

3.2. Meso Level: Solution 2—Solar Home Systems by Temasol

At the meso level, design interventions often focus on integrated combinations of products and services and new business models. Energy solutions fulfil one or more comprehensive system functions that are likely to involve product–service combinations, infrastructure improvements, and organizational arrangements. This aggregation level concerns the configuration of a number of components necessary to support the integration of products and services and, therefore, fulfil the system functions. Among others, certain technologies, user practices, regulatory instruments, business models, cultural meaning, market structures, and infrastructure are essential for the operationalization of the energy solution. An example of an energy solution at the meso level is the solar home system (SHS) by TEMASOL.

The project (Global Rural Electrification Program) was a public–private partnership combined with international cooperation for rural electrification that supplied solar electricity at affordable rates to over twenty-four thousand rural households between 2002 and 2008 in Morocco. The Moroccan Government subsidized the equipment costs through the National Electricity Office (ONE), which became the equipment owner. In addition, the system comprised five major stakeholders: TEMASOL to supply, install, and coordinate maintenance of the SHS kits; ONE to subsidize 90% of the equipment cost; French Fund for the World Environment (FFEM) to provide technical assistance and environmental funding; KfW Development Bank to give a grant to ONE in order to finance a large part of the program; and local communes to facilitate the installation and maintenance of the SHS kits. The values of the installation ranged between 82 to 470 dollars (about 10% of the equipment cost), and the equipment cost and monthly fee (ranging between eight to 18 dollars) were paid over ten years by the end-consumers [67].

3.3. Macro Level: Solution 3—Visions and Pathways for Low-Carbon Resilient Futures in Australian Cities

Design interventions at the macro level focus on changes in how societal needs are fulfilled to support the transition to a new sociotechnical system. Energy solutions at the macro level aim to meet a societal function and comprise a combination of material, organizational, policy, sociocultural, and infrastructural components. This aggregation level aims to promote radical changes that influence how societal needs, like the demand for energy, are satisfied, but which are often beyond the control or direct influence of the problem solver.

An example of energy solutions at the macro level is the Visions and Pathways 2040 introduced by the Victorian Eco-innovation Lab (Australia). Drawing on a design-led visioning and a multilevel model of system innovation, the project carries outs participatory visioning exercises (workshops) to explore how four Australian cities could become low-carbon and maintain resilience by reducing their greenhouse gas emissions by 80% by 2040. The project resulted in various future scenarios (or visions) and innovation pathways for policy and design interventions that can reorient current development towards future cities capable of dealing with transitions to sustainable, resilient, and low-carbon societies [68].

4. Methodology for the Case Study

The multilevel perspective proposed in this paper leads to the identification of several societal and technical factors that may present challenges or answers to improving energy solutions for low-income markets. This is represented in a multilevel model concerned with looking at social, economic, and environmental impacts of PSSs on the system as a whole. The study contends that a multilevel model can support problem solvers to gain a better understanding of the sociotechnical systems for the design of energy solutions capable of solving energy challenges in low-income energy markets. To do so, a multilevel analysis is applied to a major PEE project in Brazil. As explained before, PEE is an incentive program that promotes the efficient use of electric power. In this context, the study addresses the following question: What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in a low-income energy efficiency program? Based on the multilevel analysis, recommendations regarding the improvement of energy solutions in national low-income energy efficiency programs are produced.

The research design in this study drew on a literature review, a descriptive investigation of cases, field observations, an interview with a key informant, and a focus group discussion with stakeholders. Case study was adopted because it allows appreciation of the various societal and technical factors involved and the complexity of their interaction across system levels. As a starting point, a literature review and overview of the Brazilian electricity distribution sector was carried out to gain a better understanding of the Brazilian low-income energy market as a sociotechnical system, and to identify relevant cases. The strategy employed the intensive observation of a major empirical case (Case 1) and the analysis of two additional cases built upon secondary data (Cases 2 and 3) (see Table 3). The sample is meant for descriptive, not inferential, generalization. The cases were selected based on the literature review and how they met the following criteria: (I) a public–private partnership aiming at (II) energy product–service combinations for (III) low-income households in (IV) Brazil. The study deliberately selected public–private partnership cases to contemplate the complexity of social relations commonly involved in such solutions for low-income contexts.

Table 3. Overview of cases and adopted data collection techniques.

Case	Description	Research Techniques	Main Demand-Side Management Strategies (DSM) Adopted
1	Program COPEL: Energy efficiency for low-income communities of Parana	Review of available reports, databases, scientific papers, field observations, interview with a key informant, and focus group discussion with relevant stakeholders.	Affordability: guidance to the utilization of government subsidies; Educational actions: a cycle of lectures on the topic of efficient and rational use of electricity; Energy efficient diagnosis: diagnostics to identify energy waste and determine the technological upgrade suitable for each residential consumer unit; Nontechnical losses: regularization of illegal connections; Solar thermal devices: some households receive a solar thermal heating system; Surveys: conduction of socioeconomic and user behavior surveys; Technology/product replacement: replacement of energy inefficient appliances and devices.
2	Program Agent COELBA: Energy efficiency for low-income communities of Bahia	Review of available reports, databases, and scientific papers (secondary data).	Affordability: adjust energy consumption (bills) of the customer to their ability to pay and increase utilization of government subsidies; Educational actions: guidance by community agents on the topic of safe and efficient use of electricity; Income generation: training and employment of local community agents. Nontechnical losses: regularization of illegal connections; Stakeholders relationship: improve customer relationship through the mediation of agents embedded in the communities.
3	Program ECOELCE: Exchanging recyclable waste for a discount in the energy bill	Review of available reports, databases, and scientific papers (secondary data).	Affordability: provide discounts to the energy bills of customers in exchange for solid waste with market value and increased utilization of government subsidies; Educational actions: a cycle of lectures on the topic of environmental sustainability and rational use of electricity; Nontechnical losses: regularization of illegal connections; Stakeholders relationship: promote the collaboration between recyclers, associations, government agencies, and private companies; Surveys: conduct socioeconomic, environmental, and user behavior surveys.

Data Collection and Analysis

Empirical data were collected from the project "COPEL in the Community" (Case 1), which is part of the broader "COPEL Energy efficiency program for low-income communities of Parana". The project proposed stimulation of the rational use of electric power in low-income households in the State of

Paraná (Brazil). The data presented in the Results section were collected during fieldwork observations at the community Madre Teresa de Calcutá in the metropolitan region of Curitiba. The observations provide insights into the everyday life of the local community and aim to understand the social process resulting from the introduction of the low-income energy efficiency program in the local setting. Additionally, an informal, semi-structured, and open-ended interview was conducted with a representative of the state-owned electricity utility, COPEL (Interviewee C), to produce better insights regarding challenges for achieving compliance within national regulatory frameworks. Furthermore, to appreciate the challenges and opportunities of developing and implementing energy solutions in low-income contexts, a focus group discussion was carried out with three researchers/practitioners from the Institute of Technology for Development Lactec (Interviewees A, B, and D) actively involved in Case 1. Also, an expert in design for sustainability and former member of Lactec with extensive experience in energy PSS projects for low-income markets participated in the focus group discussion at the research center (Interviewee E).

The structure of the interview and focus group discussion was supported by the overview of the Brazilian electricity distribution sector and complemented by secondary cases (Case 2 and 3). Secondary data were collected and analyzed for Cases 2 and 3 to enrich the study by looking at similarities to the main empirical case. Background information, such as energy policies, identity of stakeholders, and additional information about the primary and secondary cases, was obtained from the following main sources: (I) national reports conducted by government regulatory agencies and Ministry of Mines and Energy; (II) national household consumption surveys conducted by national and international statistics offices; (III) international reports, such as those published by the World Resources Institute, the World Bank, and the United Nations Environmental Program; and finally, (IV) cases reported in scientific journals.

Based on the multilevel model, the data collected were analyzed across system levels and results were grouped at three aggregation levels. Each level attempts to describe the interplay of societal and technical factors in terms of linkages between the energy solution and the sociotechnical system. The various types of information collected during the literature review, observations, interview, and focus group were compared with each other. Further triangulation occurred by using data from all cases to inform the analysis. In the following sections, the main results of the multilevel analysis are presented.

5. Multilevel Analysis of a Low-Income Energy Efficiency Program in Brazil

5.1. Macro Level: Energy Policies for Low-Income Markets

Policy choices have a significant impact on energy trends, socioeconomic development, and environmental quality in emerging economies [29]. In Brazil, since previous legislation required energy utilities to provide electricity access to all Brazilian households by 2015, electricity has become a widely available public service when compared to other public services like water supply, sanitation, and garbage collection. For this reason, many of the national energy programs relevant to low-income households focus on two main priority areas: improvements in energy efficiency and affordability; and adoption of incentivized renewable energy.

For instance, to comply with Law 9.991/2000 of Brazil's legislation, an amount of not less than 1% of COPEL's (energy utility) net operational revenue must be allocated to projects whose purpose was to promote energy efficiency, R&D, and consumer-oriented energy efficiency programs (PEE). Until December 2014, an amount of 0.5% was destined for R&D and 0.5% for consumer-oriented energy efficiency programs. After January 2015, these amounts changed to 0.25% for R&D and 0.75% for consumer-oriented energy efficiency programs. This law was essential for the development of the low-income energy market because it mandates the application of the majority of the investments in energy solutions for low-income households. According to Interviewee C, at least 60% of this investment needs to be implemented in energy solutions for low-income communities. In addition, energy programs under Law 9.991/2000 had to comply with the following requirements: (I) cost–benefit relationship (CBR) ≤ 0.80; (II) products with energy efficiency label; (III) measurement and verification of results; (IV) performance contract; (V) administrative costs lower than 5% of the investment.

Low-income energy efficiency programs like PEE are possible due to the regulatory obligations imposed on energy utilities and the use of subsidies (Interviewee B). Indeed, between 2008 and 2012, most energy efficient projects were implemented in the low-income electricity distribution sector because PEE mandates the application of 60% of the investment in this sector. However, due to declining returns on PEE resources, adjustments to the regulations were made in 2013, including the non-obligation to invest in low-income communities. According to Interviewee A, there are many studies in the electricity distribution sector that show that the kilowatt saved per hour in such programs is often more expensive than the kilowatt that could be generated for consumption. In other words, although the cost–benefit relationship is a choice criterion for projects, it is often more expensive to decrease energy consumption in low-income energy efficiency programs than to generate it for consumption.

In contrast, "(...) such calculations do not take into consideration the whole lifecycle of the program." (Interviewee A). Moreover, the measurement and verification methodology adopted by the energy programs have limited criteria suitable for evaluation of low-income contexts (Interviewee A), which can limit the ability to assess the real benefits of the program see [69,70] (see also Appendix A). Another challenge emphasized in the focus group discussion is that nonmeasurable and noneconomic benefits have a marginal impact as selection criteria for projects. Although they can be included in the measurement and verification plan, they do not have a sufficient impact on creating incentives or encouraging innovative solutions.

5.2. Meso Level: Stakeholder Motivations and Collaboration

In low-income markets, the complexity and ambiguity between the interests and views of the stakeholders is higher than in traditional markets [71]. Therefore, the collaboration between energy utilities, non-governmental organizations, and community associations (or community facilitators) plays an important role [72]. Case 1 comprises the following major stakeholders: COPEL to coordinate and finance the project and to carry out energy usage diagnostics (energy usage diagnostics and surveys are also conducted by third-party companies); COHAPAR to install energy efficient lights and replace old refrigerators and electric showers; community associations to facilitate communication with the community; end-consumers who are responsible for implementing new energy saving habits. Based on the data analysis, it became evident that stakeholders exhibited different perceptions regarding the benefits of energy solutions and a particular motivation to engage in the development and implementation of the energy program.

In Case 1, COPEL, in partnership with the social housing company COHAPAR, aimed to tackle the waste of energy in low-income consumer units through technological upgrading and behavioral change. To do so, COPEL and Lactec carried out diagnostics to identify electricity waste in residential consumer units. The procedure included a socioeconomic survey, evaluation of household appliances and other electrical devices, and a user behavior survey (Interviewee C). Through this diagnosis, it was possible to identify changes that could be performed by the customer to improve electricity use and determine the technological upgrade suitable for each residential consumer unit. Additionally, low-income customers took part in a cycle of lectures on the topic of efficient and rational use of electricity.

Energy utilities relied on partnerships with NGOs, community associations, and key community individuals to facilitate communication with the communities where customers live. In Case 1, a third-party company was hired to search for and contact a community leader and/or a local church to help disseminate information and to create awareness (Interviewee A). Such interaction is essential to improve the company's relationship with customers, allowing better control and a reduction in household energy consumption. Also, it facilitates the implementation of educational campaigns, promotes behavioral change, and results in more effective, lasting solutions (see also Appendix B).

Such social processes play an essential role in the outcomes of the program since the low-income population generally has limited access to information and education, lacks trust in the government and state-owned companies (e.g., energy utilities), and does not actively participate in the definition of policies and priorities for the communities in which they live.

Corroboration exists in that the rationale which underlies the attention paid to energy challenges by different stakeholders varies. For example, interest from energy utilities is often the result of the need for compliance to legislation, or in anticipation of future policy instruments, rather than being a voluntary action (see [43,73]). For end-consumers, a major driving force behind the engagement in sustainable energy initiatives is gaining access to affordable and new product technologies (e.g., energy efficient household appliances). The main interests for the energy utility COPEL in Case 1 were to: (I) save energy; (II) avoid demand at peak time; (III) postpone investment in the grid; (IV) decrease nontechnical losses and illegal connections to the grid; and, (V) promote institutional marketing (Interviewee C).

In contrast, a dominant driving force for low-income consumers' adoption of the energy program was to have old/inefficient appliances replaced with new energy-efficient devices, such as household appliances (e.g., refrigerators, freezers, clothes washers, and air conditioners), lighting products and systems (compact fluorescent and LED lighting), and alternatives to electric resistance water heaters with minimum efficiency standards (solar thermal and heat recovery system). For example, to attract customers' participation in the education actions in Case 1, COPEL exchanged three incandescent light bulbs for three fluorescent lamps (in some cases two fluorescent and one LED light bulb) for each attendee taking part in a cycle of lectures (Interviewee C). Table 4 presents an overview of stakeholders' drives based on the findings of this investigation.

Table 4. Main stakeholders' drivers in low-income energy markets.

Stakeholder	Drivers
Energy utility	Reduce commercial losses from nonpaying legally grid-connected customers and the number of illegal connections; Increase the utilization of government subsidies; Invest in customer relationships.
Users	Achieve higher living standards through access to clean and modern sources of energy; Find alternatives to afford electricity services; Benefit from low-income energy efficiency programs (e.g., technological upgrade and infrastructure improvements at household level).
NGO's	Increase wellbeing of the low-income population through electricity services; Facilitate the interaction between government, private companies, and end-consumers; Stimulate entrepreneurship and create employment conditions in low-income communities.
Government	Increase access, quality, and affordability of energy solutions; Support income generation capacity in rural remote and low-income areas; Increase access to information to improve energy efficiency and conservation at household level; Promote the use of renewable energy resources.

5.3. Micro Level: Affordability, Efficiency, and Awareness

The development of energy solutions for low-income households faces many economic barriers that make it difficult to create economically viable solutions (Interviewee A). For example, the considerable initial cost involved in the implementation of energy solutions is considered a major barrier by most interviewees. Although the available income of the Brazilian low-income population is increasing, the families observed in the study still experience a certain degree of difficulty in reaching the end of the month with income still available. Additional evidence concerning the issues is that Brazil's transmission and distribution losses are higher than the averages of other emerging economies, such as Russia, China, and South Africa [74]. The high total losses are likely reinforced by nontechnical losses (distribution) due to electricity theft and illegal connections. In the cases analyzed, instances of this occurred because customers were either unwilling or unable to pay electricity bills prior to engaging in the energy programs.

Another issue pointed out by the interviewees was challenges associated with variable tariffs and changes in electricity costs due to the tariff flag system. The electricity distribution has different electricity tariff rates that are compatible with the electricity consumption of the household, as well as other variable factors like consumption time, weather conditions, local infrastructure, and nontechnical losses. Energy utilities issue indicative "tariff flags" to inform customers if energy will cost more or less depending on the conditions for its generation (e.g., rainfall forecast in hydroelectric reservoirs); the flags are green (i.e., no additional charges), yellow, or red (i.e., additional charges per 100 kilowatt hour apply). Although variable tariff rates (e.g., lower prices during off-peak hours) can result in significant energy savings for middle- and high-income consumers, it was pointed out by interviewees that it is very challenging to exploit such mechanisms to create similar benefits in low-income contexts. "In my technical opinion, I would believe much more in high-income consumers.". They have a good infrastructure and energy consumption that can be maneuvered (Interviewee A). Furthermore, consumers have to know "how much they consume" and "when they consume" (Interviewee A). Moreover, such mechanisms are more successful when sufficient understanding of the energy tariff system exists (e.g., how to benefit through the use of different tariffs) and when the use of smart meters is possible. In light of the problem, and to address the issue of affordability, energy utilities and government have focused on economic incentives such as subsidies, discounts, appliance upgrades and exchange (see Appendix C).

The main economic instrument created by the Brazilian government to tackle the issue of affordability in low-income households is the social tariff. The social tariff is a subsidiary tariff that can range between giving a 10% to 100% reduction in the regular residential electricity tariff. The conditions for consumers to qualify for the social tariff are based on consumption level, connection type, ethnicity, income level, and subscription to other social benefits. The families that participated in the project analyzed in Case 1 were oriented by COHAPAR to get their social identification number (NIS), which identifies low-income households that qualify for the social tariff. When the monthly consumption did not exceed 100 kilowatt-hours, the electricity bill was paid by the state government through an energy program called Fraternal Light.

Although the low-income households analyzed met the socioeconomic requirements for participating in the social tariff, they often could not benefit from this economic instrument. The main reason was that they failed to meet the required minimum consumption level (Interviewee A). Similarly, in cases where the families receive the social tariff, they often lose the benefit within a few months. According to Interviewee E, the major issue is that they do not have an understanding of proper energy consumption and conservation practices (see also [75]). This situation is a major issue because the inclusion of low-income households in the social tariff can make viable the implementation of shorter payback periods for the newly implemented energy solution due to the reduction of energy costs (Interviewee E). The study showed that the inability of low-income households to maintain low energy consumption levels related to four major factors: (I) deficiency in thermal insulation of the dwelling; (II) low energy efficiency of household devices; (III) undesirable behavior toward energy use; and, (IV) end-consumers with lack of education of and/or information.

The deficiency in thermal insulation has a significant negative effect on energy consumption and conservation in low-income households and results in the low environmental performance of the dwelling (Interviewee D). Renovations and expansion made in low-income households by untrained or unskilled personnel are a major cause of the problem and result in air leaks, inefficient doors and windows, incorrectly installed heating and cooling equipment, poorly sealed ducts, and poorly insulated ceilings (Interviewee A). For example, in some extreme cases reported during the focus group discussion, low-income consumers used "barbed wire" as electric cable and "plastic bags" as insulating tape (Interviewee A).

Another factor mentioned was that low-income households often use inefficient energy-using devices such old, poorly maintained, or damaged refrigerators; incandescent lightbulbs; and low energy efficiency shower heads. In low-income communities, such devices are accessible and affordable (Interviewee E). Although the substitution of old and inefficient household appliances and lighting by more energy efficient ones resulted in significant emission reductions, interviewees reported challenges related to the behavior of low-income consumers towards such devices. For example, post-occupation surveys showed that low-income households continued using incandescent lightbulbs instead of LED lighting after energy programs were implemented. Many low-income customers avoided using LED lighting because they associated better lighting (brighter light) with higher energy consumption, or they replaced broken LED lights with incandescent light bulbs due to financial reasons (Interviewee A). Similarly, Interviewee C reported an instance where the measurements performed at the end of the energy program revealed that a consumer was using the new refrigerator as an alternative to an air conditioner. "They were leaving the refrigerator door open for cooling the house." (Interviewee C).

A major issue is that the low-income population has limited access to education and lacks awareness or knowledge about energy savings potential and environmental impact. The majority of Brazilian consumers do not read their electricity bill because they cannot understand it (Interviewee A). For this reason, low-income energy efficiency programs are often associated with education projects. To be part of an energy program, the consumer must attend educational lectures and training (Interviewee A). Nonetheless, illiteracy, alongside lack of education and awareness, makes it very challenging to promote supportive attitudes on energy and results in negative energy consumption behaviors during and after the program's implementation (Interviewee A). Furthermore, low-income consumers struggle to carry out self-service activities, such as guided equipment installation and maintenance (Interviewee D).

Corroboration among the interviewees exists in saying that behavior change is a long-term process and the training promoted by energy programs has its limitations. "I cannot change the culture with a lecture" (Interviewee B). Even after the energy programs were implemented, some consumers were unable to see the long-term negative consequences of their behavior, such as electricity theft, meter tampering (fraud), irregular hookups to the network, and damages to public or shared energy devices and systems. "I saw cases (. . .) where water heating solar thermal systems were installed in entire communities, and users were removing them. The problem was lack of maintenance or that the users were selling the equipment." (Interviewee E). Similarly, in Case 1, instances occurred where consumers sold the refrigerators replaced by COPEL. With the money raised, they bought old refrigerators and used the balance for other expenditure (Interviewee C).

6. Discussion of Findings from the Multilevel Analysis

6.1. Towards Systems-Oriented Energy Solutions

Drawing on a multilevel perspective, this paper analyzes Brazilian electricity distribution by focusing on energy solutions for low-income households. The insights from this analysis have been synthesized in a multilevel analysis at three aggregation levels: macro level, which described the relevant energy policies, regulatory frameworks, and the intended societal transformation required to achieve the national energy goals; meso level, which focused on product–service arrangements, stakeholders' relationships, infrastructural development, and organizational changes taking place in the electricity distributions sector; and micro level, which looked at product technology intervention and behavioral change at household level. The study identified several aspects that contribute to the hindering of energy solutions that could increase the ability of low-income energy efficiency programs to reduce environmental impacts and increase the socioeconomic benefits of electricity distribution in low-income contexts. Results show that adopting a multilevel perspective allows new insights and identification of relevant constraints and opportunities across different system levels.

Notably, because there is high top-down interaction between levels, elements at the micro level have difficulty breaking out from the lower level and making contributions at higher levels. It is clear that the adoption of regulatory and economic tools is a success determinant for problem-solvers tackling energy challenges in low-income energy markets. In contrast, there is a missed opportunity for the collection of insights from emerging energy solutions and DSM business models for low-income contexts to support policymakers in future national energy planning. The study shows that promoting the long-term transition to sustainable energy systems in low-income energy markets does not only involve the adoption of energy policies and regulatory frameworks, but also depends largely on changes to infrastructure, stakeholders' networks, technology, user practices, and culture. Therefore, policymakers and problem-solvers have to work towards increasing the alignment between components at lower and higher system levels, in other words to create new opportunities for the improvement of energy solutions for low-income households in Brazil.

6.2. Recommendations for the Improvement of PEE Energy Solutions

The study has highlighted that in the PEE's low-income category, mostly incremental improvements can be achieved with current project guidelines for energy solutions. Although the activities in PEE projects are not limited to demand-side management (DSM), the focus group discussion revealed that energy utilities are reluctant to approve new projects that differ from more established methodologies. PEE programs have rigid methodologies for their implementation, and opportunities for developing solutions capable to produce radical improvements in energy systems are limited to the typology "pilot project". In contrast, projects in the "low-income" typology face many challenges to develop and implement solutions that go beyond incremental improvements.

It is worth noting that projects need to be contracted through public calls that must respect specific laws and procedures regarding the bidding for products and services. Therefore, new products and services that do not follow previously established methodologies, although they may be implemented as a pilot project, need to be evaluated and approved by ANEEL. Moreover, it is time-consuming and bureaucratic for energy utilities to purchase products and services that can only be designed by one specific company (e.g., due to exclusive rights over certain technologies or methodologies), which can discourage energy service companies (ESCOs) from participating in such programs through energy performance contracts.

Another major barrier, which affects the promotion of radical improvements, was the need to develop context-specific measurement and verification tools. The adoption of alternative measurement and verification tools and metrics could be an option to increase the feasibility and viability of new projects that aim to create radical improvements in low-income energy markets. The measurement and verification methodology adopted in the PEE programs is the International Protocol for Measurement and Verification of Performance by Efficiency Validation Organization (EVO). Energy utilities are required to comply with targets and protocols that reinforce the assessment of impact by predominately quantitative performance measures. For instance, the impact of energy efficiency programs is primarily assessed based on the expected cost–benefit relationship (CBR). Therefore, outcomes that cannot be objectively measured and quantified, but which are relevant to low-income markets, such as increased wellbeing, long-term effects, and indirect effects of behavioral change, are often overlooked. In particular, for the low-income category, PEE could use a mixture of measurement and verification methodologies that consider the social and technical analysis of the low-income context prior to and post implementation of the energy program.

Another challenge identified concerns the timeframe of PEE projects. The societal and technological developments taking place in energy systems have different paces of change, particularly in low-income communities. Such developments are strongly influenced by aspects such as local socioeconomic development and infrastructure change. In the cases analyzed, the implementation of the energy program had a shorter time frame when compared with the desired societal transformation (e.g., behavior change and local infrastructure development) and required infrastructure improvement (e.g., improvements at local and household level). In addition, energy programs often do not consider the whole life cycle of the energy solutions implemented. For example, the families observed in the study faced many challenges after the implementation of the energy program. Some of the challenges identified were the inability to maintain low energy consumption levels, the dependency on economic instruments, lack of repair or maintenance of the newly installed devices and appliances, lack of trained technicians, and persistent undesirable behavior towards energy use. A long-term sustainable energy system can only be achieved through continuous development and investment in the community. Policy options could include follow-up energy programs designed to ensure long-lasting solutions by means of enhancing local capacity, improving local servicing infrastructure, and promoting income-generating activities.

7. Conclusions

This paper has discussed the adoption of systems thinking as a multilevel perspective to analyze energy PSSs and gain insights that lead to the improvement of Brazil's low-income energy efficiency programs. The cases analyzed were those in national energy programs that provide integrated electricity services and related products for low-income communities, promoting clean energy solutions, changes in lifestyle, and favoring the efficient use of resources. The results were synthesized in three aggregation level analyses that require careful attention during the development and implementation of energy solutions and conclude that value creation should occur across the multiple levels.

The literature review showed that the requirements of long-term national energy goals are not likely to occur through technological improvements alone. In this context, incremental innovation has its limitations. The study demonstrates that the development of energy PSSs integrating systems thinking gives opportunities for shifting from the current technological paradigm to a sociotechnical paradigm. However, results show that barriers from policies, infrastructure, and stakeholder interests hinder opportunities to promote radical innovation through innovative energy solutions for low-income households. To identify severe constraints and relevant opportunities across system levels is a step forward to develop effective designs and propose better systems practices.

It is important to emphasize that challenges associated with the collection of information from stakeholders at higher system levels may be considered a methodological artefact in this study. Accordingly, it is recommended that future studies include stakeholders from governmental and/or regulatory agencies. Sensitizing policymakers to the unique challenges associated with providing energy solutions to low-income energy markets is an important role to be contemplated by energy utilities and problem solvers, such as designers, in future research and practice. Creating communication channels between government and problem-solvers can facilitate policy revisions and future energy planning favorable to the development of the low-income energy market towards the transition to sustainable energy systems.

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Appendix A. Educational Methodology for Energy Efficiency Applied to Early Childhood Education

Patrzyk's research [70] aimed to examine the relationship between energy consumption and energy usage habits of households based on existing energy efficiency educational projects in Brazil for children aged four to five. This research considered the influence of social relations to observe the relationship between educational activities and energy usage habits, and if the attitude towards energy by students leads to reducing the electricity bills in their homes. The data evaluation showed a positive impact on decreasing energy consumption, with an economy of energy saved during the study period of 4%. The data analysis considered a correction temperature factor since 2013 was set at a lower temperature than those related to the year before. As for the control group, who did not have the educational methodology applied, the data suggested an increase in energy consumption of 47% per month. Results indicated that the methodology developed in this study can be incorporated in the school curriculum aimed at sustainable energy consumption, to disseminate information, create awareness, and tackle energy waste.

More information available at: http://sistemas.institutoslactec.org.br/mestrado/dissertacoes/arquivos/FabianaPatrzyk.pdf (Accessed on 1 October 2019) (in Portuguese).

Appendix B. Agent COELBA. Energy Efficiency Program for Low-Income Communities in Bahia

The program Agent COELBA is an energy efficiency initiative for low-income communities created in 1999 and carried out by the nongovernmental Organization CDM (Cooperação para o Desenvolvimento e Morada Humana) in the city of Salvador (Brazil). The Program was coordinated and financed by COELBA (Companhia de Eletricidade do Estado da Bahia) with the aim of assisting low-income households by providing information to customers about the safe and efficient use of electricity [76].

Furthermore, according to AVSI Foundation [77], the program has the following objectives: reduce illegal connections and commercial losses from nonpaying legally connected customers; adjust energy consumption (bills) of low-income consumers to their ability to pay; invest in customer relations through the mediation of agents embedded in communities; use a combined approach of information and energy efficiency improvements delivered by community agents together with increased utilization of government subsidies (e.g., social tariff); and, rely on an intermediary NGO to reach customers.

The system comprises the following major stakeholders: COELBA, who coordinated and financed the program; AVIS Foundation, who offered methodological support; CMD, who carried out the project, supported the community agents, and facilitated communication with the community; community association, who oversaw the implementation and monitored activities with a high level of community engagement; end-consumers, who implemented the new habits and regularized electrical connections.

The Program Agent COELBA reached over 100 communities and 1.5 million low-income customers were served. In the beginning, the project had six facilitators who supported five communities. In 2010, the network grew to 102 facilitators providing services to 67 communities in the metropolitan area of Salvador and other cities of the state of Bahia. Besides facilitating the lives of consumers and strengthening the relationship with the community, COELBA focused on introducing low-income youth to the labor market [76]. The project and the related energy efficiency components generated employment for over 200 people (AVSI Foundation, 2010). The energy efficiency initiatives involved the replacement of energy-inefficient appliances, like incandescent light bulbs and old refrigerators.

As part of COELBA's project, the "Programa Nova Geladeria" (Program New Refrigerator) sold eighteen thousand new, high-efficiency refrigerators at a fraction of their retail cost. In 2008, to allow access to more efficient refrigerators, a 100% subsidy was offered to fifty-one thousand residential consumer units who met the following criteria: they had regular electricity connection; they paid their electricity bill on time; and they were registered for the social tariff. Additionally, five hundred and twenty-five thousand high-efficiency lamps were distributed. A survey applied among the communities targeted by the program (Nova Geladeira) confirmed a reduction of 33% in energy consumption in 2008 compared to the previous year, and a 46% reduction compared to a projection of consumption without the project intervention.

Appendix C. ECOELCE. Exchanging Recyclable Waste for a Discount in the Energy Bill

The program ECOELCE aims to provide discounts to the energy bills for COELCE (Companhia Energética do Ceará) customers, most of them low-income, in exchange for solid waste with market value. The ECOELCE pilot project was launched in 2006 for low-income communities in the city of Fortaleza (Brazil), and in 2007 was officially available to all COELCE customers [78]. After five years, it was implemented throughout the State of Ceará (Brazil), and had 64 collection posts (38 fixed and 26 mobile posts) across 27 cities, serving about 90 communities. The program involves 42 partners among recyclers, associations, government agencies, and private companies [79].

To identify the problem and develop a systematic solution, COELCE surveyed 184 low-income communities located in Fortaleza. This survey showed a relation between the low purchasing power of the population, the large volume of solid residues improperly disposed in the environment, and high rates of energy theft, leading to an increase in power losses and inefficient use of power [28]. The city of Fortaleza generates more than forty-one thousand tons of solid residues per month, from which, fourteen thousand nine hundred are potentially recyclable. However, only three thousand tons were recycled per month in 2004 [78].

The system comprises the following major stakeholders: COELCE to manage the collection system and provide the credits to the energy bills; collection posts to register customers, collect, and weigh recyclable residues; waste collection companies to determine destinations for the residues from different industries; customers who collect and exchange the recyclable residues for energy credits. The main economic impact of the program was the decrease in illegal connections and nonpaying legally connected customers. The customers, particularly those in low-income communities, benefit from discounts in their energy bill. In some cases, the customer achieves a reduction of over 90%, or even the total liquidity of the energy bill. After five years, the program provided over eight hundred thousand Brazilian reais in discounts on energy bills. Additionally, 57% of defaulting customers participated in the first year of the program, resulting in a significant reduction of debts to COELCE and illegal connections [78]. The program resulted in an energy economy of 11,684.87 MWh per year, which is related to the yearly amount of recycled material collected [80]. The program reached about four hundred and five thousand registered customers and received 12.700 tons of recyclable residues. The communities served experienced improved living conditions through the reduction in the volume of solid waste improperly disposed in the urban environment.

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