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Integrated resources planning as a tool to address energy poverty in Brazil

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ABSTRACT

This paper departs from a planning tool to assist policy makers and energy planners to improve energy access and affordability, besides developmental needs of low-income/underserved households and small entrepreneurs. The methodology aims to systematically integrate energy technologies (supply and demand-side), new and innovative business models and local developmental issues into long term power plans by applying concepts and the process known as Integrated Resources Planning (IRP). To illustrate the application of the methodology, referred to as IRP-Access in this paper, some possibilities are tested to reduce Energy Service Costs (EC), analyzing the impacts in the electricity affordability of low-income consumers. For this purpose, we use data from a Brazilian electricity concessionaire which operates in a complex socioeconomic region in the Southeast of the country, where the energy access is solved, but affordability is still a current issue. The results illustrate the potential of implementing technological alternatives in Brazil, from the supply and demand side, in order to improve affordability, to address energy poverty and to systematically incorporate such critical issues into the long-term energy planning.

1. Introduction

A precise and consensual definition of energy poverty is not widely accepted yet due to the different socioeconomic realities of countries around the world and to the different approaches when considering climate conditions or cultural contexts [1–8]. In other words, energy poverty is a relative and socially constructed concept [9].

However, among all the debate in the literature regarding the definition of energy poverty, we consider that the one stated by [10] seems to better capture its multidimensional features and is more appropriate to our approach: “The energy dimension of poverty — energy poverty — may be defined as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development”. Thus, the physical energy access itself does not necessarily attain other energy poverty attributes such as affordability, reliability, quality, safety and environmental protection.

For instance, Brazil is close to reach universal physical access to electricity, but affordable energy services are a concerning and unsolved issue for many consumers (see Section 2). Unfortunately, the Brazilian low-income energy efficiency programs for the last 20 years have not incorporated an affordability outcome as an explicit criterion in their design and evaluation in addition to the cost-effectiveness perspective.

This kind of rationale, which persists for a long time behind the design and evaluation of energy programs, must change. This paper aims to illustrate that the explicit use of energy poverty attributes as criteria by energy planners (such as affordability) discloses the energy dimension of poverty, then connecting energy programs to broader poverty policy targets and related indicators.

Concurrently, the need for new and more innovative approaches is increasingly being recognized in order to unlock the potential role of energy in socioeconomic development [8]. Especially by considering the possibilities untapped by the evolution of technologies currently available, such as distributed generation and smart appliances. Therefore, in connection with the paragraph above, this paper presents an illustration of how such cutting-edge decentralized supply technologies (solar PV, in particular) could be included in traditional low-income energy efficiency programs, when considering energy affordability from the energy planning perspective.

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However, the "complex multidimensionality" [11] and the "multifaceted notion" [12] of energy poverty is a great challenge to policy makers and energy planners, especially in developing countries. In this context, [13] proposed an adaptation to the conventional energy planning method known as Integrated Resources Planning (IRP) [14,15], called IRP-Access (see Section 3), to face these challenges.

Hence, this paper presents an analysis based on IRP-Access to illustrate how the mindset of traditional mechanisms and programs can be reoriented to explicitly consider the improvement of the affordability capacity of low-income consumers to pay for their electricity bills. For such illustration, the paper draws on the data from a regulated and mandatory low-income end-use energy efficiency program performed by a local private-owned utility operating in a large city with extensive slum areas and low-income residential customers in Brazil.

The illustration presents the impacts in the affordability conditions of an average household under three actions combining supply and demand technologies: (1) only the replacement of refrigerator, inefficient lamps and electric shower head (business as usual scenario based on data and results from one of this local utility's low-income energy efficiency traditional programs); (2) only the installation of a grid-connected photovoltaic system under a net-metering scheme to supply its monthly consumption (based on data from secondary sources); and (3) the combination of both measures.

There are low-income housing in Brazil which can have structural conditions and space for installing PV panels [16–18] and, if not, the current regulation allows the siting of the installation of distributed generation in a place other than the consumer's one.[1]

It is worth mentioning that the objective of the authors with this paper is neither to prescribe the best measure to choose for a distribution utility's low-income energy efficiency program nor to perform the evaluation of the illustrative cases presented here. Instead, we propose a different designing and evaluation approach of how to think such programs from an affordability point of view, differently than only from a cost-effectiveness perspective.

Initially, a brief overview of the public actions for promoting affordability to electricity in Brazil is presented. Afterwards, we present the IRP-Access method and the case study.

2. Energy poverty in Brazil: some remarks

The universalization of electricity access is almost a reality in Brazil. According to the Brazilian Institute of Geography and Statistics (IBGE), the national coverage of the electricity access, which is the physical connection that enables the arrival of electricity to the consumer through distribution network or distributed generation, increased from 94.5% in 2000 [19] to 98.7% in 2010 [20] (Table 1), and then to 99.8% in 2017 [21].

However, affordability conditions have been deteriorated in Brazil, especially during the economic crisis the country has been facing since 2015. The combination of the increase in electricity rates, inflation and unemployment have affected the population's ability to pay for their electricity bills, resulting in the rise in nonpayment rates, interruption of services and irregular connections. Affordability is understood here as one of the attributes of the energy dimension of poverty which relates to the ability of households to purchase the electricity in order to meet their required energy services without suffering undue financial hardship [22–26]

To illustrate such affordability deterioration, Fig. 1 presents the relation between the increase of electricity tariff rates and the impacts of economic recession on the ability of households to pay for their electricity bills. From 2013 to 2015, the average electricity service interruptions (primary axis) increased by 54.4% and the average tariff rate by 64.4% (secondary axis). The data is from one of the largest electricity utilities in the country, which serves São Paulo metropolitan area. The current regulation allows the nonpayment of electricity bills up to 3 months by the consumer before the service is interrupted. The average energy debt index had similar behavior in comparison to the average interruption rate in the period (primary axis). The index represents the number of consumers who have overdue debts of their electricity bills.

Traditionally, energy affordability issues are tackled by providing subsidies for target customers. The main Brazilian public policy in this sense is the Social Electric Energy Tariff (SEET) [8,30,31], which offers different discounts on the tariff rate for consumers whose household monthly income per capita falls below half the current minimum wage (R$ 954 or US$ 251.05 at the time of writting) [32]. These discounts are given only for the first 220 kWh consumed in the month, while the remaining of the consumption of such month is rated without discount. The details of how to calculate the electricity cost using such ruling are given in footnote 4, considering the average consumption used in the case study. The amount of such discounts (or subsidies) are collected from all consumers through electricity rates and/or from taxpayers (national budget). As the SEET-beneficiary consumers become more energy efficient and/or generate their own electricity, their electricity bills go down and, correspondingly, the required subsidies.

It is also possible to combine this national SEET ruling with state-level affordability programs which focus on the local reality. For instance, the government of the State of Paraná created in 2013 a program called "Fraternal Light" which pays the electricity bills of the consumers registered in the SEET whose monthly consumption is lower than 120 kWh.

In addition, utilities are obliged to invest in energy efficiency programs since 1998, when the first contracts after privatization were signed [33]. Afterwards, the Law n° 9991/2000 turned mandatory the investment of a minimum percentage of 0.5% of the power concessionaires' net operational revenues in end-use energy efficiency projects under the Energy Efficiency Program (PEE) regulated by the Brazilian Electricity Regulatory Agency (ANEEL). Such percentage is charged from all consumers through the electricity rate. The concessionaires are required to submit their projects to ANEEL, which must monitor them and approve their implementation after completion based on the current regulation. The ANEEL Resolution n° 176/2005 established that a minimum of 50% of these energy efficiency investments must be directed to low-income projects. In 2016, such minimum requirement to low-income projects was canceled and concessionaries could invest up to 60% in such kind of projects.

The PEE's projects are currently the major end-use energy efficiency investments in Brazil. These projects promoted, for example, the replacement of old equipment by more efficient ones, such as refrigerators, lamps and shower heads [34,35]; orientation of the population on the rational use of electricity; among several other actions to reduce electricity consumption [36]. The illustrative case brought by the authors is one of these projects.

From the supply side, the Brazilian consumers became allowed to generate their own electricity using renewable sources since 2012 [37], which refers to the ability of producing electricity for their own consumption and still sharing the surplus with the net-

[1] The constructions carried out by the My House My Life Program (PMCMV), or by other municipal and state housing programs, which have a planned infrastructure [16,17,44–46]. The houses in "shanty towns" are subnormal occupations, but it can support the installation of photovoltaic panels through technical adaptations [47,48]. In addition, Brazilian law permits shared electricity generation: the joining of consumers, within the same area of concession or permission, through a consortium or cooperative, which has a consumer unit with distributed generation in a different place from the consumer units in which the excess energy will be compensated [49].

Table 1
Electricity access in Brazil (2000, 2010).

		Total	Urban	Rural
Census 2000	Total households	44,776,740	37,369,953	7,406,788
	% households with electricity connection	94.5	99.1	71.5
Census 2010	Total households	57,324,167	49,226,749	8,097,418
	% households with electricity connection	98.7	99.7	92.6

Sources: own elaboration from [19,20].

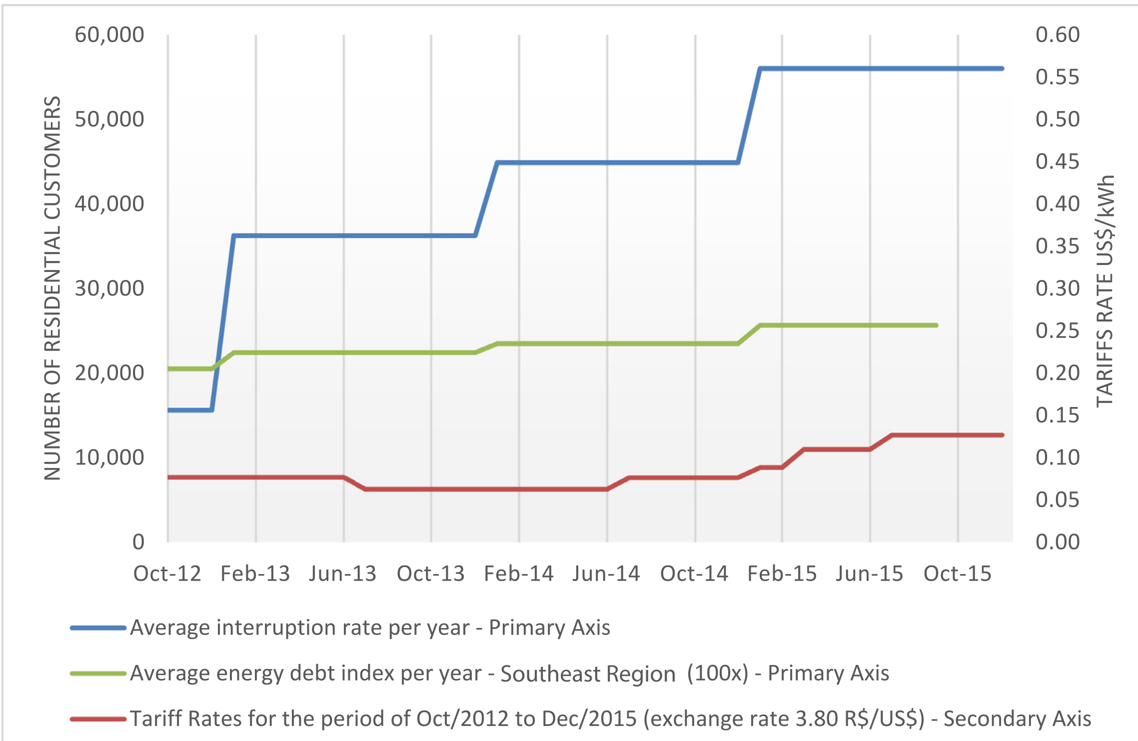

Fig. 1. Electricity services interrupted due to lack of payments and electricity tariff rates.
Source: Source: [27–29].

work [38]. The net metering adopted in Brazil is a compensation scheme in which the surplus generation becomes electricity credits (not monetary resources) that can be deducted from the electricity consumption in the current or in the next consumer bills. These electricity credits have an expiration date of five years. The electricity can be generated at the building itself where the consumption takes place, or a distributed generation can be installed elsewhere, but providing the same benefits to the consumer. Such distributed generation technologies make possible the reduction of energy expenses and income generation.

Due to the high upfront cost of such distributed generation technologies, such as photovoltaic systems, their adoption are restricted to those who can afford it, even though it could benefit more the poorest population, in particular, and the average consumer in general. Few of these technologies have been implemented in low-income households.

Despite all the above, SEET and investments in energy efficiency have not been enough to solve the affordability issues in Brazil [8]. Not only because energy policies are only part of the effort to tackle poverty alleviation, which need to be strategically linked to broader developmental programs, but also because innovative approaches to address energy affordability were not considered yet within the space where energy policy and planning play an important role.

In this sense, the next section presents the IRP-Access method used in the illustrative study, which incorporates affordability into the rationale of an energy program design.

3. IRP-Access: the methodology

IRP, as an energy planning method, shifted the traditional supply-oriented focus of the conventional energy planning to combine both, supply and demand-side resources, to provide and/or expand energy services. IRP focuses on the end-use of energy and on the services required by households, businesses and industry. This effort means that “much closer attention is paid to present and future human needs served by energy, the technical and economic details of how energy is being used, and alternative technological options for providing energy services that are needed” [39]. IRP, hence, broadens the mix of potential resources by incorporating technologies for energy efficiency, demand-side management and distributed generation.

In its turn, IRP-Access [13] includes specific aspects of energy access and energy poverty of developing countries within IRP’ scope. IRP-Access takes advantage of technologies available today,[2]

[2] For instance, distributed generation, smart metering, smart appliances, cellular phones and mobile applications.

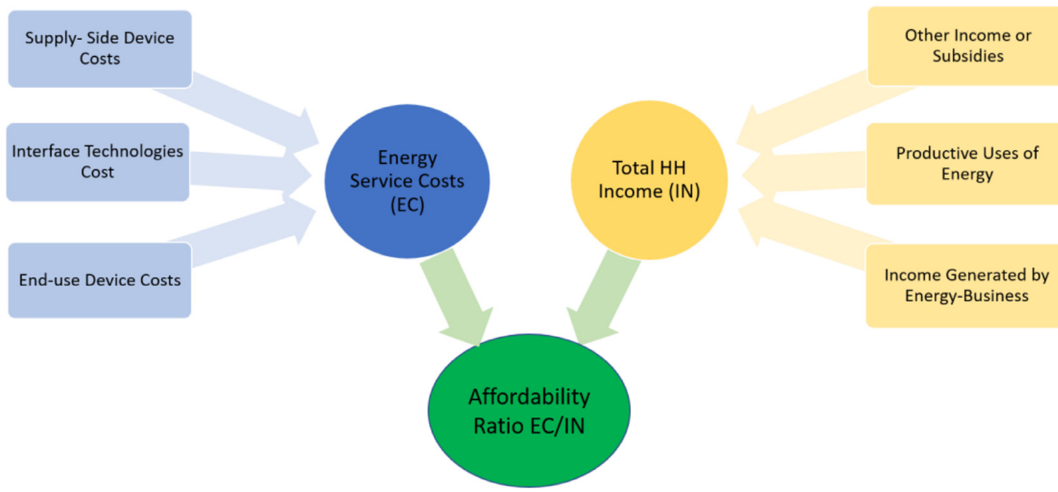

Fig. 2. Affordability as seen in Bottom-up methodology.
Source: Source: Adapted from [13].

together with new tools and practices supported by new business models to enhance "an approach to energy services that may go far beyond the usual concept of providing energy for basic needs and consumerism, permitting these households to use energy services to generate income and engage in productive activities" as well [8].

The idea proposed by IRP-Access combines two methodological approaches, Top-Down and Bottom-Up, to result in an evaluation stage whose objective "is to make sure that the proposed local solutions are consistent with the National Plans (not only the energy plan, but also socio-economic developmental plans) and vice-versa" (p.3) [13].

The Bottom-Up approach (Fig. 2), used in this paper, aims to study options in greater detail that would be more appropriate to the local conditions and to the societal segment considered. The technical and economic performance of energy technologies should be evaluated more precisely, and socioeconomic factors can influence the suitability of different business models and program designs.

The affordability indicator considered by IRP-Access is the ratio between Energy Service Costs (EC) and Total Household Income (IN), named Affordability Ratio (AR) (Fig. 2). The energy modeling should estimate electricity cost for the consumer and the income generated by the energy technologies or energy services, providing the ability of the consumer to pay for electricity or the required subsidies.

The next section presents an exercise of how cutting-edge decentralized supply technologies (solar PV, in particular) and end-use technologies could be evaluated when considering energy affordability from the energy planning perspective.

4. An illustration of IRP-Access applied to low-income consumers in Brazil

The following cases are illustrative of the role that energy end use and supply-side technologies could have on the energy affordability of consumers. The authors present the outcomes that the three actions presented at the introductory section would have had on an average low-income consumer at the State of Rio de Janeiro (Brazil) under the mandatory energy efficiency program by the local private-owned electricity distribution utility.

These illustrations are not intended to be accurate (which would require in-depth technical and socioeconomical information, feasibility and sensitivity analysis), but to showcase the methodology being proposed. Thus, some assumptions can be considered optimistic or overestimated and the results can be rather different depending on the hypothesis assumed as will be shown later. The authors do not have any intention of indicating what is the best choice to make among the presented measures or evaluate such program, but to illustrate an approach of how to think such program from an affordability point of view, differently than only from a cost-effectiveness perspective.

In addition, the examples brought here are somehow realistic in the sense that they are based on current practices of the existent Brazilian mandatory end-use energy efficiency projects and rely on costs and outcomes from a past individual project from a local distribution power company. Such approach of using an affordability ratio can be used in other countries paying attention to the respective local context (types of programs, consumption and peak demand, electricity rates and rate structure, macro and microeconomics, for instance).

Despite there is no guarantee that the current ruling is immutable, it is also uncertain what it would become. For instance, the surplus of electricity generated by a household is valued equal to the electricity supplied by the utility, even though it can be revised at some point in time. Thus, for the sake of the illustration proposed here, the examples consider that the current ruling remains the same during the entire period of analysis.

In order to compare the three measures at the same base, a yearly cash flow for each example was made for the lifetime of the PV panels (25 years) considering income, loans, costs and savings.[3] The cash flow was brought to present value using a 10% annual nominal interest rate by the consumer's perspective. The exchange rate used was 3.80 R$/US$.

To perform all calculations below, an average low-income household monthly consumption and income was defined (Table 2 and its notes) within the concession area of a distribution company in the Rio de Janeiro state. Such consumers fit in the SEET, which offers stepped discounts depending on the monthly consumption, as presented in Table 3 for the current tariff scheme.[4] To be eligible to SEET, the household monthly income per person must be up

[3] It is worth noting that a scenario that spans over the next 25 years are prone to several uncertainties, such as the path of income growth, equipment prices, inflation and electricity tariff rate and even the very existence of such mandatory low-income energy efficiency programs.

[4] The procedure to calculate the electricity bill is as follows, for the adopted monthly consumption (195 kWh): cost = 30 kWh × 0.06431 + (100 − 31 + 1) kWh × 0.11024 + (195 − 101 + 1) kWh × 0.16536 = US$ 25.35. Dividing it by 195 kWh results in the average SEET rate of US$ 0.13/kWh.

Table 2
Average family income and electricity consumption for low-income households serviced by the utility.

Average electricity consumption[a] (kWh/month)	195
Average family income[b] (US$/month)	392.90

Notes:.
[a] this average is resulted from the total electricity consumption by SEET consumers in February 2018 (42,437 MWh) divided by the correspondent total SEET consumers (217,727). Such values were taken from the tariff readjustment that came into force on May 2018 for the distribution utility called Light.
[b] It was considered that the monthly family income is half (R$ 477.00 or US$ 125.53) the minimum wage times an average of 3.13 persons per low-income family.Source: Own elaboration.

Table 3
Tariff rates for residential and residential SEET consumers for the period of May/2018 to Feb/2019.

Consumption class	Discount	Tariff rate including federal and state taxes (cents US$/kWh) Consumption range: from 51 to 300 kWh
Residential	–	19.870
Residential SEET		
- Up to 30 kWh	65%	6.431
- From 31 to 100 kWh	40%	11.024
- From 101 to 220 kWh	10%	16.536
- From 221 to 300 kWh	–	18.373

Source: Adapted from [40].

Table 4
Economic rates used for all illustrative cases.

Annual income growth rate	4%
Inflation rate	4%
Annual tariff growth rate for either non-SEET and SEET households	9%
Loan nominal interest rate per year	12%
Nominal interest rate per year: consumer's perspective	10%

Source: Own elaboration.

to half the federal minimum wage (R$ 954.00 or US$ 251.05 as for 2018).

Table 4 presents the common economic parameters used in all three examples.

Income increases[5] less than the social tariff rate, which has increased from 2013 to 2018 around 9% in average, considering the utility used in this example. It means that the affordability ratio worsens over time, increasing the burden of energy costs as a share of the family income (Table 5). This situation highlights the need to either take measures on the energy side of the equation or to use energy efficiency projects as a means to generate income if such trend endures over the years.

The affordability ratio for the period (25 years), without any energy measure, is presented in Table 6 considering both the subsidized and the full tariff rates. Such ratio is the present value of the consumer's electricity cost divided by the present value of the family income at the consumer's interest rate of 10%.

The following sections present the three measures and respective results.

[5] It was considered that the Brazilian official minimum wage grows at least the same inflation rate as the current legislation ruled at the time of this paper was written. This rule is due in 2019 and there is no prospect of either reenacting it or not. The authors also considered approximately the same Brazilian official inflation rate target of 4.5%.

4.1. Energy efficiency replacement program

The energy efficiency measures presented in this paper are: replacement of an inefficient refrigerator by an one-door, 260-l capacity efficient one; replacement of five incandescent light bulbs by 15 W-fluorescent compact lamps (LFCs); and replacement of an electric shower head by a 3500 W-maximum output electric shower head with heat recovery. The consumers benefited by this program only had to exchange their old equipment to get the energy-efficient ones at no cost. This is common practice by other utilities all over the country. Some distribution companies have performed rebate programs to replace the same equipment, such as refrigerators.

Table 7 presents the upfront costs, lifetimes and energy efficiency outputs from a previous utility program. The upfront costs are entirely covered by the energy efficiency program, and after their lifetimes, by the consumer. All equipment costs are considered at the full retail prices as a conservative assumption from the utilities side because they buy at the wholesale price due to the large amount required to implement the program.

It was considered that there is no operation and maintenance costs for the refrigerator and LFCs over their lifetime. For the electric shower, there is one replacement of its heating resistance per year at the cost of US$ 7.89. This cost is covered by the consumer. For simplicity, the decay in the efficiency of all equipment was not considered during the lifetime.

The total savings of 73 kWh (Table 7) in a month represents 37.4% of the total household electricity consumption. For the new consumption (122 kWh/month), the average SEET rate is US$ 0.10753/kWh, whose calculation follows the same procedure as presented in footnote [4]4.

4.2. Grid-connected photovoltaic system program

Brazilian legislation allows consumers, such as households, to self-generate their electricity in grid-connected systems. The measure proposed here is a low-income program of installing grid-connected PV systems in order to generate 100% of the monthly consumption of 195 kWh. Table 8 present the upfront costs and other relevant inputs to design the PV system. The upfront costs can be shared by the Brazilian energy efficiency program (lost funded) and the consumer (through bank loans or from loans by the program itself, for instance). Even if the electricity generated within a month covers the whole consumption, the Brazilian consumers must pay for the what is called cost of grid availability, which is the equivalent of the electricity cost of 30 kWh (single-phase connection) or 50 kWh (two-phase connection). The monthly cost is, respectively, US$ 1.56 and US$ 3.26. This work assumed the household is single-phased connected to the grid.

As for the energy efficiency program, the consumer pays entirely for the O&M costs. The consumer also pays for the replacement of the inverter in the end of year 10 and in the end of year 20. It was assumed, as a matter of simplification only, that there is no decline in electricity generation by the PV system.

The cost of the PV system was assumed to be 10% lower due to the scale of the utility program. Table 9 present the features of the PV system to deliver the full electricity consumption (195 kWh/month) of the average household considered in this work.

4.3. Energy efficiency and PV system

The approach used here is to first implement the energy efficiency measures to reduce the household electricity consumption and then install the PV system designed to meet this new consumption. This reduces de size of the PV system and, therefore, its

Table 5
Affordability ratio (%) without energy measure for the first ten years (2018–2028).

Tariff	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
SEET	6.45	6.76	7.09	7.43	7.79	8.16	8.55	8.96	9.40	9.85	10.32
Full	9.86	10.34	10.83	11.35	11.90	12.47	13.07	13.70	14.36	15.05	15.77

Source: Own elaboration.
Notes: The first row considers the consumer pays the social electric energy tariff (SEET) and the second one the full tariff.

Table 6
Average affordability ratio (%) before energy measures.

	Family income	Electricity bill (SEET)	Electricity bill (non-subsidized)
Present value (US$)	61,615	6,770	10,345
Affordability ratio (EC/IN)	–	11.0%	16.8%

Source: Own elaboration.

Table 7
Inputs for the energy efficiency replacement program.

Equipment	Electricity savings (%)	Savings (kWh/month)	Equipment Cost (US$)	O&M (US$/year)	Lifetime (year)
Refrigerator	45.0	26	315.79	–	10
LFC	72.0	25 (5 lamps)	11.85 (5 lamps)	–	4
Electric ShowerHead	49.0	22	131.58	7.89	10
Total	–	73	459.22	7.89	–

Source: Own elaboration.

Table 8
Input data for a grid-connected PV system.

Electricity generation ratio	1,482	kWh/kWp.year	[41]
Cost of PV system ($\leq$6 kWp)	4,590	US$/kWp	[42]
O&M	1%	% per year	[41]
Inverter	1,579	US$	Ownestimate

Source: Own elaboration and [41,42].

Table 9
Size, costs and loan tenure for the utility's grid-connected PV system program.

Size of the PV system	1.58	kWp	**Lifetime (PV panels)**	25	years
Cost of the PV system	6,527	US$	**Lifetime (inverter)**	10	years
O&M	65.26	US$/year	**Loantenure**	10	years
Inverter[a]	1,578.95	US$			

Source: own elaboration.
Note:.
[a] the consumer will pay the full cost of the inverter, without the 10% discount. On the other hand, the program could have a component replacement program for such consumers (lost funded or financed).

Table 10
Size, costs and loan tenure for the utility's grid-connected EE+PV system program.

Electricity consumption after savings	122	kWh/month
Electricity saved (37.4%)	75	kWh/month
SEET rate	0.10753	US$/kWh
Size of the PV system	0.99	kWp
Cost of the PV system	4,089.79	US$
O&M	40.79	US$/year
Inverter	987.89	US$
Lifetime (PV panels)	25	years
Lifetime (inverter)	10	years
Loan tenure	10	years

Source: own elaboration.

Table 11
Affordability ratio for the energy efficiency measures.

		Cost to consumer after measure		
	Family income	Measure	Electricity bill (SEET)	Electricity bill (non-subsidized)
Present value (US$)	61,615	238.88	3,502	6,472
Affordability ratio	–	–	6.2%	11.0%

Source: Own elaboration.

costs. Table 10 presents the inputs used of both energy measures to perform the calculations.

5. Results

Before presenting the results, it is important to highlight that future energy prices, future savings, future micro and macroeconomic indicators and even the maintenance of current regulation is uncertain. Hence, at the policy-making decision level, sensitivity analysis must be considered not only "to determine the best choice among policy options", but also to evaluate "policy problems, identifying relationships among key variables, and testing the implications of various conditions" [43]. It is important for policy makers to bear this in mind, even though the sensitivity analysis is out of the scope of this work.

It is not too much to remind that the objective of the authors with this paper is neither to prescribe the best measures choice for a distribution utility's low-income energy efficiency program nor to perform the evaluation of the illustrative cases presented here. Instead, we aim to propose an evaluation approach that goes beyond cost-effectiveness analysis of the measures by focusing on the consumers' affordability to pay for energy services as a share of the family income. Such approach can better link to poverty reduction policies and related indicators by disclosing more explicitly this energy dimension of poverty.

5.1. Energy efficiency replacement program

As a result, the energy efficiency replacement program improves the affordability ratio from 11.0% to 6.2% (Table 11). The energy cost to the consumer comprises both the upfront costs of replacements after the lifetimes of appliances, O&M and the electricity bill after savings.

In this scenario, under a year-by-year basis, the base case affordability ratio of 11.0% would be attained in the years when the consumer invests to replace the refrigerator and electric shower after their lifetime: 11.9% (year 10) and 13.1% (year 20) (Fig. 3). In the end of the analysis period (year 25), the affordability ratio is 10.9%.

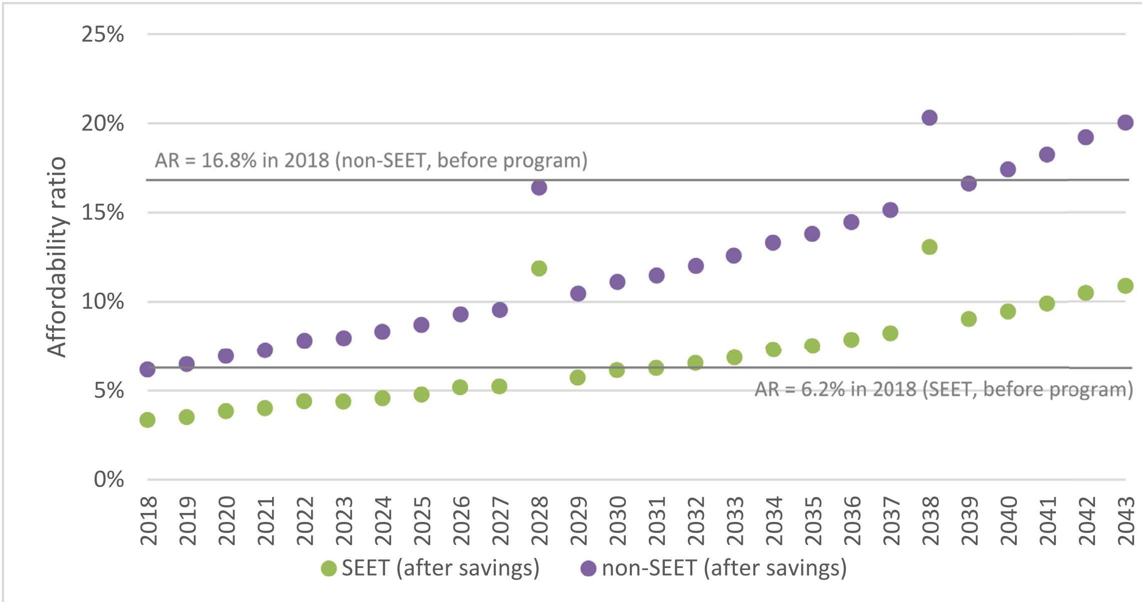

Fig. 3. Affordability ratio after energy efficiency measures
Source: Source: Own elaboration.

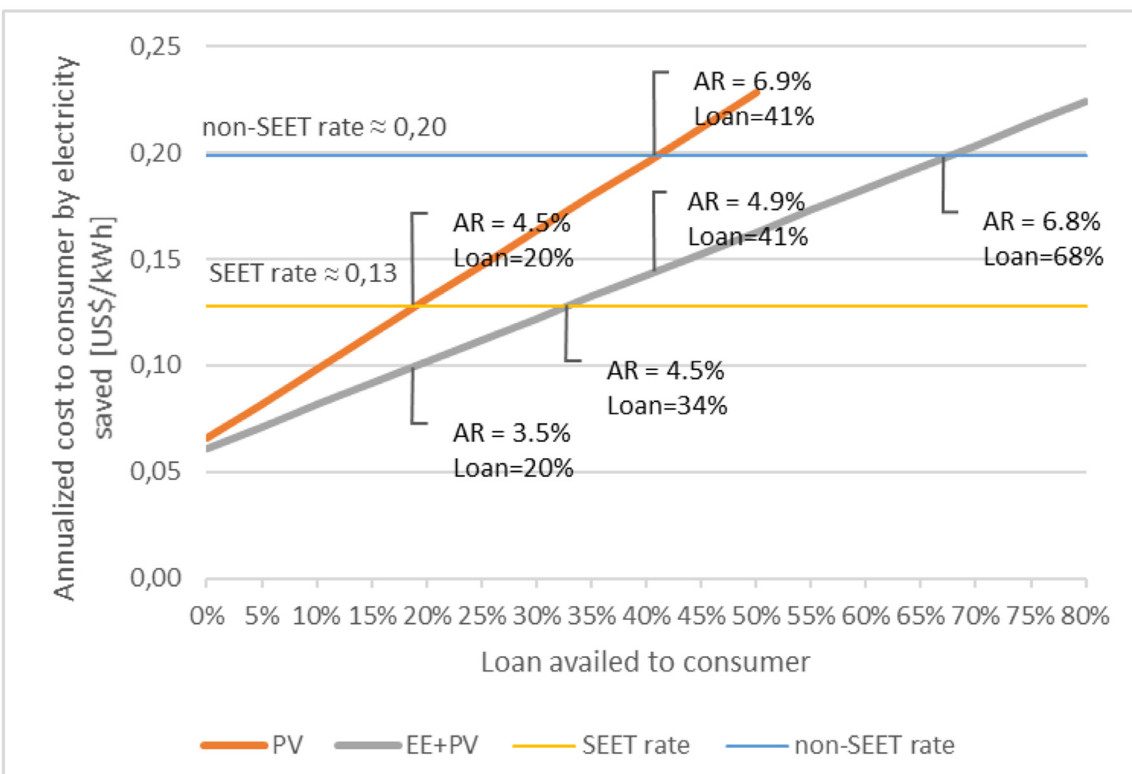

Fig. 4. Annualized cost per electricity saved for different consumer loans for either utility's PV Program or EE+PV Program.
Source: Source: Own elaboration.

In case the consumer would have to pay for the full tariff rate, the affordability ratio (11.0%) after measures would be coincidently the same as with the subsidized one (11.0%) of the base case before the energy-efficient measure. In the end of the analysis period, the affordability ratio is 20.0%.

Even though the impact of the program on affordability is important, its trend must be considered by evaluators and policy makers. For this specific illustrative case, the affordability deterioration condition over the years remains unchanged after the program, because the income growth is lower than the tariff growth (Fig. 3). New energy efficiency measures can be done, but its potential is lower once that the benefited consumers do not depart from an inefficient stock anymore. Hence, efficient energy services have a role in improving energy affordability, but they face a natu-

Table 12
Affordability ratio for different loans (consumer's share of the up-front costs) – PV Program.

Loan to consumer	20%	41%
Present value of the cost to consumer (US$)	2,788	4,228
Annualized cost per kWh saved (US$/kWh)	0.13	0.20
Reduced subsidies (US$/kWh)	0.17	0.17
Average affordability ratio (EC/IN)	4.5%	6.9%

Source: Own elaboration.

Table 13
Affordability ratio for different loans (consumer's share of the PV system) – EE + PV Program.

	EE+PV	EE+PV	EE+PV	EE+PV
Loan to consumer	20%	34%	41%	68%
Present value of the cost to consumer (US$)	2,140	2,746	3,049	4,217
Annualized cost per kWh saved (US$/kWh)	0.10	0.13	0.14	0.20
Average affordability ratio (EC/IN)	3.5%	4.5%	4.9%	6.8%

Source: Own elaboration.

ral limit which could be overcome either by broader development policies or the use of energy services to generate income in productive activities.

5.2. Grid-connected photovoltaic system program

The results of the annualized cost per electricity saved to the consumer are presented in Table 12 for two scenarios of consumer loans to repay over 10 years. It shows that the consumer would invest the same SEET rate (US$ 0.13/kWh) to cover the costs of owning 20% of the PV system, which would improve his affordability ratio from 11.0% to 4.5%. At a loan of 41% of the PV system cost, the consumer would pay the equivalent of the full residential tariff (US$ 0.20/kWh), improving the affordability ratio to 6.9%, which is still lower than the do-nothing scenario (11.0%).

5.3. Energy efficiency and PV system program

The affordability is improved from 11.0% to 3.5% if the consumer shares 20% of the upfront costs (Table 13), which is better than the 4.5% achieved with the PV system only.

Fig. 4 presents the annualized cost to consumer of the electricity saved for both programs (PV and EE+PV) as a function of the consumer loan. It shows that the combination of the energy efficiency measures and the deployment of grid-connected PV system provides the best affordability ratios for the consumer. It also highlights the limits for the consumer loan participation, so that the cost of the measures borne by him does not surpass the electricity tariff rate. In other words, the cost-effectiveness under the consumer's perspective.

6. Conclusions

The Brazilian illustration presented in this paper shows the importance to shift the yet common rationale of designing and evaluating energy policy and programs from a strict cost-effectiveness, electricity-saved perspective into one that explicitly address the energy dimensions of poverty, in our case affordability. Furthermore, this change in mindset allows the instrumental connection of energy policy and programs to broader developmental, poverty eradication policy targets and related indicators.

This approach gains more prominence with the recent technological developments, as the cost of distributed renewable electricity generation has been falling and becoming more interesting to consumers (reduction of electricity bills) and utilities (reduction of power theft, metering and billing costs). Thus, the inclusion of cutting-edge decentralized supply technologies (solar PV, in particular) into the usual end-use energy efficiency measures brings opportunities to better address affordability.

The example presented only covered solutions to improve affordability on the household consumption level (energy costs). The innovative business model turned possible by recent regulation was the possibility to share electricity generation in low-income communities.

However, productive uses of energy can be added to generate income as well. For instance, households can either rent their roofs to generate electricity from PV panels or charge a fee for customers for battery charging at a price lower than the utility's tariff rate. New business models, appropriate regulation and innovative financing schemes can help to create sustainable energy solutions to low-income households and small businesses. Minigrid technologies, mobile applications and storage technologies might also enable different approaches and business that can have significant impacts in creating jobs and income in low-income communities.

These are all open possibilities with relevant potential to foster socioeconomic development waiting to be creatively turned into reality.

Declaration of Competing Interest

None.

CRediT authorship contribution statement

Juliani Chico Piai: Conceptualization, Methodology, Investigation, Data curation, Writing - original draft, Writing - review & editing. **Rodolfo Dourado Maia Gomes:** Conceptualization, Methodology, Investigation, Data curation, Software, Formal analysis, Writing - original draft, Writing - review & editing. **Gilberto De Martino Jannuzzi:** Conceptualization, Methodology, Writing - review & editing, Supervision.

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