Distributed photovoltaic generation in Brazil

Technological innovation, scenario methodology and regulatory frameworks

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Introduction

The Brazilian energy sector has reached a paramount point in its history and has the potential to transform the livelihoods of thousands through innovative, fair energy policies. Since electric power distribution is highly centralized and strictly regulated by the state, it is critical to understand what kind of prospects exist for the diffusion of micro and mini solar photovoltaic generation in Brazil. In this study, we implement a scenario analysis and describe our process constructing the two scenarios: baseline and alternative. Later, we present a model that estimates diffusion rates based on assumptions established in each of our scenarios. However, scenarios are just one part of the puzzle, and one must recognize the key role of ANEEL and its choices. Regulating the energy sector is important because distribution is either an unrecoverable or stranded cost[1](EIA, 2000) and Brazil's economy has grown exponentially in the last couple of years, causing the solar industry to become a natural monopoly. Overall, the regulator must not only act to prevent abusive prices and guarantee quality of service, but also pursue the guarantee of economic and financial balance in electricity distribution concessionaires.

In Brazil, electricity distribution concessionaires are subject to the regulation of the Brazilian Electricity Regulatory Agency (ANEEL). In simplest terms, ANEEL applies an incentive-based regulation built upon the price cap methodology to its distributors. The regulator seeks to establish the efficiency level of revenues to the distribution concessionaire and efficiency-sharing metrics. Therefore, the study of the impacts of the micro and mini generation diffusion on distributors also requires an analysis of the basic guidelines of the current electric sector regulation.

1 In general, unrecoverable or stranded costs are historic financial obligations of utilities incurred in the regulated market that become unrecoverable in a competitive market. Stranded costs are also known as stranded investments, stranded commitments, or transition cost. In addition, transmission to competition is also considered an unrecoverable cost.

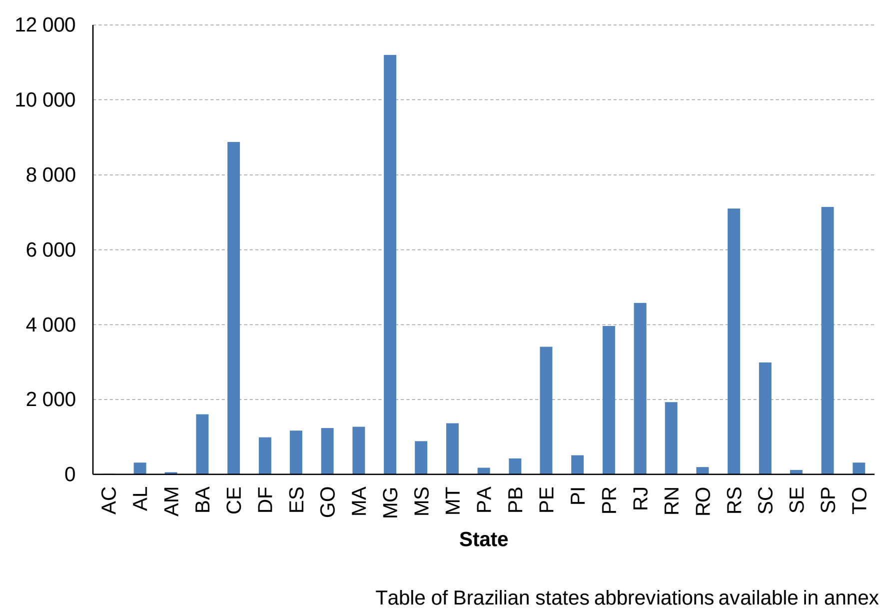
Agents in the Brazilian power sector are divided according to the activities they perform: generation, transmission, distribution, and commercialization. This division is designed to increase competition in generation and commercialization segments. It also regulates power distribution and transmission, natural monopolies that are regulated by the Brazilian government. The current power system is based on giant power plants connected by high-voltage electric transmission lines to substations located near populated areas. From these substations, electric power is distributed through local wiring by distribution agents.

Since the future of clean energy accessibility highly depends on policies created by the Brazilian government and ANEEL, we chose to utilize a scenario analysis methodology for strategic planning. First, we considered a baseline methodology, where trends in politics and social protection remain consistent for the next couple of decades. Then, we considered an alternative scenario where new policies incentivize the use of solar energy via tax exemptions, financing, and installation programs.

The first section of this paper describes the current state of the Brazilian power sector, detailing current legislation and initiatives related to solar energy. It also discusses advances in solar technology, the transformation of the Brazilian economy, and the main social challenges for public schools, businesses, hospitals, and lower income families who could greatly benefit from installing solar panels on their homes. Then, we provide some insight to technical characteristics of photovoltaic panels and an explanation and justification of our methodology. The methodology section also includes models for diffusion rates and payback calculations and a detailed look into each scenario. The second part of the paper discusses technical and regulatory frameworks of the power sector in Brazil, and what should be done to improve current policies.

A. Literature review: Brazil's electrical sector and economic transformation

Figure 1
Installation Capacity of Solar DG in Brazilian states
(kWp)



Source: Authors (adapted from ANEEL 2017).

According to the Brazilian Solar Atlas (Pereira, 2006), Brazil has an average global radiation of 5.6 kWh / m². At the end of 2016, Brazil had 61.8 MWp of installed power in distributed photovoltaic generation (ANEEL, 2016), with 7,800 connections to the grid. According to Figure 1, the state of Minas Gerais has the largest Installation Capacity with 11.2 MWp, equivalent to 18% of all installed power on the national grid. In terms of the consumer profile, the residential sector accounted for 25,6 MW and other sectors sum 36,8 MW.

Resolution 482/2012 was one of Brazil's first policies that provided specific regulations for the micro and mini generation of electric power. This regulation was later amended in Resolution no. 687/2015. In addition to providing guidelines for access to distribution systems, this policy also addressed how enterprises would be compensated for micro and mini generation initiatives. Currently, a net metering system for micro-generation systems (capacity of up to 75 kW) and mini-generation (capacity of up to 5 MW) is in place, in which surplus energy produced by the consumer is re-routed into the distribution network and rewards "energy credits" with a validity of 60 months.

Condominiums are a potential contender for connection to the photovoltaic power grid. If panels are installed, the energy generated can be distributed to each individual unit given previously defined percentages. In other words, property owners can install photovoltaic systems on their buildings and a quota of the energy generated can be used to reduce costs or as credit for the subsequent months. The possibility of solar condominiums is directly related to another possibility brought by Resolution 687/2015: remote self-consumption. Remote self-consumption is characterized by consumer units owned by the same individual or legal entity. These individuals have a distributed generation unit in a different location from the consumer unit, but in the same concession area in which excess energy will be offset (ANEEL, 2015). This idea, also called virtual net metering, allows the energy generated in one location to be compensated in another within the same concession area.

Another relevant regulatory aspect in this context is the launch of MME Ordinance No. 538 of December 15th, 2015, which establishes the Program for the Development of Distributed Generation of Electric Energy - ProGD. This is the first program in Brazil focused on the expansion of distributed generation. Its main objective is to increase electric generation from renewable sources in hospitals, residences, commercial facilities, technical schools, and federal universities (MME, 2015). The program expects to reach 2.7 million consumer units, generating 48 million MWh - equivalent to half the generation of the Itaipu power plant - and reducing emissions of 29 million tons of CO2 eq. The total investment potential is R $ 100 billion.[2]

Currently, the tax incidence on the system is:

- For the modules: PIS/PASEP[3] represents 1.65%, ICMS[4] 17%, Cofins[5], 7.6%;
- For investors: IPI[6] represents 15%, Import tax, 2%, PIS / PASEP, 1.65%, Cofins, 7.6%, ICMS 17%.

2 One of ProGD's initiatives is to create distributed generation ventures so they can sell their energy; studies on distributed energy sales in the Free Market (ACL), and the institution of the Working Group with MME, ANEEL, EPE, Cepel and CCEE propose legal, regulatory, and tax improvements to stimulate distributed generation.

3 PIS/Pasep, or Contribuição para os Programas de Integração Social e de Formulação do Patrimônio do Servidor Público, is a tax based on gross revenue earned by any types of legal entities.

4 Imposto sobre Operações Relativas à Circulação de Mercadorias e Serviços de Transporte Interestadual e Intermunicipal e de Comunicações (ICMS), is tax on the value-added tax on sales and services which applies to the movement of goods, transportation, and communication services and to supplying any goods.

5 Contribuição Social para o Financiamento da Seguridade Social (Confins) is a tax for Social Security Financing applied to monthly invoicing based on added value.

6 Imposto sobre Produtos Industrializados (IPI) is a tax applied to national and foreign products that have been transformed in some industrialised way for use.

Regarding the costs of the systems, according to Aneel (2017) they currently sum up to R$ 8500 / kW for residential systems and R$ 7600 / kW for commercial systems (Aneel, 2017).

In order to study the distribution patterns of photovoltaic generation in Brazil, we must evaluate the behavior of certain factors. These factors can be categorized as either uncertain or predetermined. Uncertain factors refer to aspects that we cannot clearly define or determine probabilities of occurrence in their possible trajectories. In this study, uncertain factors are usually public policies and government.

mandated regulation. Among the range of possible public policies to encourage photovoltaic deployment in national territory were the installation of panels in low-income households, investments in installing systems in public buildings, and the facilitation of financing for tax systems and exemptions. These policies should be adopted together so that can support each other. The financing conditions for photovoltaic systems, also addressed in ProGD, were considered in the diffusion model presented in this study with a real interest rate of 9% per year.[7]

The second group of factors are known to be certain or predetermined and are typically less problematic than uncertain ones. Modules and inverters now have reduced costs thanks to technological advances. These advances are successful in a mixed economy because of the concept of a learning economy and overcoming learning curves. "The concept of a learning curve assumes that technological progress through research and development and gains in economies of scale lead to cost savings at a rate that is related to cumulated production volumes" (Theologits & Mason, 2015).

Theologitis & Masson (2015) carried out a projection of how equipment prices dropped by overcoming learning curves and other possible vectors of cost reduction. Their study presents a reduction disaggregated by class of consumer and by component costs. These authors calculate a learning curve of 20% for c-Si modules. This means that every time globally Installation Capacity doubles, panel costs fall by 20%. IRENA (2016) points out that, between 2009 and 2013, cost reduction was greater than expected by industry players. During this period, the photovoltaic panel industry experienced a reduction in material costs, improved industrial processes, and technological innovations that allowed for significant efficiency gains. The study recognizes that the greatest opportunities for cost reduction in the modules will occur at the end of the crystalline silicon productive chain (c-Si). It is also expected that the supply of inputs necessary for the production of the modules will occur without ruptures.

With respect to small-scale micro-generation inverters, Theologitis and Masson (2015) calculated a learning rate of 18.9%, based on data from Agora Energiwende (2015). In this study, we consider inverters separately from other balancing costs, since it is expected that learning gains will be measured in a more homogeneous way in the future. Like the modules, the cost of the inverters should also lower because of an increasing installed global capacity of solar energy through learning economies.

For system-balancing (BOS) components, Theologitis and Masson (2015) consider the possibility of associated area-related gains and dynamic scale gains. However, IRENA (2016) argues that cost reduction is dependent upon adopting best practices in the photovoltaic energy sector. For example, equipment required for support and cabling could be oversized due to the design of projects elaborated by unskilled labor in this type of enterprise. In this case, costs would ultimately be greater and the equipment would be less functional.

7 It was assumed that C classified households (more than 3 and less than five times the minimum wage) was the focus of this financing program. That is because when given the choice of existing costs related to interest payments, upper classes (A and B) would avoid this kind of program. This program had an interest rate of 9%, a similar percentage as housing and construction financing.

In order to calculate the change in price of photovoltaic components, Theologitis and Masson (2015) borrow scenarios developed by the Global Market PV Outlook 2015-2019 (Solar Power Europe, 2015) until 2019. Later, they consider a scenario of low diffusion, where only 50 GW would be installed globally per year, and another with high diffusion, where Installation Capacity would grow 15% per year between 2020 and 2030.

Table 1
Evolution of the cost of photovoltaic components in 2030, by cost scenario - accumulated variation
(Percentages)

	Reduction *(percentages)*
Modules	51.5
Inverters	49.4
Balancing of System	28.2

Source: Authors, based on Theologits e Masson (2015), Agora Energiwende (2015) and IRENA (2016)

In order to contemplate cost reduction of BOS in Brazil, we considered the trend would follow suit with the rest of the world's projected reduction, as shown in the Table 1.

Data regarding the number of domiciles and commercial units and tariff rates was obtained from ANEEL (2017) and socioeconomic data was obtained from the PNAD, prepared by the Brazilian Institute of Geography and Statistics (IBGE). The most recent version is from 2016 (IBGE, 2017). The projections for commercial and residential consumption units mimicked projections from ANEEL (2017). For commercial and units, data was extracted from the Decision Support Service (ANEEL, 2017).

Amongst all predetermined factors, there is the net metering system. We consider the net metering system because it is a relatively new concept to the government (2012), so we do not expect the government to change this system in the near future. Furthermore, REN 687/2015 does not provide any new information or regulation regarding this system. The absence of new policy suggests an interest in maintaining the system as is. According to the theory of industrial economics (Kupfer et al., 2002), maintaining the stability of regulatory framework to encourage a healthy business environment is important.

B. Literature review: technical characteristics of photovoltaic panels

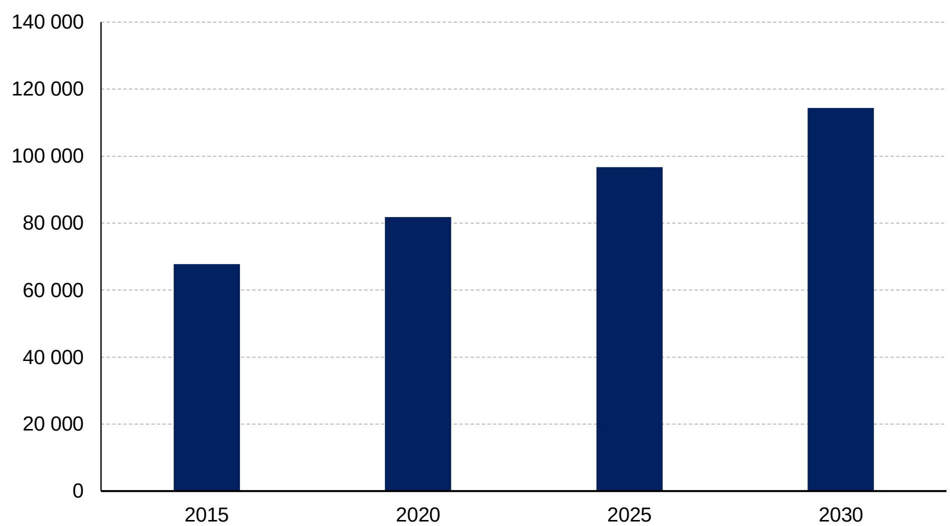
Residential AB consumers generally install 4 kWp photovoltaic panels and Class C consumers install 2 kWp panels. The power premise was based on the average of the data registered in ANEEL's Generation Information Bank (BIG), comprised of about 4,000 documented facilities. The average registered data for the residential sector is 4.88 kWp. However, some data observed was much higher than data for residential installation (photovoltaic systems with a power output greater than 50 kWp). As a precaution, this data was excluded from the calculation of the average which in this case approached 4 kWp. This was the value considered in the analysis. Like Konzen (2014), considering the current regulatory and cost conditions, we believe the people who installed PV panels first belonged to classes A and B. If financial incentives are created for Class C, photovoltaic power could be more a more feasible option. Class C represents about 20% of all Brazilian households.[8]

8 That declared their income.

Commercial consumers mostly installed 17kWp panels according to the average data of ANEEL. The lifespan of photovoltaic systems was assumed to be 25 years (IRENA, 2016). The annual operating and maintenance costs of all systems were set at 1% of the initial investment.

Photovoltaic modules are subject to a gradual drop in efficiency as a function of wear over time. To account for this wear, we assumed a 0.5% per year efficiency decrease (Nakabayashi, 2015, p.33). We also considered a "capacity factor," attributed to photovoltaic panel generation in ANEEL (2017). Changes in tariff rates are also considered a predetermined variable, and in our study, we kept them constant in all scenarios, differing only in relation to the consumption class (Sad-ANEEL, 2016).[9]

Figure 2
Evolution of the Brazilian Electricity Consumption[10]
(MWmed)



Source: Authors (adapted from EPE (2014) Distributed generation scenarios.

The last predetermined variable is the projected load of the national interconnected system (SIN). This data came from a technical note on energy demand that EPE prepared for the National Energy Plan 2050 (EPE, 2014). The cargo leaves 62,870 average MW in 2013 and reaches a 114,4 average MW by 2030, surpassing an 81,775 average MW by 2020. From these values, the annual growth rates between the periods 2013 to 2020 and 2020 to 2030 were applied to obtain the values of the load for every five years. Figure 2 shows the evolution of the load as a function of time.

C. Mathematical models for diffusion rates and payback calculation

The Bass Diffusion Model can accurately depict the diffusion rates of micro and mini solar photovoltaic generation in the Brazilian electrical system. This model features a sigmoid curve of market penetration rate amongst the study of new durable consumer goods. Equation 1 presents the model's mathematical formula.

9 Tariff with taxes from December 2016.
10 Includes technical and commercial losses.

Equation 1: Bass Model

$$\frac{f(t)}{1-F(t)} = p + \frac{q}{m} * N(t) \,,$$

Where:

- f (t) is the probability of adoption at period t;
- F (t) is the cumulative distribution of adopters as a function of time;
- p is the innovation coefficient;
- q is the imitation coefficient;
- m is the potential market, composed by the number of individuals who can implement the new technology provided there is sufficient time for it;
- N (t) is the cumulative number of adopters until period t.

The parameter p represents the proportion of the population that implements the new technology. We suggest that a portion of the population is prone to consumption of new products. Parameter q is related to the proportion of the population that is drawn to the product by "word-of-mouth." Thus, the Bass model assumes that the probability of consumers drawn to the product increases according to the amount of people who praise the product's success in previous years (Konzen, 2014).

To estimate the potential market for distributed solar generation in Brazil, we created a hypothesis. Like Konzen (2014), this study uses income levels as a parameter. We have determined a maximum number of eligible households based on gross salary above a certain limit. This criterion is possible because of Brazil's virtual net metering system, which allows consumers to adopt photovoltaic systems regardless of available space *in situ*. Regulation aspects will be discussed later in this paper. In other words, there are no technical restrictions on adopting photovoltaic technology because the panels can be installed in any place that has favorable conditions. In this study, the upper limit we considered is the total number of households in classes A, B and C.[11]

According to Konzen (2014), empirical studies (Kastovich, 1982; Navigant Consulting, 2007) show that incorporation of PV technology is estimated based on the economic and financial attractiveness of the investment, which is calculated through *payback*. The *payback* calculation includes system cost information, tariffs, discount rates, incident taxes, among other elements. Its mathematical formulation is presented in **Equation 2**.

Equation 2: payback calculation

$$n = \frac{\ln\left(\frac{1}{1-[(I_0 * r)/CF]}\right)}{\ln(1+r)},$$

where:

- n is the payback, given in number of years
- I_0 is the investment
- r is the discount rate
- CF is the cash flow

11 This data is available at PNAD (IBGE,2017). Class AB are households with income of more than 5 times the national minimum wage and Class C is for households with income between 3 and 5 times the national minimum wage. In 2016, the minimum wage was R$ 880 (monthly).

Usually, the so-called simple payback is used to simulate investment viability. Authors such as Sigrin (2012) and Denholm et al. (2009) state that it is the easiest profit to be made from the consumer's point of view. The main criticisms of this approach are related to the fact that simple payback does not consider the opportunity cost of the given time period. Mathematically, this can be represented in Equation 2, when the discount rate tends to zero. We chose to use simple payback in this study, like Konzen (2014) and Aneel (2014; 2017).

Equation 3: Maximum market-share calculation

$mms = e^{-SPB*TPB}$, where:

- mms represents the maximum market-share. This represents the share of the potential market as a function of time until the return of the investment;
- PBS is the payback sensitivity, a parameter that represents the attractiveness of the investment as a function of its payback time (Beck, 2009; Denholm, 2009). The value of this parameter is 0.3 (ANEEL, 2017), where PB is the payback of the investment in years.

It's possible to estimate households that choose to adopt PV technology as a function of payback according to the following equation:

$ah = m * mms * F(t)$

where:

- ah is the number of households that install PV technology;
- m is the potential market;
- mms is the maximum market share;
- $F(t)$ represents the cumulative distribution of households as a function of time in years.

Once the number of participating households has been calculated, we can multiply the value by the average power capacity to be installed in each household to obtain total photovoltaic power. In order to obtain a percentage of the load in each scenario, it is necessary to convert power into energy. By converting power into energy, we consider a certain capacity factor and divide this variable by the total projected load. The projection made in the alternative scenario also contemplates public policies that mandate the installation of panels in public administration buildings and in low income households.

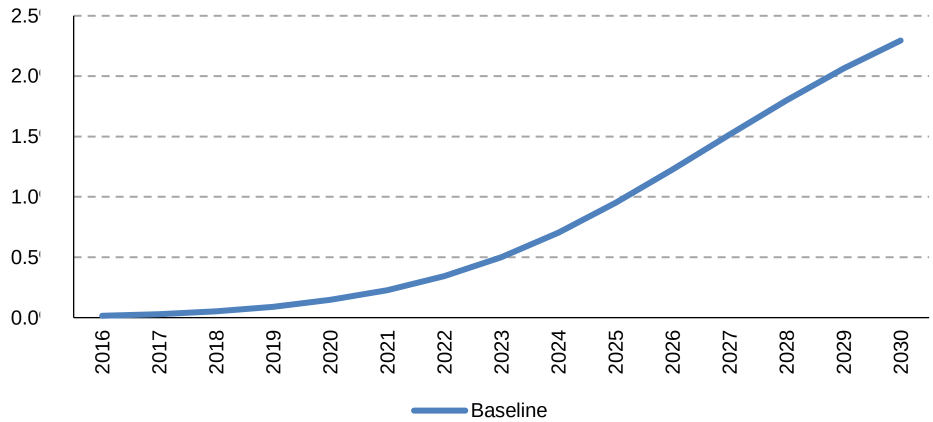
D. Methodology and scenario description

Now that we have explained the problem, described certain and uncertain factors that influence scenario creation, we will introduce our methodology for this study. We chose to create two scenarios based on the trajectory of public policies:

- Baseline Scenario: where there are no incentive policies for photovoltaic DG deployment.
- Alternative Scenario: where there are strong incentive policies for photovoltaic DG deployment.

1.Baseline scenario

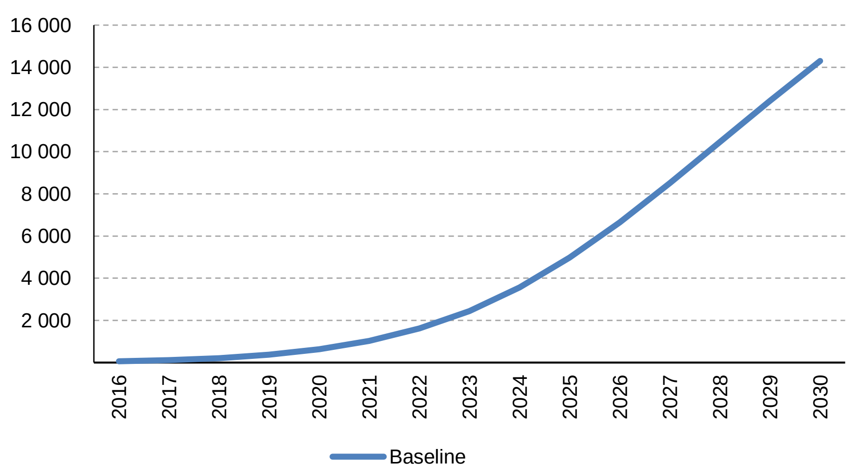
Figure 3
Share of Power Load between 2016 and 2030 – Baseline Scenario
(Percentage)



Source: Authors.

In a baseline scenario, objectives of ProGD are not achieved because not all technological and financial prospects advance, and the number of systems installed in community housing, schools, hospitals, and public buildings after 2030 does not increase. Funding that would make this technology available to lower income families are not provided by this program. So, real funding rates remain high and area not used as a mechanism that allows people with lower levels of income (C class), that need funding for the acquisition of solar panels. Figure 3 presents the photovoltaic diffusion, which reaches 2,3% of the power load by 2030.

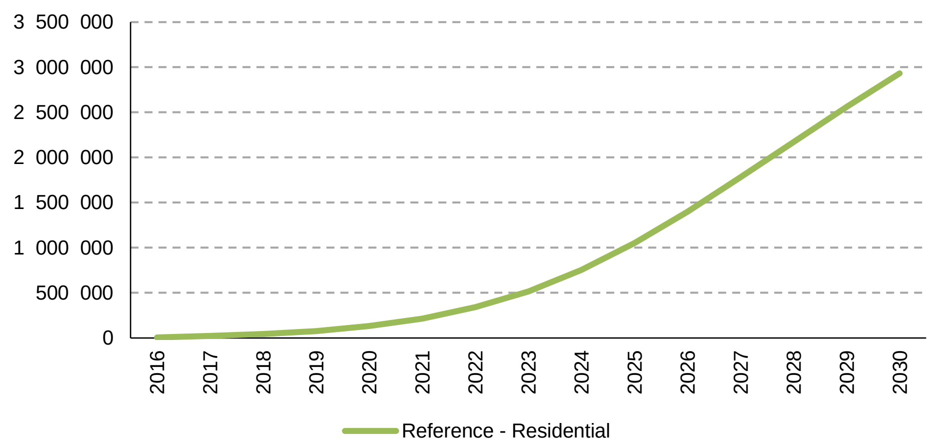
Figure 4
Evolution of Cumulative Photovoltaic DG Installation Capacity between 2016 and 2030–Baseline Scenario
(MW)



Source: Authors

Figure 4 shows the evolution of Installation Capacity for this scenario, which reaches 14 GW by 2030. The graph demonstrates an exponential growth rate from the year solar PV technology was introduced in the country. We expect there to be an inflection point in the graph after 2030 because most people who are financially able to install panels on their buildings will have already installed them at that point.

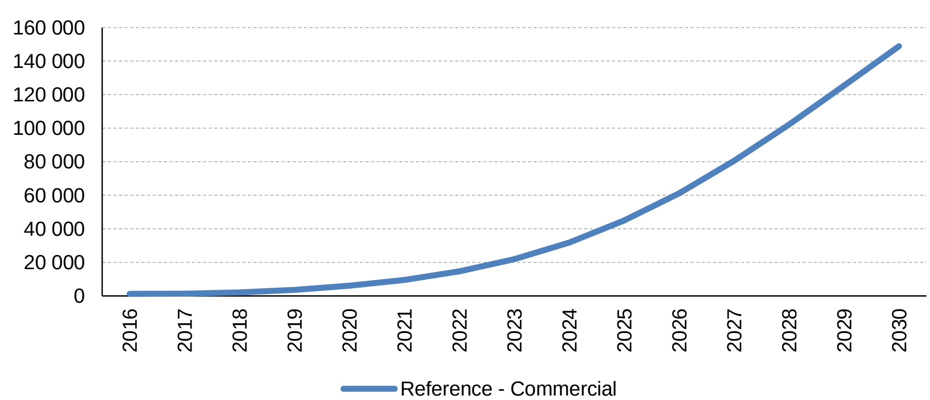
Figure 5
Evolution of Photovoltaic DG household installations between 2016 and 2030 – Baseline Scenario
(Commercial units)



Source: Authors.

The next graph, shown in Figure 5, refers to the number of households and commercial units installing panels. Residential households accounted for the greatest number of installations, reaching 3 million residential units in 2030.

Figure 6
Evolution of Photovoltaic DG Commercial installations between 2016 and 2030 – Baseline Scenario
(Commercial units)



Source: Authors.

Commercial units reached 149,000 installations by 2030, as Figure 6 shows.

2. Alternative scenario

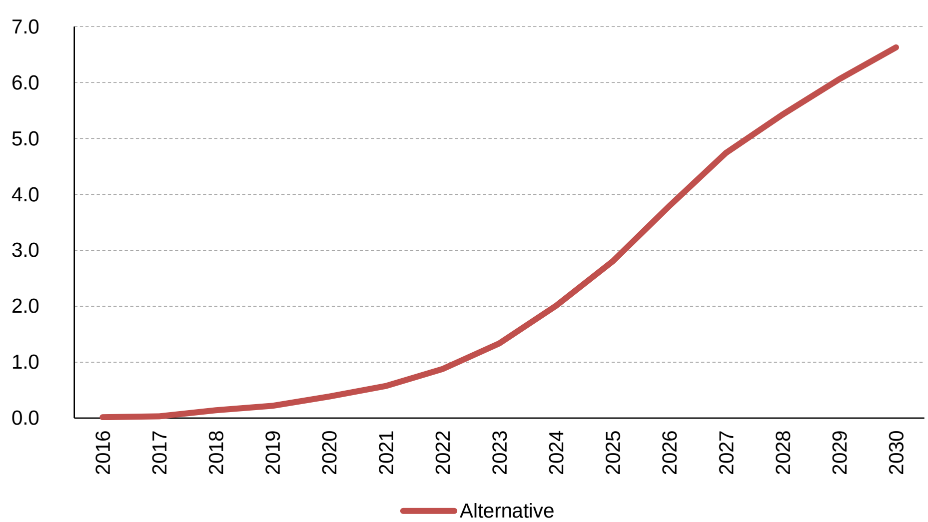
Public policies, driven by a strong preference for international agreements, fuel the national photovoltaic industry and generate incentives through tax exemptions, greater credit lines, and installation programs for low-income housing and public schools.

After COP 21, compliant countries made the commitment to increase the share of renewable sources in their electricity matrices. Thanks to this international agreement, ProGD projects have expanded, including a program of photovoltaic panel installations in public schools and low-income housing.

Another positive aspect that came out of COP 21 was more accessible lines of credit. Brazilian banks now issue lines of credit that are more accessible, with lower interest rates being offered to a larger portion of the population. The main goal of these financial incentives is to get Class C costumers to be able to afford this technology, which in this scenario, should be viable. Residential consumers in this class can get financing at a 9% per year interest rate. Because of these financial incentives, consumers are more likely to want to learn about the technology, spreading the word about this technology at a faster rate than traditional advertising methods.

In this alternative scenario, the government would install solar panels in schools, public buildings, hospitals, and in low income areas where residents are more likely to be socially vulnerable. There would be an economic incentive for the installation of photovoltaic systems in public buildings, since overcoming the tariff parity results in lower costs of electricity consumed by the government in the long term. In lower income, socially vulnerable areas, the government would seek to reduce non-technical losses and increase energy efficiency, since they are characterized by unsatisfactory results in these two criteria. Investments would amount to one billion per year over the period of 2018 to 2030 in schools, hospitals, and public buildings. In addition, the government would use resources from the Energy Development Account (CDE), finance the social tariff, and spend one billion *reais* (approximately USD 265 million) annually to install large-scale photovoltaic systems.

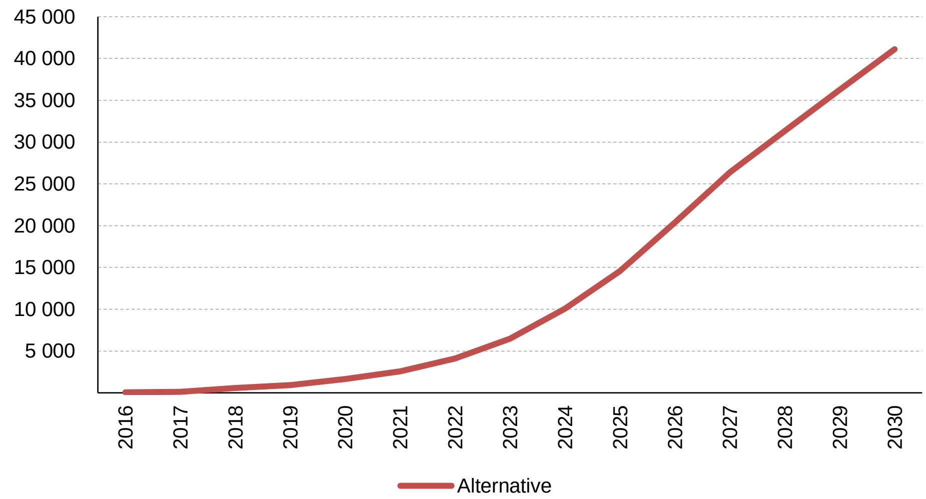
Figure 7
Share of Power Load between 2016 and 2030 – Alternative Scenario
(Percentage)



Source: Authors.

Tax exemption is an important financial incentive to installing solar panels. Since 2018, photovoltaic equipment - modules and inverters - are exempt from ICMS, PIS / PASEP, COFINS, IPI and import tax. An important factor in enabling such exemptions is the adjustment of public accounts. The set of public incentive policies generates a distributed photovoltaic diffusion of 6.6% of the 2030 load as shown in figure 7.

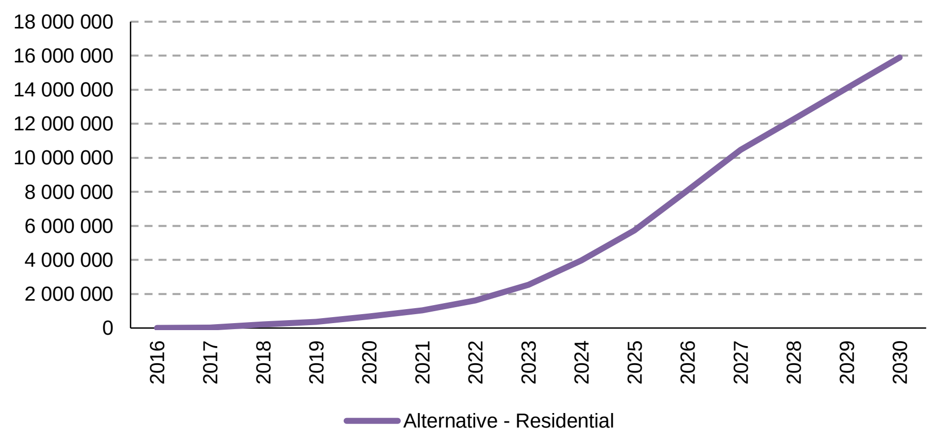
Figure 8
Evolution of Installation Capacity between 2016 and 2030 – Alternative Scenario
(MW)



Source: Authors.

Figure 8 shows the evolution of installation capacity, reaching 46.3 GW in 2030. The graph shows an exponential growth that continues to rise even after 2030 as PV technology becomes increasingly accessible for all.

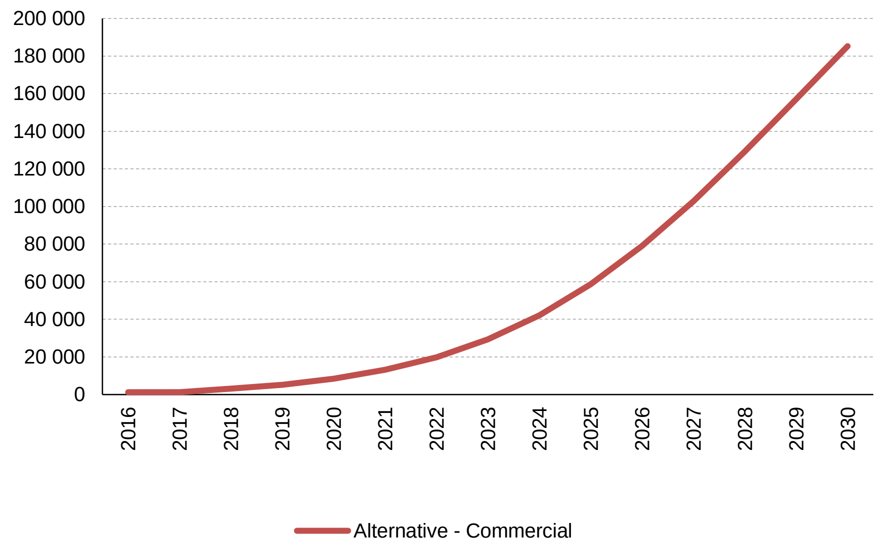
Figure 9
Evolution of Photovoltaic DG adopting households between 2016 and 2030 – Alternative Scenario
(Commercil units)



Source: Authors.

The number of households and commercial units with PV panels installed would grow considerably, reaching 16 million and 185 thousand by 2030, respectively. This is shown in figure 10.

Figure 10
Evolution of Photovoltaic DG adopting commercial units between 2016 and 2030
Alternative Scenario
(Commercil units)



Source: Authors.

The number of households is considerably higher than the number of households in the baseline scenario, mostly because Class C would finally be able to afford this technology, increasing participation from low-income households.

I. Regulatory challenges for decentralizing electrical systems

A. Government regulation of Brazilian distribution companies

Based on estimates of efficient operational costs, adequate remuneration of the investments required for the provision of electricity distribution services, and the calculation of the distributor's expenses on power purchase, transmission and sectoral charges, the regulator defines the revenue requirement for the distribution company. This revenue is divided into two components, according to the characteristics of the costs.

Portion A (Parcela A in Portuguese) includes non-manageable costs over which the distribution company does not have complete control and, consequently, are charged to consumers in full. This includes the cost of power purchase, power transportation costs, and sectoral charges. The following equation expresses the composition of Portion A (ANEEL, 2016b):

$$PAV = PPC + TC + SC$$

Where:

- PAV = Potion A value
- PPC = Power purchase costs
- TC = Transmission and distribution grid connection and usage costs
- SC = Sectorial charges defined by specific legislation

Among the cost components of Portion A, the costs of power purchases are the most significant. This is why it is necessary to understand how the power purchase contracts between generators and distributors are made. According to the current legislation[12], distributors operate in a framework where power purchase contracts are regulated[13] and the main instrument for the acquisition of power to meet their needs[14] are the energy purchase auctions, through which the Energy Trading Contracts in the Regulated Environment – Portuguese: *Contratos de Comercialização de Energia no Ambiente Regulado* (CCEAR) - are signed. In addition to these contracts, the distributors have a bilateral contracts portfolio signed prior to Law 10,848 / 2004 and energy quotas. [15] The current legislation also allows distributors to contract up to 10% of their energy demand from smaller centers directly connected to their grid.[16]

The effective spending of a distributor with energy acquisition[17] depends not only on the prices and specificities of its energy contracts portfolio, but also on the verified power demand and the dispatch made. More specifically, the Brazilian hydrothermal generation system is centrally dispatched to optimize the use of resources. Given that the level of the hydroelectric plants' reservoirs strongly influences the operation of the electric system, the Marginal Operating Cost - Portuguese: *Custo Marginal de Operação do Sistema* (CMO) - is a proxy of the opportunity cost of water use and the decision to dispatch does not consider the contractual relations in effect. Consequently, in addition to differences between contracted energy and actual demand, the distributors may also have differences to settle derived from the characteristics of dispatch performed by the National Electric System Operator[18] – Portuguese: *Operador Nacional do Sistema Elétrico* (ONS).

In contrast, Portion B refers to the costs directly related to the power distribution activity and is considered manageable. Thus, its transfer to consumers must be made through an active regulatory control so consumers are not overpaying for service and the economic and financial balance of the concessionaires is assured. This portion also is related to operational and capital costs.

The operating costs are associated with services and equipment required to the maintenance of the infrastructure of the distribution grid and with human resources. These costs are estimated using a benchmark approach that compares distributors to determine efficiency level costs. Capital costs include the amount of non-depreciated investments by the utility, denominated Asset Base – Portuguese: *Base de Remuneração*. A rate of return multiplies the value of these assets to set a payment for the invested capital

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12 The current legislation was established by Law 10,848 promulgated on March 15th, 2004. The rules herein are related to the procedures for contracting electric energy to distributors with a market greater than 500 GWh per year.

13 Regulated Contracting Enviroment – Portuguese: Ambiente de Contratação Regulado.

14 The amount of energy to be acquired by a particular distributor should consider technical and non-technical losses that are regulated. In addition, it should be noted that distributors can contract up to 105% of their demand forecast.

15 The distributors have quotas of energy associated with the Itaipu hydroelectric power plant, Angra I and Angra II nuclear power plants and the Incentive Program for Alternative Energy Sources (PROINFA). More recently, quotas have also been granted for the concessions of new hydroelectric power plants through Law 12.783 / 2013.

16 This modality includes renewable energy projects with a capacity of less than 30 MW and cogeneration plants with energy efficiency greater than 75%.

17 The quotas of PROINFA are not accounted for as cost of power purchase because they are paid through a specific charge.

18 The thermoelectric plant contracts in the regulated market are made in the availability – Portuguese: disponibilidade - modality. That is, the distributors pay a fixed income to the thermoelectric generator and have fuel expenditures only when these plants are dispatched. Therefore, if these plants are not dispatched, the distributors must acquire energy in the market of differences in amount equivalent to the contracted coverage of the contracted thermal power plant. Starting in 2013, as the energy from the hydroelectric power plants that renewed the concession was allocated to distributors, they had incorporated the hydrological risk. That is, in moments when the water generation is inferior to the contractual coverage of these plants, it becomes necessary to acquire energy in the market of differences.

of the distribution company. For capital costs, we include asset recovery of the investment made for the distribution service provision through its useful life. [19]

In the calculation of capital costs, the Regulatory Reintegration Quota – Portuguese: *Quota de Reintegração Regulatória* - is also included, which represents the recovery of the investments made to provide the distribution service over the useful life of the assets and rights. The value of Portion B is calculated using the following formula:

$$VPB = (MOMC + ACA) * (1 - P_m - QIM) - OR$$

where:

- PBV = Portion B Value;
- MOMC = Management, Operation, and Maintenance Costs;
- ACA = Annualized Cost of Assets[20];
- Pm = Market Adjustment Factor;
- QIM = Quality Improvement Incentive Mechanism;
- OR = Other Revenues[21];

As can be verified in the calculation formula of Portion B, it applies a market adjustment factor and a mechanism to improve the quality of MOMC and ACA.

The Market Adjustment Factor considers the potential productivity gains between the year prior to the Rate Case and the period of entry into force of the tariffs defined in the Rate Case. The Market Adjustment Factor (Pm) to be applied in the periodic tariff review of each utility is set based on average productivity of the distribution sector, average growth of the billed market, and the change in the number of consumer units of the concessionaire between the present and the previous Rate Cases. In the fourth Rate Cases Cycle, the following formula was utilized:

$$Pm_i = APD + 0.14 \times (\Delta MWh_i - \Delta MWh) - 0.04 \times (\Delta CU_i - \Delta CU)$$

Where:

- APD: Average productivity of the distribution segment, 1.53% per year
- ΔMWh_i: Annual average market change of the concessionaire i, between the previous and the present Rate Case
- ΔMWh: Average annual variation of distributors' market, 4.65% per year
- ΔCU_i: Average annual change in the number of consumer units billed utility of i between the previous and present Rate Case
- ΔCU: Average annual variation of the number of consuming units, 3.39% per year

19 When considering the cost of capital, associated taxes must be considered in order to ensure that the remuneration effectively earned by the regulated company is sufficient for the payment of Corporate Income Tax - Portuguese: Imposto de Renda sobre Pessoa Jurídica (IPRJ) - and Social Contribution on Net Income – Portuguese: Contribuição Social sobre o Lucro Líquido (CSLL).

20 Includes the Annual Cost of Mobile Facilities and Real Estate – Portuguese: Custo Anual das Instalações Móveis e Imóveis (CAIMI). This item refers to short-term investments, such as those made in hardware, software, vehicles, and the entire infrastructure of administrative buildings.

21 These revenues can be of two natures. On the one hand, revenues inherent to the electricity distribution service are those relating to billable services. Concomitantly, there are revenues from ancillary activities, which are activities of an economic nature incidental to the object of the concession contract, exercised at the account and risk of the concessionaires.

Regarding the quality incentive mechanism, metrics that aim to obtain the technical quality of the service (duration and frequency of supply interruptions) are used in the Rate Case. More recently, metrics have also been made to assess the commercial quality of the utilities.

All the discussion made so far about the economic regulation of the distributors and consequent definition of their Required Revenue occurs within the scope of the Rate Case process. However, this is a process that takes place every four or five years, depending on the concession area. During the regulatory cycle, the Rate Adjustment – Portuguese: *Ajuste Tarifário* - process is carried out annually.

During the Rate Adjustment process, the distributor's non-manageable costs (Portion A) provisions for the following period are revised to set the new value of Portion A. At the same time, since there are always divergences between the actual and projected markets and actual energy expenditures are dependent on the dispatch made, there is also a financial component [22] related to the previous year that aims to make the non-manageable costs for the distributor as neutral as possible to their economic result.

In Portion B, an inflation index discounted from a metric is used to capture productivity gains. This is the X Factor that is set by ANEEL at the time of the Rate Case. This index is composed of three components: PD, Q and T. The first component, PD, measures the productivity gains of electricity distributors and consists exactly of the previously market adjustment factor. The Q component evaluates the quality of the technical and commercial services provided by each concessionaire to its consumers. Finally, the T component adjusts, over a defined period, the observed operating costs of each company until it reaches efficiency (ANEEL, 2015a). Its given formula is:

$$X\ Factor\ = P_d + Q + T$$

Where:

- Pd: Productivity gains derived from the distribution activity;
- Q: Technical and commercial quality of the service provided to the consumer; and
- T: Trajectory of operational costs.

Considering that the revenues obtained by the distributors are derived from the payment of tariff rates by their consumers, the understanding of the economic regulation of the concessionaires also requires the knowledge of the components of the tariff rates charged by the distributors and how they affect different types of consumers during different hours of the day. It can be observed that the different cost items of the distributors are aggregated into two rate components: the rate of the use of the distribution system (TUSD) and the Energy Tariff Rate (TE).

TUSD is the medium through which the user of the distribution company grid pays monthly for its access. Among its cost components, TUSD transport is the most significant. This is the share of TUSD referring to TUSD FIO A and TUSD FIO B. TUSD FIO A refers to the costs of using assets owned by other network companies (basic network transmission systems, power of the basic network with a voltage lower than 230 kV and other shared transmission facilities (DIT) – Portuguese: *Demais Instalações de Transmissão Compartilhadas* - use of the grid of other distributors and connection to the transmission facilities). [23] TUSD FIO B is composed of the assets owned by the distributor itself

22 These are financial adjustments contemplated in the Portion A Variation Compensation Account – Portuguese: Conta de Compensação de Variação de Valores da Parcela A (CVA).

23 The TUSD FIO A also contemplates the expenditures with the connection to the transmission grid and other distributors grids.

Portion B, for example the Management, Operation, and Maintenance Costs and the Annualized Cost of Assets.

The composition of TUSD also includes the TUSD ENCARGOS, that covers the expenses with the following charges:

- Research and Development and Energy Efficiency – Portuguese: *Pesquisa e Desenvolvimento e Eficiência Energética* (P&D_EE).
- Inspection Fee for Electric Energy Services - Portuguese: *Taxa de Fiscalização de Serviços de Energia Elétrica* (TFSEE);
- Contribution to the National Electric System Operator – Portuguese: *Contribuição para o Operador Nacional do Sistema Elétrico* (ONS);
- Energy Development Account Quota - *Quota da Conta de Desenvolvimento Energético* (CDE); and
- Incentive Program for Alternative Energy Sources - Portuguese: *Programa de Incentivo às Fontes Alternativas de Energia Elétrica* (PROINFA).

Finally, there are existing provisions for losses coverage denominated TUSD PERDAS inherent in technical and non-technical losses recognized by the regulator. [24]

Generally speaking, all members of the distribution network must pay the cost items present in TUSD. [25] However, the form of charging varies depending on the class of the consumer. One-way tariff rates in MWh are applied to residential consumers, and two-way rates that vary according to the time of day.

In turn, the Energy Tariff– Portuguese: *Tarifa de Energi*a (TE) - responds basically to the distributor's expenditures with power purchases. It also should be noted that the TE also includes a portion referring to the coverage of charges[26] and another portion intended to cover losses in the basic grid. In addition, TE has an item to cover transmission costs related to the transportation of energy produced at the Itaipu hydroelectric power plant in the basic grid. TE is paid only by the consumers of the retail market of the distribution concessionaire.

B. Regulatory guidelines for distributed generation in Brazil

The current regulatory framework on distributed generation in Brazil is based on a Net Metering methodology. In general terms, this compensation system allows generated energy to be injected into the grid, creating energy credits to be used in moments when the consumption exceeds the electric power generation in the consumption unit.

This compensation model was implemented through Normative Resolution 482/2012 promulgated by the National Electric Energy Agency (ANEEL) on April 17th, 2012. Through this resolution, projects could be defined as micro-generation or mini-generation projects with the following characteristics.

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24 TUSD PERDAS also includes the recognition of Basic Network Losses due to distributor's regulatory losses and Unrecoverable Revenues.

25 The legislation provides for some exemptions. For example, "low income" consumers do not pay charges related to PROINFA.

26 It includes, for example, payment of the System Service Charges – Portuguese: Encargos de Serviços do Sistema (ESS) - and the Reserve Energy Charge – Portuguese: Encargo de Energia Reserva (EER).

- Micro Generation: an electric power generating plant with an installed power of 100 kW or less that uses qualifying cogeneration or renewable sources of electric energy, connected to the distribution network through consumption units
- Mini Generation: an electricity generating plant with an installed capacity of over 100 kW and less than or equal to 1 MW for hydro, solar, wind, biomass or qualified cogeneration sources, according to ANEEL regulations, connected to the distribution network through installations of consumption units

According to the established legislation, the active energy injected into the distribution system by the prosumer would be transferred as a free loan to the distributor, with the consumer unit having a credit in quantity of active energy to be consumed for a term of 36 months. [27]

Subsequently, ANEEL Normative Resolution 687/2015 amended the guidelines for distributed generation aiming to expand the scope of the regulatory framework and accelerate the diffusion process of decentralized generation. With this new resolution, the limit for a system to be classified as micro generation has been reduced to 75 kW. On the other hand, the amplitude of the mini generation rose from 5 MW. [28] The period of validity of the credits for 60 months was extended and the necessary procedures for connecting the distributed generation units to the distribution network were simplified. [29] However, more than moving on limits and deadlines, it should be emphasized that REN 687/2015 has created new possibilities for distributed generation.

There is also the possibility of creating distributed generation condominiums. This would involve dividing a major power source into smaller quantities that provide electricity to condominium units. An alternative design for vertical and / or horizontal condominiums should be considered, in which a generator system is installed in a common area of the condominium.

Thanks to REN 687/2015, consumers were able to explore opportunities for shared generation. This is an alternative of consortium creation through an association of consumers where the generation system is in a different place from the consumer units. This arrangement requires the constitution of a legal entity capable of administering the generating system and the distribution of generation credits among the different consumers participating in the consortium. [30]

In legal terms, the current energy compensation system has the following framework: the active energy injected into the distribution system by the consumption unit will be transferred as a free loan to the distributor, with the consumption unit receiving a quantity credit of active energy[31] to be consumed for a period of 60 months. After this deadline the credits expire, being reverted in favor of the other consumers without gains by the prosumer.

The prosumer electricity billing must consider the energy consumed, deducting the energy injected and any eventual credit of energy accumulated in previous billing cycles, considering different prices over the day-hours, when applicable, on which all the components of the tariff rate[32] in R$/MWh. [33]

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27 The adhesion to the electric energy compensation system does not apply to wholesale or special consumers.

28 In the case of projects based on the water source, the limit is 3 MW.

29 The access requirements for the consumer were simplified and the maximum deadline for the distributor to connect the project went from 82 to 34 days.

30 The distributor is not allowed to include consumers in the electricity compensation scheme in cases where there is a document proving ownership or ownership of the property, micro generation or distributed mini-generation on property that is rented, leased, or on lots and properties in which the value of the rent or lease is in R$ per unit of electric energy.

31 As credits are valued in terms of active energy, the amount of credits is no longer subject to variations in tariff rate values.

32 The compensation must be given first in the hour of the day in which the generation occurred and, later, in other periods.

33 In the case of an enterprise with multiple consumption units, it is necessary to consider the percentage of energy produced allocated to each of them.

However,any consumer adopting this compensation system remains obliged to pay at least the cost of electricity availability.[34]

Given the existence of multi-unit and multi-generation utility modes, it is well known that surplus energy that has not been compensated in the consumer unit itself can be used to compensate the consumption of other consumption units. [35] This possibility is extended to the case of remote self-consumption, where consumer units with the same holder can offset credits in places other than those where they were generated. The typical case is that of a network of stores that has a headquarters and several branches. For example, supposing that the matrix has produced surplus energy, they could be used to reduce energy expenditures at the branches.

In order to enable the effective diffusion of distributed generation systems, the regulation establishes that distributors should adjust their commercial systems and elaborate or revise technical standards to deal with microgeneration and distributed minigeration access, using the Electric Power Distribution Procedures in National Electrical System – Portuguese: *Procedimentos de Distribuição de* Energia *Elétrica no Sistema Elétrico Nacional*, Brazilian technical standards, and international norms as references. [36]

In the current regulatory framework, participants of the electricity compensation scheme were exempted from signing network connection and use contracts, which are typical for generating plants. The current regulatory framework also defined that the installed power of the systems is limited to the load of the consumer unit where the generating plant will be installed. [37]

The costs associated with improvements or reinforcements in the distribution system due to the exclusive connection of distributed generation system and the treatment of microgeneration and minigeneration are different. In the case of microgeneration, these costs must be taken on exclusively by the distributors and should not be included in the calculation what consumers pay in their bills. On the other hand, in the case of minigeration, such costs should be a part of the consumer's monthly bill statement.

Responsibility over energy meters in the microgeneration and minigeration projects are divided differently. For microgeneration systems, the distributor responds technically and financially by energy meters in lines with the established technical specifications. In the case of minigeration and shared generation systems, the costs of measurement system adequacy[38] are the responsibility of the interested party. After the adjustment of the metering system is completed, the distributor becomes responsible for the operation and maintenance of the metering system (including the costs of eventual replacement or suitability).

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34 Even in situations where there are credits derived from previous billing cycles, they can't be used to reduce the current balance of the current billing to the amount of energy equivalent to the cost of availability.

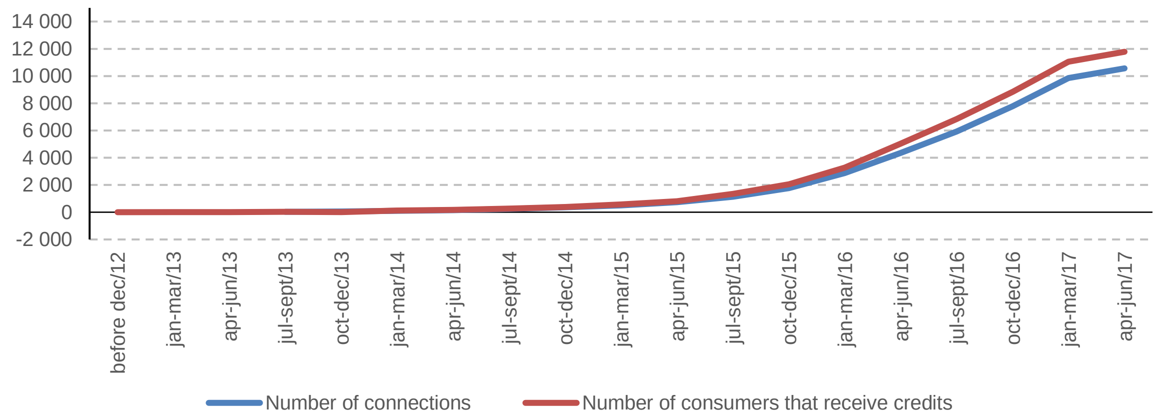
35 The owner of the consumption unit where the microgeneration or distributed mini-generation is installed must define the percentage of surplus energy that will be allocated to each participating unit of the electricity compensation system, and may request the change from the distributor, provided that it is done in writing , with a minimum advance notice of 60 days of its application and, in the case of an enterprise with multiple consumption units or shared generation, accompanied by a copy of a legal instrument that proves the commitment of solidarity among the members. When the consumer unit where the surplus generation occurred is billed in the conventional modality, the credits generated should be considered as off-peak generation in the case of use in another consumer unit. For each consumer unit participating in the electric energy compensation system, once energy compensation has been completed within the same billing cycle, the remaining credits must remain in the consumer unit to which they were destined.

36 A timeframe of 240 days was established by REN 482/2012 for the creation of preferred acquisitions.

37 The installation of systems with capacities higher than the previously established limit requires the request of increase of load.

38 The adjustment costs correspond to the difference between the component costs of the measuring system required for the electric energy compensation system and the components of the conventional measuring system used in consumer units of the same voltage level.

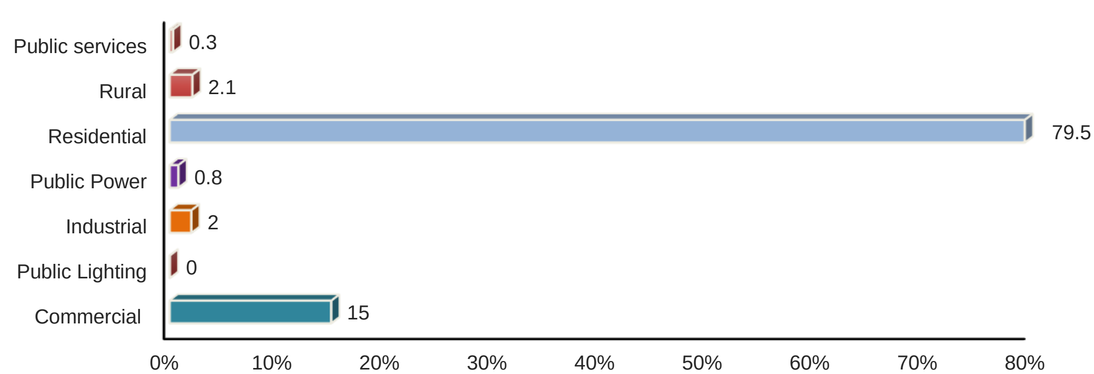
Figure 11
Evolution of distributed generation projects in Brazil – December 2012 to May 2017
(Connections)



Source: ANEEL (2017).

Now that we have presented the regulatory framework in which distributors operate, we must examine the effectiveness of these guidelines in supporting distributed generation projects. Therefore, although the number of distributed generation systems is still relatively small in Brazil, the exponential nature of its growth is significant, especially since the enactment of Resolution 687/2015. Figure shows the evolution of the number of connections and consumers participating in the compensation system between December 2012 and May 2017. It appears that the number of participants in the compensation system is higher than the number of connections. Considering the existence of condominium generation and shared systems, these results are to be expected.

Figure 12
Participation of different classes of consumption in the total of DG connections to the Grid - 05/23/2017[39]
(Percentage)

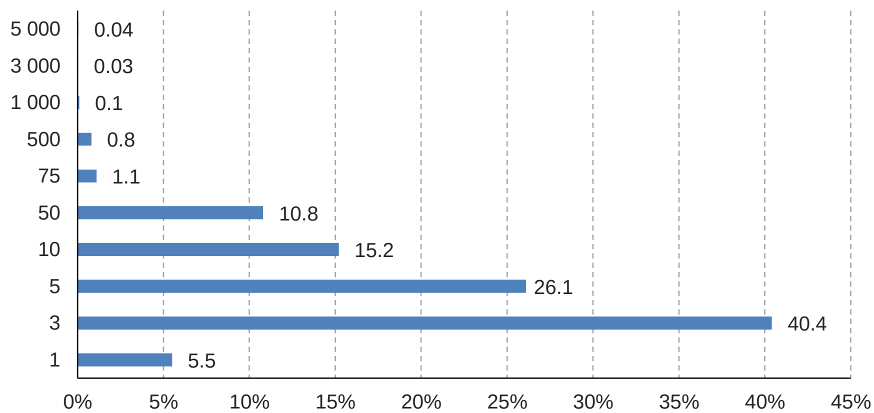


Source: ANEEL (2017).

39 Based on 05/2017 data.

The growth in the number of participants in the compensation system is led by the residential sector. Based on data from figure 12, this sector accounts for approximately 80% of the installations, followed by the commercial sector that holds a 15% share.

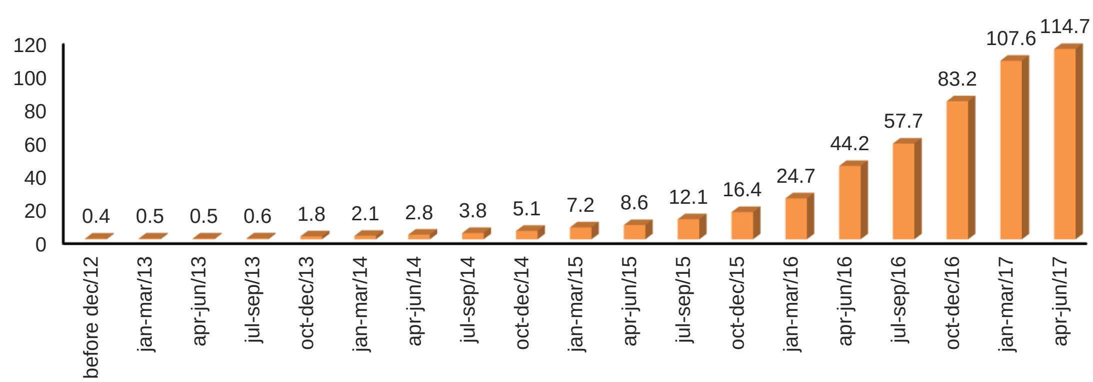
Figure 13
Division of DS Systems by Installed Capacity - 05/23/2017
(KW and percentage)



Source: ANEEL (2017).

Figure 13 shows deployment in terms of installed capacity, examining the distribution of these systems by variable. Given the predominance of the residential class, it is natural that small systems show more frequent rates of installed capacity. According to figure, approximately 70% of installed systems have power below 5 kW.

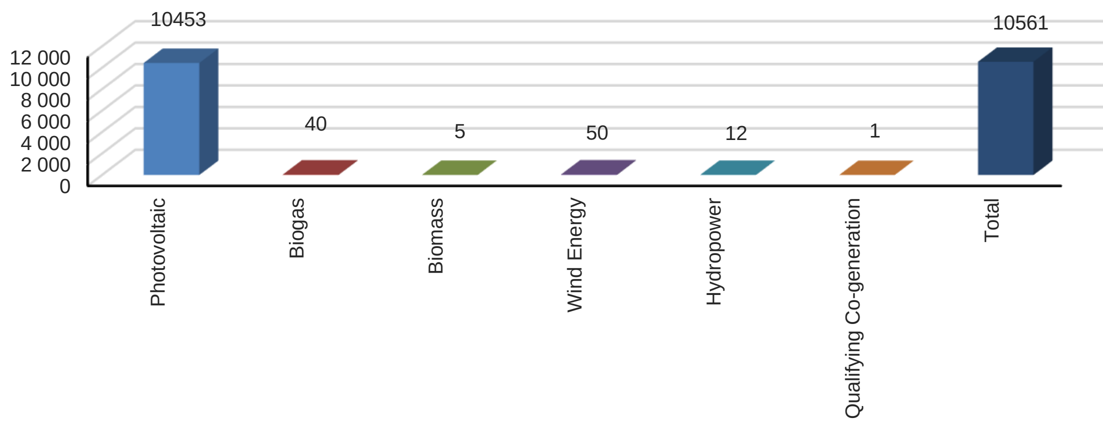
Figure 14
DG Installed Capacity from December 2012 to May 2017
(MW)



Source: ANEEL (2017).

Based on the power distribution of these systems, it is understandable that the total installed capacity is still low, totaling 114.7 MW in May 2017. Figure shows the evolution of installed generation capacity in the same period, corroborating the hypothesis that the expansion of the incentive policy through Resolution 687/2015 was key for more dynamic solar photovoltaic deployment.

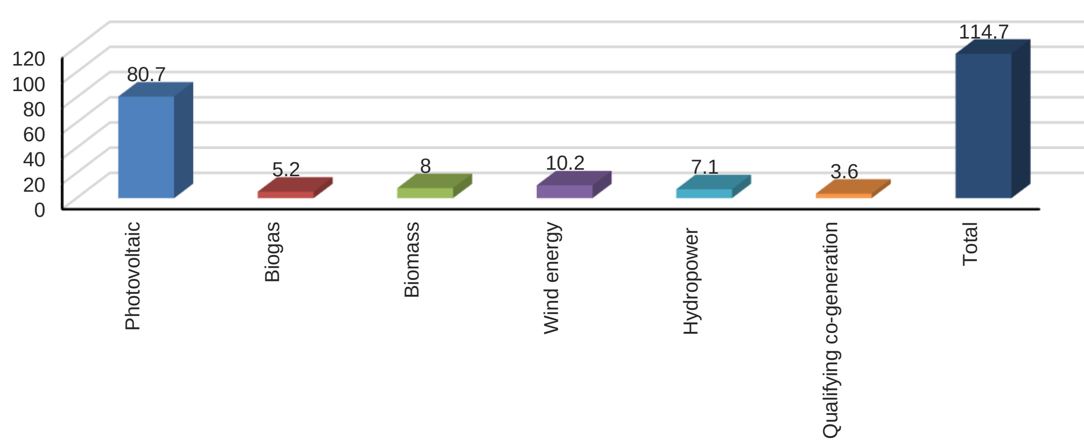
Figure 15
DG Connections by Energy Source - 05/23/2017
(MW)



Source: ANEEL (2017).

An analysis by type of source indicates an absolute predominance of photovoltaic solar projects. This result is directly related to the modularity of photovoltaic technology that make possible smaller scale designs. Based on data in Figure , photovoltaic systems account for 99% of DG connections.

Figure 16
Installed Capacity by Energy Source - 05/23/2017
(MW)



Source: ANEEL (2017).

In terms of installed capacity, photovoltaic systems account for 70% of the total centralized generation installed in the first half of 2017 according to data in Figure . The fact that the participation of the photovoltaic power source in terms of power is smaller than the participation in terms of numbers of systems comes from the smaller average size of the photovoltaic systems when compared to projects of the other sources

C. Economic impacts of distributed generation in the distribution sector

The Brazilian compensation system does not require a financial amount that directly covers for the micro and mini-generation incentive policy in Brazil.[40] This is because it does not involve payment for energy injected into the grid. However, this does not mean that there are no economic impacts on distributors and on the allocation of network costs among the different users of the system.

The possibility of surplus energy injected into the grid to generate credits that can be used over a 60-month horizon means that the grid can be used as a battery by the holder of a distributed generation system. Therefore, the reduction of the amount of power purchased from the grid by the consumers with a distributed generation system is not restricted to a situation where the amount of energy generated and consumed is coincidental.

Based on the scenarios presented in the "Impacts of Distributed Generation in Brazil" report, we estimate that all electricity distribution concessionaires may have a reduction of their retail market between 3% and 9% by 2030. Given that the variability of solar and of the value of the tariff rates make the attractiveness of the installation of photovoltaic systems varies according to the region of the country, it is notorious that this loss of market presents a very heterogeneous disposition between different distributors. Market losses tend to be limited to around 5% for distributors located in the state of São Paulo to the significant loss of 16% in the case of companies that operate in the states of Minas Gerais.

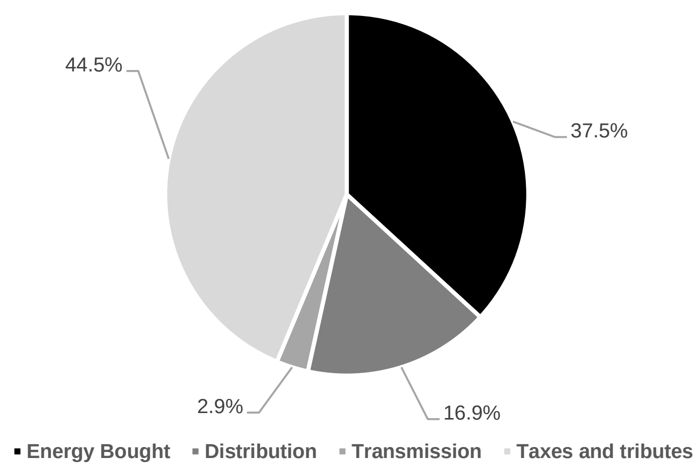
Considering that the turnover of consumers, especially those connected in the low voltage, is mainly volumetric, there are effects on the sales of the distributors of the reduction of their respective consumer markets. For access these impacts, 2016 can be taken as an example to estimate the reduction of billing that would exist if the prospected diffusion rates were verified in this year. From the average tariff rate of R$ 664,24 MWh practiced by the group of Brazilian distribution companies on commercial and residential[41] a captive market of 337,1 TWh and losses of 19,3%, it is estimated that the reduction of the sales of the distributors could reach up to R$ 12 billion in a higher diffusion scenario, and R$ 4.1 in a lower diffusion scenario.

This loss in the distributors' revenue is based on the final electricity tariff rate applied to the retail market, encompassing both TUSD and TE. Therefore, the estimated revenue loss involves a financial amount that covered manageable and non-manageable costs by the distribution concessionaire. Considering that the diffusion of the micro and the mini generation affects these cost elements in different ways, the examination of the effective economic and financial impact of this diffusion on the distributors requires prior knowledge of the relative participation of these items in the tariff rate composition.

40 These costs are present in electric systems that have opted for policies of incentives to the micro generation through feeds of type feed in. In these cases, the cost of the program goes through the collection of charges to the consumers or by contributions of the Treasury.

41 Not considering low income subsidies.

Figure 17
Division of the distributor's average costs between 2015 and 2016
(Percentage)



Source: ABRADEE (2016).

Figure shows the average cost structure of Brazilian distributors in the period 2015-2016. Costs strictly related to the exercise of electricity distribution activity accounted in this period for only 16.9% of the average distributor tariff applied to the captive market. Although this participation varies over time, Portion B represents a minor share of the average tariff rate incurring over the retail market.

Portion A represents the major share of the tariff rate. Although the costs of Portion A should charged to the consumers, the reduction of the market also has consequences on Portion A distributors. These impacts range from strictly financial effects without economic consequences for the distributor to the increase of the risk level of the business.

If taxes are levied on the electricity bill, there is no effect on the result of the distribution company because they are only collected to the extent that there is a billing. On the other hand, the need to collect the amount of charges previously defined causes the market reduction to reach the distribution concessionaires. However, these are impacts of an eminently financial nature since in the rate adjustment[42] financial compensation is made to reimburse the distributor for the difference between the charges paid and the charges collected.

The consequences of the deployment of the distributed generation on the expenditures with transmission must be analyzed according to the specificities of the load curve of each distributor. The reduction of the consumption of electric energy coming from the basic network can be seen as an indication for a smaller amount of financial expenditures related to the use of the transmission system. However, considering that the contracts for the use of the transmission grid are a function of the peak load, the reduction of the expenses with the use of the transmission grid requires a reduction of the peak load of the distributor. Such a decrease tends to occur only when the peak of the load curve coincides with the maximum photovoltaic generation.

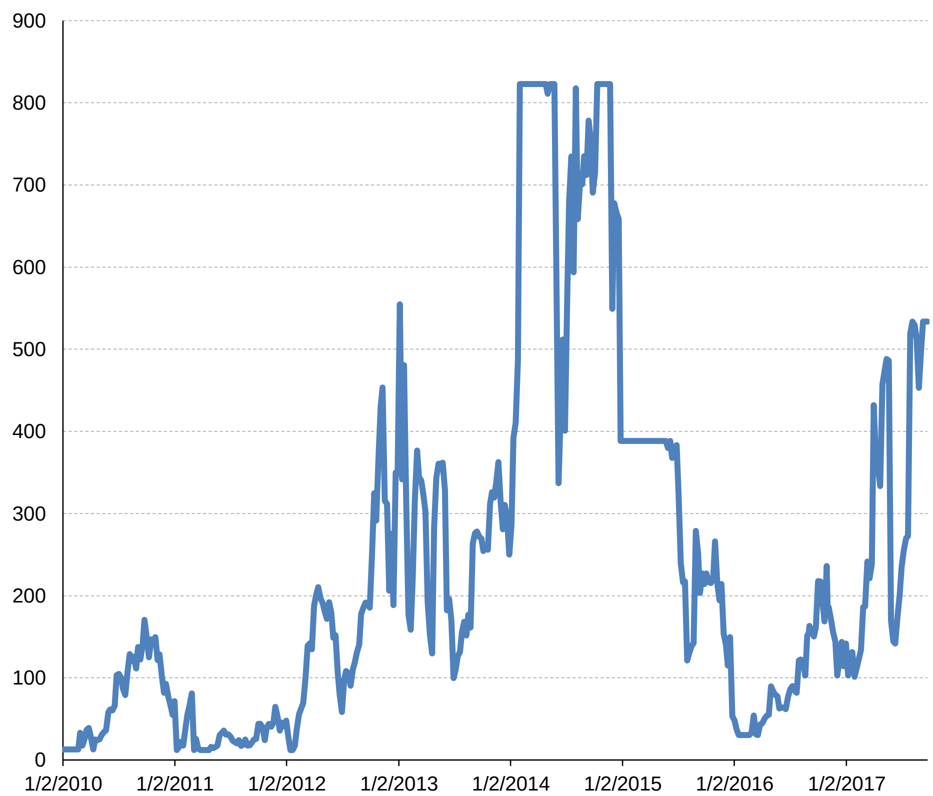
42 Last year's regulatory period used Rate Case.

Given that in most of the distribution concessionaires the isn't such coincidence, it is reasonable to conclude that there will be no major changes in the cost of using the transmission system. In this way, the distributor will have to bear the same level of expenses of TUST with a market smaller than the expected one. Therefore, as in the case of charges, there will be a need for financial compensation at the time of the Rate Adjustment in order to guarantee to the distributors the neutrality of the expenses with the use of the transmission grid.

Among the components of Portion A, the power purchase is an important component and needs to be examined in more detail is the purchase of energy. Such a need arises not only from its large share in the value of tariff rates, but also from the risk imposed on it by distributors in a context where the actual market falls short of the projections.

As mentioned in the first section of this report, Brazilian distributors acquire energy primarily through auctions in a regulated contracting environment. In these auctions, the distributors need to contract the amount of power necessary to meet their demand, and so long-term contracts are established. In a scenario where the diffusion of distributed generation results in the markets smaller than the reference markets for which the distributors bought energy. For that reason, distributors tend to be left with surplus in their energy portfolio.

Figure 18
Weekly PLD between January 2010, and September 2017
(Settlement price of differences)



Source: Adapted from CCEE (2017) data.

Within the Brazilian energy commercial framework, the differences between the quantity of energy contracted and actually consumed must be settled in the market of differences to the settlement price of the differences. However, the effective financial exposure to this market will also depend on the characteristics of the portfolio of contracts of each distributor[43] and the characteristics of the dispatch carried out, see that the type dispatch carried out (i.e., more hydro or more thermal) directly affects the request for settlement of the differences. 18 illustrates the volatility of the settlement price of differences for the period between January 2010 and September 2017.

This shows the presence of a high level of uncertainty in the revenue that the distributor will keep from the sale of its surplus energy in the difference market. As the distributor will continue with the obligation to honor the contract previously established, the net financial result will be the difference between the payment of the contract value and the income earned in the difference market.

According to current legislation, distributors can pass through tariff rates with a cost of energy equivalent to up to 105% of their market, with differences between the provision of energy expenditures in a given year and the amount actually billed to cover incurred in the subsequent Rate Adjustment. Thus, up to this limit of 105%, the risk of the reduction of the market derived from the diffusion of the distributed generation is of a financial nature. Even though the financial amounts involved may result in cash flow problems for the distributor, it is not possible to identify effectively economic impacts.

For higher differences, the cost must be entirely taken on by the distributor and, therefore, there will be risks to the distributor's economic result. Therefore, it is possible to claim that the impacts on distributors in terms of energy expenditure tend to be effectively relevant in cases of high diffusion of distributed generation.

However, considering that energy auctions are conducted periodically and there are adjustments auctions, it is reasonable to assume that distributors will be able to adjust their positions. Therefore, even if there are imbalances, they should not cause distributors to have an over-hiring of more than the limit of 105%.

It is within the scope of manageable costs on the part of the distributor where the most relevant impacts of the diffusion of the distributed generation in the economic-financial balance of the distributors are. Therefore, it is necessary to examine the dynamics between the market evolution carried out and the revenues verified by the distributors in order to understand the impact that the diffusion of the distributed generation may have.

The average value of a distributor's tariff rate is defined by the division between its Required Revenue and its reference market. Whereas the market is typically growing, the market realized is higher than the reference market. Therefore, the actual revenue turns out to be higher than the Required Revenue. Given that there is no prior recognition of an investment plan, this dynamic turns out to be essential for the capitalization of the distributors to make the necessary investments to strengthen and expand the distribution grid.

As far as the deployment of the distributed generation takes place, the distributor's realized market will be smaller, and in the limit, it will become inferior to the reference market. As the reference market is carried out annually, this effect is not cumulative. However, over the regulatory interval, the X Factor to be deducted from the inflation index to be applied for the correction of

43 Brazilian distributors have energy contracts for quantity and availability. In the availability mode, if the plant is dispatched, the difference between its power and physical guarantee (commercial covering able to be marketed) consists of energy credit in favor of the distributor to be settled in the settlement market of the differences.

portion B of the distributor in the Rate Adjustment is defined *ex-ante*. Thus, in a context of centralized generation diffusion, it will be underestimating the productivity gains derived from market growth. Consequently, the distributors will have a lower revenue to carry out their activities, and this revenue may even become lower than the Required Revenue. As the cost structure of a distributor is characterized by the strong presence of fixed costs, it is notorious that this reduction of revenues will have impacts on the financial and economic equilibrium of the distributors.

As an illustration of these impacts, it is worth presenting the study case of Light. According to Andrade (2016), Portion B represented only 13% of an invoice from Light at the end of 2015[44]. Even more relevant is the fact that regulatory EBTIDA had a mere 7.6% share of the average tariff rate applied to the retail consumer[45]. Thus, a reduction of 2.3% in Light's revenues[46] could result in up to 30% of the company's profitability.

In addition to the market reduction, it must be considered that the diffusion of distributed generation may entail costs resulting from the need to adapt the distribution grid. As can be seen in the "Impacts of Photovoltaic Distributed Generation in Brazil" report, the technical impacts of micro generation tend not to result in the need for adaptations. The investments required are essentially associated with the modifications required for the installation of mini-generation systems.

At the same time, there is a need to consider the impacts on the variation of technical losses, as this reduction is indicated as one of the main benefits of distributed generation. Based on the efficiency gains presented in the scenarios projected for distribution generation report, it is possible to claim that the reduction of technical losses occurs in a proportion higher than the reduction of the market. Thus, assuming a 0.5% reduction in efficiency gains, in the scenarios of reduction of the market of 3% and 8,6% it is possible to calculate that there will be reductions of losses in the network of the Brazilian distributors of, respectively, 27,306 GW med and 60,730 GW med in 2030.[47]

Considering the marginal cost of expansion of the Brazilian electric system of R$ 193 per MWh, it is possible to evaluate the cumulative reduction of these technical losses between R$ 5.3 billion and R $ 11.7 billion until 2030. It is a benefit of an eminently systemic nature. However, during the regulatory interval this reduction of losses tends to result in gains for distributors. [48] This is because at the time of the Rate Case, the level of losses and its trajectory to be recognized in the tariff rate are defined. Throughout the regulatory interval, losses at lower levels than those recognized in regulatory terms represent gains for distributors. It is observed that during the regulatory interval the reduction of losses results in a positive impact on the economic-financial balance of the distribution concessionaires. [49]

44 Due to the high frequency of dispatch of the thermoelectric power plant from the second half of 2013, there was a considerable increase in power purchase expenses. Therefore, Portion A significantly increased its participation in the cost structure of the distributors in detriment of the share of Portion B. In the case of Light, Portion B that had a 23% share in the company's cost structure in 2013, to have a 13% share by the end of 2015.

45 The regulatory EBTIDA is an indicator of great importance since it consists of the portion of the tariff rate that effectively remunerates the shareholder for the investments.

46 This projection is contained in the Technical Note of Public Hearing 026/2015 (ANEEL, 2015) promoted by ANEEL.

47 It should be noted that the distributor's losses involve the total market of its concession area, that is, they contemplate the wholesale market. In addition, the simplified assumption is adopted that the percentage of technical losses will not change in the analysis horizon.

48 The financial compensation made annually during the regulatory period only takes into account the deviations of the billed market from the reference market. Therefore, the result of the difference between the verified losses and the defined regulatory losses belongs to the distributor. In this way, there is an incentive for the distributor to reduce its losses at a rate higher than that established by the regulator.

49 This gain of the distributor is limited to the regulatory interval, see that in the subsequent Rate Case the regulator calculates new targets for the distributor's trajectory of losses.

According to results of the study "Impacts of Distributed Energy Resources on the Distribution Sector" – Portuguese: Impactos dos Recursos Energéticos Distribuídos sobre o Setor de Distribuição[50], considering the reduction of the market with the need for investments and variation of technical losses, the impact on the profitability[51] of the distributors is perceptible. The decrease in the rate return of the business can reach more than 3% in some years of the scenario of greater diffusion, being common reductions of the order between 1% and 1,5% in intermediate scenarios.

However, the impacts on the distributor tend to be mitigated at periods of Rate Cases and Rate Adjustments as the distributors' reference market is updated. In the case of Rate Cases, in addition to the adjustment of the reference market, there is the recognition of investments made in the previous period.

The recovery of the profitability of the distributors occurs through the increase of the tariff rates. This is a rather obvious result in that the Required Revenue by the distributor to carry out its activities does not change drastically due to the presence of the distributed generation.

The project "Impacts of Energy Resources Distributed in the Distribution Sector" estimates that the distribution of energy resources distributed will result in increases between 1.5% and 3% in the average tariff rates of retail consumers in intermediate diffusion scenarios and of 7.1% in the highest diffusion scenario.

Therefore, considering the current regulatory guidelines, the distributor's profitability suffers throughout the rate cycle with the advance of the distributed generation, mainly due to the reduction of the billed market and, to a lesser extent, to support the growth of distributed solar generation, which are only remunerated through tariffs in the subsequent Rate Case. However, this is a temporary decrease in profitability. On the other hand, the increase in the average consumer tariff rate is a permanent effect that occurs as increases in average costs are incorporated into tariffs.

1. Measures to mitigate the impacts of distributed generation in the distribution sector

In Section 2 we presented that the impacts of diffusion of distributed generation in the distribution sector cannot be neglected. The examination of the distributed generation deployment at worldwide shows that, in regions where this process is in more advanced stages, these impacts are already perceptible. Therefore, changes in regulatory guidelines are already being adopted.

More than impacts on the profitability of distribution companies there are also impacts on the level of tariffs. As only part of the consumer units adopts micro and mini-generation systems, the increase in tariffs affects consumers classes differently. Therefore, this increase results in distortions in the allocation of distributors' costs among different consumers. As consumers with lower levels of income are precisely those who tend not to be able to install systems of distributed generation, it is possible to claim the existence of a socially adverse cross subsidy, where lower income classes start to have greater expenditures with the energy consumption power.

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50 In this study project, it was also developed a financial simulator capable of calculating data on the financial profitability of distributors, tariffs, tax collection, etc. For this, in addition to the usual market and economic variables used for the analysis of a distributor, the model also includes data input from the diffusion scenario and regulatory guidelines, see also being developed to test the impact of adopting alternative regulatory guidelines.

51 Profitability is measured by the EBIT / BRL indicator. This is a measure of return on invested capital comparable to pre-tax WACC. Since all the components of Portion B, except for capital remuneration, had a counterpart in some deduction prior to EBIT, including CAIMI.

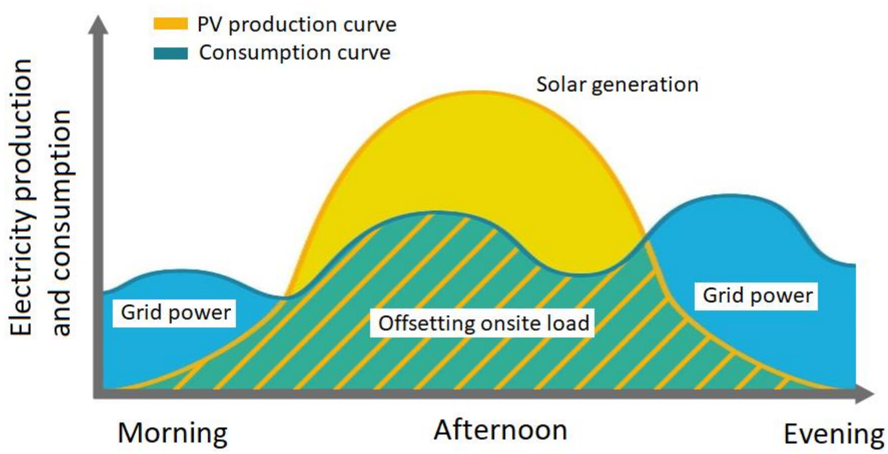
This can be already seen internationally. A report from NREL (2016) shows that residential consumers of distributed generation systems in the state of Louisiana are paying on average only 70% of the costs they impose on the network while non-adopters are paying on average 158% of these costs. The same study points that, in the state of California, residential PV adopters are paying between 54% and 84% of the costs they impose on the network.

In the Brazilian case, although the market variation results in a reduction in the financial profitability of the distributors, it can be stated that the greatest problem is also the impacts on the level of the tariffs. This is a definitive impact, while the financial impacts on the distributors are mitigated at the time of the Rate Case.

Regulatory adjustments require policy makers to consider the specificities of each incentive programs for distributed generation. In particular, it should be emphasized that the type of compensation system used helps to determinate the characteristics of the problem.

In "Feed in Tariff (FiT) schemes, the loss of the market occurs only when the photovoltaic generation coincides with the consumption. Therefore, the impacts of FiT programs on the distribution sector are limited[52] and historically the discussion of these programs is much more associated to how much they cost, and if they are within budget.

Image 1
Net Metering Dynamics
(kWh)



Source: PG&E (2016).

On the other hand, the possibility of using generated energy credits at times when there is no energy generation makes this issue more complex under a net energy metering framework. In this case, all the locally generated energy represents a loss of market for the distribution company and there is no associated payment for using the network as a "virtual battery" by the prosumer. This problem has already been seen in many US states. Image 1 illustrates the compensation logic of the net metering system.

52 With the decreasing trend of the last years regarding the payment for the energy injected into the grid, consumers with photovoltaic systems started to seek a greater coincidence between their consumption and their generation systems. This increase in self-consumption causes the impacts on the distribution sector to increase. The typical case is that of Germany where tariffs paid for energy injected into the grid were considerably higher than the value of the supply tariff. As FiT is currently worth a third of the value of the energy acquisition tariff from the grid network, consumers are encouraged to a higher level of self-consumption and, as a consequence, the problems of the distribution sector.

As the Brazilian energy compensation scheme is the net metering, the formulation of proposals to deal with the impacts of micro and distributed mini-generation should also consider the consequences of using the grid as a "battery". Following this section, we will present measures to mitigate the effects of distributed generation in the Brazilian distribution sector. [53] In addition to the description of these measures, a critical analysis will be made of each of them to examine the benefits, difficulties and challenges of implementing each one.

2. Collection of tarifa fio

By assigning a credit to locally generated and non-consumed energy capable of offsetting the same amount of energy from the grid at another time period, the current compensating system is implicitly valuing the energy generated in a distributed form at the price of the final energy supply tariff from the grid. However, this tariff includes items such as costs with the use of the transmission and distribution grids, taxes and other charges.

The option of equating locally generated energy with a tariff that is not restricted to the cost of energy aims to attract investments in distributed generation. However, it is necessary to recognize the existing subsidy as far as the *Tarifa Fio* of the energy acquired from the grid is not charged.

In this way, it is important to examine how *Tarifa Fio* is charged, since the cost largely depends on the amount of energy consumed by the grid, that is, to restrict the energy compensation system. An argument that gives a strong foundation to this alternative is that the traditional self-producer pays for the use of the network. Considering that the holder of a micro-generation system or the participant of a mini-generation system can be regarded as a small-scale self-producer, it is reasonable to equate with the treatment given to the traditional self-producer.

Looking at how the Tarifa Fio is charged depending on the amount of energy consumed by the grid and analysis the energy compensation system is important. An argument that gives a strong foundation to this alternative is that the traditional self-producer pays for the use of the grid. Considering that the owner of a micro-generation system or the participant of a mini-generation system can be regarded as a small-scale self-producer, it is reasonable to equate with the treatment given to the traditional self-producer.

The most reasonable alternative to neutralize the impact of distributed generation on the distribution sector would be the collection of TUSD. However, since traditional self-producers are exempt from payment of charges, it does not seem reasonable for consumers in the form of micro or mini-generators to pay energy costs. It turns out that collecting a payment discounted of charges as a more consistent alternative and with fewer implementation hurdles.

The charge for the use of the grid solves the problem of using the grid as "battery". However, it does not mitigate the impacts derived from self-consumption. In this way, the amount of energy consumed by the prosumer becomes a central variable in the examination of the effectiveness of this alternative. For this, it is necessary to know the load curve of the consumers for the analysis of the coincidence between generation and consumption. The lower the percentage of self-consumed energy, the greater the effectiveness of this measure. On the other hand, in the case of remote mini generation systems, the charging of the Tarifa Fio tends to be a very effective solution because all

53 In all proposed measures, a basic assumption is that the amount of energy consumed that exceeds the local generation continues to be billed normally. Given that the legislation establishes the minimum energy consumption to be paid, in the case of a three-phase consumer with a monthly franchise of 100 kWh, this means that at least 100 kWh will be billed based on the final energy tariff (TE + TUSD).

energy produced locally effectively needs to use the grid until the consumer units participating in the mini generation power station arrive.

So far, the discussion about the charging of the Tarifa Fio is restricted to the power purchase from the grid, but it is possible that this charge is extensive to the energy injected into the grid. Although they are not effectively adopted, it should be pointed out that the current legislation already uses the calculation methodology for TUSD applied to generation projects connected to low and medium voltage distributors. Considering the contribution of the distributed generation to reduce the technical losses, it is reasonable to suppose that the TUSD to be charged for the energy injection into the grid should not include the losses component.

This charging of the Tarifa Fio over the energy injected into the grid is based on the principle of causality of allocation of energy transportation costs. To be applied consistently, it requires detailed analysis of the tariff structure and cost allocation among the different consumers in a context of distributed generation diffusion. Consumers with photovoltaic systems tend to reduce the costs they impose on the grid. However, the use of the grid for energy injection also needs to be considered. Therefore, any further discussion about redefining tariff structure should also consider cost allocation for agents that are injecting energy into the grid.

3. Fixed tariff (tarifa fio)

The impacts on the distributor's profitability and on the tariff level of the distributed generation deployment[54] is directly related to the fact that the distribution tariffs are mainly volumetric, and the distributors' cost structure is predominantly fixed. Even where there are binomial tariffs, the volumetric component of the tariff tends to be predominant, especially in the low voltage segment where residential consumer units are connected.

In recent years, there has been a worldwide trend to implement binomial tariff rates and fixed cost charges in the tariff composition, which was previously based only on energy consumed. At the same time, the non-volumetric components of the tariffs are gaining greater participation even where the tariff structure already contemplated them.

Although the inclusion or increase of fixed tariff rate components attenuate the impacts of distributed generation in the distribution sector, it is not reasonable to assume that changes in the tariff structure affecting all consumers are motivated exclusively by distributed generation and its potential impacts. However, there is no impediment to applications of the same type unique to consumers holding distributed generation facilities. In this context, the cases of Flanders in Belgium and Nevada in the USA are quite illustrative.

In the case of Belgium, a flat rate for consumers with micro-generation facilities up to 10 kW[55] was established in Flanders. Given that in Flanders the energy injected into the grid is cut off from gross consumption, the objective of creating this rate is precisely to make these consumers pay for their actual use of the grid. Therefore, the consumer is granted the right to be exempt from payment of this flat rate. To do this, the consumer must give up the right to participate in the energy compensation program, with the energy injected into the grid being accounted for independently of the energy consumed.

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54 This is the same issue that emerges in a scenario of energy efficiency measures incentivizing. In fact, because it is in a more advanced stage, the impacts of measures to promote energy efficiency are even more significant historically.

55 The value of this tariff is a function of the capacity of the inverter because it is considered as the best metric of the sizing of the amount of energy to be compensated, as commonly the capacity of the inverters is lower than the peak of the installed system.

4. Two-way rates

Although measures 3.1 and 3.2 can have a great contribution in mitigating the impacts of distributed generation on the distribution sector, these do not represent structural changes in the operating logic of the net metering system. In general, there is still the possibility of compensating for the energy generated and not consumed at other times.

However, it is necessary to consider the hypothesis that the value of the energy injected into the network occurs independently of the energy consumed. As long as all the energy acquired from the grid is billed based on the final tariff (TUSD + TE), the use of the grid as a "battery" ceases to exist. In short, it is in a situation similar to that verified in FiT systems where the loss of revenue of the distributors is restricted to self-consumption.

A central issue in the implementation of the two-way rates model is the valuation of the energy injected into the grid. Ideally, this assessment should be based on the net benefits of distributed generation to the system. However, it is recognized that it is difficult to accurately measure all the systemic costs and benefits related to distributed generation. In some regions, the option has been to value this energy by the avoided generation cost. This option is very pertinent for systems where electricity generation is predominantly fossil, as is the case in Hawaii.

In the Brazilian case, given the predominance of hydro generation, we may be able to avoid generation costs since they will often be at low levels. Thus, the valuation based on the marginal cost of expansion of the Brazilian electricity system is a more adequate choice. Alternatively, this option may be made for the valuation with the average purchase price of energy by the electricity distribution concessionaires.

5. Rates that change with time

To provide consumers with more efficient price signals, the establishment of time varying use rates is a very important instrument (SCHWEPPE et al., 1987). This type of tariff can contribute to a more efficient use of the electrical system infrastructure and a more adequate allocation of costs.

However, the effective application of tariffs with time signals is still applied in a restricted way around the world, especially when it comes to the residential segment. In general terms, when the traditional flat rate does not apply, the most common option is time of use tariffs in which tariff values are previously defined. Thus, it is observed that effectively dynamic tariffs that reflect real-time conditions of the electric system are not yet used.

Adopting these “time varying use rates” is seen as a possible mechanism to mitigate the impacts of distributed generation. For example, California has mandated time of use tariffs for consumers with micro-generation facilities. However, it is a complex and dependent relationship, not only the methodology for the formation of these tariffs, but also the load profile of the concession area.

Methodologically, a central question is the scope of the temporal signaling, that is, it refers to the Tarifa Fio, the price of energy or both. Concurrently, the load profile directly influences the behavior of consumers and the impacts of distributed generation on the distribution sector.

In electrical systems where the load peak coincides with photovoltaic generation, higher prices at this time of day would lead consumers to inject as much energy as possible into the grid and shift their consumption out of peak hours. Therefore, assuming the existence of a net metering compensation system, the presence of time varying use rates tends to accelerate the diffusion process of distributed generation as it makes it more attractive. Therefore, by itself, it is not only able to mitigate the impacts of distributed generation in the distribution sector but can also increase[56] them.

Therefore, by itself, it is not able to mitigate the impacts of distributed generation in the distribution sector and could increase them.

In contrast, if the load peak of the system occurs in a period when there is no photovoltaic generation, consumers will seek to maximize their own consumption because the terms of compensation will be deteriorated.[57] This smoothing of the load curve has notably beneficial effects on the system.[58] However, from the distributor's perspective, this change in behavior would not result in a reduction in revenue losses.[59] The effect on the distribution sector tends to occur indirectly due to the reduction of the diffusion rate of distributed generation.

The analysis of the two previous paragraphs has an eminently static character. However, we must consider that this is a dynamic problem where the behavior of consumers with distributed generation systems interferes with the system load curve and energy prices. Thus, assuming a coincidence between photovoltaic generation and the end of the load, the incentive to reduce consumption and network injection in the photovoltaic generation period causes a reduction in energy prices. On the other hand, in the hypothesis that the tip of the system occurs in the period when there is no photovoltaic generation, the incentive to self-consumption causes the price of energy to rise.

Therefore, the complexity of the problems and the uncertainties involved in the dynamics between time varying rates and the impacts of distributed generation in the distribution sector are perceptible. Although its adoption in isolation should not equate such impacts, the adoption of tariffs with time signals may possibly be present in the set of measures to be adopted. It is an initiative that transcends the specific discussion of distributed generation, since it is related to the need to give more efficient price signals to consumers in a context of increasing their participation.

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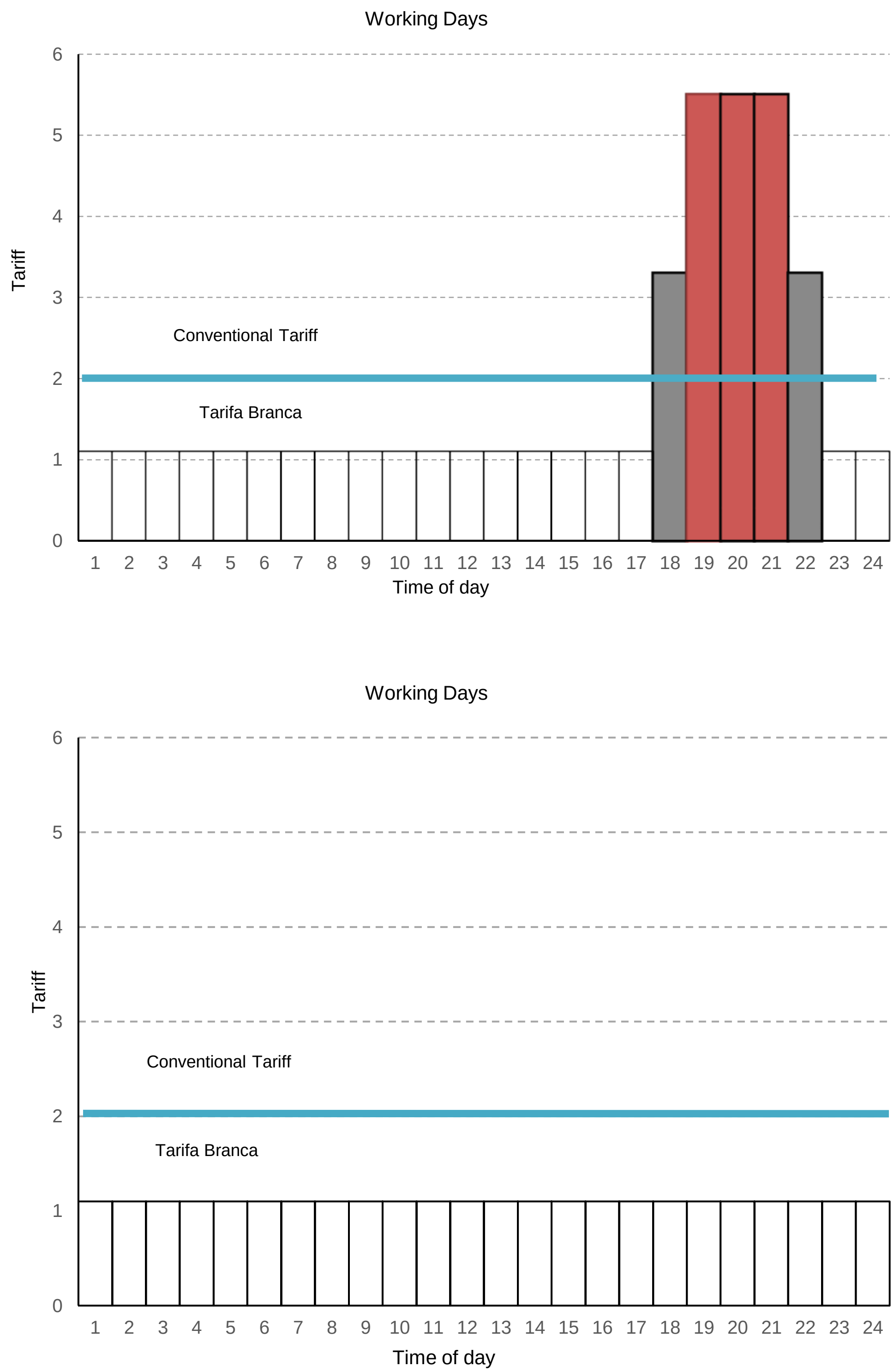
56 In this scenario, the terms of trade would become more favorable to the consumer holding a distributed generation system because the energy injected into the grid would have a value greater than the energy consumed outside the peak hours. It is noticeable that there would be a trend towards greater use of the grid as a "virtual battery" of distributed generation. Finally, it should be emphasized that this reasoning assumes that the tariff for the use of the network is being charged only on the energy consumed. If there is a charge for the use of the network in relation to the energy injected into the network, this attractiveness would be reduced. In situations where the time signal is mostly associated with the tariff for the use of the grid, the relationship could be reversed, and the incentive could increase self-consumption.

57 As photovoltaic generation occurs at times where energy has a lower value, the amount of credits associated with this generation is lower. Therefore, self-consumption becomes more attractive because this generation is equivalent to a smaller amount of consumption during peak hours.

58 For example, smoothing the load curve decreases the need to dispatch high-cost, variable-charge, high-pollutant plants. From the point of view of the grid, the smoothing of the load curve can represent the postponement and / or reduction of the investment need. The financial consequences for the distributors depend on the way in which the investment is treated, and it is possible to have positive impacts in the short term. However, in the long run this means a smaller asset base for distributors. Given that in the current regulations the remuneration of distributors is based on assets, it is possible to affirm that this reduction of the necessary amounts to be invested tends to be a problem.

59 The shift of consumption towards the moment of photovoltaic generation reduces the use of the grid as a "virtual battery". However, considering that this occurs at the expense of increasing self-consumption, the impact on distributors' revenues remains unchanged.

Figure 19
Tarifa Branca Dynamics



Source: Adapted from Brancher (2014).

In Brazil, there are Critical Peak Pricing (CPP) tariff rates for large consumers. In general terms, the adopted CPP has a time signal that aims to distinguish peak time from other times, with a significantly higher price. [60] In the context of low voltage consumers, it is planned to make available, on an optional basis, tariffs of the type of time of use from 2018. The *Tarifa Branca* ("white tariff" in Portuguese – Figure 19 seeks to distinguish the price of energy in hourly terms. The time signal is much more related to the wire component than to the energy portion of the tariff. [61] In short, peak hours were set between 6 pm and 9 pm on weekdays; an intermediate time composed of the hours immediately before and after the business day's business day; outside the tip including the other schedules.[62]. Figure 19 shows the operating logic of white rates.

6. Distributed generation incentive policy for low income consumers

It was highlighted that the increase in tariffs derived from the diffusion of distributed generation especially impacts the consumers with lower level of income since they are those with less capacity to make investments in micro generation systems. Therefore, the presence of a socially perverse cross subsidy.

At the same time, as part of policies to encourage renewable sources and distributed generation, it is highly questionable whether a portion of low-income consumers is a constraint on these policies. This situation is especially problematic in a country such as Brazil where a large part of the population has low levels of income.

In this context, we note the pertinence of the adoption of incentive policies focused on the diffusion of distributed generation in low-income segments. Strategies of this type help mitigate the impacts of tariff increases on low-income consumers while minimizing the restriction on the diffusion of renewable sources imposed by the low level of income of the population.

A central issue for implementing such policies is the costing of the program. In this sense, it is emphasized that in many localities there are social tariffs for the low-income segment. Therefore, the relevant analysis is whether investments in micro-generation systems can reduce the expenses related to the costing of the discounts in these tariffs. From the point of view of distribution concessionaires, the results will depend on how the costs of this incentive policy will be allocated to distributed generation in low-income sectors, as well as the methodology for costing social tariffs.

In the Brazilian case, an alternative to implementing a specific program for consumers in the low-income category on which social tariffs are applied could be plausible. In order to minimize the cost of the program, one supposes is that the option would be for installing mini-generation plants instead of micro-generation systems due to the lower unit cost of larger systems investment. Considering that the social tariffs discounts are borne by the Energy Development Account (CDE), the impacts on the revenues of the distributors are similar to those observed when there is diffusion of distributed generation in high income consumers. It is explained: the reduction of the market of

60 Studies indicate that industrial consumers effectively respond to this tariff signaling.

61 The Normative Resolution n. 733 of September 06, 2016, introduces the conditions for the use of Tarifa Branca tariff modality (ANEEL, 2016). There are 3 different times of a day that are set by ANEEL in the Rate Cases.

62 The effectiveness of the Tarifa Branca requires the use of smart meters, and the vast majority of consumers continue to have their energy consumption measured through electromechanical meters. According to Normative Resolution 502/2012 of ANEEL, distributors should provide smart meters to consumers who opt to adhere to this rate modality. The cost of the measure must be borne by the distribution concessionaire, with the consumer only having the difference between the conventional meter and the meter with additional features, if the consumer chooses the latter.

low-income consumers will be accompanied by a proportional reduction in the amount of CDE resources received by the distributor to cover social tariffs. It is thus observed that the effect is similar to diffusion in other classes of consumers.

7. Mitigation and its impacts on distributed generation

Regulatory alternatives presented in this study need to consider their impacts over the diffusion of the distributed generation. The central issue is to reconcile the adoption of these measures with the energy policy guidelines to encourage renewable sources and distributed generation.

To the extent that it ends up using the network as a free virtual battery, charging for grid usage is an effective mechanism to minimize the impacts of distributed generation on the distribution sector. However, this is at the expense of a reduction in the financial attractiveness of investing in micro-generation systems by consumers. Therefore, there is a reduction in the diffusion rate of distributed generation. In the case where a fixed tariff is adopted, the dynamics are similar. In contrast, the adoption of two-way rates methodologies reduces the attractiveness of the investment but does not necessarily mitigate the impacts on the distribution sector.

By reducing the attractiveness of investment, these measures negatively impact the rate of diffusion of distributed generation. This also indirectly reduces the impacts in the distribution sector because it reduces the magnitude of the problem. For this reason, such measures tend to be conflicting with the objective of diffusing distributed generation from renewable sources.

In turn, the other two measures have potential systemic and social benefits, but their effects on minimizing impacts on the distribution sector are uncertain or limited. As discussed, the implementation of time varying use rates results in benefits to the system due to the smoothing of the load curve, but the impacts on the distribution sector are controversial. As it was previously explained, policies focused on the installation of photovoltaic systems in low income consumers tend to be very effective in mitigating the existing social subsidy due to the increase in tariffs derived from the diffusion of distributed generation. However, they are typically neutral in terms of revenue impacts of distribution concessionaires.

Thus, it is difficult to implement strategies that minimize the impacts on the economic and financial balance of the distributors and increase the electricity rates without reducing in the rate of diffusion of distributed generation. This problem stems from the inadequacy of the regulatory models traditionally in force in the distribution sector to a paradigm characterized by the presence of distributed generation. Given that the transformation prospected for electrical systems is not restricted to distributed generation systems, a broader discussion of the regulatory norms affecting the distribution sector is needed to deal with the trend toward decentralization of the electrical systems.

II. Rethinking the regulation of the distribution sector

As a network industry with characteristics typical of natural monopolies and the presence of unrecoverable costs, the distribution of electricity consists of an economic activity subject to strict regulation. The regulation is necessary to guarantee the economic and financial balance of the concessionaires and to prevent the practice of abusive prices. Historically, regulators have used regulatory models of the cost of service type, and more recently, profit-sharing (revenue cap and price cap) models.

The cost of service models uses the guaranteed compensation of the asset base to set the electricity rate. They are models that mitigate the risk associated with investments, but usually fail to provide incentives for efficiency gains. On the other hand, profit-sharing models establish caps on revenues or prices and allow distributors to benefit from cost reductions within the regulatory range, which are gradually shared with consumers. That is, it is clearly a regulatory model focused on encouraging distributors to pursue efficiency gains, where there are metrics related to quality standards of service provided.

In fact, the electricity regulation usually relies on hybrid models in which there is guaranteed remuneration based on assets and incentive mechanisms are adopted for efficiency gains, especially in operating costs. Despite the difficulties and challenges inherent to the exercise of regulatory activity, especially those related to the presence of asymmetric information and uncertainties of the cost path, these models fit to the conventional logic of the distribution sector.

Although several countries have implemented liberalizing reforms in their electric sectors over the past 30 years, these reforms have focused on the unbundling of the industry. That is, reforms focused on the use of competitive energy markets with the network (transmission and distribution) segments remaining regulated. However, this process was essentially restricted to the organization and economic guidelines of the electricity sector.

In the scope of physical operation of the system, there were no significant changes. In general, the paradigm remains centralized generation with the electric energy following a unidirectional flow of energy through transmission lines and the distribution network until reaching the final consumers, i.e. the principle is "generation follows the charge". It is thus observed that the electrical systems continue mostly based on unidirectional flows of energy. In this way, the electricity distribution activity consists in planning the expansion of the network compatible with the load forecast, making investments, performing grid maintenance procedures, and the operation of the grid is performed passively, that is, not there exists the function of network operator as it occurs in the scope of the transmission. It is the paradigm known as fit-and-forget.

However, there are evidence that the electric sector may be about to undergo a process of technological paradigm rupture. This process is associated to a trend of decentralization of the electric systems, with the accelerated diffusion of micro and mini solar photovoltaic systems already verified in some regions the most noticeable face of this transformation. In parallel, that demand response measures are becoming more relevant to make the demand for electricity more flexible. In addition, energy storage systems may become economically feasible soon. In the field of electric vehicles, more than the increase in demand for electric power that can cause, the relevant is the possibility of using the batteries of vehicles for energy storage and subsequent injection into the grid (vehicle to grid systems).

In a system where consumers will have more active behavior, demand will be flexible and multidirectional power flows and for that it is imperative to use communication and information technologies that enable the establishment of smart grids. In short, such networks are characterized by the high level of automation and the presence of smart metering systems that allow the monitoring of all energy flows in real time. The Distributed Energy Resources paradigm also includes smart grids.

This dynamic of transformation of the electric sector is complex and not only technological. It must be emphasized that these innovations tend not to occur endogenously to the dynamics of the sector as the opportunities to obtain extraordinary profits from innovations are limited.[63] Therefore, it is necessary to examine, from the relations of the electric sector with the socio-economic regime in which it is inserted to its relations with related industries to its economic dynamics and its regulatory directives.

It is noteworthy that the matter of sustainability is a central point in the contemporary world political agenda, especially considering the need to mitigate climate change. In addition, there is a growing trend in consumer demand for quality of goods and services. At the same time, the technological advance in other industries contributes to the creation of an environment conducive to the transformation of the electric sector. In this way, it can be verified that the environment in which the electric sector is inserted and with which it establishes social, economic, and technological relations is an element that induces transformations.

The change in consumer behavior gains relevance, particularly, because a large part of the expected changes is associated with a more active and participatory behavior by the consumers. Therefore, as these new technologies and behavioral measures allow for reductions in energy expenditures and an increase in quality that compensates for investments, the interest of consumers increases. In addition, in many cases there is an implicit desire of the consumer to be self-sufficient

63 The motivation of the economic agent to innovate is the expectation of making profits above the normal profit rate of the economy (extraordinary profits) through the insertion of a differentiated product in the market or the adoption of a technology that reduces the cost of production. Considering that the electric sector is a regulating network industry with essentially homogeneous product and little elastic demand, the opportunities to obtain extraordinary profits are limited.

minimizing in its supply by electric energy and to position itself in the society as an individual adhering to sustainable practices.

However, since these new technologies present higher costs than the conventional ones, the implementation of public policies is important to support the transformation of the electricity sector. Within this dynamic, the importance of R&D expenditures is apparent, enabling the identification of technical challenges, increasing efficiency, and reducing the costs of new technologies. In fact, there are investments in research and development projects of distributed energy resources and smart grids in Brazil in lines with the world trend, including the implementation of pilot projects that seek to validate the contribution of the developed technology.

Subsequently, the commercial insertion of these new technologies requires the creation of favorable conditions. While the granting of tax incentives and tax relief consist of a strategy typically used to provide the new technologies for competitiveness, in many cases it is necessary to create specific niche markets. For example, in the promotion of renewable sources and alternative electric power generation, the adoption of feed-in tariffs and specific auctions for these sources were vital instruments to boost the expansion of these sources in recent years.

However, considering the incompatibility of the regulatory directives in force in the electric sector and the emerging technological paradigm, the mere implementation of public incentive policies tends to be insufficient. It is observed that the current regulatory framework commonly encourages companies to make investments in conventional technology due to the compatibility between the cost structure of these technologies and traditional regulatory models. That is because the investments recognized in the remuneration base of a distributor are those considered prudent, there is a natural tendency of the concessionaire to invest in conventional technologies and in this way to minimize the risk of not having their investment recognized by the regulator. At the same time, the discussion of which assets should be recognized on the asset base of the distributor's and how the remuneration should be made are topics to be discussed further on. This is an important matter because many of the new technologies have a smaller participation of CAPEX in their structures of costs.

It should be noted that the concept of the asset base itself as a central element of regulatory models may be questionable as far as emerging technologies are characterized by less intensive capital structures. In other words, it is not enough to recognize investments in more efficient technologies and, possibly, the guarantee of rates of return that contemplate a risk premium in the case of projects with a higher level of risk. Perhaps one of the major challenges to the regulatory agenda in the next few years is the need to examine regulatory models that are compatible with these new technologies, but that keep incentives to search for efficiency.

In this new context, it is important to highlight the growing importance of remuneration methodologies that do not distinguish between CAPEX and OPEX. By equalizing the incentives given to fixed capital and operating expenses, such methodologies allow companies to choose more efficient technologies without cost structure being a criterion of choice as far as they no longer influence the profitability of the distributor. As an illustration, we mention the recently implemented RIIO model in the United Kingdom that works with the TOTEX concept rather than the classic approach to covering operational costs and applying a rate of return on the asset base of the distribution company.[64]

64 RIIO (Revenue = Incentives + Innovation + Outputs) has been implemented by the UK regulator (OFGEM) with a view to spurring innovations in the UK power sector. In general terms, it is a reformulation of the price cap model through the insertion of elements that induce innovations. Among the measures implemented, we highlight the introduction of the TOTEX concept (Crispim et al., 2014).

In addition, the issue of information asymmetry tends to be accentuated by the uncertainties inherent in the trajectory of new technologies, changes in grid usage patterns, and new cost drivers. Therefore, the methodologies normally used to define the Required Revenue by the distribution companies become more fragile amid the increased uncertainties. Changing the paradigm of the distribution sector results in additional difficulties in the elaboration of benchmarking that serve as a basis for the definition of the trajectory of efficient costs.

Thus, it is well known that the prospective changes make it imperative to discuss the formatting of a regulatory framework compatible with this new technological paradigm. On the one hand, distributors need to be encouraged to adopt new and more efficient technologies. Concomitantly, there is a need for the expected transformation in the distribution activity not to compromise the economic-financial equilibrium of the concessionaires, given that the distributors have no control over the speed and intensity of many of the possible transformations expected.

The impact of increased uncertainties on regulatory activity can be mitigated through measures that make regulation stricter. In this direction, a possible measure could be the reduction of the regulatory interval. However, in addition to the regulatory cost of this type of strategy, it reduces distributors' incentive to adopt more efficient technologies as it reduces the opportunities for gains.

It appears that there is still a need for incentives for distribution companies to seek efficiency gains, but they must be shared with consumers later. Thus, considering the uncertainties derived from the diffusion of new technologies, it is imperative that the regulatory framework moves towards greater cooperation between the regulator and companies.

The logic behind this increased cooperation between regulator and companies is to mitigate the distributor's intrinsic interest in capturing the regulator. The operationalization of this cooperation can occur, for example, with firms actively participating in the process of defining incentive vectors. The relevant fact is the existence of guidelines that place the concessionaire in a situation where the best expected results occur when the costs revealed are true to their real expectations.

More broadly, the reasonableness of adopting regulatory models of the output-based model over traditional input-based models should be examined. It is explained that from the assumption that distribution concessionaires are the entities with the greatest capacity to stipulate investment needs and to identify the best technologies to be adopted, it would be plausible to allow companies the freedom to decide which investments should be made. The regulator would have the function of defining the standards of reliability and quality to be met, as well as penalties for non-compliance and, if applicable, awards for results that are higher than goals. However, for distribution utilities to be able to choose the most efficient technologies effectively, it is necessary to eliminate the existing bias towards more capital-intensive technologies.

Therefore, the presence of a set of new technologies capable of causing a rupture of the technological paradigm of the electric sector is evident. However, the effective verification of this transformation passes, not only by public policies, but also by the evolution of regulatory guidelines. It is not just the need to establish guidelines that encourage companies to invest in new technologies. It is necessary to establish a regulatory framework that makes these technologies feasible to the extent that their systemic benefits justify them, and the allocation of costs meets basic efficiency criteria. Finally, it is noteworthy that it is extremely natural for regulation to evolve to adapt to technological changes. This evolution can take place actively to anticipate technological changes and at the same time to try to direct them. However, this process may have a reactive character with the modifications adopted aiming mainly to correct distortions and difficulties resulting from the new technologies.

Besides the difficulties inherent in the definition of the revenue that allows the economic and financial balance of the distributor, there is a need to discuss rate structures. Broadly speaking, the issue of network cost allocation and tariff structure requires detailed analysis in a context of diffusion of distributed energy systems. Since distribution tariffs are mostly valued on a volumetric basis ($ / kWh), measures to promote energy efficiency and investments in micro and mini-generation systems will reduce the revenues of distributors. This impact tends to be mitigated at times of Rate Cases where the distributor's economic and financial equilibrium is re-established. But this rebalancing occurs at the expense of an increases in the tariff rate. Therefore, it is noticeable that it results in an increase in energy expenditure by consumers who have not adopt these new technologies, which in the case of micro and mini generation are precisely the consumers with less resources to invest in these systems.

In this way, the imperative character of changes in the tariff structure is discernible in order to encourage the optimal use of the grid and, at the same time, to allow the correct allocation of costs among the different users. Although with the focus on distributed generation, Section 4 presented tariff alternatives that aim precisely to deal with this problem. In addition to the options discussed, it is important to emphasize the increasing importance of tariffs with locational signals as far as they may encourage the diffusion of distributed energy resources in order to maximize their systemic benefits. At the limit, it is possible to think of a tariff system based on the principle of causality where tariffs consider temporal and locational signals. However, tariffs based on the principle of causality tend to have unwanted social outcomes as far as many cases make lower-income consumers have higher rates.

In this changing environment, the distribution company tends to become a system operator. Thus, traditional fit-and-forget strategies will no longer be relevant, distribution planning will need to be reviewed and its operation will need to be more active, especially considering the increasing need to perform load management. All this scenario will cause distributors to demand ancillary services and how this will be done will depend on the commercial arrangements that may be adopted. Concurrently, the exercise of the grid operator function will cause the distributors' relationship with the transmission network operator to be modified as well.

Considering these transformations prospected in the activities of the distributors, there is a need to examine what should be the possible organizational arrangements of the distribution sector. On the one hand, the distribution system operator could remain as the owner of the grid, in a model where it is possible to exploit economies of scope. However, its efficiency requires that there be an effective unbundling to allow access to the grid. Alternatively, it is possible to have an independent system operator. Like independent transmission system operators, it would be intrinsically neutral in the dispatch and management of the grid and could act as a neutral platform for the commercialization of energy services. In this case, the owners of the distribution grid can act in competitive activities because they are not responsible for the operation of the grid. However, the independent system operator model tends to have higher transaction costs and smaller economies of scope, see that the planning and operation of the system is done by the independent entity while investments and grid maintenance are carried out by its owner.

In an even broader analysis, it is necessary to consider the modifications in the relations between the agents together with the emergence of new agents. Therefore, there is a need to examine new market structures and the regulation of new business models. In this context, a first issue to be examined is the limits of regulated businesses and non-regulated businesses. For example, what framework should be given to the figure of the load aggregator and / or the person responsible for the distributed energy resources trading platform? This discussion has direct implications for the definition of the asset base of the traditional distributor see the need to define the framework to be given to new infrastructures and devices (smart meters, electric vehicle recharging stations, big data, etc.).

Therefore, the presence of a set of new technologies capable of causing a rupture of the technological paradigm of the electric sector is evident. However, the effective verification of this transformation passes, not only by public policies, but also by the evolution of regulatory guidelines. Aside the need of encourage companies to invest in new technologies, it is necessary to establish a regulatory framework that makes these technologies feasible to the extent that their systemic benefits justify them, and the allocation of costs meets basic efficiency criteria. Finally, it is noteworthy that it is extremely natural for regulation to evolve to adapt to technological changes. This evolution can take place actively to anticipate technological changes and at the same time to try to direct them. However, this process may have a reactive character with the modifications adopted aiming mainly to correct distortions and difficulties resulting from the new technologies.

The Brazilian electricity sector is not an exception to this dynamic. However, it is necessary to consider some peculiarities in its electrical sector. It is a market with high growth rates and distributors still need to make considerable investments in grid expansion. Given the lack of prior recognition of an investment plan, the fact that tariffs are calculated based on a reference market becomes a fundamental element to enable the expansion of the grid. The growth of the market results in a higher turnover for the distributors and, consequently, distributors capitalize on these investments.

In addition, the Brazilian electrical system still presents challenges related to improvements in quality levels and universal access. Due to the socioeconomic disparities in the country, these challenges are present in the agenda of the Brazilian distributors in different ways. For example, for distributors located in the state of São Paulo, there is a market with a considerable level of income, and the decentralization of electric systems with increasing consumer participation is a relevant issue. For distributors operating in the North and Northeast regions, the challenges are more associated with improving service quality and universal access to energy.

Discussing advances in the regulatory guidelines of distributors in Brazil needs to consider specifics of the Brazilian market. Considering that the regulatory framework applied is the same for all distributors, ANEEL will have some challenges ahead. In sum, regulatory changes should be compatible with the emerging technological paradigm and the challenges already present in the Brazilian electricity distribution sector.

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Annexes

Table A1
Abbreviations of the states

Abbreviation	State
AC	Acre
AL	Alagoas
AP	Amapá
AM	Amazonas
BA	Bahia
CE	Ceará
DF	Distrito Federal
ES	Espírito Santo
GO	Goias
MA	Maranhao
MT	Mato Grosso
MS	Mato Grosso do Sul
MG	Minas Gerais
PA	Pará
PB	Paraíba
PR	Paraná
PE	Pernambuco
PI	Piauí
RJ	Rio de Janeiro
RN	Rio Grande do Norte
RS	Rio Grande do Sul
RO	Rondônia
RR	Roraima
SC	Santa Catarina
SP	Sao Paulo
SE	Sergipe
TO	Tocantins

Source: Authors.

The Brazilian energy sector has reached a preeminent point in its history and has the potential to transform the livelihoods of thousands through innovative and fair energy policies. Since electric power distribution is highly centralized and strictly regulated by the State, it is critical to understand what kind of prospects exist for the diffusion of micro and mini solar photovoltaic generation in Brazil. In this study, a scenario analysis is implemented and the process of constructing the two scenarios, baseline and alternative, is described. Later, a model is presented that estimates diffusion rates based on assumptions established under each of the scenarios. However, scenarios are just one part of the puzzle, and one must recognize the key role to be played by the Brazilian Electricity Regulatlory Agency (ANEEL) and its choices.

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