Conjecturas

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Incidence of taxes as a determining factor on the combined adoption feasibility of photovoltaic microgeneration and the electricity economy tariff in the southeastern Brazil

Incidência de impostos como fator determinante na viabilidade da adoção combinada de microgeração fotovoltaica e a tarifa branca de energia na região sudeste do Brasil

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ABSTRACT

This article aimed to analyze the factors that guarantee the feasibility adoption of the Electricity Economy Tariff simultaneously using photovoltaic microgeneration in the low voltage group in southeastern Brazil. With the aid of the computational tool HOMER® Energy, it was evaluated in which scenarios the electricity economy tariff combined with photovoltaic microgeneration becomes more attractive to the consumer through the analysis of discounted payback, present value of costs, estimated costs of operation and energy. To have these results, simulations of the ANEEL Conventional and Economy tariffs, without taxes, were compared. Then, the modulation capacity of a residential unit and the increase of the load factor were considered, in the search for an ideal residential load curve, which would guarantee the feasibility. Finally, ICMS and PIS/COFINS were added to the rates approved by ANEEL. The results allowed to conclude that there is a capacity for exploration and immediate growth of photovoltaic microgeneration in the southeastern region of Brazil concerning low voltage consumers immediately. It was also concluded that the tax burden has a greater influence on the economic feasibility of the adoption of Solar Photovoltaic Panels, allied with the distributed generation and that a possible change in consumer habits. The city of Niterói demonstrated to have greater feasibility among those analyzed.

Keywords: Solar energy; Photovoltaic microgeneration; Economic viability; Barriers; Economy Tariff.

RESUMO

Objetivou-se com presente artigo analisar os fatores que garantem a viabilidade de adoção da Tarifa Branca utilizando concomitantemente a microgeração fotovoltaica no grupo de baixa tensão na região sudeste do Brasil. Com o auxílio da ferramenta computacional HOMER® Energy foi avaliado em quais cenários a Tarifa Branca aliada a microgeração fotovoltaica se torna mais atrativa ao consumidor por meio da análise do payback descontado, valor presente dos custos, custos estimados de operação e da energia. Para chegar

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aos resultados primeiramente foram confrontadas as simulações da tarifa ANEEL Convencional e Branca, sem impostos. Em seguida, foram consideradas a capacidade de modulação de uma unidade residencial e o aumento do fator de carga, na busca por uma curva de carga residencial ideal, que garantisse a viabilidade. Finalmente foram adicionados ICMS e PIS/COFINS nas tarifas homologadas pela ANEEL. Deste modo os resultados permitiram concluir que há capacidade de exploração e crescimento da microgeração fotovoltaica na região sudeste do Brasil no tocante aos consumidores de baixa tensão de forma imediata, que a carga tributária incidente tem uma maior influência na viabilidade econômica da adoção de painéis fotovoltaicos aliada a geração distribuída, que uma possível mudança de hábitos dos consumidores. Assim a cidade de Niterói demonstrou possuir maior viabilidade dentre as analisadas.

Palavra-chaves: Energia solar; Microgeração fotovoltaica; Viabilidade econômica; Barreiras; Tarifa Branca.

INTRODUCTION

The more efficient use of energy resources, with less impact on the environment, is an increasingly latent concern, and it is present in the proposals for expanding Brazil's energy capacity. Hydroelectric and thermal plants are central elements of energy (MME, 2017). However, the environmental impact produced by the implementation of the previously mentioned forms of generation is increasingly at the heart of environmental discussions due to the vast flooded areas (URBANETZ, 2010). Furthermore, the economic agenda includes dissatisfaction due to the significant increase in energy tariffs when the thermal plants are fully activated.

In addition to the environmental advantages, photovoltaic microgeneration also works as a partial mechanism for the independence of the concessionaires, thereby generating electricity from the solar source advances considerably in Brazil and around the world. A considerable part of this progress is due to the granting of incentives to distributed generation, in which consumers can generate part or all of the energy needed to supply their personal needs (EPE, 2014). In 2019, the Brazilian photovoltaic energy installed capacity had a growth projection of approximately 44%, taking Brazil to the mark of 3.3 GW of solar source in operation (ABSOLAR, 2019).

According to the National Electric Energy Agency - ANEEL (2017), among the renewable energy sources found in Brazil, the photovoltaic solar was the one that grew the most after REN 482/2012, with 99% of the total number of installations in the country. Also, distributed photovoltaic microgeneration was the one with the greatest presence in the market, with 72% of the systems with installed power less than or equal to 5 kW, with 80% belonging to the household class (MME, 2018).

The possibility of generating its energy paves the way for the dissemination of the most intelligent distribution systems, also known as Smart Grids (SG). Energy consumers, significantly change the role they play in the market and awaken to the insertion of a new tariff modality according to a measurement structure that allows greater awareness of the use of electricity, given the high costs charged, when they can manage their habits more efficiently (CAVALVANTE et al., 2019).

In this way, aware of the global change, ANEEL improved the models tested over the last decades and created the Economy Tariff to restructure the national tariff system. Consistent with international models, this tariff modality corresponds to the introduction of the concept of SG in the Brazilian market, allowing, among others, the smoothing of peak loads at On-peak period of the system (BEZERRA et al., 2018). Congruent with the current proposals and doubts about in which situations there is an advantage in adhering to the hourly-seasonal tariff together with photovoltaic microgeneration, this study aimed to evaluate the factors that guarantee the economic feasibility in the adoption of microgeneration projects in southeastern Brazil, particularly in the photovoltaic sector within the scope of the combined adoption with the Economy Tariff.

MATERIAL AND METHODS

Exploratory research procedures involving bibliographic and documentary research were used, from sources such as books, websites, public documents, and scientific articles. HOMER® Pro 3.11.4 software was used to simulate the scenarios with and without photovoltaic solar energy, besides tested levels of charging, modulation, and load curve adjustments. The data used in the simulations comprised: a) average housing energy consumption designated by a typical consumer profile from this class; b) current energy tariff of the distributor responsible for the predetermined concession location; c) solar resources estimate from NASA and INPE data, and; d) equipment costs with current values in the market.

Topology

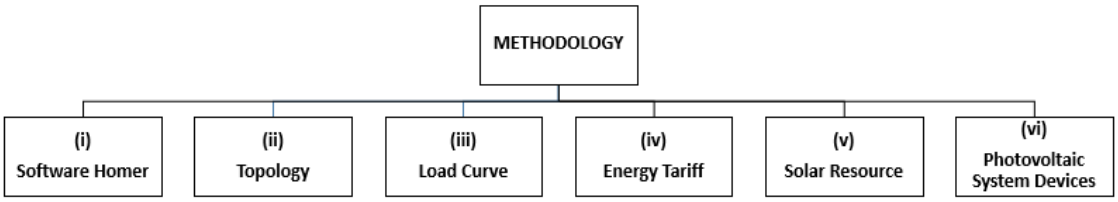
For the study, the southeastern Brazil states were analyzed. For each state, the capital and city of greatest economic relevance were considered, according to data from the Brazilian Institute of Geography and Statistics - IBGE (2018) (Table 1).

Table 1 – Energy distributors and related cities

State	City	Distributors
Rio de Janeiro	Rio de Janeiro	Light
Rio de Janeiro	Campos dos Goytacazes	Enel Rio de Janeiro
São Paulo	São Paulo	Eletropaulo
São Paulo	Campinas	CPFL
Minas Gerais	Belo Horizonte	CEMIG
Minas Gerais	Muriaé	Energisa Minas Gerais
Espírito Santo	Vitória	Escelsa
Espírito Santo	Colatina	ELFSM

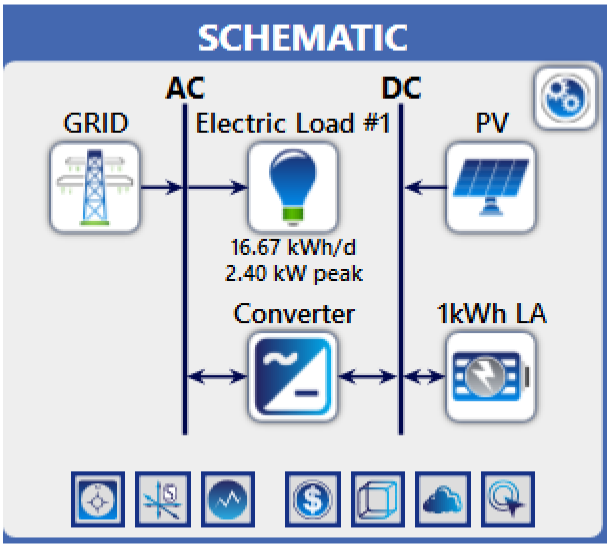
The scheme as shown in Figure 1 was used for the simulation in the HOMER® Pro 3.11.4 software. This schematic diagram was based on the methodology used by Cunha (2016) and Santos (2014).

Figure 1 - Steps covered in the methodology



The studied system was composed of the electric grid, electric load, CC-AC inverters, presented as CC-AC converters, photovoltaic modules (PV), and batteries storage. The first step for the simulations consisted of forming the system with these components, resulting in the diagram in Figure 2.

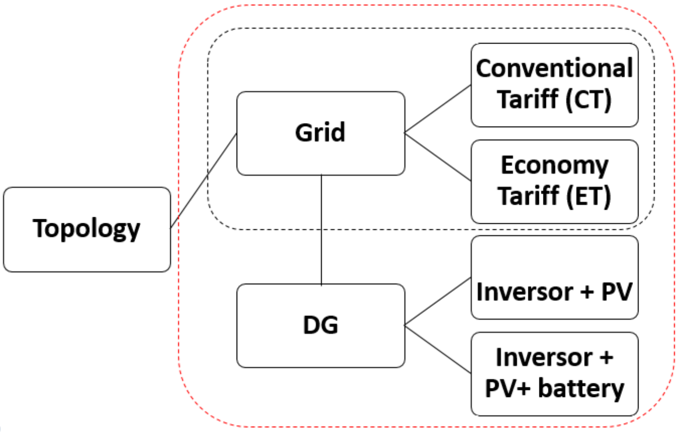
Figure 2 - Scheme of the simulated system in HOMER® Pro



Source: HOMER®

With the presented topology, the use of the Conventional Tariff was simulated and evaluated in comparison with the Economy Tariff. In Figure 3, it is possible to observe the schematic configurations.

Figure 3 - Possible topology configurations



Energy tariffs

The tariff for the supplied energy initially considered was that established by ANEEL, with the base year of 2019, per concessionaire, as shown in Table 2. For the analysis of their viability over the return period, a discount rate of 15% a year was defined and an inflation rate of 4.5% a year. In the course of the study, as alternatives became necessary, taxes were added to the tariffs.

Table 2 - Electricity tariff ANEEL 2019

Distributor	FU	TUSD Conventional R$/kWh	ET (Energy Tariff) Conventional R$/kWh	Economy Tariff On Peak	Intermediate Economy Tariff	Economy Tariff Off Peak
Enel RJ	RJ	0.39726	0.28481	1.260	0,824	0.553
Light	RJ	0.34189	0.29941	1.163	0.78	0.567
Eletropaulo	SP	0.21276	0.27087	0.865	0.562	0.412
CPFL Paulista	SP	0.20737	0.27726	0.828	0.537	0.406
Cemig-D	MG	0.31883	0.26801	1.136	0.73	0.479
EMG	MG	0.28635	0.27883	1.089	0.691	0.461
ELFSM	ES	0.31354	0.30214	1.257	0.796	0.519
EDP ES	ES	025897	0.30331	1.024	0.667	0.484

Initially for the study, it was considered only tariffs approved by ANEEL, without the incidence of fees and taxes, but it was noted that the tax burden is a large part of the energy bill paid by the consumer, contributing considerably to the definition of the viability of photovoltaic systems. Right after the comparison of the ANEEL Conventional and Economy tariff simulations results, that is, without taxes, it was necessary to search for an ideal residential load curve that would guarantee viability. Such demand had considerations to the modulation capacity of a residential unit and with the load factor increase. Finally, when it was found that a possible change in habits had little influence on viability, ICMS and PIS/COFINS were added to the tariffs approved by ANEEL, which became evident that the tax burden had a greater influence on the economic viability.

Discounted payback

For an accurate measure of the return time and, thus, the viability of the investment, the discounted payback was used as an indicator. The entry and exit values were referred to as the present time and the discounted capital costs. The software HOMER® Pro 3.11.4 for having an economic bias calculated all the necessary factors being considered economically viable the scenarios that obtained a return on investment less than the useful life of the enterprise.

Use of batteries

During the simulations, the use and dispatch of the batteries were made in order to find the most economically viable solution. Battery charging was done in two possible ways, Load Following (LF) and Cycle Charging (CC). At each stage, HOMER® calculated the cost of discharging the batteries, comparing them with the cost of each available energy source, choosing the lowest cost combination in order to meet the load. The cost of discharging the batteries results from the sum of the cost of battery energy and the cost of battery wear. The dispatch of type CC considered the generators in a full load whenever they were turned on, and the battery was charged with the surplus of energy. In the LF dispatch, the system considered the generators according to demand, with battery charging only in cases of surplus energy.

RESULTS AND DISCUSSION

The results obtained and demonstrated below are intended to create a horizon on the economic advantages of possible configurations, which, in line with the other aspects addressed throughout this study, have the capacity to enable consumers to make a decision on the adherence to the Economy Tariff and the installation of residential photovoltaic systems in the states of the Southeast region of Brazil.

Below you can see the results divided according to the stages which they were simulated.

Configurations for the ANEEL Conventional Tariff

After inserting the data presented in the methodology, the simulations were performed by the HOMER® software for all quantities of equipment, exposing the best results in order. The best physical and economic configurations for the Conventional Tariff calculated by the program according to the imputed parameters, respectively, can be found in Charts 1 and 2.

Chart 1 - Best physical configurations found by the HOMER® software

CONVENTIONAL TARIFF + GD			
Concessionaire	Architecture	PV	Converter
Enel RJ	CT+ PV+ CONVERTERS	20	4
Light	CT+ PV+ CONVERTERS	20	3
Eletropaulo	CT+ PV+ CONVERTERS	20	3
CPFL Paulista	CT+ PV+ CONVERTERS	20	3
Cemig-D	CT+ PV+ CONVERTERS	20	4
EMG	CT+ PV+ CONVERTERS	20	3
ELFSM	CT+ PV+ CONVERTERS	20	3
EDP ES	CT+ PV+ CONVERTERS	20	3

Source: HOMER® (adapted)

Chart 2 - Best economic configurations found by the HOMER® software

CONVENTIONAL TARIFF + GD					
Concessionaire	Cpv Cost Present Value	Energy Cost	Operation Cost	Initial Cost	Discounted Payback
Enel RJ	R$ 20,804.00	R$ 0.197	-R$ 425.53	R$ 24,500.00	8 years
Light	R$ 22,397.00	R$ 0.231	R$ 31.31	R$ 22,125.00	9 years
Eletropaulo	R$ 23,114.00	R$ 0.235	R$ 113.84	R$ 22,125.00	18 years
CPFL Paulista	R$ 20,302.00	R$ 0.198	-R$ 209.86	R$ 22,125.00	11 years
Cemig-D	R$ 16,562.00	R$ 0.146	-R$ 913.34	R$ 24,500.00	7.4 years
EMG	R$ 22,958.00	R$ 0.237	R$ 95.91	R$ 22,125.00	11 years
ELFSM	R$ 22,191.00	R$ 0.228	R$ 7.63	R$ 22,125.00	9,1 years
EDP ES	R$ 23,530.00	R$ 0.245	R$ 161.73	R$ 22,125.00	11 years

Source: HOMER® (adapted)

The search space in which the ideal configurations were found was limited to 20 panels, 5 batteries, and 10 converters, as it is the average adopted in the residential market due to costs and reduced demand. This search space is similar to the study by DANTAS (2018), which found the best energy cost production in the photovoltaic solar generation system composed of 18 solar panels over a 15-year investment horizon.

In the simulated cases, there was viability in the use of photovoltaic solar energy combined with the conventional energy tariff in 100% of the cases, as Rodrigues (2019) concluded in scenarios similar to the one proposed in this study. It can be observed that the energy injection in the electric grid brought more savings, and thus advantages to the consumer when inserted in the scope of the conventional tariff. However, the use of batteries was not among the most economically viable options, being indicated as pointed out by Nascimento (2019) in alternatives with low cost of acquisition, thus, it can be dispensed from the studied scenarios.

Configurations for the ANEEL Economy Tariff

Simulations were carried out with the Economy Tariff, similar to the one presented for the Conventional Tariff. The best calculated configurations are explained below, where it is possible to observe in Charts 3 and 4 the best scenario within a universe limited to 20 solar panels, 5 batteries, and 10 converters. In this scenario, HOMER® software was also used, and it was possible to find the actual current configuration capable of bringing better gains in a defined search space, where the purchase of energy from the electric grid was not limited.

Chart 3 - Summary of the best physical configurations with a search space of 20 panels

ECONOMY TARIFF + GD			
CONCESSIONAIRE	ARCHITECTURE	PV	CONVERTER
Enel RJ	GRID + PV + CONVERTERS	20	3
Light	GRID + PV + CONVERTERS	20	3
Eletropaulo	GRID + PV + CONVERTERS	7	1
CPFL Paulista	GRID + PV + CONVERTERS	20	3
Cemig-D	GRID + PV + CONVERTERS	20	4
EMG	GRID + PV + CONVERTERS	20	3
ELFSM	GRID + PV + CONVERTERS	20	3
EDP ES	GRID + PV + CONVERTERS	20	3

Source: HOMER® (adapted)

Chart 4 - Summary of the best economical configurations with a 20-panel search space

ECONOMY TARIFF + GD					
Concessionaire	CPV	Energy Cost	Operation Cost	Initial Cost	Discounted Payback
Enel RJ	R$ 31,954.00	R$ 0.326	R$ 1,131.00	R$ 22,125.00	12 years
Light	R$ 30,978.00	R$ 0.320	R$ 1,019.00	R$ 22,125.00	12 years
Eletropaulo	R$ 26,893.00	R$ 0.260	R$ 635.04	R$ 21,273.00	22 years
CPFL Paulista	R$ 23,600.00	R$ 0.231	R$ 169.79	R$ 22,125.00	21 years
Cemig-D	R$ 22,309.00	R$ 0.197	-R$ 252.22	R$ 24,500.00	11 years
EMG	R$ 26,710.00	R$ 0.275	R$ 527.72	R$ 22,125.00	24 years
ELFSM	R$ 26,145.00	R$ 0.269	R$ 462.66	R$ 22,125.00	13 years
EDP ES	R$ 26,385.00	R$ 0.274	R$ 490.26	R$ 22,125.00	21 years

Source: HOMER® software (adapted)

The case where the photovoltaic systems adoption combined with the ANEEL Economy Tariff adoption proved to be less viable were in the Eletropaulo concession area, which despite having good radiation rates, has no advantageous relationship since the ANEEL Conventional Tariff is among the country's lowest. It can be seen in Chart 5 that the average cost of energy supplied by the system in the case of Eletropaulo remains high with the adoption of the hourly-seasonal tariff modality, which denotes an unlikely consumer interest in adapting their habits.

Chart 5 - Summary of Economy Tariff Grid configurations

ECONOMY TARIFF + GRID			
Concessionaire	CPV	Energy cost	Operation cost
Enel RJ	R$ 38,027.00	R$ 0.719	R$ 4,377.00
Light	R$ 37,097.00	R$ 0.702	R$ 4,269.00
Eletropaulo	R$ 27,730.00	R$ 0.525	R$ 3,191.00
CPFL Paulista	R$ 24,945.00	R$ 0.472	R$ 2,871.00
Cemig-D	R$ 30,317.00	R$ 0.573	R$ 3,489.00
EMG	R$ 27,053.00	R$ 0.512	R$ 3,114.00
ELFSM	R$ 30,354.00	R$ 0.574	R$ 3,493.00
EDP ES	R$ 27,671.00	R$ 0.523	R$ 3,185.00

Source: HOMER® software (adapted)

Although feasibility has been achieved in some cases, the long periods of return on investment, as also seen by Mattar et al. (2019), can discourage consumers. Haddad et al. (2019), in their study, reinforces the small interest in investing in photovoltaic technology where similarly a high turnaround time was observed. It is possible to observe a reasonable amount of rejection to the system for financial reasons in their research, due to the fact consumers do not view such technology as an investment.

Best Configurations Comparison: ANEEL Conventional x Economy Tariff

Based on the data evidenced in the previous sessions, a confrontation between the two tariff modalities, as can be seen in Chart 6, was designed so that it was possible to obtain the most economically viable result.

Chart 6 - Comparison between ANEEL Conventional and Economy Tariff combined with Solar Photovoltaic Generation

COMPARATIVE CONVENTIONAL AND ECONOMY TARIFF + GD						
Concessionaire	Architecture	CPV	Energy Cost	Operation Cost	System Cost	Discounted Payback
Enel RJ	CT+ PV+ CONV	R$ 20,804.00	R$ 0.197	-R$ 425.53	R$ 24,500.00	8 years
	ET+ PV+ CONV	R$ 31,954.00	R$ 0.326	R$1,131.00	R$ 22,125.00	12 years
Light	CT+ PV+ CONV	R$ 22,397.00	R$ 0.221	R$ 31.31	R$ 22,125.00	9 years
	ET+ PV+ CONV	R$ 30,978.00	R$ 0.320	R$1,019.00	R$ 22,125.00	12 years
Eletropaulo	CT+ PV+ CONV	R$ 23,114.00	R$ 0.235	R$ 113.84	R$ 22,125.00	18 years
	ET+ PV+ CONV	R$ 26,893.00	R$ 0.260	R$ 635.04	R$ 21,273.00	22 years
CPFL Paulista	CT+ PV+ CONV	R$ 20,302.00	R$ 0.198	-R$ 209.86	R$ 22,125.00	11 years
	ET+ PV+ CONV	R$ 23,600.00	R$ 0.221	R $ 169.79	R$ 22,125.00	21 years
Cemig-D	CT+ PV+ CONV	R$ 16,562.00	R$ 0.146	-R$ 913.34	R$ 24,500.00	7.4 years
	ET+ PV+ CONV	R$ 22,309.00	R$ 0.197	-R$ 252.22	R$ 24,500.00	11 years
EMG	CT+ PV+ CONV	R$ 22,958.00	R$ 0.237	R$ 95.91	R$ 22,125.00	11 years
	ET+ PV+ CONV	R$ 26,710.00	R$ 0.275	R$ 527.72	R$ 22,125.00	24 years
ELFSM	CT+ PV+ CONV	R$ 22,191.00	R$ 0.228	R$ 7.63	R$ 22,125.00	9.1 years
	ET+ PV+ CONV	R$ 26,145.00	R$ 0.269	R$ 462.66	R$ 22,125.00	13 years
EDP ES	CT+ PV+ CONV	R$ 23,530.00	R$ 0.245	R$ 161.73	R$ 22,125.00	11 years
	ET+ PV+ CONV	R$ 26,385.00	R$ 0.274	R$ 490.26	R$ 22,125.00	21 years

According to the results presented in chart 6, the most economically viable configuration, which denotes the lowest Cost Present Value (CPV), corresponds to the ANEEL Conventional Tariff configuration combined with the photovoltaic energy system composed of panels and converters. This viability is unanimous. In all cases, the ANEEL Conventional Tariff presented not only lower energy and operating costs, but also a shorter return on investment when compared to the scenarios in which the ANEEL Economy Tariff appeared.

Besides, for both Conventional and Economy modes, 100% of the photovoltaic panels sizing showed values with cost reduction when compared to the exclusive use of the electric grid.

For the ANEEL Economy Tariff, in 50% of the scenarios, the most economically viable configuration has a discounted payback over 20 years, a factor that tends to discourage enthusiasts for technologies with low environmental impact, as previously discussed. For all other scenarios, the composition of the ANEEL Economy Tariff with the addition of photovoltaic solar energy had a lower CPV, being indicated as the configuration with the greatest economic viability.

Regarding low voltage consumers, as in the study by Finotti et al. (2018), the use of batteries linked to the option for the ANEEL Economy Tariff made the investment too expensive, and, even adhering to the hourly-seasonal tariff modality, the acquisition of batteries in a photovoltaic system was not an advantageous alternative. However, as seen in the same study with the reduction in prices, in the future, batteries will no longer be an expensive item for acquisition and complementation in distributed generation, becoming an indispensable item concerning energy storage and the provision of ancillary services. (FINOTTI et al., 2018).

Similar to what was found in the study by Silva et al. (2015), it was possible to realize that the implementation of this type of system becomes economically viable for consumers with a moderate income range, with the average return time approximately 9.5 years for use with the Conventional Tariff, and 16.3 years for the Economy Tariff, considering a favorable scenario for the energy sale to the grid.

Load Modulation Strategies in the ANEEL Economy Tariff

For the case where distributed generation combined with hourly-seasonal tariff modality was not the most advantageous solution, the adoption of demand displacement strategies emerged as a possible alternative capable of providing a reduction in the cost of the photovoltaic energy system. Relevant changes in the load curve, mainly at On-peak period, were carried out in order to obtain results in line with what was found in the study by Cunha (2018). The relocation carried out can be seen in Table 3.

Table 3 - Load shifting among tariff stations

Tariff station	Energy consumed in the month (kwh/month)	Percentage distribution	Modulation capability (%)	Modulated energy consumed in the month (kwh/month)
Off peak	11.353	67%	0%	11.918
Intermediate	2.146	13%	7%	1.996
On Peak	3.46	20%	12%	3.045
Total	16.959	100%	-	16.959

However, differently from the results obtained by Cunha (2018), where consumers only with the adaptation of habits tended to achieve savings that would enable the photovoltaic system adoption. This did not happen in the cases studied in the Southeastern. The difference between ANEEL tariffs, which can be seen in Table 4, was not very relevant given the average between the cheapest rank in the ANEEL Economy Tariff and the ANEEL Conventional Tariff being only 16%. Therefore, considering tariffs without tax, as seen so far, the adaptive efforts of the consumer are larger than the economic benefits possibly obtained with load redistribution, making the adoption of the Economy Tariff allied with photovoltaic generation not an attractive option for the consumer.

Table 4 - Comparison between Conventional Tariff and Economy Tariff Off-Peak

CONCESSIONAIRE	DIFFERENCE BETWEEN CT AND ET OFF PEAK	DIFFERENCE BETWEEN CT AND ET OFF PEAK (%)
Enel RJ	R$ 0.178	-19%
Light	R$ 0.101	-12%
Eletropaulo	R$ 0.095	-15%
CPFL Paulista	R$ 0.117	-17%
Cemig-D	R$ 0.149	-17%
EMG	R$ 0.142	-18%
ELFSM	R$ 0.129	-16%
EDP ES	R$ 0.104	-14%

The discounted payback after the load modulation remained stagnant by several curves aimed at flattening the On-peak period. This is partly due to the equilibrium of the internal rate of return, which has reached its maximum point since the investments necessary to adapt a sunroof have become fixed within this equation.

Use of the Load Factor Concomitant with the ANEEL Economy Tariff

The load factor obtained by the ordinary consumption curve, without considering adaptations in the routines, was 0.29. By softening the system pressures during On-peak period, it was possible to obtain a load curve with a factor of 0.50, thus ensuring larger energy efficiency for the installation.

It was observed that the maximum flattening of the peak load was not enough to make the scenarios feasible in the states studied in the Southeastern. The cost of producing solar energy because it is lower than the tariff practiced at the Off-Peak tariff station led the Software to inject the energy produced by solar panels at the time of generation. Again, batteries were not considered to be the most profitable options for achieving benefits that were too small compared to the expenses imposed on the system configuration architecture.

Although consumption has been redistributed to guarantee a similar average monthly level, the system proposed and usually adopted in homes has a fixed cost. The consumption in the On-Peak period, even minimized, did not cease to exist, which was a significant financial burden. Thus, the flattening of the On-peak period was not enough to direct anticipation of the payback since the need for consumption during On-peak period, although reduced, has remained, again, removing the attractiveness of the project.

Addition of Taxes in Conventional and Economy Tariffs

The simulations results observed so far make it evident that the feasibility of implementing photovoltaic systems combined with the adherence of the hourly-seasonal charging system is not only intrinsic to the habits of residential consumers and their capacity to modulate loads. The price of the tariff, which is directly influenced by the incidence of taxes in each tariff modality, dictates the average time of return on investment, reflecting in numbers the consumer's ability to adhere.

Only with the tax addition of ICMS and PIS/COFINS, without considering other fees or load modulation, it is possible to appreciate that in some Southeastern states, the adoption of photovoltaic systems allied to the Economy Tariff already present larger viability than the joint use with the Conventional Tariff. In Charts 7 and 8, it is possible to compare the extent to which the taxes levied vary the weight of the initial investment and the economic return on investment.

Chart 7 – Taxes influence on return on investment

CONVENTIONAL TARIFF + GD WITH TAXES							
Concessionaire	CPV	Energy Cost	Operation Cost	Initial Cost	Descounted Payback (years)	ROI	IRR
Enel RJ	R$ 15,626.00	R$ 0.148	-R$ 1,021.00	R$ 24,500.00	4.8	23%	28%
Light	R$18,423.00	R$ 0.177	-R$ 699.38	R$ 24,500.00	5.5	20%	25%
Eletropaulo	R$20,875.00	R$ 0.643	-R$ 417.18	R$ 24,500.00	8.4	14%	18%
CPFL Paulista	R$15,731.00	R$ 0.141	-R$ 1,009.00	R$ 24,500.00	6.4	17%	22%
Cemig-D	R$10,042.00	R$ 0.088	-R$ 1,664.00	R$ 24,500.00	4.5	24%	29%
EMG	R$19,928.00	R$ 0.191	-R$ 526.21	R$ 24,500.00	6.5	17%	22%
ELFSM	R$18,811.00	R$ 0.180	-R$ 654.73	R$ 24,500.00	5.8	19%	23%
EDP ES	R$21,311.00	R$ 0.207	-R$ 367.08	R$ 24,500.00	7	16%	20%

Chart 8 - Return on investment Conventional tariff with taxes

ECONOMY TATIFF + GD WITH TAXES							
Concessionaire	CPV	Energy Cost	Operation Cost	Initial Cost	Descounted Payback (Years)	ROI	IRR
Enel RJ	R$ 8,875.00	R$ 0.084	-R$ 1,798.00	R$ 24,500.00	3.1	34%	39%
Light	R$13,049.00	R$ 0.126	-R$ 1,318.00	R$ 24,500.00	3.6	30%	35%
Eletropaulo	R$ 7,951.00	R$ 0.069	-R$ 1,905.00	R$ 24,500.00	4.3	25%	30%
CPFL Paulista	R$24,762.00	R$ 0.227	R$ 30.10	R$ 24,500.00	8.8	13%	17%
Cemig-D	R$16,553.00	R$ 0.146	-R$ 914.63	R$ 24,500.00	6	18%	23%
EMG	R$22,956.00	R$ 0.237	R$ 95.66	R$ 22,125.00	6.3	11%	15%
ELFSM	R$31,242.00	R$ 0.330	R$ 1,049.00	R$ 22,125.00	7.4	15%	20%
EDP ES	R$29,788.00	R$ 0.318	R$ 881.92	R$ 22,125.00	8.6	13%	17%

It is of utmost importance to detach that in the whole study, changes were not considered due to the incidence of taxation related to the current tariff flag.

In the studied cases, it is possible to observe in Charts 7 and 8 that only the addition of PIS/COFINS and ICMS was able to bring investment in four cities to the feasibility scenario. In other words, in 50% of the cases, without the modulation of cargo with only taxes, the Off-Peak Tariff became more competitive compared to the Conventional Tariff, being able to seduce the consumer to possibly adapt his consumption habits. The same was observed by Santos (2019) in his work that proves the higher incidence of ICMS in the state of Rio de Janeiro and by Neto (2019) in his study that describes that the tariff structure in Brazil is one of the main aspects that encourage the generation of photovoltaic solar energy combined with the horo-seasonal tariff. The study also attributed that the feasibility of combined adoption is closely linked to the acquisition cost, the differentiated public policy, the purchasing power, and the Brazilian solar radiation.

It is important to note that, despite not being among the lowest energy tariffs in the country, the state of Minas Gerais has a unique public policy to encourage the photovoltaic market, since the compensation of energy on the consumer's bill exempts the payment of ICMS, that is, the producer consumer compensates the energy credits including the tax, obtaining larger savings when energy is injected into the grid.

It should be pointed out that the solutions demonstrated by the HOMER® Software did not consider the technical feasibility of the configurations, being analyzed only from the economic points of view. However, the data imputed in the software presupposes authentic systems in advance, which allows admitting that the compositions correctly operate when subjected to real conditions of installation and operation.

CONCLUSIONS

In the case of immersion in the Economy Tariff scenarios, the association with photovoltaic solar generation proved to be viable and profitable when inserted in an actual context, with the addition of ICMS and PIS/COFINS taxes.

The State of Rio de Janeiro for having good levels of solar irradiation and high energy tariffs with expensive taxes establishes the most favorable scenario for the installation of photovoltaic solar generation systems combined with the Economy Tariff adoption, thus becoming the Southeastern state with larger potential for such implantation.

The small difference between the hourly-seasonal off-peak tariff station and the Conventional Tariff can be seen as a barrier, as it does not become relevant to the point of the consumer endeavoring to modulate his load, changing habits that promote the viability of adopting the Economy Tariff.

Another barrier resides in the fact that residential ET consumers do not have a tariff with the hourly distinction of electric energy consumption, thus they maintain a behavior insensitive to the consequences of putting pressure on the electrical system during the On-peak period, resulting in high costs of expanding distribution to service to small periods. One of the big challenges of the Economy Tariff is the management of demand for cultural reasons and the incidence of taxes on equipment for the composition of a photovoltaic power generation system in Brazil.

Due to the variation characteristic of the solar resource according to the region of the country, simulations that list cities different from those considered in this study can lead to different consumption profiles, resulting in new configurations.

That said, it is concluded that when it comes to the combined of the Economy Tariff adoption and solar photovoltaic generation, the incidence of taxes is more significant in the definition of economic viability than the consumption habit itself, thus it is not possible, at this moment, to define an ideal load curve that dictates the viability of the seasonal hourly tariff modality combined with distributed generation.

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