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On the regulation of solar distributed generation in Brazil: A look at both sides

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ABSTRACT

In the last few years, a considerable growth of rooftop photovoltaic systems has been experienced in Brazil, and according to the Ten-Years Energy Plan, developed by the Brazilian Energy Research Company, it is expected to increase even more in the coming years. As a result, the Brazilian Regulatory Agency (ANEEL) has been actively working in the sector, acting to smooth the impacts on Distribution Companies (DisCos) and prosumers. The two major negative impacts of the current Distributed Generation (DG) regulation in Brazil are the cross-subsidy for consumers to prosumers (i) since non-PV owners subsidize network costs that prosumers avoid paying, and the "death spiral" (ii) in which a DisCo lost a considerable share of the market continuously. To overcome these issues, the Brazilian government approved Law 14300, which includes a new compensation scheme for energy injected into the grid. In this way, the main objective of this paper is to conduct a technical-economic analysis of photovoltaic systems with this new structure by considering the impact on both sides: new investors in DG and DisCos. The analysis is compared against the previous regulation and the results proved a detriment to economic viability for prosumers as the amount paid in the Net-Metering Scheme increases, reducing the interest in the investment and the economic impact on the DisCos. On the other hand, when the amount paid in the Net-Metering Scheme gets reduced, it increases the interest of consumers to invest in DG and the DisCo's market losses. The present work quantifies these statements and indicates the appropriated regulation, which is in between these two extremes.

1. Introduction

a. Motivation

Recent changes in the world's energy mix have been generally driven by the penetration of renewable sources, like wind and solar power plants, as a way to give an appropriate answer to global warming and climate change issues by reducing the use of fossil fuels and, consequently, GHG emissions. In this direction, in the electricity sector, the expansion of centralized generations and the construction of long transmission lines are now increasingly difficult because of social and environmental barriers. On the other hand, the modernization and digitization of the network, as well as technological development, have made the price of eco-friendly technologies drop exponentially. Furthermore, as renewable energy sources are less affected by geopolitical crises, price spikes, or sudden interruptions in the supply chain (REN21, 2019), the investment in this type of technology becomes very attractive in the last few years.

In Brazil, Distributed Generation (DG) is characterized by renewable sources using mainly the rooftop photovoltaic (PV) system. Recently, a considerable growth of DGs, essentially due to the energy potential from solar sources, has been experienced, and according to the Ten-Years Energy Plan, developed by the Brazilian Energy Research Company (EPE), it is expected to increase even more in the coming years (EPE, 2020). As a result, the Brazilian Regulatory Agency (ANEEL) has been actively working in the sector, acting to smooth the impacts on Distribution Companies (DisCos) and prosumers in general.

One of the major and polemic impacts of the current DG regulation is due to a cross-subsidy for consumers to prosumers since non-PV owners subsidize network costs that prosumers avoid paying (Eid et al., 2014). This scenario may contribute to increasing social inequality, as there would be a transfer of income from people with adverse financial conditions (non-PV owners) to those in a more favorable financial situation (PV investors).

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As a way to reduce the mentioned cross-subsidy for consumers and its impacts on the other network users and DisCos, in 2022, the Brazilian government published a new Law 14300, which set up the Legal Framework for DG, stipulating a new method of compensation for energy injected into the electrical network. In this way, the main objective of this paper is to develop a technical-economic analysis of PV systems under the new Brazilian regulatory framework. This analysis is conducted taking into account the impact on both sides: new investors in DG and DisCos, furthermore, comparing it against the previous regulatory framework.

b. Related work

Since 2012, when the specific regulation of Brazilian DG was published, many studies have been carried out on the technical and economic feasibility of installing rooftop photovoltaics in Brazil, as well as market forecast analysis. In this way, the work (Ribeiro et al., 2016) develops a methodology for the study of the economic feasibility of PV systems, from analysis of solar irradiation to the economic feasibility of investment through the following criteria: weighted average cost of capital, minimum attractiveness rate, internal rate of return, and simple and discounted payback. The studies were carried out for a case study located in the region of Campina Grande in Brazil, considering an installed capacity of 3MWp and different scenarios for financing the initial investment.

The work conducted in (Marchioro et al., 2018) has proposed a feasibility analysis of installing rooftop photovoltaics in a residence in the federal unity of Rio Grande do Sul in Brazil, the proposed methodology uses the factors minimum attractiveness rate, net present value, internal rate of return, and discounted payback. In (Pinto et al., 2016), a novel study is carried out showing the importance of PV systems in the Brazilian energy crisis, the analysis of the PV economic feasibility was conducted using internal rate of return, net present value, cash flow, and payback. In the study, DG is used to supply the electricity demand of social housing in the country.

In (Vila ç a Gomes et al., 2018) is analyzed an estimative of the minimum monthly residential demand so that there is the economic feasibility of installing PV systems in different DisCos in Brazil, this analysis was carried out using the Levelized Cost of Electricity (LCOE). On the other hand, the work conducted in (Konzen, 2014) developed a diffusion model for DG, ideal for use in Brazil, it considers data as the national territory with geographic and population diversity. The model considers the mathematical foundation of the Bass diffusion model. In this way, the market forecast for 10 years is made, considering different scenarios with the application of incentive measures. This work was used by EPE for the market forecast carried out in the technical reports available in (EPE, 2014) and (EPE, 2018).

Likewise considering the distributor side, the work conducted in (Simone, 2019) assesses the impact of the growth of the PV DG on the distributors' revenue and the consumers' tariff. The projection developed in (Konzen, 2014) is considered in this study. In (de Andrade, 2020), the impact of DG on the distributor's revenue through the so-called "death spiral" is explored. It is also important to highlight studies such as (de Faria et al., 2017), which analyzes the impacts and regulation of DG in Brazil, showing the importance of solar energy for energy diversification, in addition to the government incentives that were given in the country and the main obstacles already encountered. Similarly, the work developed in (Lacchini and dos Santos, 2013) presents a comparison of the costs of the PV system against a coal-fired thermal generating plant, an option used mainly in southern Brazil.

Finally, the impact of the mentioned cross-subsidy coming with net-metering policies on the network cost recovery is studied in (Eid et al., 2014). In the same line, the quantification of the cross-subsidies from consumers to prosumers is considered in (Picciariello et al., 2015).

c. Contributions

Different from the works presented in the prior sections, this study introduces a technical-economic analysis of the new compensation scheme for the net-metering policy proposed by the Brazilian regulatory body ANEEL. In this way, the contributions for the scientific community, regulatory bodies, and stakeholders are presented as follows:

i. A technical-economic analysis for new investments in rooftop photovoltaic systems considering the new compensation schemes for the net-metering policy. This analysis considers the following economical indices:
- Levelized Cost of Energy (LCOE).
- Payback time.
- Cost-benefit index.

ii. A technical-economic impact analysis on the DisCos by considering the new compensation schemes for the net-metering policy, regarding the following aspects:
- PV Market forecasts.
- DisCo Cost recovering.
- Volumetric tariff's impact.

iii. A comparison of the new compensation scheme for the net-metering proposed by the new Law 14300 against the compensation based on the in-force regulation. The comparison is conducted using a technical-economic analysis of new investments for prosumers and their impact on DisCos.

Finally, as secondary contributions, this work presents and discusses the international experience in net metering policies issues, the Brazilian tariff structure, and electricity regulation that can also be useful for the scientific community, regulatory bodies, and stakeholders.

d. Structure

This paper is organized as follows: Section 2 presents the conflict between utilities and solar and the international approach, Section 3 brings the Brazilian DG as well as the related tariff structure and electricity regulation. The novel methodology to access the technical-economic impacts of the new compensation scheme for both new investors and DisCos is presented in Section 4. Numerical results, data, and assumptions are properly handled in Section 5, and finally, the discussion regarding the results and conclusions are presented in Sections 6 and 7 respectively.

2. Solar DG and net-metering: The international experience

The exponential growth of solar energy, warmer climates, and more efficient equipment have reduced the demand for electricity from DisCos (Rucinski and Kaye, 2014). This reduction has resulted in conflicts between consumers who support DG and the utilities. Utilities claim that when electricity consumption is compensated by DG, the payment is insufficient to cover fixed costs and forces them to charge other customers (Trabish, 2014).

Due to this problem, in the United States, utilities are sending different proposals to the states, including the increase in fixed monthly charges and the imposition of a monthly charge on prosumers. However, despite the distributors' allegations, the states are refusing the requests, claiming that there is not enough data to change energy costs (Trabish, 2014). In addition, there have been conflicting trends in the country between the expansion of transmission systems to avoid congestion and the number of residential consumers disconnecting from the network due to DG installations (Silverstein, 2014).

In Spain, in 2013, the government issued a law that would force PV energy establishments to pay a punitive fee, resulting in the removal of many panels. However, the law was not approved, but the threat of punishment was enough to curb the growth of this technology in the country (Rucinski and Kaye, 2014) (Rodriguez and Binnie, 2018). Just six years later, in 2019, photovoltaic DG was regulated in the country.

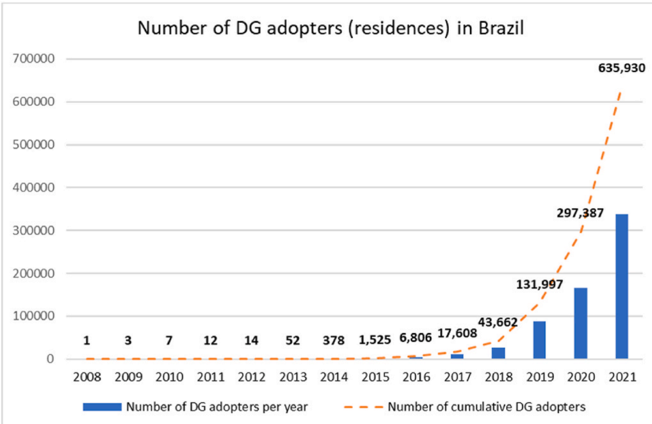

Fig. 1. Adoption of residential DG in Brazil.

Where it was determined that all DG's surplus energy will only offset energy-related costs, that is, the energy consumed from the grid has a value greater than the energy generated (Merodio, 2020).

In Australia, as a way to block the growth of PV generation, the government defined the controversial "solar tax", characterized by a reduction in discounts on the energy injected into the system and an increase in fees for connecting the DG. This tax did not come into force, but the government guaranteed the reform of the tariff so that the price of energy is the same for all (Rucinski and Kaye, 2014).

On the other hand, in the UK, a company that operates the grid guaranteed operational flexibility capacity including large-scale renewable energy and tenders with generators connected to low voltage. These new bids and adjustments by the company proved to be less costly than the investments in the network needed to allow the growing number of DGs (John, 2020).

Finally, in Chile, the PV generation has surprisingly evolved. For the first time in the world, this type of energy was used in power system control plants, approved to carry out automatic generation control. The plant is helping to ensure the reliability and stability of the country's electricity grid through frequency management (Energy Industry Review, 2020).

The development of this plant in Chile encourages and favors the development and use of renewable sources for this type of service in the rest of the world since responses to load changes through the balancing of generation were carried out exclusively through thermal and hydraulics (Energy Industry Review, 2020).

3. The Brazilian DG, regulation and tariff design

a. The distributed generation in numbers

DG can come from different sources such as solar, wind, small hydroelectric plants, biogas, and cogeneration. In Brazil, there is a predominance of photovoltaic DG, which represents 99.9% of all installed DGs, due to the good productivity of this source in the country. In addition, the high government incentive enabled exponential growth of this generation, especially from 2015, as presented in Fig. 1 (ANEEL, 2020a).

b. The residential electricity tariff design

In Brazil, tariffs are defined by ANEEL during the distributor's tariff review process, which takes place every four years (on average) and undergoes annual adjustments, to re-establish the utility's purchasing power (Simone, 2019) (ANEEL, 2017a).

In general, tariffs include remuneration for generation, transmission, distribution, and sector charges. It can be divided into two distinct portions, one referring to the use of the system (*TUSD*) and the other related to the energy tariff (*TE*). In addition, federal (PIS/Cofins), state (ICMS), and municipal (street lighting) taxes are also applied to the tariff. Fig. 2 presents the division of residential electricity tariffs into *TUSD* and *TE* and their respective subdivisions that are defined as follows (ANEEL, 2021):

- *TUSD Transport*: referring to the use of assets belonging to third parties. Where Fio A refers to the use of transmission assets and Fio B refers to the use of distribution assets.
- *TUSD Losses*: to recover the costs of technical and non-technical losses of the distributor.
- *TUSD Charges*: for cost recovery related to different projects, such as Contribution to the National System Operator (ONS); Alternative Energy Sources Incentive Program (PROINFA); among others.
- *TE Energy*: for cost recovery for the purchase of electricity that will be passed on to the consumer.
- *TE Transport*: for recovery of transmission costs related to Itaipu.
- *TE Losses*: for recovery of costs with losses in the Basic Network due to the reference energy market.
- *TE Charges*: for the recovery of costs related to the Contribution to the Use of Water Resources; Research and Development and Energy Efficiency.

c. The normative resolution 482 and Law 14300

The Normative Resolution 482 (NR482) was published in 2012 by ANEEL to reduce barriers to distributed mini and micro generations and encourage the development of the Brazilian market in this type of generation. It was the first regulatory document to make energy generation official by the consumer and allow them to inject the energy generated into the electricity grid to offset the electricity bill.

The method of compensation of the energy injected into the network defined by the standard NR482 is called Net-Metering and allows the active energy injected into the network by DG to be transferred to the distributor to be subsequently compensated through the consumption of the electrical network (ANEEL, 2015). Thus, if the energy consumed is higher than that injected into the network during a month, the energy to be billed will correspond to the difference between these two values. On the other hand, if the injection is greater than the consumption, credits will be accumulated (in kWh) so that it can be consumed within 60 months. Note that the compensation of injected energy is performed considering all tariff components presented in Section 1.b.

In 2022, Law 14300 was published, creating a legal framework for DG in Brazil and updating the rules in NR482. The law will go through a grace period, where projects approved before approval or until 2023 will follow the guidelines of the previous standard NR 482 until 2045. Projects approved after the year 2023 will be subject to the new law

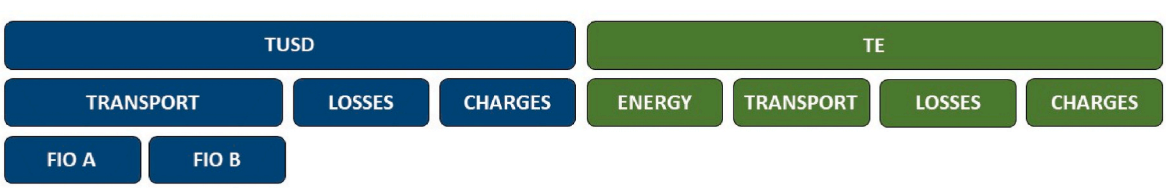

Fig. 2. Brazilian residential electricity tariff design.

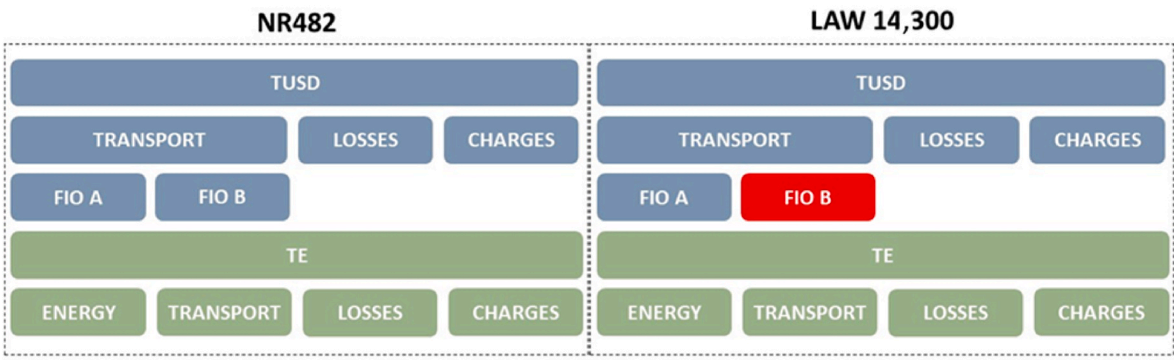

Fig. 3. Compensation schemes in NR482 (compensation on all tariff components) and Law 14300 (Fio B is not considered in the compensation).

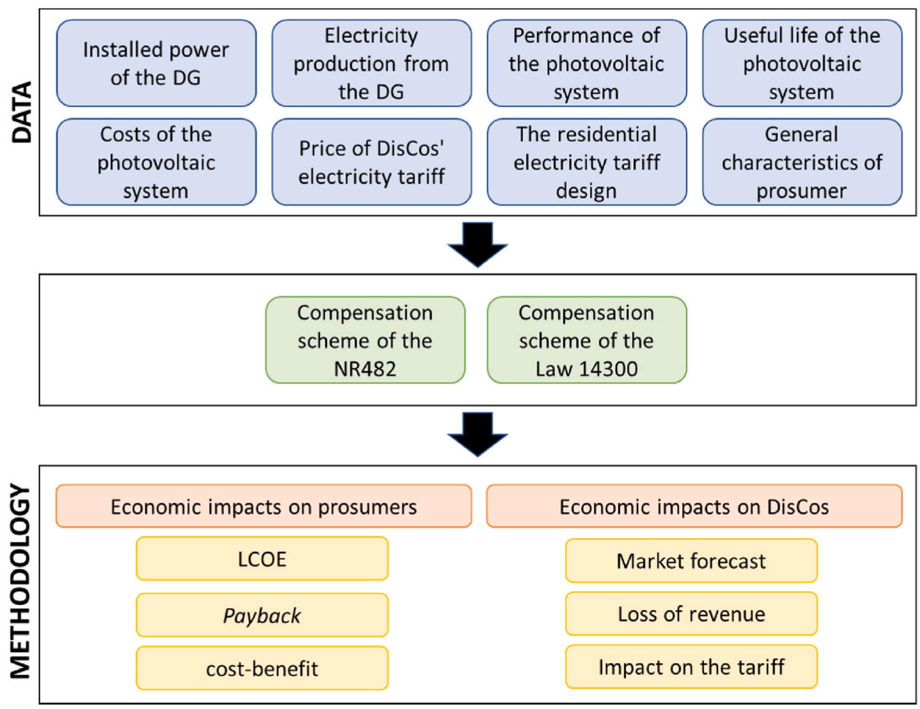

Fig. 4. Methodology.

14300. According to the new law, the micro and mini generation can be classified as follows (ANEEL, 2015) (Governo do Brasil, 2022):

- Distributed microgeneration: electric power generating plant with an installed power of less than 75 kW from qualified cogeneration or renewable sources, connected to the distribution network through installations of consumer units.
- Distributed mini-generation: electric power generating plant with installed power, in alternating current, between 75 kW and 5 MW for dispatchable sources, and between 75 kW and 3 MW for non-dispatchable sources, from qualified cogeneration or renewable sources, connected to the distribution network through installations of consumer units.

The dispatchable sources are hydroelectric plants (including run-of-river variable speed hydro plants), qualified cogeneration, biomass, and biogas.

According to Law 14300, the period for the compensation of energy injected into the distribution network remains equivalent to 60 months, however, the compensation of injected energy is no longer performed considering all tariff components. Namely, the portion of the TUSD *Fio B* tariff must be paid on all energy consumed from the network, regardless of compensation (Governo do Brasil, 2022). The two compensation schemes used in Brazil are presented in Fig. 3.

4. Methodology

In a simplified way, for the development of the methodology, information was collected such as: general consumption characteristics of the consumer; price of each DisCos' electricity tariff; installed power of the DG unit; electricity production from the DG unit; performance of the photovoltaic system over the period under study; useful life of the photovoltaic system; and acquisition, installation and maintenance costs of the photovoltaic system. It is then possible to evaluate, for compensation schemes of the NR482 and the Law 14300, the technical and economic aspects of new investors in DG and the impacts on electricity DisCos in Brazil. The analysis will include three technical-economic criteria for the analysis of the prosumer (LCOE, discounted payback, and cost-benefit) and three criteria for the analysis of the DisCos (market forecast, loss of revenue, and impact on the tariff). Fig. 4 summarizes the methodology.

In this way, the LCOE is the economic factor that represents the cost per unit of electricity produced, expressed in reais per kilowatt-hour (R $/kWh). Usually used in the analysis of tariff parity, which represents the relationship between the local electricity prices and the price of the photovoltaic system (Konzen, 2014) (Branker, Pathak, Pearce) (D á vi et al., 2016). The investment will be viable if the LCOE value is lower than the current electricity tariff (Vila ç a Gomes et al., 2018). Assuming the LCOE as a constant value, it can be calculated according to equation (1).

$$LCOE = \frac{\sum_{t=0}^{T} \frac{Cus_t}{(1+TMA)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+TMA)^t}} \tag{1}$$

where:

- Cus_t is the total cost for energy production in the year t.
- E_t is the energy used by the household in the year t.
- TMA is the discount rate (%).
- T is the total years of the useful life of the photovoltaic panel.

However, as the decision-making of the new prosumer involves not only the LCOE of the photovoltaic system but also the residential tariff, the relative difference between the tariff and the LCOE will be used to access the prosumer's analysis.

The TMA (Minimum Attractiveness Rate) will be used, which is the minimum rate that an investor proposes to receive for an amount invested in a good, as a discount rate (Marchioro et al., 2018).

The discounted payback, calculated for the LCOE feasibility cases, will analyze the payback time in years, taking into account the time value of money. The investment will be unfeasible if the payback time exceeds the useful life of the photovoltaic panels.

To bring the values to present value, the Net Present Value (NPV) was used, which reflects in the present time the annual series of cash flow during the lifetime of the photovoltaic panel. To bring the value to the present, a discount rate is considered, which for this work will be equivalent to the TMA (Landeira, 2013). The formula for calculating Payback is presented in equation (2). When the difference shows a positive result, t is the payback time.

$$NPV = -investment + \sum_{t=0}^{T} \frac{Ben_t - Cus_t}{(1+TMA)^t} \tag{2}$$

where:

- Ben_t is the annual return on investment.
- Cus_t is the annual costs due to the investment.
- T is the total years of the useful life of the photovoltaic system.

In turn, the cost-benefit is an indicator that assesses the economic costs and benefits of a given project concerning the base scenario. For this, the costs and benefits involved in the analysis must be determined and priced and brought to present value to carry out the analysis. The formula for the calculation is represented in equation (3).

$$BC = \frac{\sum_{t=0}^{T} \left| \frac{Ben_t}{(1+TMA)^t} \right|}{\sum_{t=0}^{T} \left| \frac{Cus_t}{(1+TMA)^t} \right|} \tag{3}$$

On the other hand, for the DisCos, a forecast of the DG adherent market for the next 10 years will be carried out through the Bass-based model developed by Kozen in (Konzen, 2014), which was also used by ANEEL in (ANEEL, 2017b) and by EPE in (EPE, 2014). The model considers payback as a decision factor and two main parameters that directly influence the probability of adoption, p which is called the innovation coefficient, and represents the innovative portion of the population, and q which is the imitation coefficient, those who will take the action to invest from existing cases (Konzen, 2014). Equations (4)–(7) are the representation of the model.

Table 1
Percentages of Brazilian residential electricity tariff design, based on (ANEEL, 2020c) (Rubim, 2018).

TE		TUSD			
Energy	Charges	Fio A	Fio B	Charges	Losses
38.30%	10.00%	6.00%	31.30%	7.00%	7.40%

$$N(t) = m^* F(t) \tag{4}$$

$$m = fmm^* mp \tag{5}$$

$$fmm = e^{-SPB^* TPB} \tag{6}$$

$$F(t) = \frac{1 - e^{-(p+q)^* t}}{1 + \frac{p}{q}^* e^{(-p+q)^* t}} \tag{7}$$

where:

- $N(t)$ is the accumulated number of adopters.
- m is the final potential market.
- mp is the potential market.
- fmm is the fraction of the maximum market.
- SPB is the payback sensitivity.
- TPB is the payback time (in years).
- $F(t)$ is the probability of adopters over time t.
- p is the innovation coefficient.
- q is the imitation coefficient.

Based on the market forecast, the DisCos' revenue loss per year was calculated through the difference in the DisCos' billing not considering adhesion to the DG and the billing considering the entire DG installation evolution, in the studied universe.

The impact of DG on the electricity tariff of consumers was also calculated in a simplified way, dividing the total loss of revenue by the consumption of the DisCos' customers, considering all consumer classes at all voltage levels.

5. Numerical results

a. Data and assumptions

All studies carried out in this work were carried out considering a horizon of 25 years, equivalent to the usual lifetime of the PV systems (Marchioro et al., 2018) (Miranda et al., 2015). For the technical-economic analyses, a TMA is equivalent to 9.2844%, based on the *Sistema Especial de Liquidação e Custódia* – SELIC, the basic interest rate in Brazil, an average of the last 10 years (de Freitas and Hollanda, 2015) (Banco Central do Brasil, 2021).

Regarding prosumers, only three-phase consumers were considered with payment of the availability cost equivalent to 100 kWh. Energy tariffs were used as determined by ANEEL in (ANEEL, 2020b), with increases in taxes related to the Tax on Circulation of Goods (ICMS) with amounts per federative unit; Social Integration Program (PIS) equivalent to 0.77%, and Contribution to Social Security Financing (Cofins) equivalent to 3.53%. In addition, these tariffs underwent an annual adjustment of 4.71%, whereas the taxes, which represent 29.5% of the tariff, did not suffer a percentage change (ANEEL, 2017a). Finally, the tariffs were structured as described in Section 3.b and divided according to the percentages in Table 1, where the TE portion of Charges also includes losses and transport (ANEEL, 2020c) (Rubim, 2018).

For DG, an average installed generation power per DisCo was considered. It is worth noting that these values were not updated during the study period. From this, the productivity (energy in kWh supplied by the System for each installed power in kWp) for DG was calculated

Table 2
Cost of the PV system (Greener, 2020).

Material	Installation
3.12 R$/Wp	1.65 R$/Wp

according to the average irradiation of the federative unit where the DisCos is located and the overall system yield, equivalent to 80% (Simone, 2019). A linear drop in the production of the PV System equivalent to 0.8% per year was also considered (Marchioro et al., 2018). Finally, the cost of the PV system can be divided into materials (PV modules, inverters, installation structure, and accessories) and installation (project, labor, tax, and profit margin) according to Table 2, this value was used for the entire Brazilian territory (IBGE, 2021). These costs were readjusted annually, reducing the price of materials by 3.26% and increasing the installation cost by 5.73% (IBGE, 2021) (Konzen, 2014). An operation and maintenance cost equivalent to 1% of the initial investment was also considered, including the replacement of the inverter in year 15 (Konzen, 2014) (Miranda et al., 2015).

All prosumers were considered to be consuming 40% of all the energy generated by the DG at the same time, that is, the injection of only 60% of the energy into the grid for credit generation and subsequent consumption is considered (Konzen, 2014) (ANEEL, 2018).

Finally, for market forecasting, we considered innovation and imitation coefficients equivalent to p = 0.0015 and q = 0.38, respectively. In addition, only house-type residences with monthly consumption above 200 kWh, which are already paid off or still in the payment phase, were considered as a potential market (Konzen, 2014) (EPE, 2014) (ANEEL, 2017b).

b. Compensation scheme of NR482

The compensation model presented in the NR482 regulation, presented in Section 3.d, represents the model currently in force in the country until the beginning of 2022 and used until 2045 for prosumers who install the system until 2023. In this model, the compensation of the injected energy towards the main grid is performed considering all tariff components. The technical-economic analysis for prosumers and DisCos is presented below.

- Prosumer's analysis

For this injected energy compensation case, the analysis on the prosumer's side lead to investment feasibility for all DisCos in the country according to the three criteria analyzed: LCOE, discounted payback, and B/C. The results for LCOE, discounted payback and B/C for all DisCos are presented in Fig. 5, Fig. 6, and Fig. 7, respectively. For the LCOE, taking into account the percentage difference between the tariff and the LCOE value found, prosumers located at DisCo CELESC, in the Federal Unit of Santa Catarina, obtained the worst result, 0.42 R$/kWh, while the best result was obtained for prosumers located at ETO, in the Federal Unit of Tocantins, 0.41 R$/kWh. The average LCOE was 0.41 R$/kWh. The longest payback time was also obtained for prosumers located at CELESC, equivalent to 9 years and 8 months, while the

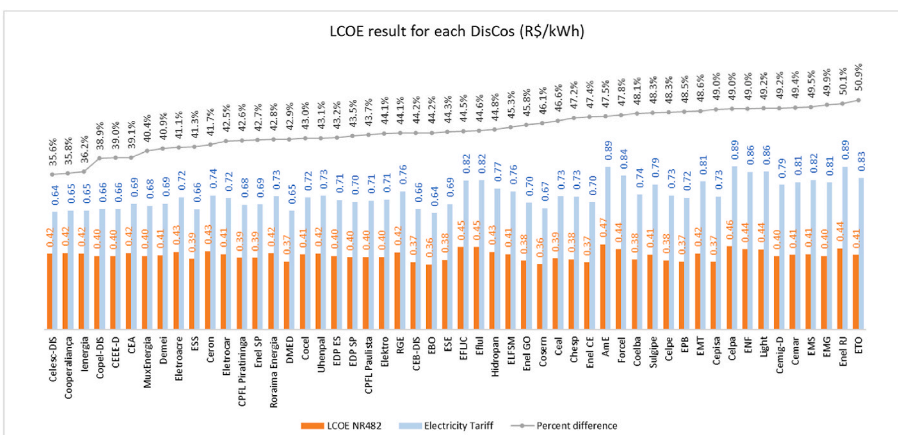

Fig. 5. LCOE for prosumers in NR482.

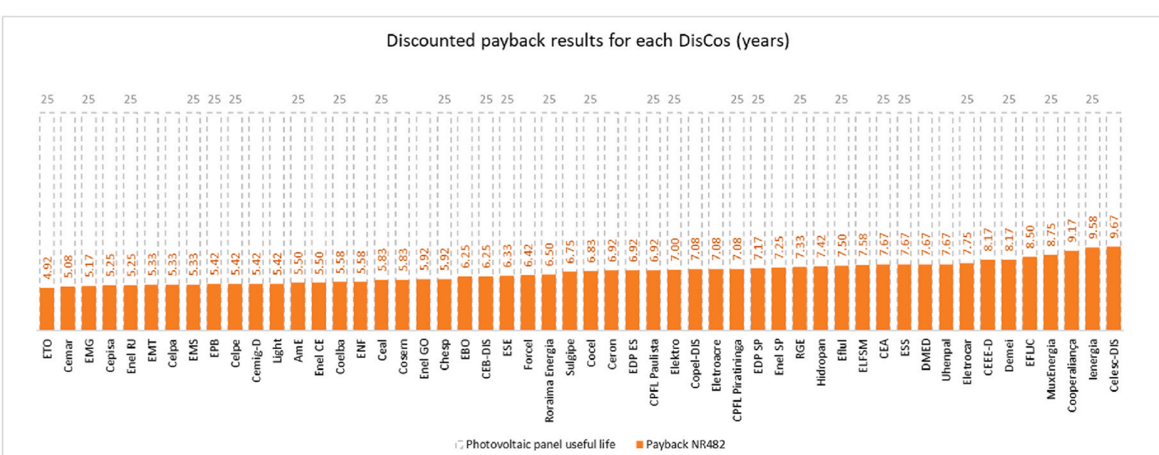

Fig. 6. Discounted payback time for prosumers in NR482.

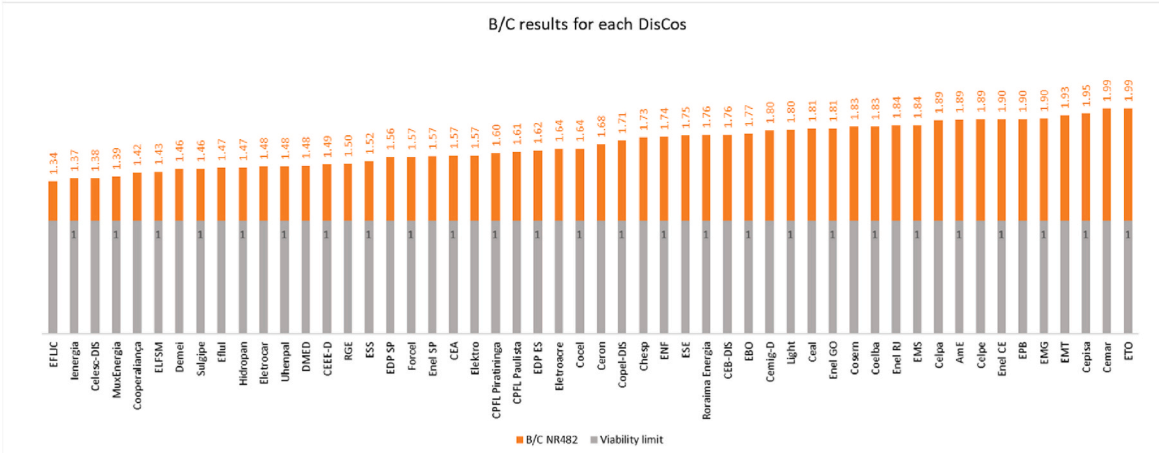

Fig. 7. B/C for prosumers in NR482.

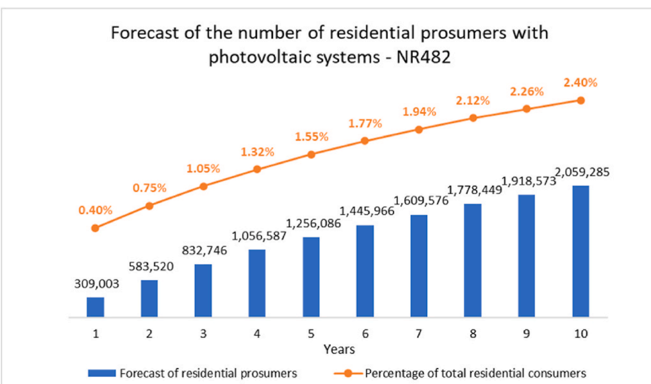

Fig. 8. DG market growth in NR482.

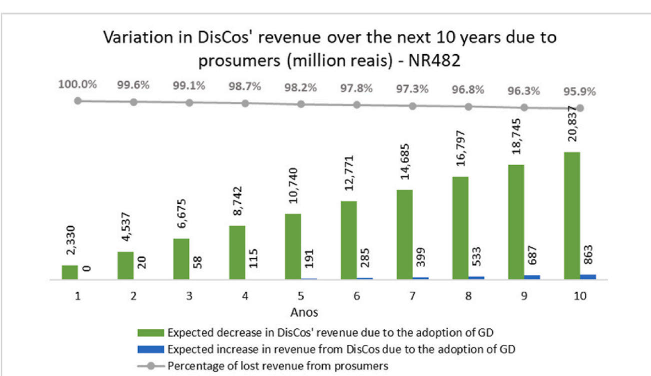

Fig. 9. Loss of revenue at the DisCos in NR482.

shortest payback time was obtained for prosumers at ETO, corresponding to 4 years and 11 months, the average payback time was 6.69 years. Finally, prosumers located at EFLJC, in the Federal Unit Santa Catarina, presented the worst result for B/C, equivalent to 1.34, while the best result for this parameter was obtained for prosumers located at ETO, equivalent to 1.99, the average B/C was 1.67.

- DisCos' analysis

From the DisCos' point of view, the simulation resulted in a growth in the DG market in the country, reaching 2.4% of residential consumers as shown in Fig. 8. The mentioned DG penetration will result in a loss of

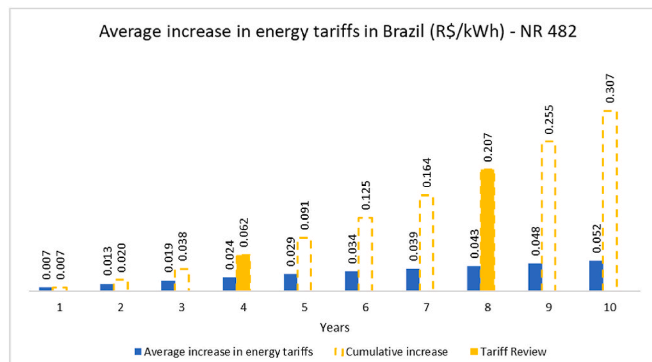

Fig. 10. Average increase in the energy tariff in NR482.

market for the DisCos and, consequently, in a loss of revenue at the DisCos due to the net-metering energy compensation system, these losses are shown in Fig. 9. To recover the mentioned lost revenue, it is expected that the energy tariffs increases during the tariff review processes, the average increases are presented in Fig. 10. It is worth noting that currently CEMIG, in the Federal Unit of Minas Gerais, presents the largest market, representing 13% of the entire national market.

c. Compensation scheme of Law 14300

In the new compensation scheme proposed in Law 14300, also presented in Section 3.d, the Fio B portion of de tariff will be levied on all the energy consumed from the network. The technical-economic analysis from the perspective of prosumers and DisCos is presented below.

- Prosumer's analysis

For this injected energy compensation case, the analysis on the prosumer's side lead to investment feasibility for all DisCos in the country according to the three criteria analyzed: LCOE, discounted payback, and B/C. The results for LCOE, discounted payback and B/C for all DisCos are presented in Fig. 11, Fig. 12, and Fig. 13, respectively. For the LCOE, taking into account the percentage difference between the tariff and the LCOE value found, prosumers located at DisCo Cooperaliança, in the Federal Unit of Santa Catarina, obtained the worst result, 0.50 R$/kWh, while the best result was obtained for prosumers located at Sulgipe, in the Federal Unit of Sergipe, 0.49 R$/kWh. The average LCOE was 0.50 R$/kWh. The longest payback time was also obtained for prosumers located at CELESC, equivalent to 13 years and 2 months,

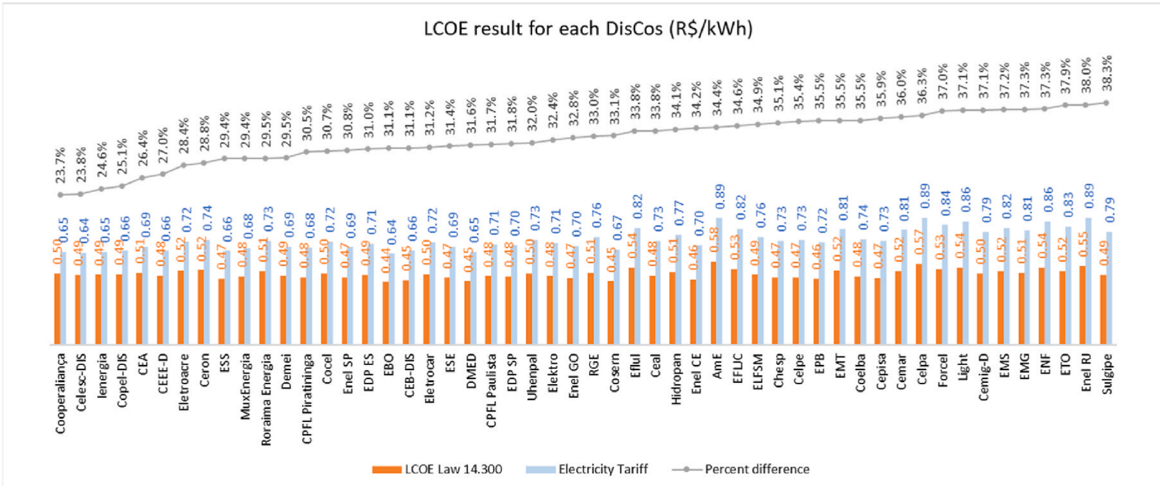

Fig. 11. LCOE for prosumers in Law 14300.

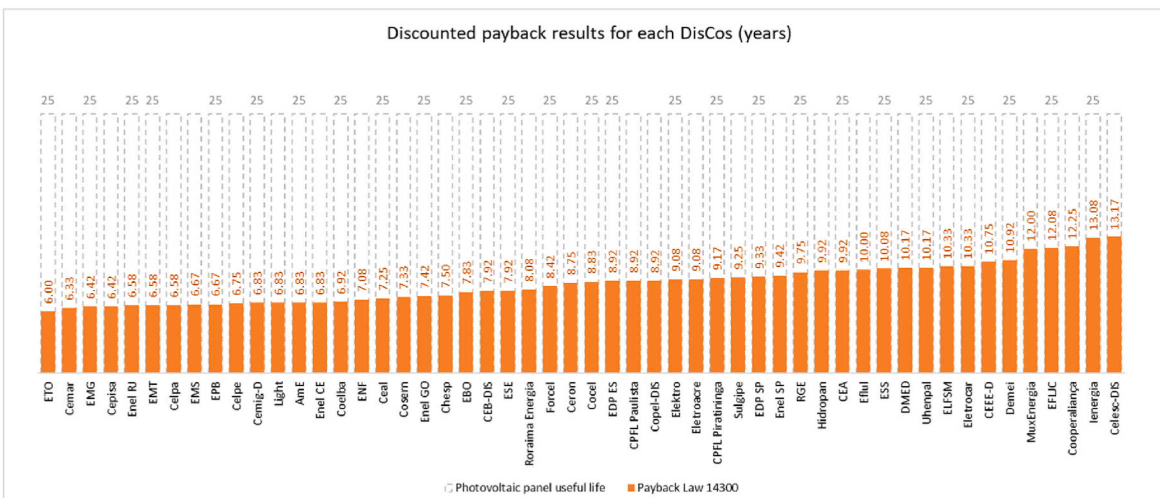

Fig. 12. Discounted payback time for prosumers in Law 14300.

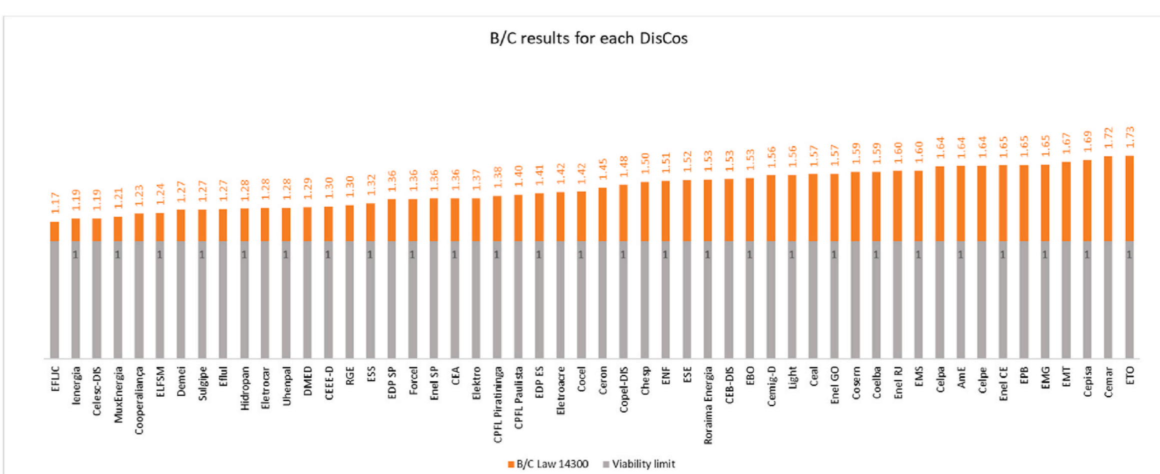

Fig. 13. B/C for prosumers in Law 14300.

while the shortest payback time was obtained for prosumers at ETO, corresponding to 6 years, the average payback time was 8.67 years. Finally, prosumers located at EFLJC, presented the worst result for B/C, equivalent to 1.17, while the best result for this parameter was obtained for prosumers located at ETO, equivalent to 1.73, the average B/C was 1.45.

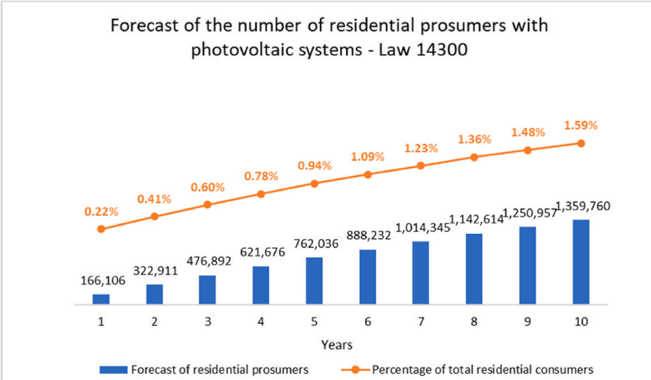

Fig. 14. DG market growth in Law 14300.

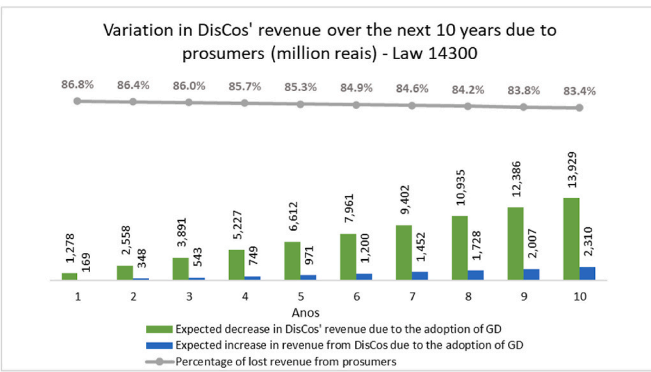

Fig. 15. Loss of revenue at the DisCos in Law 14300.

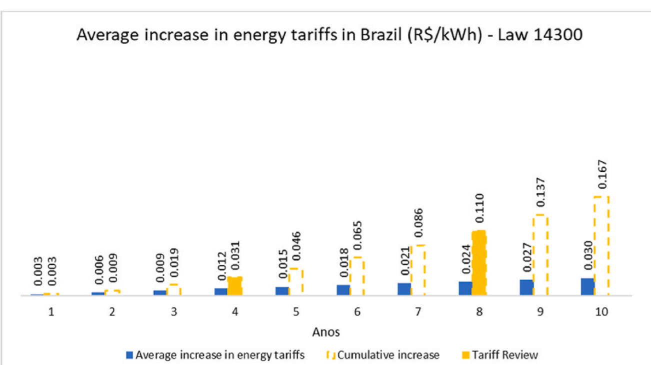

Fig. 16. Average increase in the energy tariff in Law 14300.

- DisCos' analysis

From the DisCos' point of view, the simulation resulted in a growth in the DG market in the country, reaching 1.59% of residential consumers as shown in Fig. 14. The mentioned DG penetration will result in a loss of market for the DisCos and, consequently, in a loss of revenue at the DisCos due to the net-metering energy compensation system, these losses are shown in Fig. 15. Therefore, to recover the lost revenue, it is expected that the energy tariff gets increased during the tariff review processes, the average increases are presented in Fig. 16.

6. Discussion

In this section, a thorough discussion of the results is presented by considering a direct comparison of NR482 against Law 14300. This analysis takes into account both perspectives, impact on prosumers and DisCos.

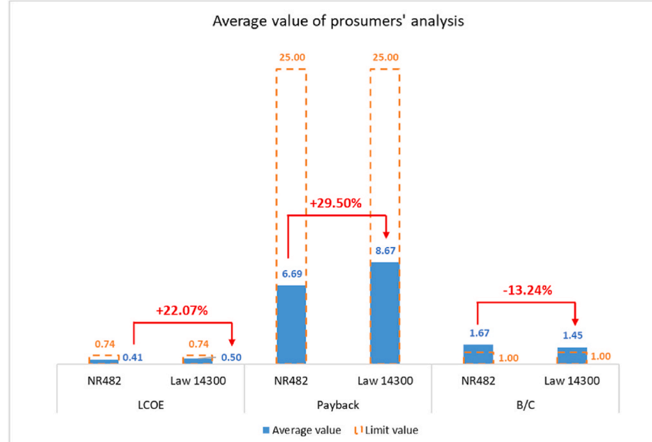

Fig. 17. Average value of prosumers analysis.

From the prosumer perspective, the attractiveness of the PV system's investment gets reduced when the percentage of the tariff paid to the DisCos gets higher. The mentioned reduction in the investment attractiveness happens because there is an increase in costs without the corresponding increase in PV generation. In this context, the change in the results can be noticed in Fig. 17.

Regarding the DisCos' perspective, with the changes in scheme compensation, there is a reduction in the number of prosumers, motivated by the reduction in the investment attractiveness presented before. Despite this, it is still possible to notice an annual growth in the total number of prosumers over the years, as seen in Fig. 18.

Alongside this prosumer increasing behavior, it was possible to notice a reduction in the loss of revenue as the energy consumed by the prosumer passes to be taxed by the percentage of the tariff, as shown in Fig. 19. Finally, there is a reduction in the DisCos' losses over the years, as energy consumption by the prosumer increases due to the drop in production of photovoltaic panels. Consequently, there is a reduction in readjustments, in both tariff revisions, with the different alternatives, due to the reduction in the DisCos' revenue loss, as shown in Fig. 20.

Thus, the change in the compensation scheme will lead to an improvement for the DisCos due to the increase in revenue compared to the current methodology. Table 3 presents the comparison of Law 14300 with the compensation scheme of NR482.

Therefore, analyzing the investor's perspective independently, the scheme compensation of the NR482 is the best option, since investment incentives are greater. Consequently, this case presents the largest market among all predictions. On the other hand, from the DisCos' point of view, the compensation scheme of Law 14300 is the best option, since there is less lost revenue, impacting less on the tariff of other consumers, and less likely to enter the so-called "death spiral".

7. Conclusions and policy implications

The present work aims at conducting a technical-economic analysis of the adoption of photovoltaic distributed generation in Brazilian homes, taking into account the alternatives for valuing the energy injected into the network by the prosumer proposed in the NR482 and Law 14300. The studies were conducted taking into account the economic impact on prosumers and distribution companies.

According to the results obtained in this work, the update of the NR482 energy compensation system through Law 14300 leads to a detriment to the economic viability of investing in photovoltaic systems, since the average LCOE increases by 22% while the payback time average increases by 29%. This occurs since the net-metering

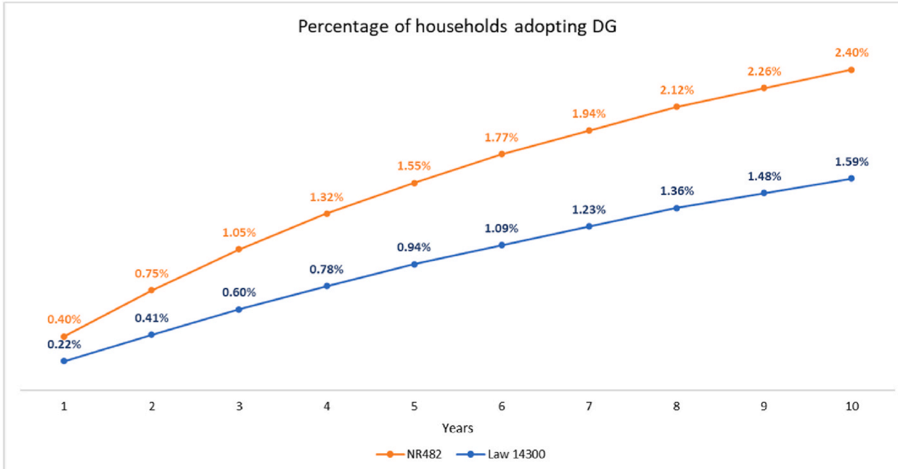

Fig. 18. Percentage of adhesion of residences to the DG.

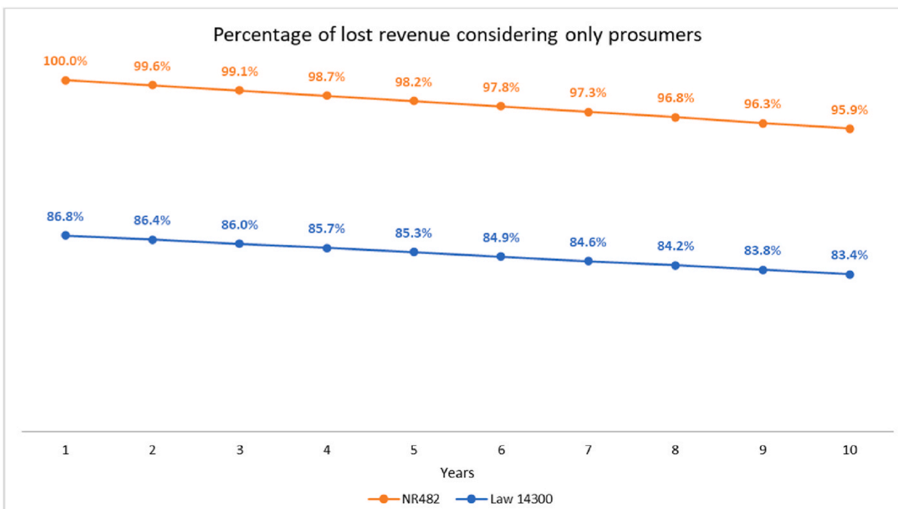

Fig. 19. Percentage of lost revenue by distributors due to regulatory alternatives.

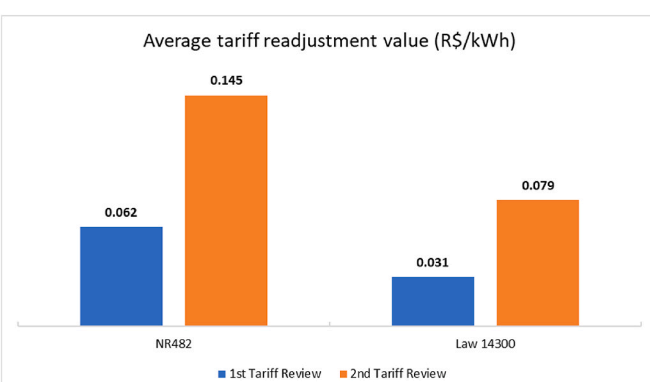

Fig. 20. Average tariff readjustments every 4 years by regulatory alternative.

compensation is no longer conducted through all components of the residential tariff, as in NR482, being required the payment of the transport component called *Fio B*, over the energy consumed independently to the energy injected into the grid.

The aforementioned detriment in the economic feasibility of investing in photovoltaic systems leads to a reduction in the expected number of adopters of this technology, according to the results obtained, the expected growth of the distributed generation market is reduced by 34% due solely to the updating of the compensation system proposed by Law 14300. On one hand, the photovoltaic market growth reduction may directly impact Brazil's commitment to reducing CO_2 emissions, especially in light of the current water crisis in 2021 in which DG can be considered one of the main sources of complementary thermal power plants shares.

On the other hand, the distributed generation market growth reduction leads to a decrease in the expected revenue losses by distribution companies by up to 42%. This is a remarkable impact of the new Law 14300 once the reduction in DisCo's revenue directly affects the quality of their services, in addition to being passed on, through the tariff to other consumers (cross-subsidies) and increasing, even more,

Table 3
Percentage variations of regulatory alternatives compared to the current model.

	Variation of Law 143000 x NR482
Market Forecast	−33.97%
Loss of revenue	−13.24%
Impact on the tariff	−47.78%

the distributed generation market, which can lead the DisCos to the so-called "death spiral". Finally, with the new law, the increase in tariff due to cross-subsidies from distributed generation gets reduced by 48%.

CRediT authorship contribution statement

Caroline Iglesias: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Visualization. **Phillipe Vilaça:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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