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Master in International Studies

Supervisor: Prof. Catarina Roseta Palma, Associate Professor, Department of Economics, Iscte Business School

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SOCIOLOGIA
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Matteo Cervelli

Resumo

O mercado de energia solar fotovoltaica encontra-se em fase de forte crescimento mundial. Esse crescimento é promovido por estruturas regulatórias nacionais e internacionais, projetadas para iniciar e garantir a difusão em larga escala da tecnologia. O Brasil é considerado um dos mercados mais promissores para o sucesso da energia fotovoltaica, principalmente graças às condições favoráveis para a implantação deste tipo de geração. No entanto, a representatividade da energia solar na matriz elétrica brasileira continua abaixo do esperado, o que abre a porta para considerações interessantes. O presente estudo investiga a adequação das mais importantes políticas energéticas, da legislação, da regulamentação e dos apoios económicos, financeiros e fiscais. Nesse contexto, foi desenvolvida uma ampla revisão do marco regulatório brasileiro para a energia fotovoltaica. Depois disso, foram realizadas algumas entrevistas semiestruturadas com profissionais do setor para explorar essa adequação da política de uma forma mais aprofundada. O estudo conclui que, apesar do quadro regulatório atual ter impulsionado um desenvolvimento fotovoltaico significativo no Brasil, melhorias urgentes são atualmente necessárias. Para acompanhar um processo de modernização do setor elétrico, a recomendação para o Brasil é a criação de um marco regulatório mais coerente, estável, aberto e competitivo, tanto para o setor fotovoltaico centralizado quanto para a geração distribuída.

Palavras-chave: Energia renovável, Energia solar fotovoltaica, Brasil, Marco regulatório, Adequação de políticas

Abstract

The market for photovoltaic solar energy is in a stage of strong growth, worldwide. Such growth is fostered by national and international regulatory frameworks, designed to launch and secure large-scale diffusion of the technology. Brazil is considered one of the most promising markets for photovoltaic energy, mainly due to favourable conditions for the implementation of this kind of generation. However, the representativeness of solar power in the Brazilian electricity matrix remains lower than expected, which opens the door to interesting considerations. The current study investigates the adequacy of the most important energy policies, legislation, regulations, economic, financial and fiscal support schemes. In this context, a comprehensive review of the Brazilian regulatory framework for photovoltaic energy was developed. Then some semi-structured interviews with photovoltaic professionals were conducted, to explore policy adequacy in a deeper way. The study finds that, despite the current regulatory framework having driven significant photovoltaic development in Brazil, urgent improvements are currently needed. To follow a process of modernization of the electricity sector, the recommendation for Brazil is to create a more coherent, stable, open and competitive regulatory framework, both for centralized and distributed photovoltaic generation.

Key words: Renewable energy, Photovoltaic Solar Energy, Brazil, Regulatory Framework, Policy Adequacy

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Introduction

A wide range of complex challenges has gradually grown over the past decades around a relatively new concern, the concept of sustainability (Sovacool and Brown, 2009). Considering the electricity industry, many players nowadays tend to focus on renewable energy as the most suitable and attractive low-carbon source to drive a sustainable transition (IRENA, 2018). In particular, several international agencies, a vast number of varied corporations, individuals as well as government bodies have begun to promote the implementation of solar photovoltaic (PV) technology as a tool to improve businesses, not only in terms of environmental management, but, most meaningfully, both in socio-economic and political terms (REN 21, 2018; Torres, 2019: 99; Ferreira et al., 2018).

This new preference has had a good ally in the commitment of policy-makers, worldwide. The commitment, depending on each state`s peculiarities, often takes the form of a specific regulatory framework responsible for the start and further development of PV solar. Under this new recognition, PV solar has emerged as one of the most attractive and reliable renewable electricity sources, marking the entry of a prosperous “solar power age” (Held, 2019: 2). Data confirms the statement. In the last three years, PV solar was the fastest-growing power generation source, adding alone more capacity than all other renewables combined and reaching globally the historical mark of 102 GW of installed capacity.

The promising global insertion achieved by PV solar as a source of electricity has recently hit a new prosperous market, the Brazilian one. The opportunity to foster the deep penetration of PV into the electricity matrix is very significant because Brazil satisfies some of the major requirements for the implementation of PV technologies: access to quality raw materials, one of the world`s best geographical locations for PV generation, attractive cost competitiveness and an historical legacy of environmentally-friendly legislation, among others (Vieira & Dalgaard, 2013; Lago, 2007; Ferreira et. al 2018; Pereira et. al 2017). Yet notwithstanding the great potential for PV solar electricity in Brazil, and despite undeniable growth, the PV solar sector is still described as incipient (Ferreira et.al, 2018; Ranieri, 2019: 10). Many international experiences have shown that at the very core of large-scale solar PV adoption there is, above all else, a coherent, elaborate and stable regulatory policy framework (Chowdhurry et. Al, 2014; Zhou et. Al, 2020).

Starting from this last consideration, the dissertation aims to investigate the adequacy of the Brazilian regulatory framework in terms of barriers and potential. The regulatory framework of PV solar energy includes energy policies, legislation, regulations, direct mechanisms of economic and financial supports (De Melo et. al, 2016: 223) as well as fiscal incentives and sectoral directives, in the Brazilian context. Many studies have presented different national regulatory frameworks and consequent recommendations, using qualitative analysis, for instance Dusonchet and Telaretti (2015) for the most representative EU countries or Huo and Zhang (2012) for China. Another type of PV solar policy study is recognized in the efforts of García-Álvarez et. al (2018) to produce a comprehensive evaluation of EU`s policy effectiveness and policy performance, in economic and quantitative terms.

In Brazil, scholars have followed similar paths, with an important difference: the systematic separation, during the analysis, between the centralized generation (CG) regulatory framework and distributed generation (DG) policy schemes. On one hand, studies on PV centralized generation system have assessed the regulations of large utility-scale solar plants, primarily focusing on government auctions, fiscal and financial support (Held, 2019; Silva et. al, 2019; Viana and Ramos, 2018). On the other hand, a more extensive literature has stressed distributed, decentralized or self-consumption regulation, analysing net metering policy design of small-scale systems, which is called, in Brazil, Distributed Microgeneration and Minigeneration (Rigo et. al, 2019: 2; Garcez, 2017).

The dissertation suggests a gap in the theory in existing literature, regarding the analysis of both centralized and distributed generation. Looking into the entire and complex policy framework should help policymakers and regulators to identify legal, practical and sectoral changes required for this source of energy to find a favourable environment to grow, in Brazil.

The dissertation therefore emphasizes the necessity of collecting, reviewing, assessing and debating the existing PV solar regulatory framework, as a whole. Consequently, the main objective of the dissertation is the analysis of the Brazilian PV solar regulatory framework in broad terms, bringing out the most significant gaps and related challenges under a "policy adequacy" point of view.

Within context, the research questions this work wishes to address are therefore: *How adequate is the current Brazilian's PV regulatory framework and why? How can it be improved?*

The work is organized in six chapters. After this introduction, chapter 2 provides a PV industry overview, firstly presenting the PV technologies and some of the top international cases before focusing on the Brazilian PV sector, its governance and the main players. This chapter contains an extensive literature review. The methodology is stated in chapter 3, where the research approach, the research design and the research method are elaborated. Chapter 4 initially collects and reviews the Brazilian renewable energy framework as the basis to present the entire and complex regulatory framework of the PV solar energy, both for centralized and for distributed generation. Based on the previous review and on interviews with professionals of the PV sector, chapter 5 develops the dissertation`s results and discussions. Finally, the conclusion identifies the most relevant implications of the current PV regulatory framework for both the centralized and distributed sector, its consequences and potential improvements.

2. Industry Overview

2.1 PV Technologies

Solar energy is progressively gaining momentum as a vast, inexhaustible, clean and disruptive source of energy (de Paulo and Porto, 2018; Held, 2019; Zhang et. al, 2020). By using solar energy as the basis, many different technological applications have been developed and one of the most relevant is PV technology. Coming from a systematic literature review, which analysed more than 140 articles published between 1996 and 2016 in 37 different countries, Sampaio and González (2017) established a minimum-consensual definition of PV solar energy as "electricity obtained directly from the conversion of solar energy". The solar conversion into electricity occurs thanks to the semiconductor materials[1] composing the PV module. Thus, semiconductor materials are responsible for the physical and chemical phenomenon known as a photovoltaic effect – the generation of voltage and electric current whenever a semiconductor material is exposed to light.

[1] Semiconductor materials are some specific raw materials incorporating into photovoltaic solar cells, which make up the photovoltaic module. Currently, the most utilized semiconductor material in photovoltaic modules is silicon, the second most abundant element on Earth.

Some basic equipment composes a typical PV system: PV module, charge and discharge controllers, the inverter, and battery. The PV module is the surface, composed of cells, that generate electricity. Charge and discharge controllers are the devices responsible for preserving the batteries from being overcharged or discharged, extending its useful lifetime. As for the inverter, it has the function to convert direct current (DC), generated by the PV module, into alternating current (AC), since the national grid and every electrical item in the house runs on AC. Batteries, in turn, are utilized to store electricity that is produced by the PV (Hosenuzzaman et. al 2015: 288).

There is a main technical requirement explaining the current establishment of PV technology in the marketplace: its excellent efficiency rate. As pointed out by Zhang et. al (2020: 580), the PV cell efficiency, that is, the rate of energy in the form of sunlight that can be converted into electricity via photovoltaic effect is widely considered the most important technical improvement reached by the modern PV technologies. Nevertheless, it should be stressed that every PV technology can suffer from low-efficiency performance, depending on latitude, temperature, solar irradiance and dust (Tyagi et. al., 2013: 451; Devabhaktuni et. al, 2013).

Nowadays, PV solar technology can be divided into the following categories - each one with its own efficiency parameter, peculiar features, and subcategories. First, monocrystalline silicon (m-SI) and polycrystalline silicon (p-SI) modules. Both are considered the first generation of PV technology, featuring high efficiency (up to 20 - 22 % in commercial scale) and higher cost, yet nonetheless accounting for almost 80% of the global market share, in commercial scale. Second, thin film cells, a less costly response to silicon-based technology, recognized as the second generation of PV technology. To date, the efficiency rate of that solution is approximatively 16 - 17% in commercial scale and, therefore, still suffering a competitive disadvantage vis-à-vis the PV first generation (Sampaio and González, 2017: 597). Finally, in the search for a PV technology that is economically and ecologically more viable, organic and hybrid (organic and inorganic) cells are, currently, being tested. These cells have the potential to be flexible, semi-transparent and easier to manufacture; however, they are not yet efficient, and their long-term reliability is still very low (Awasthi et. al, 2020).

Further, a wide range of PV applications and related markets are recognized: building integrated PV systems, PV thermal hybrid solar installations, floating PV, agricultural PV, off-grid PV systems and PV grid-connected systems (IEA PVPS, 2019: 8). In line with the purpose of the dissertation, the analysis will uniquely focus on PV grid-connected systems, considering its two main segments, namely, centralized generation (CG) and distributed generation (DG) systems.

On one hand, CG refers to large utility-scale systems, with a power capacity between 5 MW and 100 MW, connected to the network and producing a lot of electricity in a single point. Through utility-scale systems, the main idea is to feed energy from a large power plant to the public grid and, consequently, to consumers (Held, 2017: 8). Thus, the context in which CG operates is based on the traditional structure and market of a centralized electricity system.

On the other hand, DG is intrinsically linked with the concepts of decentralized production and self-consumption, namely, the production of power at or near where it will be used, by multiple and local actors, with lower costs on transmission and distribution, therefore emphasizing a new configuration for the electricity system. (Garcez, 2017: 104). In Brazil, DG, which is called Distributed Microgeneration and Minigeneration (DMM), is referred to as small-scale systems that cannot exceed 5 MW (Rigo et. al, 2019: 3).

2.2 PV sector in the World: panorama and perspectives

Thanks to more than twenty years of growth and innovation, at the end of 2019, the PV industry displays the development of over 585 GW of cumulative installed capacity, worldwide (IRENA, 2020). From 2017 to 2019, PV solar energy was the fastest-growing power generation source. As an example, figure 2.1 presents the new PV installed capacity in 2018, which, historically, exceeded the 100 GW level (102 GW), adding more capacity than all other renewables combined – impressively, more than twice as much as added for the second-best-renewable performer, wind power (49 GW). A similar trend was found in relation to fossil fuels, mainly natural gas and coal. With 46 GW and 50 GW, even gas and coal taken together has less new capacity than PV (Solar Power Europe, 2019: 7).

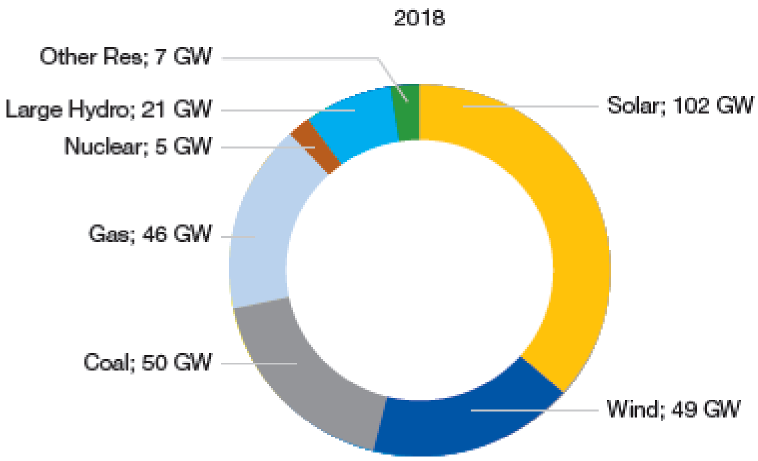

Figure 2.1- Global annual power generating capacity by main technology (2018)

Source: Solar Power Europe, 2019, p. 7

Almost all the entire global installed capacity is based on PV grid-connected systems. As shown in figure 2.2, while utility-scale photovoltaic systems (CG), which amount to around 62% of the global installed capacity, retain the PV market dominance, distributed PV generation, in parallel, is gaining more space, at least since 2017. In 2018, distributed PV systems represented up to 36 GW of annual installed capacity, reaching approximately one-third of the new deployed PV projects (IEA PVPS, 2019: 16).

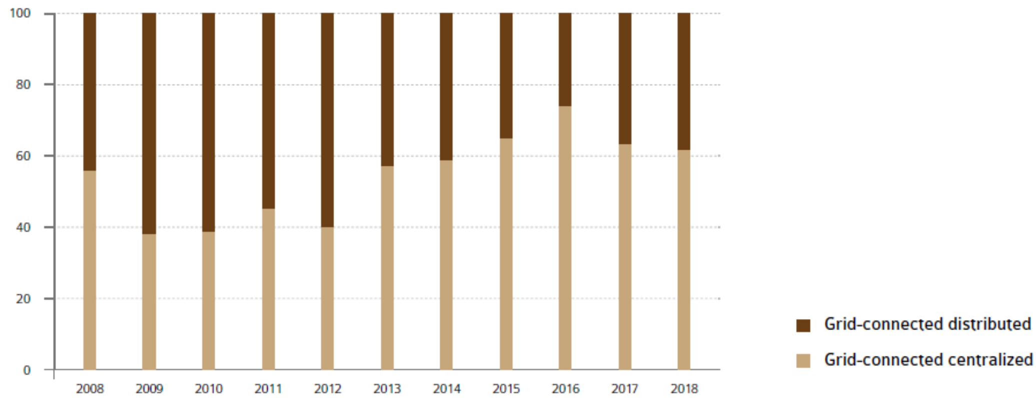

Figure 1.2- Annual share of centralized and distributed grid-connected systems

Source: IEA PVPS, 2019, p. 16

The financial amount invested in solar energy is also used widely by the international PV industry to emphasize current results and prospects. As reported by the Frankfurt School - UNEP Centre, UN Environment and BloombergNEF (2019), solar energy – particularly solar PV – has captured the largest flow of investments in renewable energy since 2010. And, in almost a decade, it has reached an impressive USD 1.3 trillion, equal to half of the total global investments in renewable energy – USD 2.6 trillion (Frankfurt School - UNEP, UN Environment, BNEF, 2019: 13).

The promising global insertion achieved by PV solar energy opens the door to interesting considerations. According to the main literature (Zhang et. al, 2020; Awasthi et. al, 2020; Sampaio e González, 2017; Ferreira, 2018), four elements directly influence the increasing adoption of PV solar energy: technical innovation, cost competitiveness, sustainability, and public policy support.

First, as argued in section 2.1, it is essential to consider PV cell efficiency as a critical parameter of technical innovation. Nowadays, PV technologies, primarily silicon-based modules, have reached excellent conversion efficiency (Sampaio e González, 2017: 596). Second, the cost competitiveness of the PV solar system has become tremendously attractive, as can be seen using the combination of PV installed cost trends in a given location, the level of local retail electricity prices, and the average net present cost of electricity generation for a generating plant over its lifetime (levelized cost of electricity - LCOE) (IRENA, 2017: 3; Ferreira, 2018: 184). Also, the unit cost of photovoltaic modules has dropped significantly in the last few decades [2], emphasizing the importance of innovation, learning and economies of scale (Hagerman et. al, 2016: 85; Candelise et al, 2013: 98; Ferreira, 2018: 184).

Third, sustainability is an increasingly relevant criterion in determining the position of an energy power source in the marketplace (Sampaio and González, 2017: 598). Undoubtedly, PV solar technologies meet that need not only as regards to the well-known low greenhouse-gas emissions' target, but also for their recyclable features – at least considering the second and third generation solar modules – (Rainieri, 2019: 12) and for their low threats potential to remote communities in which a large PV solar park is installed, unlike, wind parks or

[2] Researchers observed a PV unit cost module reduction (for the first-generation crystalline silicon module, c-SI) from 76.67 USD per Watt in 1977, to 5 USD per Watt by early 2000, ending to around 0.35 USD per Watt by late 2017. Using the famous learning curve, is possible to argue that solar module price decreased 20% for each duplication of industry capacity. The learning curve (or experience curve) has been widely utilized to draw historical performance trends and future cost projection of energy technologies. See Candelise et. al, 2013: 97.

hydropower dams (Silva, 2019: 4). Fourth, the support of specific PV solar policy regulations must be considered the driver of the worldwide growth observed. International experiences (Chowdhurry et. al, 2014; Zhou et. al, 2020) have shown that the development of a coherent, elaborate and stable regulatory policy framework is the core of successful PV solar implementation cases.

Deeper reflections are allowed by the illustrations of some of these cases. First and foremost, China is the country which added the most PV power in 2018, a capacity of 44.4 GW, keeping its worldwide leadership for the sixth year in a row (IEA PVPS, 2019: 26). China`s cumulative installed capacity, 175 GW, is, alone, almost one-third of the global total installed capacity. Curiously, the country has already experienced four development phases since the Renewable Energy Law, in 2005, kicked off PV growth: start-up, growth, explosion, and recession. Every phase has been characterized by specific regulatory policies – mainly supply, demand and environmental policies [3] - totalizing around 80 PV-related policies aimed to regulate and promote the application of PV power generation (Zhou et. al, 2020: 6). Most of the successes have been associated to the well-known feed-in-tariff (FIT) mechanism, that is, policy support designed to offer long-term renewables contracts to producers which would, normally, receive a cost-based price for the electricity from PV power they supply to the grid. In addition, the government`s direct subsidies and the world`s number one PV manufacturing industry have been equally important factors in boosting PV penetration (Marcolino, 2016: 33).

One more relevant player in the Asia-Pacific region is India. The country has experienced in 2018, a PV annual capacity addition between 10.7 and 11.2 GW, reaching approximately 25 GW of cumulative capacity, which has been exponential growth in relation to just a few MW operating in 2012 (Jäger-Waldau, 2019: 23). These fast improvements are results mainly of the federal government`s direct support through a mix of national targets and policy schemes. Great importance has been given to the Jawaharlal Nehru National Solar Mission (JJNSM) launched in 2010 and revitalized after President Narendra Modi won the 2014 national election. While the initial targets of the JJNSM, 20 GW of grid-connected PV capacity

[3] According to Zhou et. al (2020), supply-type policies include technical supports, funding and financial support – mainly feed-in-tariff (FIT) and green electricity certificates – carried out at the start-up and early growth phases (preparation and construction stage) of PV development. Demand-type policies cover sale policies, green subsidies and tax incentives. They are important during the growth and explosion phases (operation stage). Finally, the environment-type policies, involved in all the phases, are statutory regulation, goal programming, public guidance and infrastructure construction.

by 2022, were reached in 2018, the current targets ambitiously foresee 100 GW from solar energy by 2022 (IEA PVPS, 2019: 29). India has two peculiarities: (i) in contrast to China, it adopted reverse-auctions – a policy instrument in which developers submit the lowest bids at which they could sell power to the distribution companies so to gain a "Power Purchase Agreement (PPA)" over the medium-long (10-25 years) time - to drive PV market expansion (Behuria, 2020: 6); (ii) the average of distributed installed capacity is particularly low, accounting only for 10% of the PV total cumulative installed capacity. (IRENA, 2019: 23).

Globally, the second place for PV installed capacity is taken by the United States of America, with a PV cumulative capacity equal to 62.5 GW. Although most capacity relies on utility-scale projects (6.2 GW in 2018), distributed PV generation represents a significant share, accounting for 4.5 GW out of the around 10.6 GW of the 2018 deployment (IEA PVPS, 2019: 22). The PV solar market in the U.S has been accelerated, mostly, by various types of policy support both at federal and state-level. Almost all policies have had in common a focus on reducing PV system costs (Barbose and Darghouth, 2017: 5). From the federal side, the solar Investment Tax Credit (ITC), introduced in 2006 and extended for a five-years in 2015, is widely recognized as fundamental. ITC represents a mechanism allowing the PV owners – either residential, commercial or utility-scale – to apply a current 26% tax credit to their personal income taxes, in a dollar-for-dollar scale reduction (SEIA, 2020). From the States' side, instead, new adjustments have been advocated, providing more complex net-metering systems – a compensation framework used by PV customers to send excess electricity back to the grid and accumulate kWh credits. The North Carolina Clean Energy Technology Center (2019), the host of the most comprehensive renewables policies database in the U.S, highlighted the importance of those new adjustments in strengthening the penetration of relatively new business model, such as community solar programs, third-party ownership, and/or solar leasing (NC Clean Energy Technology, 2019: 11). Finally, by early 2017, some U.S electric utilities have experimented a new approach in response to the growth of PV grid-connected systems. Instead of fighting for suppression or revision of PV supporting mechanisms, they started to invest in large-scale projects so as to diversify their portfolios and take part profitably (REN 21, 2018: 93).

In the European Union, the top deployers are represented primarily by Germany, United Kingdom, France, Netherlands or Italy, yet the counterexample of Spain is probably the most controversial. Indeed, it represents the rare case in which a country with an annual installed capacity of 2.7 GW in 2008 – the largest worldwide PV market-place at that time – reached a tiny annual increment of 6 MW only a few years later, in 2014 (Talavera et. al, 2016: 234). The main reason for this lack of growth is a number of new regulatory frameworks, designed by the Spanish government, which have created strong instability, low profitability and, consequently, limited growth of the PV sector over the years (Jäger-Waldau, 2019: 20). As pointed out by Talavera et. al (2016), the Spanish case illustrates how much the regulatory framework influences the promotion or tardiness of PV market growth.

As a final point, PV prospects can be assessed. Several international companies have modelled feasible scenario for solar power`s share of electricity generation. As exemplified in figure 2.3, all scenarios, excluding the IEA-WEO SDS 2040, foresee PV generation equal to at least 20-25 % of total electricity needs globally. Some optimistic cases have gone even further. Indeed, Shell Sky (2018), DNV-GL (2019, p. 170) and Teske (2018, p. 13) calculate a likely share of solar generation of, respectively, 37%, 40% or even 49% by 2050.

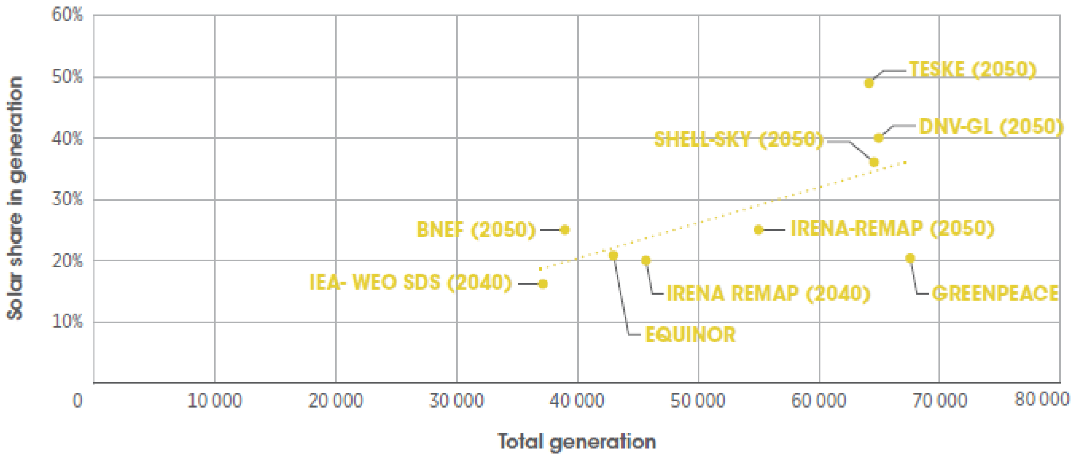

Figure 2.3- Solar generation projections in 2040 and 2050 for different energy scenarios

Source: IRENA, 2019, p 33

Such an impressive transformation projected for the next three-decades, while emphasising the prominent role of solar power within the future global electricity mix, also reflects the acknowledgement that the solar sector, primarily PV technologies, still has a long way to go.

2.3 PV Sector in Brazil: panorama and perspectives

Brazil possesses one of the cleanest electricity matrices in the world, displaying a rare case study of a country with a very large integrated electricity network that is predominantly fed by renewable sources. According to the latest data provided by the Brazilian Ministry of Mine and Energy (MME, 2020), 83,6% of the total installed capacity within power generation, as of February 2020, came from clean energy sources. Specifically, the main share of electricity production is, by far, supplied by hydropower sources (63.3%). Wind power, alone, is responsible for around 9% of the total energy share, whilst solar energy has already reached a promising 2.9% of the total system. Thermoelectric plants (primarily powered on natural gas, biomass and petroleum) provide a modest 25% of the total operated capacity (MME, 2020: 15).

Having an electricity matrix heavily dominated by hydro sources underlines a dangerous negative effect. To secure uninterrupted power to the electric grid, a suitable amount of water within the national reservoirs is required; this entails a strong dependence on climatic factors, mainly from regular rainfall. Dry seasons, as increasingly registered over the recent years, have tested the resilience of the Brazilian electricity matrix, showing an increment of severe power shortages (Held, 2017: 7). The result was a growing awareness of the necessity of furthering a system transformation toward more diversification and security of the national electricity supply. As noted by Freire (2015: 13), it is exactly because of the need for diversification and energy security[4] – defined as the linkage of four criteria: availability, affordability, efficiency, and environmental management of national energy sources – that renewables (mainly wind, biomass, small hydroelectric plants and solar) have been recently incentivized in Brazil.

Faced with these new premises, the national PV potential has undergone an accelerated development. According to the Brazilian Electricity Energy Agency (ANEEL) database, PV centralized generation is, in May 2020, equal to 2.9 GW and PV distributed generation has reached 2.7 GW, for a total of 7 GW [5]. Comparing this with data from February 2019 provides a clear measure of the fast progress: the PV total installed capacity roughly one year before was 2.7 GW, split into almost 2 GW of PV centralized and 700 MW of PV distributed. Thus,

[4] The definition of energy security is based on an influential survey elaborated by Sovacool and Brown (2009: 7). The survey relies on an extensive literature review (91 academic articles) and designs 10 metrics that constitute an Energy Security Index. However, it should be stressed that energy security, as a concept, has evolved, and it has been differently interpreted by States depending on perspectives, priorities, geography and time.

[5] Data are referring to the real-time statistics found on the ANEEL` website, available at the https://www.aneel.gov.br/informacoes-tecnicas.

capacity grew 29.2% for PV centralized and, impressively, 245.3% for PV distributed (MME, 2020: 15).

As for the international cases, in Brazil, the four elements presented in chapter 2.2 – technical innovation, cost competitiveness, sustainability, and public policy support – have been considered the main causes of the promising growth of PV technologies.

In technical innovation terms, Brazil is at the beginning of its PV technology development. Even though it has quality raw materials and industries that can be adapted for the production of PV components, the Brazilian market still relies on an imported value chain (Ferreira et. al, 2018: 189). While this has avoided technological lags and provided standardized high quality of PV products, in parallel, it has disadvantaged the growth and consolidation of a strong PV national supply chain. Souza and Cavalcante (2016: 151) argued that, if Brazil intends to foster the competitiveness of its national PV industry in order to become a new international hub of PV manufacture, it should develop a mechanism of tax reduction for PV local components, along with national content clauses – also known as nationalization factors – for access to public financing, as was done for the wind industry.

From the cost-competitiveness standpoint, PV technologies have recently set record low prices in Brazil, too. As related by Greener, an influential solar consultancy in Brazil, PV solar energy has dropped from 215,12 (R$/MWh) in the first dedicated auction in 2014 to 67,48 (R$/MWh) in the June 2019 auction, one of the lowest costs for PV power plants ever achieved around the world (Greener, 2020). Further, according to Ferreira et. al (2018: 185), the cost to install a (typical) residential PV system can vary, depending on the States in question, from a maximum of around R$ 26.000 and a minimum of R$ 14.000, much lower than in the past, but, still not fully competitive with some of the other renewables. Eventually, as the learning curve is in continuous evolution, there is a window for further cost decreases as well as for grid parity to happen – when the cost of generating energy from PV module is less than or equal to the cost of purchased power from the electricity grid.

Since Brazil has historically articulated an environmentally friendly discourse in multilateral climate-change negotiations while struggling to establish a favourable legal structure within its borders, the sustainability discussion has always occupied a central role. Although the commitment to renewable source development has not always been unquestionable [6], Brazil is nationally and internationally recognized as "undoubtedly well positioned in the global race for leadership in sustainable development" (Vieira & Dalgaard, 2013: 624; Lago, 2007; Freire, 2015: 36). With this role in mind, the country has planned an interesting model in which higher electricity demand is met with lower carbon emissions.

While the policy support element of PV energy will be fully addressed in chapter 4, all that remains now is to consider a few further advantages of Brazil. First, the availability and variability of solar resources – scientific data associated with the region`s weather, climate, location and Earth`s motion - are particularly favourable, over the whole territory. Very high levels of irradiation (availability) with low monthly variability are distinguished, classifying Brazil as one of the best places for PV electricity generation, worldwide. As claimed by Pereira et. al (2017: 67) through the influential Brazilian Atlas of Solar Energy survey, the potential of PV electricity in Brazil is much greater compared with countries such as Germany, Spain or Italy, where this technology is already well established.

Second, as noted by Bagatini et. al (2017: 516), it is a point of interest to make sure that the available renewables sources complement one another in time or in space (or both), to prevent the need for thermal plant activation, since the latter is a dirty and more expensive option. This complementarity can then benefit the operation, reliability and economy of the Brazilian integrated electrical system, since a strong complementarity reduces the effect of the fluctuation of one renewable[7] compared to the others, in a given time and location. Many studies (Costa Souza Rosa et. al, 2017: 9; Mouriño et. al, 2016: 555; Bagatini et. al, 2017: 524) have verified the temporal complementarity between hydro, wind and PV energy for different regions, concluding that wind and PV energies have the potential to complement hydroelectric generation in a time of minimum availability. This coincidence, ultimately, ensures a balanced and optimal Brazilian electric energy matrix.

[6] Several scholars have noted as Brazilian governments, in the last two decades, have been able to manage the important environmentally friendly successes achieved in the past without convincingly reaffirm a further genuine commitment to powerfully sustainable energy policies. The claim of a full commitment to clean energy development, in this sense, clashed with the enormous investments on the exploration of the newly discovered offshore oil and gas fields, called "pre-salt", showing risky conflict of interests.

[7] As is widely known, renewables are intermittent sources. The intermittency of each renewable depends on the unpredictable availability of that source in a given time and location. In this sense, fluctuations can appear over a monthly, daily, and even hourly scale in each specific location. Those fluctuations directly influence the reliability of energy supply, which means, the security of the entire electric systems. See Costa Souza Rosa et. al (2017: 1).

Third, since Brazil owns one of the world's most extensive integrated electric systems, the costs and associated losses of the transmission and distribution infrastructures are considerable. In these terms, the distributed nature of PV generation is perceived as a high-quality asset to minimizing investments in the expansion, operation and maintenance costs of the electric grid (Garcez, 2017: 106). Fourth and final, the increasing price of electricity, observed in the country since 2015, has powered the customers` transition toward more autonomy. As explicated by Datt (2019: 31), one of the main motivations that leads residential, commercial and industrial customers to produce and consume solar energy is to reduce the electricity bill, moving away from constant tariff increases.

Conclusively, since Brazil satisfies some of the major requirements to foster the deep penetration of PV energy into its energy matrix, the implementation of new prospects is now on the agenda. One of the most up-to-date national estimates, the 10-year Energy Expansion plan (2019-2029), considers the future demand and supply for each of the main electricity sources. The predictions are very ambitious: PV centralized generation would add 7 GW of capacity, while PV distributed generation would roughly install 10 GW of new capacity. This implies, on one hand, that almost 1.3 million Brazilians will be powered by distributed generation sources with a total investment estimated at almost R$ 50 billion (EPE, 2020). On the other hand, it would represent enough capacity to supply more than 3.6 billion of households and an investment over R$ 20 billion, until 2025 and not even counting new auctions.

In this context, both PV centralized and distributed generation form the baseline of a renewable portfolio, which, with declining costs and technical improvements offer the opportunity, for Brazil, to align the goals of diversification, energy security, and low carbon emissions in the medium to long term perspective (Agora Energiewende & Instituto E+ Diálogos Energéticos, 2019: 43). There is great potential for PV solar electricity in Brazil, but, despite undeniable growth, the PV solar sector is still described as incipient (Ferreira et.al, 2018; Ranieri, 2019: 10). Through detailed and comprehensive assessments, as proposed in chapter 4, this dissertation will thoroughly investigate the adequateness of Brazilian regulatory framework in search of barriers and potential.

2.4 Governance and Stakeholders

Historically, the Brazilian power sector was based on a vertical centralized system with large government companies and public institutions located at the top of the pyramid, acting as the main electricity agents (Agora Energiewende & Instituto E+ Diálogos Energéticos, 2019: 11).

After a series of attempts to shift to a more private sector[8], finally, starting from 2004, this ancient state-controlled structure has progressively been replaced by the current hybrid system, also known as the new model of the electricity sector (da Silva et. al, 2016: 330).

This new electricity model established two separate marketplaces for electricity purchase agreements: one regulated and one free. The former is founded on regular or reserve auctions which are fostered, respectively, from utility companies (distribution companies) or from the government. Utility companies buy the amount of energy required to meet demand growth in the regulated electricity market (ACR) from producers and resell it to consumers. The responsible entity for fixing electricity rates on the regulated market is the ANEEL which, on the basis of energy costs, transmission/distribution costs and taxes, stipulates fair prices for all the actors involved (ibid.). In this process, consumers have no choice and receive the electricity supplied by the utility companies responsible in their area. Instead, reserve auctions – contracting processes used to improve supply adequacy or in emergency cases (e.g., droughts) – are entirely planned by the government, and less utilized. Both types of auctions are considered public tasks, since they are provided following government estimates of economic development, increase in energy demand and related supply security (Martelli et. al, 2020: 4). Nowadays, the ACR covers 70% of the market, by number of consumers, and includes all residential, commercial and industrial consumers with a demand up to 500 kW.

In the free electricity market (ACL), where consumers can freely choose their sellers, the purchase of energy is, by definition, independent from direct state control. To date, only two categories of consumers are qualified to join the free market: the special consumers, end-users with an electricity demand between 500 kW and 3 MW, and the free consumers, which are big industries with demand of above 3 MW (Lopes, 2019: 56). While the former has the requirement to contract energy supplied by wind sources, PV solar, biomass or small hydropower plants, for the latter no type of restrictions are recorded. As for a few main rules on the ACL, the following are mentioned: independent negotiations between the parties, bilateral contracts, final prices freely agreed and open competition.

[8] Started during the 1990s, the process of privatization, in Brazil, aimed at the alteration of the legal framework to initiate structural reforms of the energy sector. The precarious financial position that Brazil had inherited from the 1980s and the domination of the sector by state-owned companies, had led a decline in investments, showing the necessity to inject private capital into the electricity market, mostly, faced increasing energy demand. In this sense, since President Fernando Henrique Cardoso came to power in 1994, the project of privatization has strongly entered the heart of the political agenda. To the point see Kingstone (2004).

It is a point of interest, now, to assess the governance and the role that key actors can play within the Brazilian hybrid structure. First, public policy setting and the national planning actions arise from the directives of both the National Council for Energy Policies (CNPE) – a multi-ministerial board works as an advisory body – and the Ministry of Mines and Energy (MME). The Energy Planning Enterprise (EPE), through technical studies, data and energy scenarios, offers coordination and inputs on national energy planning on behalf of MME. Further, the Electricity Monitoring Committee (CMSE) aims to permanently assess the continuity and reliability of the national electricity supply. Fundamentally, all these institutions play a political role (Cardoso and Hoffmann, 2019: 1155).

On the other hand, the regulatory role is, to a large extent, met by the ANEEL. As stated in law 9.427 of 1996 [9](its founding law), the ANEEL is an autonomous federal agency linked to the MME which performs multiple functions, although regulation, supervision and control of the production, transmission, distribution and commercialization of electricity are considered its main responsibilities. In a nutshell, ANEEL provides the regulatory base, establishes the conditions as well as oversees the regular conduct of all the private and public firms in carrying out their businesses into the Brazilian electricity sector (Bradshaw and Jannuzzi, 2019: 2).

The economic role, in turn, is placed in the hands of the Electric Energy Commercialization Chamber (CCEE). The CCEE, as the operator of the wholesale market, manages and promotes a fair trading environment along with solid businesses for all the actors of the Brazilian electricity sector, acting from the realization of public auctions in the ACR (delegated by the ANEEL) to the settlement of payments and sanctioning of defaults (Agora Energiewende & Instituto E+ Diálogos Energéticos, 2019: 15). Another relevant organization is the Brazilian Development Bank (BNDES), a state-owned financial institution, through which the main funds for development plans in the energy sector are subsidized, especially when these plans are related to environmental and social issues, as is the case for solar energy (Martelli et. al, 2020: 3).

Finally, the National Operator of the Brazilian Electric System (ONS), a non-profit private entity under ANEEL supervision, is responsible for the physical operation of the complex transmission grid, known as the National Interconnected System (SIN). The ONS is crucial to determine and organize all the operation related to generation, transmission and

[9] The law 9.427 is the federal regulation that set up the ANEEL. The law is available at the http://www.planalto.gov.br/ccivil_03/leis/L9427compilada.htm.

distribution of well-balanced electricity within the SIN, according to grid constraints, resource availability and seasonality (ibid.).

As for the major firms in the electricity sector, the mixed public and private entity, Eletrobras, while having lost almost entirely its ancient monopoly, remains one of the largest companies in the sector, benefiting from the presence of its subsidiaries (Eletronorte and CHESF, among others) in the generation and transmission segments, notably. The four segments composing the structure of the electricity sector – generation, distribution, transmission and commercialization – are divided between private and mixed capital companies. Currently, in the segment of commercialization, private firms enjoy a wide domain (Agora Energiewende & Instituto E+ Diálogos Energéticos, 2019: 13). While a similar trajectory has also been experienced in the generation segment, which, after 2004, accelerated its path toward privatization, in the segments of distribution and transmission an opposite experience has been observed. Since they are natural monopolies, the State has tried to maintain wide protection, mainly, through the requirement of non-discrimination in network access for all end-users (Xavier et. al, 2015: 284).

Regarding the PV solar sector, some further key players complete the entire scheme of stakeholders and governance, in line with the scope of the present section. Besides the public institutions and private firms, another extremely valuable set of actors is recognized in civil society (mainly associations and NGOs). These have the ability to influence and spread public discussions and mobilisations (Schäfer et. al, 2018: 7). Two main examples are international environmental organizations such as Greenpeace and WWF, and the respected Brazilian Photovoltaic Solar Energy Association (ABSOLAR).

Additionally, according to the ABSOLAR (2019), the expansion of PV energy in the country has increased research and development activities, resulting in a vibrant academic ecosystem, in which universities and professional training institutes have arisen as key forces.

This stakeholder map would be incomplete were it not accompanied by a more in-depth assessment of the last two groups of actors: PV centralized generation actors and PV distributed generation actors. In the first group, a strong presence of large multinational energy firms, who usually are the investors and holders of large PV utility deployments, stands out. It is possible to mention, among others, the Italian utility Group Enel, as the owner/investor of South America`s largest solar power project (São Gonçalo solar plant) as well as EDF Energies Nouvelles, Omega and Canadian Solar Inc (CSI), respectively, holders and supplier of the most powerful solar plant (321 MW) in operation in Brazil, known as Pirapora Complex (Datt, 2019: 28).

Concerning the PV distributed generation groups, new players have emerged since the ANEEL Normative Resolution (REN) 482 – later amended by the REN 687 [10] – came into effect, in 2012. From this context, and thanks to the creation of unusual business models, such as remote self-consumption, shared generation and solar condominiums, the PV sector, on one hand, has seen the rise of a large number of innovative start-ups, which, in search of opportunity, started to challenge the former governance of the electricity sector (Ramos et. al, 2017: 183). In this sense, solar start-ups, along with all the Cleantech rising within the Brazilian electricity sector, are taking advantage of the insertion of new technologies and business models to gain more scalability and, therefore, visibility and authority. On the other hand, the sector has progressively experienced the introduction of a modern and empowered electrical agent, known as prosumer – an individual who is, simultaneously, allowed to produce (producer) and to consume (consumer) its own electricity, independently from utilities (de Castro et. al, 2017).

As a final point, due the introduction of private firms in 2004 and, more recently, the rise of new, potentially very powerful, actors (primarily PV start-ups and the prosumers), the Brazilian electricity sector has accelerated the process of sectoral modernization, eroding the traditional centralized structure of governance. However, as noted by many scholars (Silva et. al, 2016: 330; Campos et. al, 2020: 3; Martelli et. al, 2020: 3), even though the new model displays organizational openness and changes in the balance of power, the bulk of the sector still is structurally under the control of the Brazilian government.

3. Methodology

3.1 Research Approach

There are three basic ranges of techniques to compose a research approach: quantitative, qualitative and mixed methods (Grover, 2015: 2). In order to answer the research questions, the approach chosen by the dissertation is based on qualitative techniques. Through a qualitative approach, the research first employs an exploration, understanding and capture of the contemporary PV industry characteristics, globally and nationally, a so-called industry

[10] Both Resolutions are widely discussed in chapter 4.2. To this point, is important to understand that REN 482 and REN 687 are considered milestone of the Brazilian regulation on distributed generation.

overview. This process involved general themes, emerging questions, specificities and first interpretations. Sequentially, a qualitative approach has served to investigate the entire and complex Brazilian policy framework, regarding both PV centralized and distributed generation. The emphasis was placed on collection of the existing regulatory framework, detaching the analysis from personal opinions or judgements. The result was a comprehensive review of the PV regulatory framework. Finally, coming to a more analytical part, qualitative data have been built starting from the PV regulatory framework and incorporating the contributions of PV professionals. This last part of discussions and results was guided by four semi-structured interviews and, consequently, by using the answers to provide reliable, comparable and comprehensive evaluations of adequacy and potential improvements, in light of the research questions.

3.2 Research Design

The research design refers to the procedures of inquiry or, following Creswell`s (2014) suggestions, the act of choosing the type of inquiry for the research. This design can be developed from five different starting points: descriptive research design, experimental research design, correlation research design, historical research design, and exploratory research design. To inquire about the existing PV regulatory framework, its adequateness and potential improvements, the dissertation chooses a descriptive research design and uses interpretation and attribution of meaning to the collected data as a rational basis. Moreover, many scholars (Owen, 2014: 5; Creswell, 2014) suggest some categories of conducting research: narrative research, grounded theory, survey research, case study methodology, and ethnography. The present dissertation is founded in case study since this type of research helps to gain an in-depth understanding of a specific phenomenon within its real-life context. On one hand, the phenomenon refers to the “case”, namely the PV regulatory framework. On the other hand, the case is analysed based on a national context, the Brazilian one.

3.3 Research Method

The research method involves data collection, analysis, and interpretation of the study. According to Creswell (2014: 239), data collection is the process of setting the boundaries for the study and its contents. First, data collection has taken place in Brazil since the research focuses on the Brazilian regulatory framework of PV solar energy. Second, the sources of data collection are developed on the basis of primary data from national and international institution`s official documents, such as, among others, MME, ANEEL, BNDES or IEA, IRENA and REN21. However, secondary data such as other surveys, reports and scientific articles, was sought. Secondary data are directly connected with sectoral scientific journal such as “Renewable and Sustainable Energy Reviews”, “Energy Policy”, “Renewable Energy” and “Utility Policy”, among others. Third, data have been collected through semi-structured interviews. This method allows the interviewer to adjust the question during the interview as to make the most from interviewees answers, to keep the conversation flowing and stimulate the debate. Moreover, based on qualitative research techniques, the questions were open-ended (Weller et. al, 2018: 17). Interviews lasted between 30 and 45 min each and were carried out during September 2020. Interviewees were identified among stakeholders related to the PV solar sector and represented a specific segment of the Brazilian electricity sector. The profiles are described below.

Respondent 1 is a first-hand PV professional, performance and studies engineer with almost four years of experience in the renewable industry. He works for one of the biggest multinational groups in the Brazilian renewable market: Brookfield Renewable. Respondent 2 works as the project development specialist at Brookfield Renewable. He has almost 5 years of experience in developing utility-scale solar project in Brazil.

Respondent 3 worked as an electrical engineer responsible for solar energy at SDE Distribuidora, an important distribution company in Rio de Janeiro. He concluded more than 100 PV distributed projects. Recently he has been working autonomously and founded his own company. Respondent 4 is a professional specialized in PV distributed generation, working for a private firm operating in the commercialization segment.

Thus the four candidates bring diverse sector knowledge: two experts from the PV centralized segment, namely respondents 1 and 2; and two experts from the PV distributed PV segment, respondent 3 and 4. The result has been a plurality of answers that embrace different views, contributing to a comprehensive analysis for both PV segments on which the dissertation is based.

The structure of the semi-structured interviews is as follows. The two guiding questions for interviewees correspond to the two research questions: how adequate is, and why? How can it be improved? Each guiding question is applied to each of the major topics in chapter 4: the Brazilian renewable energy policy framework (sub-chapter 4.1); PV national policies (sub-chapters 4.2.1 and 4.3.1); legislations (4.2.2 and 4.3.2); regulations (4.2.3 and 4.3.3); economic, financial and fiscal support (4.2.4 and 4.3.4). Before placing the guiding question, each interviewee was presented with a summary of the most relevant issues addressed within each topic. In this way the boundaries of the answer were defined in order not to risk going off topic. The structure of the interviews did not change depending on the PV segment, that is, the same two guiding questions are applied to both distributed and centralized PV segments and their major topics. Table 3.1 includes the semi-structured questionnaire.

Table 3.1 - Semi-structured interview questionnaire

	PV centralized segment		PV distributed segment	
	Topic	Interview question	Topic	Interview question
1	Renewable energy policy framework	How adequate are the national policies related to centralized PV energy, and why? How can it be improved?	Renewable energy policy framework	How adequate are the national policies related to distributed PV energy, and why? How can it be improved?
2	PV national policies	How adequate are the national policies related to centralized PV energy, and why? How can it be improved?	PV national policies	How adequate are the national policies related to distributed PV energy, and why? How can it be improved?
3	Legislations	How adequate are the legislations related to centralized PV energy, and why? How can it be improved?	Legislations	How adequate are the legislations related to distributed PV energy, and why? How can it be improved?
4	Regulations	How adequate are the regulations related to centralized PV energy, and why? How can it be improved?	Regulations	How adequate are the regulations related to distributed PV energy, and why? How can it be improved?
5	Economic, financial and fiscal support	How adequate is the economic, financial and fiscal support related to centralized PV energy, and why? How can it be improved?	Economic, financial and fiscal support	How adequate is the economic, financial and fiscal support related to distributed PV energy, and why? How can it be improved?

Source: own illustration

Regarding the analysis and interpretation of data, the dissertation takes as its perspective the question of "policy adequacy". Energy adequacy studies are widely used to assess the influence of intermittent energy sources, mainly wind and solar, and potential failures of communications infrastructure (Xiang et. Al, 2018: 369). Adequacy objectives aim to assess the capacity and reliability of solar or wind energy for uninterrupted electricity supply (Billimora and Poudineh, 2019). The dissertation adapts this assessment to solar PV policy, maintaining capacity and reliability as adequacy measures. Data analysis, as suggested by Gerhard and Silveira (2009), must be performed in an intuitive, interpretive and organized way. To assist in the organization of the analysis process, the interviews were recorded, and the data regrouped, in search of common points or unexpected answers. The interviewees answered the questions in Portuguese. The interpretations of data were drawn from the joint analysis of all the material collected: from primary data to secondary data ending with semi-structured interviews. Finally, it was the respondents themselves who resolved potential doubts or unexpected answers, either directly during the interview or in a subsequent round of questions and answers via email.

4. Reviewing the PV policy regulation in brazil

Brazil is potentially capable to secure the growth and maturation of the PV segment, both in centralized and in distributed PV generation, as shown so far. However, for PV to succeed, the commitment of policy-makers and firms is critical. As interestingly pointed out by Mallon (2006: 9), this commitment ought to take the form of a specific regulatory framework, since an inappropriate regulatory framework can disrupt the start, and further developments, of PV solar energy. In the remaining lines, the main national policies, legislation, regulations and economic, financial and fiscal supports, directly or indirectly related to the Brazilian PV regulatory framework are identified.

4.1 The Brazilian renewable energy policy framework

Brazil established its voluntary national commitment to climate change issues in December 2009, through the adoption of the National Policy for Climate Change (NPCC). Among the main institutional instruments provided by the NPCC, article 8, specifically refers to the promotion of a low-carbon economy via clean energy. The main task of the NPCC regarding the energy sector is to set principles, goals, guidelines while fostering public policies to the mitigation and adaptation to climate change (Wedy, 2017: 4). In a long-term national planning context, under the NPCC umbrella and, specifically, within the framework of the Paris Agreement, in 2015, Brazil implemented its Nationally Determined Contribution (NDC). This commitment aims to build "a broad scope including mitigation, adaptation and means of implementation to achieve the ultimate objective of the Convention (UNFCC)" (Brazil, 2016). Through the NDC, Brazil proposes the reduction of its GHG emissions 37% below 2005 levels by 2025 as well as 43% below 2005 by 2030. As for the renewables, the plan sets targets to increase the share of non-hydro renewable sources, mostly, biomass, wind and solar, to a minimum of 23% of the domestic energy supply (Bastidas and Mc Isaac, 2019: 3; Fraundorfer and Rabitz, 2020: 656).

In financial and economic terms, major investment for renewables has been fomented by the creation of the National Fund on Climate Change (Climate Fund), an instrument of the NPCC to finance projects and studies related to climate change impacts. According to Climate Fund directives, the main agent appointed as responsible for funding lines and access mechanisms is the Brazilian National Development Bank (BNDES) (Ipea et. al 2016: 80). In 2016, the BNDES has announced the inclusion of financeable items with low and, long interest rates for solar energy systems[11].

4.2 Centralized Generation

4.2.1 National policies related to centralized PV energy

The growth of centralized PV systems in Brazil has been possible thanks to its durable framework of environmental policies. The government, already in 1981, even before the Constitution (1988), had created a reference point regarding environmental concerns, which has come to the present day, called the National Environmental Policy (PNMA). Under the PNMA directives, many public bodies and institutions have been established, such as, for example, all federal, state and local environmental ministries and/or secretariats responsible for the

[11] More specific details on BNDES`s credit lines and their access are provided in section 4.2.4.

permissions and licensing on construction and management of a large power plant, including a PV generation project (Fonseca et. al, 2017). Those permissions and licensing became, over the years, environmental mandatory requirements subjected to federal, state or municipality jurisdiction. More details are explained in section 4.2.2 and 4.2.3.

4.2.2 Legislation

Two of the key legislations to regulate the electricity market are the Law no. 10.848/2004 and the Federal Decree no. 5.163/2004. The joint action of both has been responsible, among others, for the establishment of the Brazilian auction-based scheme, described in section 2.4, which scaled up the use of renewables in the country. PV utility-scale projects made their debut in the Brazilian auction-based scheme at the 6th Reserve Energy Auction held in 2014, where the dominant criterion was based on descending-clock auction, following the so-called hybrid or Anglo-Dutch model. In accordance with the legislation, in this mechanism, the winners are those who, during the two rounds of bids, one oral and the other in a "sealed envelope", offer the lowest prices for the quantity demanded (Rego, 2013: 218). The goal of the lowest price should stimulate competition and, in theory, an even further final lower price. The winners gain a 20-year commercial deal, known as Power Purchase Agreement (PPA). A PPA includes the date when the commercial operation began, the schedule for delivery of electricity, the expected volume to be delivered, the tariffs and the terms of payment (IFC, 150).

In order for new PV large power plants to participate in the auction-based-scheme, the Brazilian legislator, through the complementary Law no. 140/2011, established a few environmental licensing and other technical-economic parameters, such as land requirements, water grant use, environmental impact assessment (EIA) and environmental licensing (EL)[12]. As s complement, just a few years later, the Federal Decree no. 8.437/2015 fixed the rules of competence, setting out that a project`s environmental authorization has to be issued by only one agency – federal, statal or local – depending on the location of the activities. Also, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), as the federal agency, will be responsible for roads, railways, generation systems as well as for projects located or developed in two state territories or in protected areas (da Silva, 2019: 507).

As for financial incentives to attract investments in PV centralized generation, the Brazilian government has several. The Law no. 11.448/2007, accompanied by decree 6.144/2007 and by the MME directive no. 274/2013 founded the so-called Special Incentive

[12] More details about the definitions, criteria and specific activities related to EIA and EL are presented in sub-section 4.2.3, since they are regulated by special Regulations.

Regimen for the Development of Infrastructure (REIDI), a tax incentive for, among others, the infrastructure of a large PV system (SEBRAE, 2017: 82). In addition, Law no. 10.762/2003 includes solar plants (up to 30 MW) among the beneficiaries of the discount on the tariff for use of transmission systems (TUST) and for distribution systems (TUSD). The offered discount has been of 80% – reduced to 50% for projects that starting their operation from 1 January 2018. The combined operation of both legislations provides a specific tax exemption tool for centralized photovoltaic projects, as noted in section 4.2.4.

Moreover, Law 12.431/2011 granted capital market access for the infrastructure of PV centralized generation projects. On one hand, there is an income tax exemption for natural persons intended on the earnings from debentures created to fund the deployment of the PV infrastructure. On the other hand, for legal entities, the law ensures a 15% discount on income tax on the earnings from debentures (Silva, 2015: 11).

4.2.3 Regulation

Linked to the success of a PV large power plant, as anticipated in sub-section 4.2.1, a critical issue is to guarantee environmental permits and licenses[13], through environmental impact assessments (EIA) and environmental licensing (EL) (da Silva, 2019: 506). There are two regulatory frameworks that regulate both EIA and EL: the Environment National Council (CONAMA) resolution 001/1986 and the CONAMA resolution 237/1997, respectively. As for the EL, resolution 237/1997 sets three phases to be completed. The initial phase, in which the project developer is required to obtain a preliminary environmental license related to design, location and planning approval, is commonly named Prior Licence (PL). If initial conditions are met, the process enters the phase of the Construction Licence (CL), allowing the project to be executed according to the approved plans. The conclusive phase is the Operating Licence (OL) permitting the activities to finally start (Lima and Magrini, 2010: 109). On the other hand, CONAME Resolution 001/1986 refers to general and technical directives for EIA, pointing out the need for specific assessments for energy generation sources above 10 MW, PV centralized projects included (da Silva, 2019: 509). Among the obligations under the EIA are: geological, physical, biological, and socioeconomic analysis, along with negative impact evaluations and

[13] According to data presented by da Silva (2019), at the 6th Reserve Energy Auction, where PV projects for the first time were allowed to participate, around 70% of the enterprises did not qualify due to environmental impediments, mostly, caused by negative results in permits and licensing approvals.

related mitigatory and compensatory plans (Bond et. al, 2010: 8). It should be noted that an EIA must be presented by an independent team, to prevent any potential conflict of interest.

4.2.4 Economic, Financial and Fiscal support

Economic, financial and fiscal supports are generally aimed at guiding a reduction in costs and an increase in competitiveness of renewable energy technologies (de Faria Jr et. al, 2017: 471). Below some more specific data is provided to contextualize and quantify the importance of the PV centralized regulatory framework exposed above.

The main policy instrument utilized to increase the use of renewable energies was the reserve-auction. Since 2014, the government has started to include centralized PV generation projects, through more direct economic and financial support, into this mechanism. Data below refers to the period from 2014 to 2018. First, PV centralized generation projects were able to participate in five Brazilian auctions, three between 2014 and 2015 and the remaining two between 2017 and 2018. Figure 4.1 summarizes the relevant information regarding each of the auctions (represented in columns). The first three rounds (2014-2015) were conducted through the reserve-auction (LER) mechanism since centralized PV generation activities were not yet competitive. Already from 2017, however, solar energy was sold on the regulated market through the New Energy Auction (LEN) mechanism, demonstrating a rapid acquisition of competitiveness and maturity faced to the other energy resources (Barbosa, 2020: 355). Every PV auction showed a relatively stable number of qualified projects, staying within a minimum of 315 in LEN 2017 and a maximum of 493 in LER 2015. Similarly, the number of winner plants and installed capacity did not significantly change across the five PV auctions. What did change was the price of energy in dollars per megawatt-hour, which dropped from USD 82-90/MWh in 2014 to USD 35/MWh in 2018. The price reduction for PV utility-scale plants, in the Brazilian auctions, has been around 62.2% between the first and fifth auctions.

Type		LER/2014	1°LER/ 2015	2°LER/ 2015	25°LEN/ 2017	27°LEN/ 2018
Qualified proposals	Number of plants	331	341	493	315	422
	Installed capacity (MW)	8,871	11,261	13,159	14,030	13,380
Winners	Number of plants	31	30	33	20	29
	Installed capacity (MW)	889.6	833.6	929.3	790.60	807
	Electricity Production in 20 years (TWh)	32.4	40.6	43	29.84	40.06
	Price of energy (US $/MWh)	82-90	84-87	77-80	43-44	35
	Investment (billions of US$)	1.67	1.61	1.65	1.17	1.27

Figure 4.1- Results regarding Brazilian solar auctions (2014-2018)

Source: adapted from Barbosa, 2020, p 356

Along with the auction mechanism, a local funding landscape has been developed based on financial incentives and capital investments, mostly provided by the BNDES (Held, 2017: 14). As the national economic and financial supporting agent, the BNDES, used preferential credit lines to allow solar developers to access to favourable funds. Within the BNDES portfolio, there are some initiatives a PV power plant can be eligible for: FINAME- Renewable Energy, FINEM- Energy Generation or BNDES- Automático. Each of those financial incentives maintains its interest rates, its terms and specificities (SEBRAE, 2017: 82). In summary, depending on which incentive is chosen for a given project, the bank is able to cover 100% of the total investment with interest rates between 9% and 13.56% payable within 10, 20 or a maximum of 24 years (BNDES, 2020). In order to obtain a BNDES loan, a local content criterion is required. In other words, whenever a solar developer wants to gain access to BNDES`s public funding, some local accreditation factors for its PV equipment are required. To have an idea, the process of module assembly, frame, encapsulation, along with the electrical components and metal structure, are intended as the local content criteria that ought to be supplied locally (Held, 2017: 16). Finally, it is presented the case of Pirapora Solar Complex. For the first time, via the approved financing of around R$ 530 billion, the BNDES, in 2017, has covered 79.6% of the total investment value, referred to five PV solar plants with an installed capacity of 30 MW each one. According to the local content requirement, most of the equipment has been manufactured in São Paolo (BNDES, 2017).

As presented in section 4.2.2, and following the directives established by REIDI and by Law 10.762/2003, a large PV system in Brazil can even enjoy some fiscal incentives. More specifically, REIDI is a granting that suspends for a short period, typically 5 years, the tax contributions intended for the infrastructure services of a utility-scale PV project. The exemptions apply to the acquisition or import of new machines, construction materials, services and, in more general terms, to the infrastructure project equipment (SEBRAE, 2017: 82). The Portuguese multinational EDP Renovaveis SA, as an example, has recently invested in the construction of seven PV power plants, which will cost around BRL 567.3 million. After being allowed to enter REIDI support, the company estimated a saving of up to BRL 58 million (Renewable Now, 2020).

4.3 Distributed Generation

4.3.1 National policies related to distributed PV energy

At the beginning of 2003, the government set a few electrification goals via the National Program of Universalization of Access and Use of Electricity, specifically called Light for All. The main objective was to provide universal access to electricity to all Brazilian communities independently from their location, to reduce poverty and hunger by using the energy as a vector of development (de Souza and Cavalcante, 2016: 150). A few years later, in 2008, within the Light for All framework, the MME began to understand the importance of planning for a reversal of the fossil-fuel-based electricity matrix of rural communities, through the fostering of distributed renewable projects, mainly, by using biomass, small hydro and PV solar energy (Bezerra et. al, 2017: 5). The initial target of the program was to empower 10 million rural people through electricity access by 2008. However, an unexpectedly large number of families was found not be served by electricity, so the program was extended from 2008 to 2014, from 2014 to 2018 and, recently, until 2022. The massive funds required by the program have been made available from the Inter-American Development Bank, the Energy Development Account (CDE), directly from States and prefectures funds, and as part of the Global Reversion Reserve (RGR). No communities had to pay the costs of electrification (Diniz, 2011: 2699).

Later, through Ministerial Decree 538/2015, the government implemented a specific national program for distributed generation, called ProDG. The major aim was to foster and revitalize tax incentives and lines of credit, prioritizing the use of PV energy (de Melo et. al, 2016: 229). Also, such initiative sought to stimulate consumers to become energy generators, to reduce electricity costs of transmission and distribution and to increase the commercialization of distributed energy in the ACL. The goals of the ProDG are distinguished: BRL 100 billion in investments until 2030, with 2.7 million of consumers converted into prosumers, generating renewable energy from houses, businesses and industries, with an expected saving of around 29 million tons of CO_2 from being emitted into the atmosphere (SEBRAE, 2017: 83).

4.3.2 Legislation

In favour of the development of PV mini and micro generation and linked to REN 482 (sub-section 4.3.3), Law 13.169/2015 stipulates a few tax exemptions for those who feed solar energy (and other distributed energies) into the grid. Specifically, art. 8 introduced tax exemptions on distributed generation projects for the Social Integration Program (PIS) tax, Heritage Training for Public Servants (PASEP) tax, and the social Contribution for the Financing of Social Security (COFINS) (Rigo et. al, 2019: 9).

4.3.3 Regulation

The ANEEL normative resolution (REN) 482/2012 established the general conditions for the access of Distributed Microgeneration and Minigeneration (DMM) to the electricity distribution system and to the electricity compensation mechanism. On one hand, this modality is based on the possibility for the consumer to supply excess power generated by its DMM installation to the distribution network. On the other hand, to regulate the electricity compensation mechanism, it allows the Consumer Unit (CU) to accumulate power credits that can be discounted from the electricity bill, what is called, Net Metering system (Faria Jr et. al, 2017: 471). Those credits are obtained by the monthly positive difference between the injected and consumed energy. Both the access to the distribution and to the compensation systems are valid for consumers that generate their own electricity from renewable sources. To date, 99.8% of all DMM in Brazil are PV solar projects (ABSOLAR, 2020).

REN 482 has undergone two main revisions through REN ANEEL 687/2015 and REN ANEEL 786/2017. For the purpose of these regulations, the following criteria have been adopted: Microgeneration systems are renewable generators with an installed capacity of less than or equal to 75 kW, while Minigeneration systems are those with an installed capacity greater than 75 kW and less than or equal to 5 MW; the credits accumulated through the compensation mechanism expire 60 months after the date of billing; the associated connection costs to access to the distribution network be borne by the local utility company; the owner of the DMM must request access to the network, while the utility company shall evaluate and respond to the request in up to 34 days[14]; ANEEL reserves the right to review these regulations by December 2019 (SEBRAE, 2017: 76).

There are three new generation modalities and three related business models introduced by the aforementioned regulations. Each refers to the creation and use of energy credits (Morais and Yaneva, 2017: 6; Assunção and Schutze, 2017: 9). First, remote self-consumption allows a residential or commercial consumer to allocate the energy surplus of its PV system to other consumer units, according to predefined percentages. Those consumption units must be owned by the same consumer and within the same distribution area. Second, shared generation enables

[14] The processes indicated in the text are parts of the entire procedure for accessing to the compensation mechanism in the case of micro and mini distributed generation. Among the main documents mandatory for the request, for example, there are certificates of equipment conformity (primarily for the inverts), the list of the consumer units participating in the compensation system and the electrical design, along with the presentation of a Technical Responsible for the project. Other roles are specified for the utility company too. The Electricity Distribution Procedures in the National Electric System (PRODIST), within section 3.7, details all the specific procedures.

the sharing of electricity produced by a PV micro or mini-generation system between a group of individuals or legal entities. The group is formed through the creation of a consortium or cooperative. The PV system needs to be installed in a different location from the consumer units, albeit within the same distribution network. Also, only the holders of the consortium or cooperative can decide how to divide the percentages of excess credits shared by the consumer units. Finally, the third modality refers to the generation of energy in multiple consumer units, also defined as a condominium. It is characterized by horizontal and vertical condominiums, residential or commercial, interested in the installation of a central PV system and to share the electricity generated, both for the own use of each resident and to feed the common areas of the condominium. The PV system must be in the same property or on contiguous properties and the energy generated is divided individually for each condominium.

4.3.4 Economic, Financial and Fiscal support

The Light for All national program, presented in sub-section 4.3.1, came as a policy commitment to universalize the access to electricity in Brazil, directly empowering poor rural communities with the socio-economic benefits of electrification. To meet this goal, government incentives, primarily in economic and financial terms, have been essential (Diniz, 2011). Since 2004, 16.8 million rural people have benefitted from Light for All support. During the first phase of the program, between 2004 and 2008, BRL 2.3 billion were invested, without much concern for the use of renewables. Conversely, starting from 2009, the program revitalized funding projects, reaching an overall investment of BRL 27.62 billion by 2019 and including the use of distributed PV, biomass and small hydro projects (Eletrobras, 2019). Once grid-extension costs became unviable, due to the increase in distance of the communities from the existing grid, distributed and decentralized generation projects started to be more cost-effective (Bezerra et. al, 2017: 3). The results in the energy mix used by households were significant: whereas 90% of a rural family`s total energy demand, before access to the program, came from LGP, firewood and diesel, after the program, the share of those resources dropped to 65%. The use of distributed and decentralized energy occupied 25% of the difference, including, considerably, small PV distributed generation projects (Ibid.: 6).

In fiscal terms, the National Council for Farm Policy (CONFAZ), within Agreement 16/2015, sets an optional tax exemption on circulation of goods and services (ICMS) for distributed generation output. Specifically, the exemption from ICMS is granted for the amount of electricity sent back into the distribution network by the owner of a DG system. Despite being an optional exemption, to date, only two Brazilian states have not yet adopted this tax benefit. The rate of the ICMS varies depending on States and types of consumers (SEBRAE, 2017: 81). Further, PV distributed generation has been included in fiscal incentives related to access to the compensation system.

4.4 Centralized Generation and Distributed Generation

Some financial and fiscal incentives are granted to both the PV centralized and the distributed generation. First, the National Council for Farm Policy (CONFAZ) established the exemption of tax on circulation of goods and services (ICMS) for equipment involving the generation of PV electricity, with some exceptions, as is the case, among others, of inverters and meters (SEBRAE , 2017: 80). Furthermore, thanks to the program to support the technological development of the semiconductor industry (PADIS) [15], the production of semiconductors used in PV cells and equipment, in turn, has benefited from a tax incentive designed to attract investments. Lastly, another specific tax benefit has been offered for computer and automation goods, including those related to the production of equipment for PV generation, by Law 8.248/91 – amended by Law 11.077/04 – also known as Computer Law (Ibid., 81).

Ultimately, a commitment from the Brazilian authorities, primarily the ANEEL, is acknowledged as supporting investments in research and development (R&D), benefitting the entire PV sector. ANEEL Resolution 316/2008, in this sense, sets out the coordinates for the generation of new technological knowledge in many sub-themes of relevance to the electricity market. On one hand, based on this resolution, ANEEL R&D Project 013/2011 as the "technical and commercial arrangements for inserting solar PV generation in the Brazilian Energy Matrix". The project objectives were listed as a follows: to properly allocate human and financial resources to the entire PV national ecosystem; to encourage by technological improvements the economic viability of production and installation; as well as to promote the emergence of courses, technical schools and private qualification companies (ANEEL, 2011). On the other hand, joint action between the ANEEL, the BNDES and the Ministry of Science of Technology has created a strategic partnership, known as "Inova Energia" plan, aimed at coordinating actions to foster innovation in the energy sector. One of the scopes of the plan refers directly to the support of the Brazilian PV supply chain, mostly through new investments on the development of silicon technologies, thin-cell technologies, inverters and equipment

[15] The PADIS was introduced and regulated by Law 11.484/07 and by Decree 6.233/07. Later it has been amended by both Decree 7600/11 and Decree 8.247/14.

applied to PV systems, nationally. According to the BNDES website[16], within the "Inova Energia" plan, BRL 3 billion were made available for the years 2013 to 2016.

5. Results and Discussions

After the four interviews and taking into account chapter 4, the dissertation presented two macro results on the Brazilian regulatory framework for PV generation, one linked to the centralized generation and the other referring to distributed generation. Each holds its own major topics, most relevant issues and discussions. All the results detailed below were considered relevant keeping in mind a main perspective: policy adequacy, potential barriers and possible improvements.

Starting from the PV centralized regulatory framework five major topics, eight most relevant issues and related discussions were identified. First, in terms of the renewable energy policy framework (topic 1) respondents agreed that Brazil holds a favourable position with regard to the generation of energy from renewable sources, both because there is an abundance of renewable resources and due to the need for more diversification of the national electricity supply, a claim also made in the literature (Held, 2017; Freire, 2015). Within topic 1 one of the eight most relevant issues was raised: the Nationally Determined Contribution and the targets to increase the share of non-hydro renewable sources to a minimum of 23% of the domestic energy supply. Among other arguments there is a statement made by respondent 1, who affirmed that "I believed that 23% of non-hydro renewable in the matrix is a considerable number. Because on the other side of the coin, we have to consider the technical characteristics of a highly renewable electrical system and, in particular, the problem of supply reliability". In this sense, respondent 2 also added: "we have to have some goals, a bureaucracy, but in general, it is necessary not to leave the process too restricted".

Topic 2, the national policy related to centralized PV energy, had modest interactions because the respondents did not have first-hand knowledge. However, respondents 1 and 2 emphasized the importance of another relevant issue (issue 2): the presence of an Environmental National Policy (PNMA) composed by federal, state and local bodies and responsible for environmental permissions and/or licensing. Strong agreement exists with the

[16] Data are available on the BNDES website. See https://www.bndes.gov.br/wps/portal/site/home/financiamento/plano-inova-empresa/plano-inova-energia.

idea that “the conservation and respect of the Environment is a delicate matter, there must be public agencies, region by region, specialized in managing direct environmental requirements”. However, respondent 2 completed the reflection by observing that: “the discrepancy in the requested environmental prerequisites turns out to be very large depending on states and this can change project viability. Sometimes, taking two different states and two similar solar projects, the requirements vary significantly form one state to the other.” In other words, there is a need of standardization in environmental permissions and licensing at the federal level.

The third, fourth and fifth relevant issues were identified through the topic 3, namely the PV centralized legislations. The third issue refers to Law no. 10.848/2004 (and the Federal Decree no. 5.163/2004), the well-known Brazilian auction-based scheme. Both respondents 1 and 2 explained: “the auctions are effective solutions for contracting in the regulated market, mainly guaranteeing the supply side”. Respondent 2 also pointed out that “the auction system is organized around the Government's search for energy that can be cheaper for the consumer; the search for the lowest price for selling energy” by using what is called in the literature a descending-clock auction. Additionally, according to da Silva et. al (2016), the ANEEL, directly charged by the Government, would aim to establish prices as fair as possible for all the actors involved, as shown in sub-chapter 2.4. In contrast with this statement, respondent 2 countered that “on the companies side, this mechanism, depending on specific expectation, can make the return on investment (ROI) unfeasible and the company is forced to migrate to the free market since in the free market the company sells its energy for a higher price, increasing profitability.” Regarding the fourth and fifth relevant issues, literature and respondents agreed with the claim that the founding Laws[17] which created financial incentives (issues five and six), such as REIDI or the discount for solar plants up to 30 MW on the tariff for use of TUST and for distribution systems, have been a great benefit. Both respondents 1 and 2 justified their responses stating that “discounts are a very considerable value for companies on the cost of construction and operation. And it is a gain especially in terms of new activities.” Respondent 2 also added that, in the case of REIDI, this “is extremely important because it does not take just the part of infrastructure of a large PV system, but also the workforce.” Another statement that characterized this part was strong agreement with the idea that the limit of 30 MW to access the discount on TUST and TUSD brings some bureaucratic difficulties. As explained by

[17] The Law no. 11.448/2007, accompanied by decree 6.144/2007 and by the MME directive no. 274/2013 founded the so-called Special Incentive Regimen for the Development of Infrastructure (REIDI). Law no. 10.762/2003 includes solar plants (up to 30 MW) among the beneficiaries of the discount on the tariff for use of transmission systems (TUST) and for distribution systems (TUSD).

respondent 1 “what it happens is the following: a large solar complex is divided into smaller plants in order to respect this 30 MW and earn the discount. Once you divided the complex into smaller plants, each plant starts to function and works independently. Although the project is owned by the same agent and developed by the same team, the division generates different interfaces with the ONS, different contracts with the CCEE, and different CNPJ.” In a nutshell, it creates more bureaucracy and higher costs.

As for the PV centralized regulations (topic 4), respondents identified the sixth relevant issue, namely the scheme of environmental impact assessments (EIA) and environmental licensing (EL) regulated by both the CONAMA resolution 001/1986 and the CONAMA resolution 237/1997. According to the literature, for a PV utility-scale project to succeed, environmental permits, licenses, impact evaluations, and pre-established mitigatory and compensatory plans are required. By referring to those environmental requirements, respondent 2 reinforced the need for resolutions that ensure the development of environmental analysis, evaluations and studies before the participation in the auction itself. Data presented by da Silva (2019), for example, show that about 70% of the PV projects presented at the 6th Energy Reserve Auction were unable to enter the auction due to the negative outcome of environmental permits and approvals. However, the real problem is when a qualified project is faced with the volatility of these environmental standards along the enterprise journey. As continued by respondent 2, “when companies sign a contract for the development of a large solar plant there is a risk, after 1 or 2 years, that the environmental body starts asking for environmental standards, permits and approvals other than those initially submitted. On the part of the project developer, this risk ends up generating uncertainty and makes the contract less attractive.”

Finally, the results of topic 5 (economic, financial and fiscal support) represented what the dissertation called the seventh and eighth relevant issues. Respondents agreed with the literature (Martelli et. al, 2020; Held, 2017) on the recognition of BNDES as a significant provider of economic and financial support to the electricity sector. In more specific terms, respondent 1 argued that “speaking in the Brazil scenario the BNDES is essential, it has an important role to finance enterprise in the PV centralized system.” In addition, as SEBRAE (2017) specified, the BNDES portfolio allows solar developers to access different credit lines, each one with selected interest rates, terms and guarantees. Respondent 1, after its first statement, offered a warning on the BNDES`s credit lines, which in terms of guarantees “have physical limitations when it came to renewable energy contracts.” Indeed, in an interesting way he noted: “BNDES uses a system of guarantees coming from a model of the past, the hydrothermal electricity model. In a more dynamic model, such as that of renewable energies, it is necessary to favour short-term contracts with an increasingly faster rate of return and/or bilateral contracts with companies to avoid the high risk of abandoning projects." Similarly, respondent 2 perceived that “projects sometimes get public support despite not being very competitive in terms of guarantees. These projects were able to access financing and in the middle of the operation they stopped working” because with a slow rate of return they would not have provided financial returns. Lastly, the local content criteria to access BNDES loans was reported as the eighth-most relevant issue in PV centralized regulatory framework. From their side, Souza and Cavalcante (2016: 151) defended national content clauses, such as the local content criteria, as necessary mechanisms to foster the competitiveness of the Brazilian PV industry in relation to the international supply chain. Respondent 2 agreed with this statement, suggesting that “they are adequate and valid” while respondent 1 said “the local content criteria is necessary because we were not totally dependent on foreign imports and because our market does not depend on backward materials or technologies, negatively influencing the efficiency of the equipment.” Ferreira et. al (2018), however, argued that even though Brazil tries to consolidate a PV national supply chain, the internal market still is incipient and unreliable. Further, respondent 1 described an interesting scenario: “If, on the one hand, the objective of local content criteria is to encourage national industry in search of technological improvement, on the other hand, what in practice happens is that foreign companies come to produce and manufacture here in Brazil without worrying about local technological development. The only concern is with respecting the minimum local content criteria to obtain the loan.”

As regards PV distributed regulatory framework, five major topics, seven most relevant issues and related discussions were selected. As for the PV centralized regulatory framework, topic 1 and its most relevant issue were the renewable energy policy framework and the NDC, respectively. The starting point also was similar: “Brazil has a very high potential to be one of the world leaders in renewable energies”, claimed respondent 3. Further, respondent 4, in accordance with the literature[18], clarified that “the energy matrix in Brazil, based on its magnitude, is one of the most renewable in the world, with great renewable representativeness”. Instead, what seems to identify a new perspective concerns the affirmation of the respondent 3, who, called to deepen his thoughts, warned: "Brazil is following a good path to increase the share of non-hydro renewable sources to a minimum of 23% of the domestic energy supply,

[18] More details are identified in sub-chapter 2.3 “PV Sector in Brazil: panorama and perspectives.”

however, there are some conflicts of interest, which have a negative influence. In the case of solar energy, for example, it is possible to see power games between the ANEEL, often influenced by the interests of utility companies, and the Government which in theory would be responsible for ANEEL itself."

Concerning topic 2, namely the national policy related to PV distributed energy, a main issue was recognized: the national program for distributed generation (ProDG). First, as respondent 4 wanted to underline "in Brazil, when we refer to DG (and any program related to it) we refer directly to solar energy." As confirmed by ABSOLAR (2020), within the total distributed energy in Brazil, the representativeness of solar exceeds 95% of installed power. There are two reasons: "solar energy is modular and can be installed where the available space is minimal, unlike, for example, a wind system", concluded respondent 4. According to literature (de Melo et. al, 2016), the main objective of the ProDG was to foster and revitalize financial and fiscal incentives for the use of PV distributed energy. Respondent 3 agreed with the statement, but raises another significant question saying that "the program sometimes values the foreign market much more than the domestic one." In this sense, some benefits of the program remain in the hands of foreign capital and are not redistributed internally.

The third most relevant issue was identified through topic 3, that is, PV distributed legislations. The third issue refers to Law 13.169/2015 and its grant of a few federal tax exemptions on PIS, PASEP and COFINS for PV mini and micro owners. Specifically, as respondent 4 underlined "the law exempts the PIS and COFINS tax on power credits accumulated through the compensation mechanism", in line with the claim of literature (Faria Jr et. al, 2017). Both respondents 3 and 4 specified that this mechanism of tax exemptions has advantages, and it was very beneficial for Brazilian prosumers. On one hand, respondent 3 focalized the discourse on the benefits in terms of ROI, and on the statement that "if solar energy is accessible to a large majority, this has been possible, to a large extent, through a process of tax reduction and exemption." On the other hand, respondent 4 used a wider perspective saying that "all these tax incentives are necessary for a sector with little representation, as the solar distributed one, to assert itself." Interestingly, by making reference to PV distributed legislations, the respondents uncovered an unexpected issue (the fourth issue). According to both, "it is known that there is a tendency to have specific legislation related directly to the DG segment. This is not an easy process, but a strong discussion is emerging between who is in favour of real legislation and who is in favour of leaving the sector to be regulated through ANEEL regulations." Respondent 3 appeared to be more inclined to have solar distributed legislation, stating that “this transformation can help defuse ANEEL's strength in defence of the interests of large monopolies, such as utility companies." In contrast, respondent 4 felt that: “it is important to have ANEEL as the regulatory body to take care of the technical part of the regulatory framework. The politicization of the PV sector can be beneficial in the 4 years of political mandate, but it can prove less beneficial in the long run, at a technical level. In my opinion, there must be a distinction between what is technical regulation and what is purely political.”

PV distributed regulations represent topic 3 and generated the fifth and sixth most relevant issues: REN 482/2012 and its amendment, REN 687/2015. First and foremost, REN 482/2012 is defined as the most important norm capable of defining the role of the entire DG segment in Brazil. This statement strongly agrees with beliefs of respondents 3 and 4: "when we talk about DG we are referring to REN 482/2012 since the latter regulates the entire market and the net metering system." REN 687/2015 then provided many important improvements, mainly in terms of business models created as well as from the electricity credit`s standpoint. In the words of respondent 3 "from REN 687 very dynamic market has sprung up and companies have begun to see the PV distributed sector as attractive. REN 687 accelerated a beneficial growth in financial activities linked to the sector. " Instead, respondent 4 referred to the importance of having increased the time for credit consumption generated by a PV distributed system while decreasing the time for the concessionaire to provide its opinion on network access.

According to the literature (Bradshaw, 2017; Faria Jr et. al, 2017), the regulation on PV distributed generation, despite its many benefits, is too recent to access. However, nowadays, the segment is undergoing a profound transformation. The ANEEL, with public consultation number 10 of 2018, initiated a discussion on the necessity of modifying the charging system for energy generated from an enterprise in DG. As confirmed by the respondents “public consultation number 10 presented five alternatives, in order to review the whole system of exemptions and benefits granted to the PV distributed energy, to date.” The logic behind the five alternatives is as follows. The energy price in Brazil is calculated starting from the value of energy in kWh, adding two more elements: the so-called TE (energy tariff) and the TUSD. What regulates the distributed generation market today is what ANEEL calls alternative 0, that is, 100% exemption on TE and TUSD for DG systems. As respondent 4 clarified “The 5 alternatives are linked to the revocation of the TE and TUSD benefits and work as follows: alternative 0 would mean not losing any benefits (the situation remains as it has been up to now) while alternative 5 would mean losing the full exemption on the TUSD and staying only with the TE exemption.” Choosing an alternative between 1 and 4 would mean losing proportionally some of the exemptions that make up the TUSD. According to respondent 3, “it is known that this transformation would have happened because in REN 687 the ANEEL reserved the right to review these regulations by December 2019”, a statement also made by literature (SEBRAE, 2017). However, as both respondents 3 and 4 noted, from a market standpoint it is premature to remove a large part of the exemptions and benefits granted to PV distributed energy. In any case, literature and respondents agree that the utility companies do not benefit from the current compensation system, since prosumers de facto use their network without paying for such use. The result is a loss of revenue for utility companies and a consequent need to increase rates for other customers.

As a final topic and seventh most relevant issue the economic, financial and fiscal support and the state tax exemption on ICMS are distinguished. It must be premised that this exemption is allowed on compensated energy from a PV distributed system. Each state has both the power to apply or not the tax exemption within its jurisdiction and the power to decide the amount of the exemption (SEBRAE, 2017). In line with this statement, respondent 4 added "ICMS is mainly allowed thanks to the Agreement 16/2015 and although each state has its own peculiarities, the whole of Brazil is part of this Agreement". Shortly thereafter, the same respondent also offered a warning, pointing out that “some states grant 100% discount, but others don't. Why? Because the agreement specifies that the tax exemption can be applied on compensated energy. The TUSD cannot be seen as energy, it is actually the granting of a discount on utility companies' electricity line.” In other words, there is a misunderstanding about what can be understood as an energy exemption. Some states exempt 100% and interpret TUSD as compensated energy and others do not.”

6. Conclusions

Driven by the purpose to analyse the PV regulatory framework adequateness in Brazil, this dissertation identified some barriers and potential improvements in order to foster the deep penetration of both PV centralized and distributed energy into the Brazilian electricity matrix. In line with the best international cases, four elements directly influence the increasing adoption of PV solar energy in Brazil: technical innovation, cost competitiveness, sustainability, and public policy support. Brazil is potentially capable to secure the growth and maturation of the PV segment, both in centralized and in distributed PV generation. However, for PV to succeed, a strong policy commitment is required, mainly taking the form of an appropriate, fair and attractive regulatory framework. This dissertation analysed the extent to which the main national policies, legislation, regulations and economic, financial and fiscal supports, directly or indirectly related to the Brazilian PV regulatory framework are adequate.

The findings show five major topic and eight most relevant issues among the regulatory framework for PV centralized generation. The five major topics are: the renewable energy policy framework; the national policy related to centralized PV energy; the PV centralized legislations; the PV centralized regulations; the economic, financial and fiscal support related to centralized PV energy. The most relevant issues were identified through each major topic as shown below. In terms of renewable energy policy, the Nationally Determined Contribution is the relevant topic. As for national policy, the Environmental National Policy is appointed as the relevant topic. The PV centralized legislations, in turn, led to three different relevant issues, namely the Brazilian auction-based scheme, the REIDI and, the discount on TUST and TUSD. Coming to the PV centralized regulations, the most relevant issues are the schemes of EIA and EL. Finally, from the economic, financial and fiscal support standpoint, the last two relevant issues indicated are the BNDES credit lines and the local content criteria to access BNDES loan, respectively.

Notably, there is a consciousness, shared among stakeholders in Brazil`s PV sector, recognizing the country as one of the most significant international actors in renewable energy. Concerns on how to manage a very large integrated electricity system highly dependent on renewable sources are well-founded, especially in technical terms and from a reliability and security point of view. Another point of interest is the need for more diversification of the national electricity supply to avoid the unreliability of an electricity matrix heavily dominated by hydro sources. At the same time, the traditional governance of the electricity sector still plays a significant role in Brazilian PV development (Silva et. al, 2016: 330; Campos et. al, 2020: 3; Martelli et. al, 2020: 3). The findings indicated the presence within the electricity sector of some conflicts of interest, structural resistances, and a stagnant bureaucracy behind Brazilian renewables policymaking. Major improvements are expected, leaving the Brazilian electricity system technically more reliable, clean and less vertically and politically controlled.

Furthermore, it was possible to recognize a rooted legal structure for environmental protection. Brazil is historically well-positioned in environmental national policies (Vieira & Dalgaard, 2013; Lago, 2007; Freire, 2015) as demonstrated by the accurate system of environmental permissions and licensing for the development of a PV utility-scale projects. However, this system is considered an obstacle when referring to the divergences created by state environmental requirements. The findings suggest the articulation of common criteria that can be applied to the sector without geographical discriminations. This process would help reduce bureaucratic setbacks and thereby increase attractiveness of centralized solar projects in new regions, benefiting many different stakeholders.

Most of the energy supplied within the Brazilian electricity system is fuelled by power coming from the so-called auctions scheme (Martelli et. al, 2020). The analysis demonstrated that since 2014 one of the main policy instruments to foster the use of PV energy was the reserve-auction followed by the call of New Energy Actions in 2017, when solar energy already showed very high competitiveness attributes. Data showed an impressive cost reduction of around 63% for PV utility-scale plants in just five auctions. However, there are some important concerns. First, companies seem to perceive the free electricity market as more profitable than the regulated market because, from their point of view, a very low price to sell energy at an auction means less profit at the same time. Second, from an environmental standpoint, although it is important to ensure a complete structure of environmental permits, licenses, impact evaluations, and mitigatory or compensatory plans, the latter must not be transformed into obstacles to new PV projects. Likewise, this environmental structure must not be changed suddenly, at the risk of creating operational delays and additional costs. As for the near future, the hope is a reformulation of the auction schemes, prioritizing more competition between the sources in search of fairer prices without losing sustainability and reliability.

The analysis of the laws linked to tax incentives showed these supports as perceived crucial assets in the Brazilian context. In fact, the extent to which the success of PV centralized new investments depend on financial incentives or tax discount is plain to see. Therefore, from a purely economic and financial point of view, the results support the thesis that instead of focusing on improvements, the problem is trying to maintain the current systems of benefits. By contrast, many concerns are identified regarding the development and practical operation of a large PV solar plant, as demonstrated by the discussion on the 30 MW limit to access discounts on TUST and TUSD. The findings suggest that this limit can be increased while still delivering the same benefits. A real improvement would be recorded in terms of cost reduction, less bureaucracy, wasting of technical time and facilitating the operation itself.

Specifically, on the local funding landscape, it is noted that the only bank with attractive economic and financial funds for plans related to environmental and social issues is the BNDES. The state-owned financial institution is availed as an essential agent in the PV centralized segment. However, many barriers and potential improvements are highlighted. There is a structure behind the way contracts are awarded, which refers to an outdated electricity model characterized by long-term projects, typical of investments in the hydroelectric or thermal segment. The major concern is how much this model of public funding can delay the realization of projects related to solar renewable energy since the latter are based on a more dynamic model, short-term contracts, speed of execution and operationality. Another point of attention focuses on the idea of local content rule to qualify for interest loans from BNDES. Although these are protective mechanisms to safeguard the local solar supply chain, the Brazilian PV market is highly depended on imported components. The domestic industry, still incipient and not large scale, provides less competitive prices. Ultimately, it is important that policy makers avoid aggressive nationalization policies that could create barriers to imports, a poor supply chain of PV components and, consequently, a disruption on the development of new centralized solar projects.

As for the regulatory framework for PV distributed generation five major topics and seven most relevant issues were seen. The five major topics are equivalent to those listed for centralized generation. The policy framework for renewable energy is, again, the most relevant issue. Therefore, the results have already been set out above. Regarding the national policy relating to distributed PV energy, the relevant issue refers to the ProDG, while in terms of distributed PV legislation, the federal tax exemptions (PIS, PASEP and COFINS) are the most relevant issues. Furthermore, another relevant issue arose from the discussion on the introduction of specific legislation relating directly to the DG segment. The PV distribution regulations, in turn, have provided two other relevant issues, namely REN 482/2012 and REN 678/2015. Finally, the state tax exemption on ICMS is recorded as the main issue of the economic, financial and fiscal support related to distributed PV energy.

In general terms, the adoption of distributed generation is widely recognized, in Brazil, as a significant improvement toward a sectoral modernization (de Castro et. al, 2017). The ProDG, for example, works specifically in this line. Stimulating the transition from a mere consumer to the modern prosumer would lead to relevant consequences in the whole electricity sector. On the one hand, prioritizing a decentralized and distributed power network might reduce costs of transmission and distribution as well as increase cleaner technologies and new business models. On the other hand, a decentralized and distributed power network would mean, among others, a gradual loss of revenue for utility companies.

In line with the conclusions drawn from the analysis on the centralized PV sector, when it comes to tax exemptions or economic, financial and fiscal support, the sense of policy adequacy is remarkably high. For example, federal tax exemptions on PIS, PASEP and COFINS or the state tax exemption on ICMS are considered essential tools for the financial attractiveness of any mini or micro distributed systems deployed in Brazil. As the sector is young and immature, the current dependence on tax exemptions is visible, especially in the effort to make possible the access to solar energy to more people. Furthermore, there is a debate over the importance of leaving regulatory control in the hands of ANEEL or not. The results show that legislation specific to the distributed PV sector would work in favour of greater political control. However, such a choice could easily generate technical gaps in legislation, a politization of the distributed PV segment and, finally, more bureaucracy. The debate is relevant and still open.

Finally, to date, REN 482/2012 and its amendment, REN 687/2015 are widely recognized as the main regulatory framework in the distributed PV sector. Thanks to both regulations, a vibrant and very promising market, which recorded a 245.3% growth in installed capacity from 2019 to 2020, has been created (MME, 2020). Furthermore, the creation of new business models, mainly self-consumption, remote self-consumption, shared generation and solar condominiums, have influenced the birth of new important players: start-ups and prosumers. To some extent, they collaborated on the erosion of the traditional state-controlled electricity system. However, this process of modernization is running into strong resistance, mainly from traditional monopolies. The latter, feeling threatened by potential transformations, have begun to put pressure on the ANEEL, calling for a new regulatory revision of the systems of compensation. In this sense, an international case, the Spanish one, already showed the dire consequences of creating new regulatory frameworks when the market is still in an incipient phase of development[19]. Ultimately, the right to review distributed PV regulations is in the hands of ANEEL. The main recommendation is to seek the right balance between remunerating utility companies and providing benefits for other stakeholders.

Overall, it is possible to conclude that both the regulatory framework of centralized and distributed PV generation has proven adequate, at least until recent time. In fact, the high and

[19] The dissertation deals with the Spanish case in sub-chapter 2.2.

fast growth of solar energy in Brazil was, to a large extent, fostered by its main national policies, legislation, regulations and economic, financial and fiscal supports. Nowadays, however, many issues and barriers are emerged, revealing the need for further and urgent improvements. The country displays an ancient legacy rooted in an electricity system based on top-down control which is challenging the process of modernization. Furthermore, a high level of bureaucracy, conflicts of interest, political uncertainty and low standardization has had a substantial impact on regulatory adequacy, both for centralized and for distributed PV systems. Ultimately, all this may explain why, despite the great potential for solar energy in Brazil, its solar PV industry still has a long way to go.

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