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RATIONALES FOR TECHNOLOGY-SPECIFIC RES SUPPORT: THE IMPAIRED BRAZILIAN SOLAR EXPANSION

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Rationales for technology-specific RES support: the impaired Brazilian solar expansion□

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Abstract

Renewable energy promotion mechanisms have two main dimensions: enhancing project revenue and decreasing costs. Capital costs are one of the most relevant. Brazil is used as case study. Financial tools intertwined with industrial policy were applied: first to successfully promote wind generation, and then for solar photovoltaic (PV). The tools applied for wind were transposed to solar PV. Nevertheless, this has led to important challenges caused by the maladaptation of incentives to the solar PV industry specificities (e.g. high effort of innovation, lower transportation costs, and high importance of soft costs). We show how the use of similar financing support mechanism indistinctly for renewable sources (such as solar and wind) can create actual disincentives. We conclude that the financing mechanism has been fundamental for the viability of renewable energy projects, especially in countries without mature capital markets, where most of the infrastructure has received some sort of government financing support. The design of this mechanism needs to take into account the technological specificities and the national characteristics in order to successfully insert a certain renewable source in a determined country. The framework developed can be applied to other study cases.

Keywords: Financing, Development Bank, RES-E, Wind, Solar, Mechanism design

JEL Codes: D02, D82, G20, L94, O33, Q42

1 Introduction

Promoting renewable energy has become a viable option for countries willing to expanding its energy mix without relying on fossil fuels and nuclear power. Besides the obvious climate implications of a move towards renewables, this movement away from traditional sources has spread throughout the world for a variety of reasons: economic, political, or even in regard to public opinion. Nevertheless, this move has its fair share of problems and issues associated with it. These need to be dealt with a larger share of renewables in an energy mix, including the electricity mix, to become reality for most countries.

As a case study, Brazil is a country with a clean electricity mix, mostly comprised of hydro plants. However, it cannot rely as much on hydropower as it used to: its expansion has severe environmental problems associated with; and safety of supply, due to overreliance on this source, is becoming an issue for the country. A first move towards new renewables was taken during the 2000's to early 2010's, concluding with a successful insertion of wind power generation in this Brazilian electricity mix. A second move towards new renewables is currently underway, focusing on the insertion of solar photovoltaic (PV) as a viable energy source in the country. Albeit at its first steps, this second move has been unsuccessful, especially when in comparison with the first one.

In this paper, we analyse the causes and factors for success (or failure) of support frameworks, while focusing primarily on the financing and funding of the renewable power plants. The financing of those is considered a pivotal part of the investment and of the expansion of renewable energy in Brazil (our case study in this paper) and in the world. The analysis of the Brazilian case is interesting for the analysis of policy choices because it provides two recent cases of promotion of alternative renewables (wind and solar PV) in a country with an expressive portion of renewables in its mix[1]. Furthermore,

[1] IEA(2015) states that Brazil had 61% of all non-OECD Americas renewable capacity, which would grow to 64% in 2020 (from 104 GW to 144 GW). According to EPE (2014a), the State planning agency, Brazil

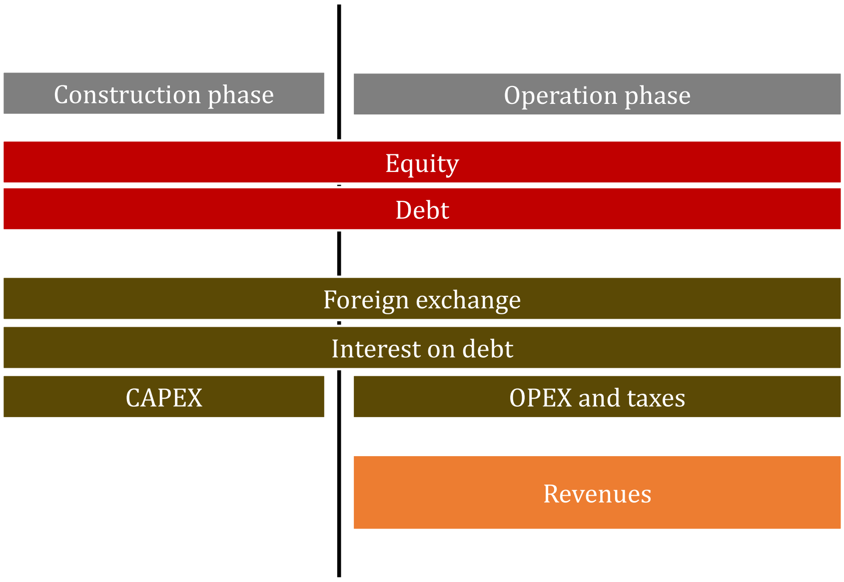
Brazil is the largest country in Latin America. We construct a robust analytical framework for the analysis of various financing mechanisms (in regard to elaboration and implementation).

This paper is comprised of eight parts, including this introduction. We then introduce the analytical framework. Afterward we analyse the viability and usage of incentive frameworks. Then, we analyse the expansion of wind power generation and solar power generation in Brazil. We then validate the failures as appointed by our framework. Lastly, we conclude. The last section is comprised of the bibliographical references used.

2 Analytical framework

In order to provide a structure for the analysis of renewable projects in Brazil, we will develop a description of the main elements of the financing problem. We will use it to clearly identify the aim and consequences of the policies implemented in Brazil.

Projects to install power production capacity based on renewable energy sources (RES) are often thought of as infrastructure projects. These projects have a distinct risk profile, as they are long-term investments with at least two different phases: **(i)** the construction phase, where most capital expenditures are made and almost no cash flow is generated; and **(ii)** the operation phase, where little capital expenditures are made and cash flows are generated[2]. To understand how RES are may be financed, the related policy instruments and their consequences, we begin by describing an elementary infrastructure project. Figure 1 contains this basic representation.



would have over 170 GW (83% of its mix) of renewable capacity, with more than half comprised of biomass, wind, run of the river hydro and solar PV plants. As of October 2017, Brazil has 131 GW (80%) of renewable capacity. Brazil has one the world's most clean electricity mixes and it plans to intensify the use of alternative renewables (IEA and IRENA, 2017).

[2] Slightly more detailed schemes may be designed (e.g. including phases where part of the infrastructure is built and some cash is generated). For instance, some turbines of a power plant might be ready and able to sell energy before the total completion phase.

Figure 1. Schematic representation of a generic infrastructure project.

First (in grey) there is separation of the project in two phases (construction and operation), second, we represent (in red) the financing source (equity and debt) that theoretically can be used to finance both phases. Third we represent (in green) the costs associated to the project that must be financed, the foreign exchange (especially important to Latin America and Caribbean countries), the interest that must be paid on debt, CAPEX (considering the costs of the construction phase) and OPEX (considering the costs of the operational phase. Forth, we represent the revenue, which is the positive cash flow of the project which must be able to cover all the cots and remunerate equity. When analysing support mechanisms to incentive renewables we can imagine policies impacting in different parts of the project illustrated in the scheme above.

Following the logic of Figure 1 we can group the mechanisms to promote investment in RES projects under two broad headers: i) financial instruments devoted to promote RES projects, and ii) "revenue-enhancing" instruments, including dimensions related to contract design, and to "cost-reducing" measures.

Traditionally, energy production projects have been often considered as infrastructure projects, so RES projects are typically associated with infrastructure financing. In this section, we will review the main characteristics of infrastructure project from an investor's point of view, and discuss the implicit assumptions behind dealing with RES as infrastructures. Regardless we consider an equity or debt investor, infrastructure is a special asset. Some of its main characteristics are the following:

- Long-lived assets
- Low technological risk
- High entry barriers (and hence usually strongly regulated assets with predictable and stable revenue streams)

The two basic generic categories are project and corporate finance. Project finance for infrastructure became a trend recently after the 1990's with increasing use of public and private partnerships. It builds on the idea that financing does not depend on creditworthiness of sponsors but only on the ability of the project to repay debt and remunerate capital, (Gatti, 2013). In that sense, it deals with the financing of a precisely defined economic unit, (Weber et al., 2016). Typically, because cash flows are more stable, project finance tends to allow a higher level of debt.

Corporate finance is the more traditional channel for financing new projects, especially private ones. Firms in charge of the investment issue shares or borrow in capital markets to obtain the required funding. Such firms will often have a portfolio of projects. In energy markets, utilities will have a portfolio of energy projects with different risk profiles. An important distinction when defining promotion mechanisms is whether the market design assumes project finance (as in LAC countries, particularly in Brazil) or corporate finance (as in the EU or the US).

Another, and more detailed, scheme OECD (2015a) considers the differences between project and corporate finance and between debt and equity instruments, see Figure 2.

Category	Instrument	Project Finance	Corporate Finance
Debt	Bonds	Project Bonds Green Bonds	Corporate Bonds Green Bonds
	Loans	Syndicated Loans Direct Lending (to project)	Direct Lending (to corporate) Syndicated and Securitised Loans
	Hybrid	Subordinated Debt Mezzanine Finance	Subordinated Bonds Convertible bonds
Equity	Listed	YieldCos	Listed Stocks, etc
	Unlisted	Direct Investment in Project (SPV) Equity	Direct Investment in Corporate Equity

Figure 2. Basic financing instruments. Source: Own elaboration drawing on (OECD, 2015a) and (OECD, 2015b).

The main financing instruments in infrastructure projects are loans and bonds. Debt markets are structured to form long-maturity products coherent with the long lives of infrastructure project. Moreover, such debt instruments may benefit from the existence of players in debt markets with a preference for long-term investments. Insurance companies or pension funds tend to prefer long-maturity products to hedge their long-lived liabilities. Consequently, a large portion of the project is typically financed through debt instruments (predominantly loans).

A relevant part of debt instruments is subordinated debt and, in general, instruments both for project (as mezzanine) and corporate finance that have characteristics between debt and equity (OECD, 2015a). Subordinated debt can be seen as an instrument designed to absorb credit loss before senior debt. The main effect is thus that it increases the quality of such senior debt. In that sense, subordinated debt can be designed to have different risk/return ratios, constituting a bridge between traditional debt and equity.

Finally, equity finance may be seen as the risk capital of the project (usually required to begin the project or refinance it). Listed shares would be traded in public markets whereas unlisted shares would provide direct control of the project. Project equity finance may be placed closer to debt instruments in the sense that infrastructure contracts may impose relatively low risk/return ratios. In any case, we understand equity investment as receiving residual claims on cash flows, thus being the highest risk investments.

From the point of view of our research, the relevance of equity in the project will be a central element of analysis[3]. We began by assuming that RES projects are

[3] One instance of a private response to the fact that some RES projects are riskier than others is the increasingly used Yieldcos. A Yieldco is a company that is formed to own projects in the operational phase

infrastructure projects, which are characterized by low technological risk. This may not be the case for all RES projects. From the financing point of view, this will mean that equity financing plays a more important role that in traditional infrastructure projects. This is also relevant from the policy design standpoint.

From the previous point of view, policies can be thought of as risk mitigation instruments. We will use two broad categories: i) Financial instruments; and ii) Revenue-enhancing mechanisms.

Risk mitigation and financing facilitation are the main objectives under this broad header. In order to identify the aim of the particular policy, we represent them in Figure 3. In general, there is a potentially wide range of instruments[4] that can be used by public and private parties to mitigate risks associated with RES projects.

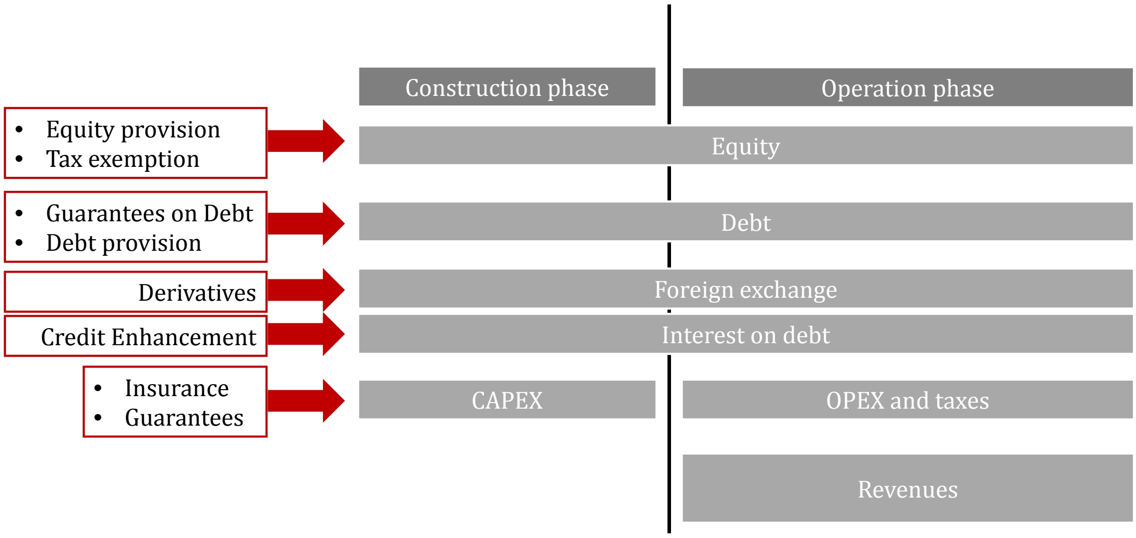


Figure 3. Schematic representation of potential financial instruments to mitigate risks. Source: Own elaboration.

Public participation in financing infrastructure projects can be seen as divided into two main tools: capital provision and guarantee provision. Capital may be provided directly by governments or by national or international development banks. Such capital may be equity or debt (junior or senior), with market or below-the market interest. There is a wide range of tools that can be used by the public sector with varying amounts of risks absorbed by the public sector. Analogously, guarantees may be provided by governments or development banks. Those guarantees are varied, from guarantees on

(hence with a stable revenue stream). In the energy industry, the idea is that utilities place RES projects in the operational phase into a subsidiary and issue shares in public markets (listed). With this, utilities separate the riskier part of a RES project and are able to create companies that are closer to the idea of an infrastructure project. This may be viewed as a response to a weak commitment of the (usually regulated) long-term contract. SunEdison, a large player in the Chilean market (as we will discuss in this study), is one instance of a Yieldco and of their importance in the RES market in LAC countries.

[4] OECD (2015a) provides a taxonomy of infrastructure projects risks, which is similar to the one provided here.

debt to guarantees on revenues. In Brazil, as we will see, the main instrument is (primarily senior) debt provision by the BNDES, with below-the-market interest.

The header "revenue-enhancing mechanisms" contains all possible measures related to mitigate risks associated with revenue streams.

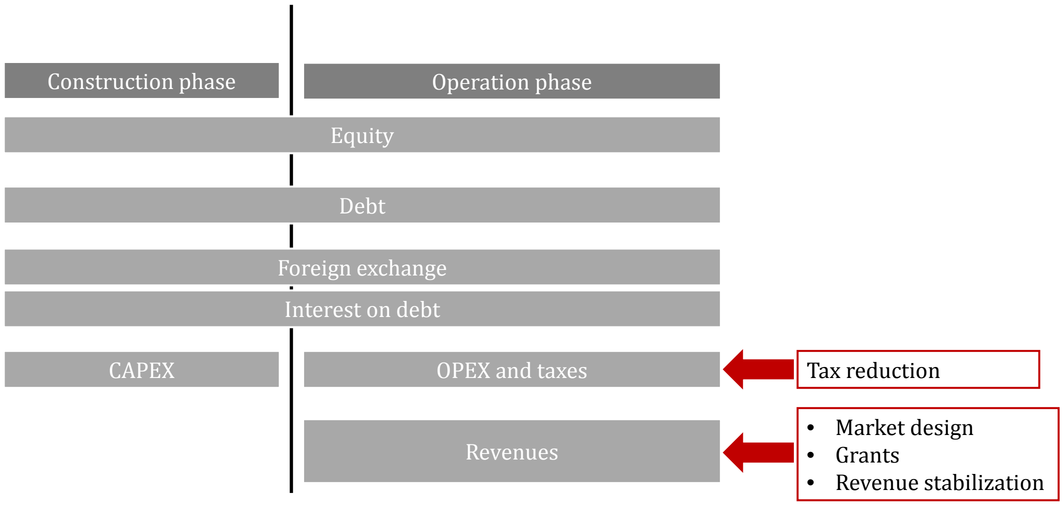


Figure 4. Schematic representation of revenue-enhancing instruments to mitigate risks. Source: Own elaboration.

Although one may consider a wide range of instruments with varying degrees of details to perform this function, in Brazil the main tool to guarantee the revenue has been the long-term contracts. These long-term power purchase agreements (often 20 years long) are typically offered in public tenders (in fact, auctions and tenders are often referred to as instruments to promote RES).

3 Incentive framework: why and how?

In terms of policy design, this paper is concerned with the definition of the beneficiaries. In that sense, it is necessary to determine whether the previous policies are technology neutral or not. That is, whether they are specifically targeted to one or several technologies (e.g. RES) or they are offered to all generation technologies.

According to Gawel et al (2017), the principal argument against technology-specific incentives are that they are unnecessarily more costly than technology-neutral schemes, being more complicated to formulate and implement. This argument however does not hold if: the RES learning process is heterogeneous; there are heterogeneous externalities[5]; and if the capital markets are underdeveloped. There will be obstacles to the long-term risk taking related to RES in an non-incentivized context or with technology-neutral incentives[6] under these circumstances (Lehmann and Söderholm, 2016; Neuhoff, 2005; Winkler et al., 2016; Wüstenhagen and Menichetti, 2012). Moreover, Gillingham and Sweeney (2010) also state that externalities are technology-

[5] The presence of externalities validate the use of an incentive framework. The presence of heterogeneous externalities validate the use of a technology-specific incentive framework.
[6] There is also a possibility for hybrid frameworks (de Mello Santana, 2016).

specific and therefore, incentives dealing with these externalities cannot be technology-neutral.

This has relevant implications for our paper. Problem identification is a relevant part of the design of policies. If one decides to implement a certain technology-specific policy, the objectives of that policy should be clear. We will show that, in Brazil, the application of a policy to support solar PV investment, which was designed for wind generation, did not cope with the technology-specific challenges, and hence it was not successful.

To that end, we next review the case for technology-specific policies according to the two dimensions of the previous section: revenue enhancing mechanisms and financial instruments.

3.1 Technology-specific mechanisms to enhance project revenues

The case for technology-specific, revenue-enhancing policies has to do with the implementation of responses to asymmetric learning. According to Gatti (2013), technology imposes risk on the project in the pre-completion phase. The author states that almost all projects that utilize RES technologies have an intrinsic risk of failing to pass performance tests, which impact on the perception of risk of it and its funding prospects.

Huenteler et al (2016b) and Peters et al (2012) demonstrate how there are different technology life-cycles (long-term innovation process patterns) related to different RES-E. According to the authors, solar and wind have opposing characteristics: wind is a design-intensive technology; whereas solar is a process-intensive technology. Wind has a higher complexity of design, whereas solar has a higher complexity of production process. Due to this, home markets are more important to establish wind than to solar, while the market size or its growth is more important for an establishment of solar. Wind is considered a mature industry, and in it, home markets are especially important for its large transnational companies (the standard in this industry) (Baker et al., 2013; Helm et al., 2014; Huenteler et al., 2016a; Moriarty and Honnery, 2016; Podcameni, 2014). Furthermore, deployment of solar PV is highly dependent of local learning (Neij et al., 2017). There is little evidence that learning is uniform across various technologies.

Lehmann and Söderholm (2016) construct an analytical model that corroborates the fact that, under these circumstances, technology-neutral policies will lead to underinvestment in the technology with higher short-term costs and also potential for larger future costs reductions. Innovation is closely related to climate mitigation technologies like the RES and is a source of uncertainty by nature (Anadon et al., 2016; Baker et al., 2015; Baker and Solak, 2014; Heal and Millner, 2014; Helm et al., 2014; UNEP, 2015; UNEP and EPO, 2014)

Technology market failures can detain future costs reductions. Because of these failures, weak or misleading incentives can make private investors not undertake the investments needed for reduction of costs. Through learning-by-doing and learning-by-using, an increase in the deployment of certain RES can contribute to lower generation costs in the future (through increasing adoption returns). Moreover, little market share, a consequence in this case, leads to less private R&D and could also lead to less public R&D. In this sense, a support policy for RES cannot be technology-neutral if its supported technologies have different: learning effects and curves; and means of appropriation of such learning by innovative private companies or public organizations[7] (Baker et al., 2015; Gawel et al., 2017; Lehmann and Söderholm, 2016, 2015).

Additionally, inevitable lock-ins and path dependencies determine market failures. Lock-ins (the totality or the larger share of adopters) are not only sector specific, but also technology-specific: different types might be locked-in. Lock-in processes are different for any combination of technologies competing for adopters, and are normally non-ergodic, i.e., history matters. Lock-in processes can lock-out (no adopters or a very low share of them) costly technologies with potential to become more efficient in the future. This process is not always reversible and the window for intervention is normally not large. Locked-in technologies benefit from larger increasing returns of adoption. Locked-out technologies, on the contrary are less favoured because of less adopters[8] (Arthur, 1989, 1988).

Path dependencies also shape the technology market failures. This institutional framework co-evolves with the technology, which could lead to increased costs related to exploring alternative technological path. Baker and Solak (2014), through a dynamic simulation, state that R&D in energy technologies is highly influenced by the policy framework for sustainability. Their results for solar PV were robust. Vazquez and Hallack (2017) show the importance of considering coevolution by identifying a lock-in situation to utility-scale PV caused by technology specific support mechanisms based on auctions.

3.2 Technology-specific financial instruments

In this subsection, we consider policy responses to imperfect financial markets. The basic idea is that perfect credit and capital markets would make investors indifferent between two different RES-E technologies, with different risk profiles, if the expected return is equal. When risk-averse private RES-E investors cannot hedge perfectly their portfolios, they introduce a risk premium on their capital. Risk is heterogeneous among RES technologies and so is its risk premium (Arrow and Lind, 2014; Gatti, 2013; Gawel et al., 2017; Lehmann and Söderholm, 2016; Neuhoff, 2005).

According to Stein (1989), short-term best solutions may not be long-term best solutions, so maximizing short-run outcomes may lead to inefficient long-term payoffs. This is a myopic behaviour. According to Ferreira (2011), corporate strategies and the different corporations' decisions are not necessarily similar: different firms with different managers, corporate boards and stakeholders may have different goals and strategies

[7] Moreover, there are multiple learning curves for one single technology inside a single country, regarding geographical location, sector deployed (residential, commercial, industrial, utility-level, off-grid application), subtechnology used (thin film panels and vertical axis wind turbines are different technologies than the majorly used in solar PV and wind applications respectively) and even if it is an off-shore or on-shore application (when considering wind power generation) (Gillingham et al., 2016; IEA, 2015; IRENA, 2016; MITEI, 2015)

[8] Additionally, opposition to technology (influential non-adopters) is essential for the determination of the outcome of the lock-in process (Cavusoglu et al., 2010).

regarding renewables. Moreover, sponsors and lenders react differently to exogenous factor variations (Borgonovo et al., 2010).

According to Lehmann and Söderholm (2016), RES technology risks vary in function of its: maturity; and technological complexity. Mature technologies have more established markets and industries and a decline in the degree and variance of possible learning effects. Technological complexity and capital intensity are positively correlated to risk. The political framework is also relevant[9]. Furthermore, according to Kim and Park (2016) more developed capital and credit markets have a positive outcome on the deployment of RES-E, especially on those that are considered riskier. Solar PV is a prime example of how more developed financial markets lead to larger deployments and to a higher, faster and more sustained growth.

Risk is a relevant determinant of choice among investors of solar PV (Lüthi and Wüstenhagen, 2012). The structure of patent systems is also capable of creating a bias towards the development of "close-to-commercial technologies" according to Budish et al (2015). A shorter time between the maturity of the technology and the expiration of its patent can lead to less interest in it. Still incipient or underdeveloped RES technologies, or even some relatively novel ones, can therefore face this problem, which would lead to underinvestment and underperformance. Once again, the expensive technology with great potential for cost-reduction is neglected in favour of a less costly (in the short-term) technology. Lastly, according to Gawel et al (2017), there might even be a genuine lack of financial institutions in some developing or underdeveloped countries. In those cases, the imperfect capital market problem is intensified. This is the case of various LAC countries, as Brazil (IEA, 2015; Vazquez et al., 2016).

In the presence of imperfect capital markets, private investors will under-invest in RES technologies perceived as riskier than other investment options. Technology-neutral mechanisms or no incentives at all do not extenuate this outcome. Technology-specific incentives are thus capable of lessening the negative outcomes of risk-aversion over RES in the presence of imperfect capital markets (Gawel et al., 2017; Lehmann and Söderholm, 2016).

4 The first Brazilian case: the successful Brazilian wind expansion

We now analyze the planned expansion for wind[10]. We focus on the expansion with the RES deployment framework composed of an auction mechanism and a public financing mechanism. Nevertheless, we also highlight important factors of the promotion programs for wind prior to the consolidation of the current incentive framework.

[9] For a mathematical analysis and a bibliographical review of political and country risks, we recommend Belghitar and Clark (2011).

[10] We do not analyze the political, environmental or social aspects of wind energy. For more on that matter we recommend Silva (2013) for the analysis of the wind expansion in Brazil, and also Strunz, Gawel and Lehmann (2015) for the analysis of the political economy regarding the German and European renewable energy policies. These authors emphasize the role of lobbies and groups of interest.

4.1 The planned expansion

Brazil tried to promote wind unsuccessfully between 2001 and 2009. First through two programs: the PROEÓLICA and PROINFA[11] and later through the insertion of the source in the auction mechanism. The first program[12] was unsuccessful, and the second was mildly successful, contracting capacity and deploying it, albeit with a delay of five years in relation to schedule. It became clear that the low financial capability and cash flow of investors would need to be addressed to promote a successful insertion of wind or any other source in the Brazilian electricity mix (Dutra and Szklo, 2008; Ferreira et al., 2014; Hochstetler and Kostka, 2015; Martins and Pereira, 2011; Podcameni, 2014).

Regarding the cash flow mechanism, since 2004 the new regulated market is primarily expanded through auctions. Three principal auctions were determined: two with open competition between all sources, and therefore not suited for incipient ones; and one with restricted competition among some selected sources. This is the reserve energy auction (LER[13]), in which the safety of supply is increased. All types encompass long-term power purchase agreements (PPA). There are penalties for companies that have capacity contracted and fail to deliver the agreed amount of energy. In 2009, with a wind-exclusive auction, the source was first contracted. The scheme in response to cash-flow problems in Brazil for wind is an auction mechanism with related long-term PPAs (tenders) (ANEEL, 2016a; Dutra and Menezes, 2005; Held et al., 2014; Pinto Junior, 2007; Podcameni, 2014; Porrua et al., 2010).

It is important to notice that the main mechanism to promote renewables (LER auctions[14]) has been based on reserve auctions which the objective is to guarantee enough capacity in the system to attend point demand. It is not and it does not aim to be a mechanism with periodicity and volume calculated to guarantee specific flow of new renewables capacity in the system. It is security mechanism aiming to guarantee the system security adapted to promote renewable when it is possible. The advantage of this mechanism as it minimizes costs of introducing renewables in the system, the cons is that it does not give enough predictability about the pace of renewable capacity development.

Regarding the mechanism related to the financing of enterprises, the National Development Bank of Brazil[15] (BNDES) is an important player in the financing of the wind capacity contracted since the PROINFA. At the start of the program, it was established an “index of nationalization”. It was later abandoned: there was little domestic supply of the necessary components. After being abandoned, the financing of imported

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[11] Respectively, “Programa Emergencial de Energia Eólica” and “Programa de Incentivo às Fontes Alternativas de Energia Elétrica” in Portuguese. Pinto Junior (2007) has more information on Brazil’s early 2000’s electrical crisis. For more information on the programs, we suggest Podcameni’s (2014), Dutra and Skzlo’s (2008), Silva’s (2013), Hochstetler and Kostka (2015) reviews of them.

[12] Regarding specifically PROEÓLICA we recomend Kissel and Krauter (2006), Olz (2003), and Wachsmann and Tolmasquim (2003).

[13]Acronym for “Leilão de Energia Reserva” in portuguese.

[14] There has been some renewable energy auctions, but they happen less often than LERs.

[15] “Banco Nacional de Desenvolvimento Econômico e Social” in Portuguese.

equipment was recommended. The financial problems faced by investors led to the understanding that the use of BNDES' funds for infrastructure would be necessary for a sustained insertion of novel sources in the mix (Ferreira et al., 2014; Ferreira, 2017; Hochstetler and Kostka, 2015; Juárez et al., 2014; Podcameni, 2014).

In 2012 the BNDES elaborated a methodology for wind turbines based on weight and parts, with clear requirements, a calendar of progressive requirements and relatively low initial local content requirements. Furthermore, it was also a more flexible way to internalize and promote the source and the related industrial chain than the previously attempted index of nationalization. The scheme in response to financial problems in Brazil for wind is a public financing mechanism focused on the use of BNDES' funds for the development of infrastructure (BNDES, 2012; Ferreira, 2017; Hochstetler and Kostka, 2015; Podcameni, 2014).

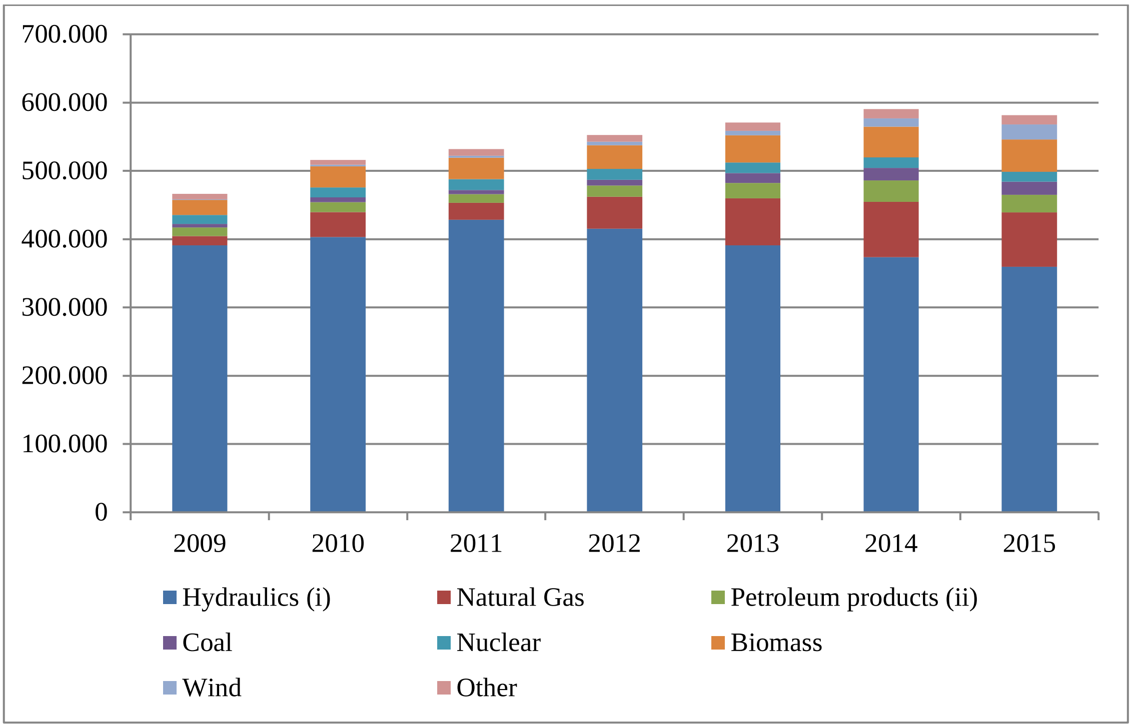
The auction mechanism for reserve energy, public financing mechanism (through BNDES) and progressive local content obligations compose the incentive framework for deployment of wind capacity and component industry in Brazil, however, it was possible after a period of specific (even if not so successful programs) and increase technological maturity of wind technology.

4.2 The realized expansion

The expansion is considered a success (EPE, 2016a; Ferreira, 2017; IEA, 2015). Since March 2009, the source rose in contracted capacity: from 1.8 GW in its first LER to over 13 GW in 2016[16]. The prices for the wind MWh indicate a downward tendency (ANEEL, 2016a; Ferreira et al., 2014). In October 2017, 11.55 GW (7%) was the wind installed capacity (ANEEL, 2017a).

The methodology for financing wind turbines was established by the BNDES in 2012, with already 5.4 GW and 1.8 GW of contracted and operational wind capacity respectively (EPE, 2014b, 2016a). The requirements were initially made upon items with low technological content or items that were already produced in Brazil[17]. This financing mechanism is understood as a determinant factor for the sustained growth of this source However, there is little effort done in regards to industrial policies that goes beyond the use of BNDES' funds for wind projects (Ferreira, 2017; Hochstetler and Kostka, 2015; Nascimento, 2015; Podcameni, 2014; SITAWI and CEBDS, 2016). According to Tomelin (2016) BNDES has financed 89% of the solar expansion in Brazil. The funding performed by the bank (over 6 billion dollars until 2016) was essential for the development of the source.

[16] For comparison, PROEÓLICA and PROINFA were not capable of contracting and deploying over 2 GW of wind capacity for 9 years. From 2000 until 2008, its capacity grew 379 MW, whereas, from 2009 until May 2017it grew over 9000 MW (ANEEL, 2017a; EPE, 2016a).
[17] Which is appointed by Podcameni (2014) as one a decisive factor for the successful deployments

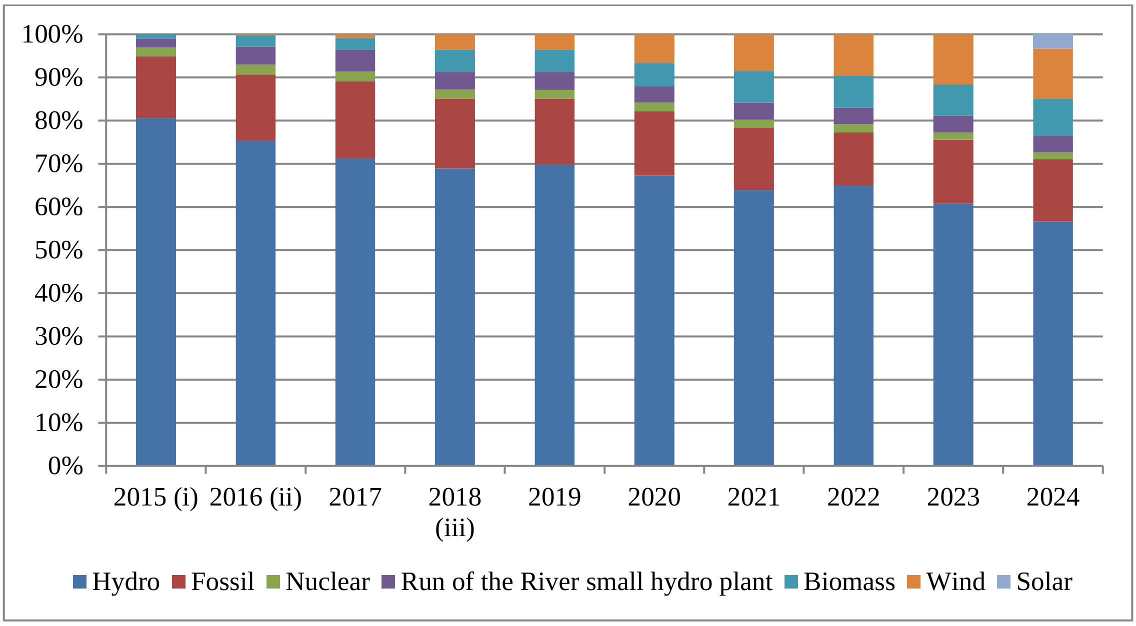


Graph 1- Power generation according to source - Brazil - 2009-2015
(i): including autoproduction
(ii): diesel oil and fuel oil
Source: Adapted from EPE (2014b, 2016a)

Graph 1 depicts its growth in Brazil. Between 2009 and 2015[18], wind grew its participation in the output: 64% annually in average, the highest average annual growth in the period for any source. The variation between 2009 and 2015 also appoints wind as the most prominent source: it ranks higher with a 1647% variation; being followed by natural gas (496%); coal (252%); and biomass (117%) (EPE, 2010, 2014b, 2016a). This growth is confirmed by the analysis of the evolution of capacity.

Similarly, it grew its participation in regards to capacity, from 0.6 GW (0.55%) to 7.6 GW (5.44%) between 2009 and 2015 (EPE, 2016a). Moreover, wind capacity grew 55.83% annually in average in the period, higher than any other source[19] (EPE, 2010, 2014b, 2016a).

[18] Currently, 2015 is the last year with a released National Energy Balance released for.
[19] Solar grew 122% annually in average in the period. However, its growth is not representative, as its capacity had yet to reach 0.1 GW.



Graph 2 - Planned last year of 10-year plan for the Brazilian electricity mix - % - Brazil - 2015-2024

(i): The 2015 PDE did not separate the run of the river hydro plants and wind plants
(ii): From the plan for 2016 on, the importation of Itaipu was credited inside the hydro capacity
(iii): There was no plan for 2018. We used data from the plan for 2019
Source: Own elaboration based on EPE (2006, 2007, 2008, 2010, 2011, 2012a, 2013, 2014a, 2014c)

Besides the increase of the current capacity, we also observe an increase of the planned capacity. The evolution of the 10-years expansion plan in Brazil (PDE[20]) shows an evolution of the expected increase in wind capacity, when compared to the documents published in 2011[21] and 2015 (depicted by Graph 2).[22]. It is expected that, in 2024[23], the wind farms installed capacity will add up to 24 GW, continuing its current growth[24] (EPE, 2015).

5 The second Brazilian case: the impaired Brazilian solar expansion

We now analyse the planned expansion for solar PV in Brazil. Brazil has a relevant solar resource in its continental country. It has a significantly higher average irradiation than Germany (a leading country in the use of solar PV), and the availability of land in Brazil is also higher (ABSOLAR, 2016; EPE, 2012b; Pereira et al., 2006). We analyse the planned and attempted expansion of utility-level solar PV. The Brazilian State, as

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[20] Acronym for "Plano Decenal de Expansão de Energia" in Portuguese.
[21] With the exception of the PDE 2024, all plans are established 9 years prior to its execution (e.g. the plan for 2022 was established in 2011). For the year 2018 we utilized the PDE 2019, as there were no PDE 2018
[22] For comparison, wind and biomass were respectively expected to comprise less than 4% and 1% (4.3 GW) of the Brazilian electricity mix. The actual numbers for the wind and biomass capacity in 2015 were: 5.4% (7.6 GW) and 9.4% (13.3 GW). In 2017, the difference between the planned and the realized is also notable regarding wind: 0.9% (1.4 GW) and 6.84% (10.4 GW) (ANEEL, 2017a; EPE, 2006, 2007, 2008, 2010, 2011, 2012a, 2013, 2014a, 2014c, 2016a).
[23] Currently, the last year with a related PDE published. The 2026 PDE is yet to be officially published, however, it also reinforces the growth trend in wind power generation (EPE, 2017).
[24] As of October 2017, wind comprises most of the capacity under construction Brazil: 3.41 GW and 30.44% (ANEEL, 2017a)

shown by EPE (2012b), perceived it as a more feasible mean to promote this source, rather than an expansion of distributed solar PV[25]. Similarly to the previous case, we first analyse the expansion as it was planned and then as of its current state.

5.1 The planned expansion

Regarding capacity, solar is underdeveloped. Currently, the solar PV capacity in Brazil is of 368 MW of utility-level capacity, with almost capacity belonging to: Enel, with 42.9% and Pirapora (a joint-venture between *Electricité de France* (EDF) and Canadian Solar Inc) with 40,7% (ANEEL, 2017a, 2017b). Solar PV has a planned installed capacity of 7 GW (3.3%) for 2024. It was the first year when it was explicitly considered in the PDE (EPE, 2014a).

Solar was supposed to enter into the traditional incentive framework for deployment of RES (IEA, 2015). It was expected to be inserted into the auction mechanism. This would contract the capacity and thus mitigate risk. Furthermore, a consistent calendar of solar auctions (at least 1 additional GW per year) would be the least necessary for a consolidation of this source as a viable option for the expansion of the Brazilian electricity mix. Similar to wind, the cash flow support scheme is an auction mechanism with long-term PPAs (EPE, 2012b; SITAWI and CEBDS, 2016).

BNDES was expected to finance the Brazilian solar expansion. The bank prepared and implemented a methodology for solar panels focusing on the funding of solar projects contracted by auctions. Enterprises would be able to access the Finem fund (Financing to Enterprises)[26] through its methodology, similar to wind power generation. Similar to wind, the support scheme for financing and funding of solar PV power plants is a public financing mechanism utilizing BNDES' funds (BNDES, 2012, 2014a, 2014b, 2017a; Reuters Brasil, 2017a).

5.2 The real dusk: the failure of the "technology-unspecific" mechanism and its consequences

Regarding the auction mechanism, specific solar auctions are considered a necessary, but insufficient incentive for the promotion of solar source generation (ABSOLAR, 2016; Jannuzzi, 2009; Sekiguchi, 2014; SITAWI and CEBDS, 2016). It is present in three auctions (all of them LER auctions), with 94 plants and 2,652.8 MW of installed capacity contracted. The auctions assure the demand guaranteeing: output (contracted for the regulated market); and price (through a long-term PPA) (Dutra and Menezes, 2005; EPE, 2012b; Jannuzzi, 2009; Moreno et al., 2010; Sekiguchi, 2014; SITAWI and CEBDS, 2016).

Among the companies that won the three auctions involving solar PV, LER 08/2014, LER 08/2015 and LER 09/2015, there are four main companies, as depicted by Table 1. Those are: the Italian group Enel; Canadian Solar Inc; Lintran do Brasil

[25] GTM Research (2017) understands that this preference is due to a greater possibility of centralized planning, being common throughout Latin America.

[26] "Financiamento a empreendimentos" in Portuguese.

Participações S.A., a subsidiary of a Spanish company; and the French Solairedirect. The French company Électricité de France (EDF) is also present in some consortia alongside Canadian solar Inc. There was over 4 billion dollars of planned investment involved with the solar power plants, with over 50% allocated in the top four companies. The contracted capacity was expected to enter into operation between 2017 and 2019 (ANEEL, 2016a; Reuters Brasil, 2016a).

Companies	Plants		Potency		Investment in Apr. 2017 US$(i)	
	Units	%	MW	%	$1,000.00	
Enel	22	23.40%	619.98	23.64%	$	1,275,460
Canadian Solar Inc	11	11.70%	329.97	12.58%	$	492,619
Lintran do Brasil Participações S.A.	9	9.57%	269.97	10.29%	$	428,599
Solairedirect SAS	7	7.45%	199.98	7.62%	$	301,083
Sune Solar B.V.	5	5.30%	148.57	5.66%	$	205,777
Renova Energia S.A.	5	5.32%	129.59	4.94%	$	228,241
STEELCON	3	3.19%	90.00	3.43%	$	205,751
Rio Energy EOL IV Geração e Comercialização de Energia Ltda	3	3.19%	89.91	3.43%	$	156,362
European Energy A/S	2	2.55%	60.00	2.29%	$	121,393
Fotowatio do Brasil Projetos de Energia Renováveis III Ltda.	2	2.13%	60.00	2.29%	$	104,065
SPE CESP COREMAS	2	2.13%	60.00	2.29%	$	95,816
Grupo Gransolar S.L.	2	2.13%	60.00	2.29%	$	86,781
Kawa	2	2.13%	54.00	2.06%	$	83,276
Companies with less than 50 MW of contracted capacity (38)	19	19.82%	450.93	17.19%	$	856,302
Total	94	100%	2622.89	100%	$	4,641,524

Table 1 - Contracted capacity of solar PV at LER auctions - MW, %, US$ 1000 - Brazil - 2015-2016

(i): corrected by the IGP-M index and the exchange rate of April 28th 2017.

Source: Own elaboration based on ANEEL (2016a)

Therefore, between 2014 and 2015, solar PV was successfully inserted into the auctions in Brazil selecting winners. From the first to the last auction, the average MWh price has fallen in US$ 10 according to ABSOLAR (2016). The contracted capacity had an assured demand, and was therefore guaranteed. This indicates that part of the incentive framework for solar PV functioned between 2014 and 2015 (ANEEL, 2016a, 2017b).

However, in 2016, no solar PV capacity was contracted. There was only one LER that year, which contracted run of the river small hydro plants and thermoelectric plants. The second LER was delayed and then cancelled, because of a decrease in the demand for electricity. Brazil later promoted a "Cancellation" Auction, where agents could bid to forego projects without the usual penalties, however, fewer solar PV projects were cancelled than expected (less than 300 MW total). It was not nearly as successful as expected, which raises serious questions about the upcoming auction for December 2017. Therefore, the auction tool, regardless of an initial success in contracting solar capacity, is currently in an uncertain state (Bloomberg new energy finance, 2017; EPE, 2016b, 2016c).

Regarding the financing mechanism, in April 2017, the first disbursements of BNDES towards solar PV were analysed. They encompassed, in May 2017, the first disbursement of the bank towards solar PV power plants, three years after the elaboration of the methodology and two years after the financed power plant (Pirapora Solar PV power plant) was contracted. Pirapora has some parts of the investment delayed (it is a solar complex composed of ten solar PV power plants) and BNDES is not financing all the enterprise: only the Pirapora V, VI, VII, IX and X. The Pirapora II, III and IV have yet to being its construction, and the remaining plants of the complex (Pirapora I and VIII) were not contracted in the auction (ANEEL, 2017c). The total disbursement for the project is 20 million dollars, meaning the participation of 79.82% of the bank in the financing of the project, near the maximum possible participation (BNDES, 2017b; Reuters Brasil, 2017b).

The public funding of power plants is linked to the internalization of its industrial chain[27]. In 2016, no national manufacturer was able to provide panels for those enterprises. In May 2016, BNDES expected to have, until the end of the year, three manufacturers in the country able to produce panels according to the local content criteria. In the second semester of that year, only Canadian Solar Inc started to build its first production facility in the country, according to local criteria. Completed in December 2016, it is able to produce up to 350 MW of solar modules per year. However, in January 2017, the local content requirements were supposed to be increased. The facility was not developed to produce solar modules according to the local content criteria of 2017, but to that of 2016. Had the local content requirements been increased[28], the economic viability of the facility will be highly jeopardized: without subsidy, the domestic panels are at least 15% more expensive than Chinese panels (Bloomberg, 2016; BNDES, 2014b; Canadian Solar Inc, 2016; PV Magazine, 2016; Reuters, 2016; Reuters Brasil, 2017a, 2016b; SITAWI and CEBDS, 2016). Therefore, the current situation of the traditional financing mechanism is highly uncertain and deficient. In sum, both mechanisms of the incentive framework appear to not be working properly, especially the public financing mechanism.

We now analyse the numbers and figures for the impaired expansion. We first analyse the capacity in regards to restrictions for entering into operation. We then analyse the capacity according to schedule and construction.

According to the auction's results, up until September 2016[29] there was 2652.8 MW contracted for commercial operation beginning in 2017 and 2018. However, the

[27] According to Hochstetler and Kostka (2015) and EPE (2012b), the fact that Brazil is currently unable to refine solar-grade silicon is the largest constraint to the sustained implementation of the solar PV industrial chain in the country.
[28] We later discuss the June 2017 revision of the methodology.
[29] From September on there were later auctions, but none had solar farms as winners (EPE, 2016c, 2016b).

figures clash with the planned expansion and the insertion of solar in the Brazilian electricity mix has failed (ANEEL, 2016b, 2016a, 2016c, 2016d, 2016e, 2015; Hochstetler and Kostka, 2015).

		2017		2018		2019	
		No restrictions	Some restrictions	No restrictions	Some restrictions	No restrictions	Some restrictions
Capacity (MW)	2016 Forecast	202.00	885.99	0.00	1029.47	0.00	835.66
	2017 Forecast	483.40	0.00	580.00	971.46	0.00	506.00
Difference between both years	MW	281.40	-885.99	580	-58	0	-329,66
	%	139.31%	-100%	-	-5,6%	-	-39,4%

Table 2 - Forecast for entry into operation - 2017-2019 – Brazil

Source: Own elaboration based on ANEEL (2017b, 2016f)

Regarding the viability of enterprises, tables 2 and 3 display a concerning figure: only 7.34% of all planned solar capacity had no restrictions for entering operation in 2017 according to the conditions in 2016. The revision of 2017 showed a less problematic situation in which the capacity expected to enter into commercial operation that year (2017) has more than doubled. This means that 2017 has no solar PV capacity with restrictions. However, it is clear that the capacity previously forecasted to enter into operation in 2017 was relocated to 2018, if not given the "no forecast" status.

		No forecast Severe restrictions	2017 Total	2018 Total	2019 Total	Total
Capacity (MW)	2016 Forecast	0.00	1087.99	1029.47	835.66	2953.12
	2017 Forecast	439.66	483.40	1551.46	506.00	2980.52
Difference between both years	Δ	439.66	-604.59	521.99	-329.66	27.40

%	-	-55.57%	50.70%	-39.45%	0.93%

Table 3 - Total forecast for entry into operation - 2017-2019 – Brazil

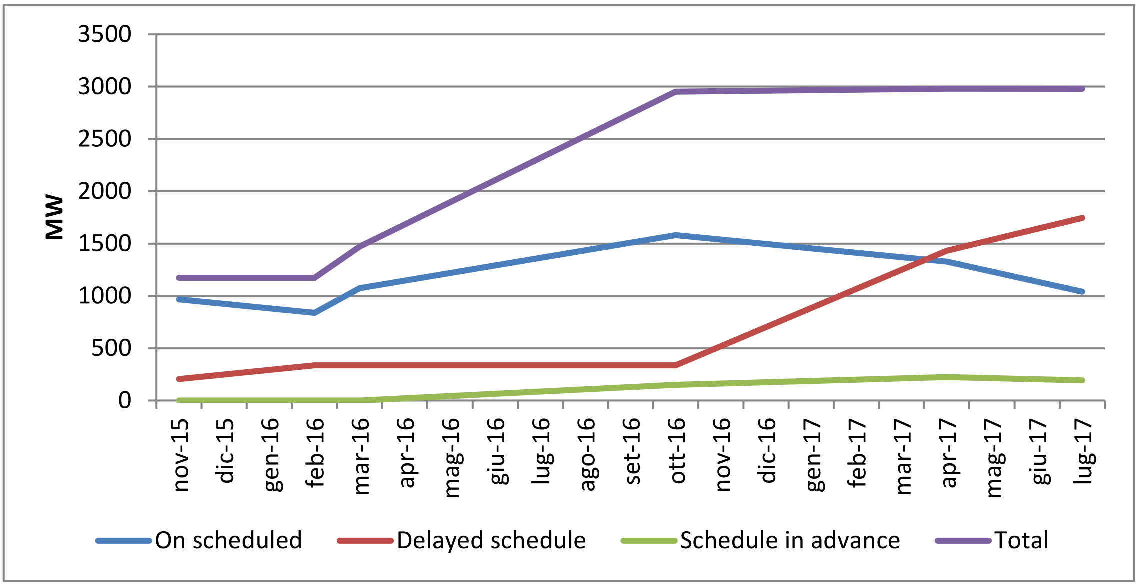
Source: Own elaboration based on ANEEL (2017b, 2016f)

In sum, out of the 2980 MW forecasted to enter into operation between 2017 and 2019, only 35.67% (1063.4 MW) of all solar capacity had no restrictions to enter into operation when scheduled. The capacity with some restrictions to enter into operation remains the larger out of the three groups (without restrictions, with some restrictions and with severe restrictions): 2,751.1 MW (93.16%) and 1,477.5 MW (49.57%) respectively in 2016 and 2017 (ANEEL, 2017b, 2016f).

ANEEL (2016d, 2016e, 2016c, 2015) analyse the expansion of planned plants by: viability (probability of entering operation on schedule); schedule (how close the construction is to its schedule); and progress of construction (if they are on construction or not, or halted). Analysing the commitment to schedule and the progress of construction of the Brazilian solar plants, the numbers are concerning: before October 2016, there were no solar PV plants under construction (ANEEL, 2016e). All 9 plants under construction (270 MW total) were owned by the Enel Green Power.

In April 2017, the number of solar power plants under construction grew to 37 plants (1063.4 MW), however, the plants not under construction were still the majority, with 86 plants (1917.15 MW). Out of the 3 GW planned expansion, only 35% were under construction, however, 60.22% of all solar PV capacity had a delayed schedule. In comparison with the wind source, in April 2017, 3091.5 MW (41.13%) of the capacity was under construction (145 power plants), and 40.84% of the capacity (3,070 MW) had no restrictions to enter into operation accordingly to schedule. Lastly, out of the total capacity of all sources with restrictions to enter into operation by 2018 and 2019 (5,178.4 MW), solar PV power plants constitute almost 30% of the total (1,477.46 MW) (ANEEL, 2017c, 2017d, 2017b, 2016g, 2016e). The data for July 2017 only corroborates this analysis: 1041 MW were on scheduled, in contrast to 1745 MW with a delayed schedule; and over half of all capacity had yet to begin construction (1802,03 MW or 60% of the solar PV capacity analysed) (ANEEL, 2017e). According to Aneel (2017a), as of October 2017 the solar PV capacity under construction and yet to begin construction are 911 MW and 1651 MW respectively. We reiterate that these number are from after the cancellation auction and the start of operation of the most prominent plants (the 148 MW of Enel[30] and the 150 MW of BNDES' financing EDF and Canadian Solar Inc joint venture)

[30] The company also has more than 50% of the solar PV capacity under construction (ANEEL, 2017a)



Graph 3 - Solar PV capacity regarding its schedule to enter into operation - MW - November 2015 to July 2017 – Brazil

Source: Own elaboration based on ANEEL (2017c, 2017e, 2016c, 2016d, 2016e, 2015)

From graph 4, it is clear that, even if the number of power plants (and capacity) is rising, schedule is becoming problematic. The number and capacity of solar PV power plants with a delayed scheduled has surpassed the power plants on schedule: as of July 2017, the solar PV capacity on schedule and with a delayed schedule are 1041.36 MW (41 plants) and 1745,07 MW (59 plants) respectively. This tendency has no reasonable signs that it will stop in the near future (ANEEL, 2017c). Therefore, the construction risk appointed by Gatti (2013) is present: most projects are expected to delay its completion.

In conclusion, the investments in solar farms are falling short in regard to their viability, commitment to schedule and expected beginning of commercial operation. Expanding such source to 2.65 GW of installed capacity between 2017 and 2018 seems rather unlikely. Even if all capacity with no restrictions to enter into operation when scheduled does commit to it, the expansion would be of less than 1 GW between 2014 (the year of the first auction) and 2018: less than a third of all contracted capacity. It confirms our analysis of an evolution of investments much slower than expected, alongside with performance issues. That jeopardizes the planned expansion of such source and therefore the internalization of the industrial chain: to reach 7 GW of solar PV capacity in 2024, as according to plan, the source would need to, in the best-case scenario, grow more than 600% in only six years. The only domestic facility capable of providing the necessary PV panels for these enterprises produces 350 MW of PV panels per year maximum. The factory cannot provide for the full planned expansion and there are no signs of new solar PV panel manufacturers planning to install factories in Brazil.

We consider the incentive framework for solar not a technology-neutral mechanism, as it is purposefully devised for solar. However, it is not technology-specific either, as the specificities and characteristics of solar were clearly disregarded when it was implemented: the inspiration in the prior wind case is evident. The public financing mechanism for solar is clearly adapted from the previously successful public financing mechanism for wind. It is therefore a technology "unspecific" mechanism.

6 PV solar challenges within the wind successful framework

There are two severe problems with the promotion of RES in Brazil: on the revenue-stream side (related to the cash flow mechanism, i.e., auction and tender mechanism); and on the financial market (related to the financing and funding mechanism, i.e., public financing mechanism). There are policies to deal with both challenges: generation auctions (with PPAs) and public financing. The auctions associated with PPAs play an important role in the current expansion of Brazil's installed capacity. Also, through the auction, the winners have the potential to access special state financing lines. This is cardinal in order to promote infrastructure in the country (Held et al., 2014; IEA, 2015; Vazquez et al., 2016). However, even if solar generation has been contracted through the auctions, the BNDES financing mechanisms has been hardly accessed in practice and plants construction is delayed. We will justify this situation using the reasoning developed in section 3 to motivate technology-specific policies.

6.1 Regarding technology

Solar was left out of PROEÓLICA and PROINFA programs in the early 2000's. This is a relevant factor for the differences in markets for power sources in the country: solar, unlike wind, was not incentivized since the early 2000's; only since the mid 2010's (Hochstetler and Kostka, 2015; Nascimento, 2015; Pinto Junior, 2007).

Regarding the lock-in status of hydro in Brazil, it is being successively weakened by the policy makers (ANEEL and EPE) and by BNDES through planning, auctions and public financing (EPE, 2016a). This confirms the active role of policy makers and public organizations in the lock-in process, as theorized by Arthur (1989, 1988) and stated by Mitchell and Woodman (2010) for sustainable power sources. The role for alternative RES can be of a niche market, but larger deployments for both wind and solar are expected. It was expected to enter into the Brazilian electric mix, according to EPE's (2014a) plan for 2024. Moreover, Martins and Pereira (2011) corroborate the importance of the objectives and goals stipulated by the policy-makers related to the deployment of alternative RES-E sources.

This has been enough to promote wind generation, in which we observe a relatively mature industry with high internalization: the Brazilian industry is able even to export some components to other countries. On the contrary, solar technologies do not have expertise and industrial organization for it. The absence of auctions continuity (which is important for the demand stability to components industry) represents a difficulty for wind generation, but is even more acute for solar panels (EPE, 2012b; Held et al., 2014; Hochstetler and Kostka, 2015; Huenteler et al., 2016b; Pinto Junior, 2007; SITAWI and CEBDS, 2016).

The absence of industrial components in Brazil for solar can be observed by its low number of PV solar patents (De Paulo et al., 2016; UNEP and EPO, 2014). Regarding the scientifically and research situations in Brazil, Nascimento (2015) understands that there is a clear gap between wind power and solar power research when comparing Brazil to the rest of the world. Moreover, the country is not very relevant in terms of cooperation for patent filings in solar power generation, which could be a mean to improve research. The solar market in Brazil is still incipient, which, alongside its weak R&D situation in such area, can restrict a future Brazilian solar industry to a less dynamic state than other prime mover countries. Brazil has, on the contrary, currently a reasonable position regarding the industrial chain for wind: with over eight suppliers with various factories located in the south-eastern, southern and north-eastern regions. The country has a well-established supply chain for hydro power generation and a general electric equipment supply chain necessary for the deployment of power plants (ABDI, 2014; EPE, 2012b; Ferreira, 2017; Podcameni, 2014).

Considering risk a function of the maturity of a technology and of its complexity, Lehmann and Söderholm (2015), Gatti (2013), solar PV has currently more risk as a technology than wind: solar PV has more complex industrial processes (especially the refining of silicon), (Hochstetler and Kostka, 2015; Huenteler et al., 2016b); and wind has a more mature industry than solar PV (Cleantech Group, 2016; Helm et al., 2014; Huenteler et al., 2016a).

Besides facing different technological risk profiles, Huenteler (2016b) shows that domestic markets are more important to wind, whereas solar depends more on the growth or size of markets for a larger deployment[31]. However, in Brazil, the financing mechanism for solar and wind is institutionally tied to a certain degree of internalization of the supply chain in the country (BNDES, 2014a, 2014c, 2012). Solar has a more challenging supply chain to internalize than wind, having a production process with higher complexity, however it is offered the same incentive as wind: internalize its supply chain in order to be deployed in Brazil. This worked for wind, but is problematic for solar PV. Also, the current price of solar panels in the country is an important non-regulatory economic constraint, which makes it less competitive than other sources in Brazil, although all components show signs of reduction of cost internationally. (ANEEL, 2016a; EPE, 2012b; IEA, 2015; IRENA, 2016; Reuters, 2016; Reuters Brasil, 2017a; SITAWI and CEBDS, 2016).

6.2 Regarding capital markets

The BNDES plays an important role regarding the electrical sector in Brazil (Campos Neto, 2016; Hochstetler and Kostka, 2015; IEA, 2015; Mazzucato and Penna, 2015; SITAWI and CEBDS, 2016; Tomelin, 2016). Since the bank's financing schemes have lower interest rates than most private financing mechanisms, accessing its financing lines is essential to most infrastructure companies in Brazil, due to the high interest rates in the country (Trading economics, 2017; Vazquez et al., 2016).

Although we observe significant differences between solar and wind projects, BNDES uses an essentially equivalent mechanisms to determine financing sources. We

[31] Also because the transportation costs associated with solar PV equipment are much smaller when in comparison with the transportation costs of wind turbines equipment.

observe that the slight modifications have not been enough: there is lack of financing (BNDES, 2017b, 2017c; SITAWI and CEBDS, 2016). This is indicated by the fact that most solar PV plants under construction are not financed by BNDES and are highly concentrated: 70.9% of all solar PV capacity under construction as of October 2017 belongs completely to Enel Green Power, whereas the company has participations in others plants under construction (ANEEL, 2017a).

6.3 Results and discussion

There are signs that the cause for the impaired Brazilian solar expansion is internal. The Brazilian exchange rate grew steadily since the first auction[32] (IPEADATA, 2017). This made imported PV panels, an option to BNDES' funded domestic panel, an unfeasible possibility. However, it does not impact in the outcome of the mechanism regarding the internalization of the value chain: were the exchange rate low, the companies could easily import solar panels. Additionally, even if most auction winners are foreign companies, the traditional mechanism is the BNDES, which means that they entered the auctions counting on such mechanism: using other financing sources is a second best option (for the few companies capable of such, as the Enel group). Lastly, solar PV was largely deployed in Latin America (especially Chile and Mexico) with basically the same players as the ones contracted in the Brazilian auctions (Enel, EDF, Solairedirect for example) during the same period Brazil struggled to finance its already contracted capacity (Cleantechies, 2016; EDF Energies Nouvelles, 2015; Enel Green Power, 2015a; GTM Research, 2017; IEA, 2015).

EPE (2012b) predicted the growth of solar PV based on the success of the prior success of wind power generation. Similarly, BNDES (2014a) was optimistic about the solar expansion[33] in the country, drawing conclusions from the prior success of wind power. Although both sources are RES-E, the differences between them are enormous and to adapt a methodology from one source to other made little sense(Gawel et al., 2017).

We understand that this is the cornerstone of the financing problems regarding the Finem fund and the funding of solar farms. By not respecting the economic and technical differences between both sources, BNDES developed an unsuited mechanism for the financing of solar power generation, as the lack of companies accessing such fund suggests. We emphasized that there is already contracted demands for solar power generation, with schedules for construction and for entering commercial operation, alongside established and well-known penalties and sanctions for delayed or abandoned projects. The lack of financing by BNDES for majority of projects can be appointed as a the reason for their several delays and high uncertainties regarding its schedule (ANEEL, 2017a, 2017b, 2016b, 2016e, 2016a; Hochstetler and Kostka, 2015; Reuters Brasil, 2017b, 2017a; SITAWI and CEBDS, 2016).

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[32] Sitawi and CEBDS (2016) expand upon the analysis of the different macroeconomic situations of the start of wind and solar expansions.

[33] Furthermore, the deployment of solar PV was linked to the internalization of its value chain, an unfeasible short-term objective for the source (BNDES, 2014c; Huenteler et al., 2016b).

The contracted capacity took four years to have its first capacity financed by the bank. The financing mechanism for solar PV, in relation to the financing mechanism for wind: shared the same fund (Finem fund); and had more favourable conditions for financing (higher participation of the bank, larger amortization period, etc.).

The financing of wind by the bank happened as early as the PROINFA program was started, prior to the establishment of a clear methodology and to the establishment of an auction mechanism. When BNDES established a methodology for wind turbines, it rapidly started financing wind projects in Brazil. The methodology for wind was created three years after the first auction with wind projects among the winners and more than ten years after the first incentive program for wind, whereas the methodology for solar was implemented in the same year that solar PV capacity was first contracted[34]. When the methodology for wind turbines was established, there were already 1.4 GW of wind capacity deployed, whereas, when the methodology for solar panels was established, there was only 5 MW of installed solar capacity. Timing is not an issue, as well as flexibility: the institutional learning acquired by the bank permitted it to developed more flexible methodologies (ANEEL, 2016a; BNDES, 2014c, 2014a, 2012; EPE, 2016a; Podcameni, 2014).

BNDES fails to incentivize the internalization of this industrial chain and also hinders the construction and expansion of the solar power generation. The bank fails to achieve its local content objective (industrial policy) and by consequence implies on the failure of the electrical mix objective (its expansion). Therefore, the bank, the regulator and other instances of decision and policy makers have to decide its short-term and long-term objectives: to incentivize a local industry of PV panels, a highly concentrated market that would require a serious development plan; or to promote the use of solar source in the country, by allowing and financing imported solar panels.

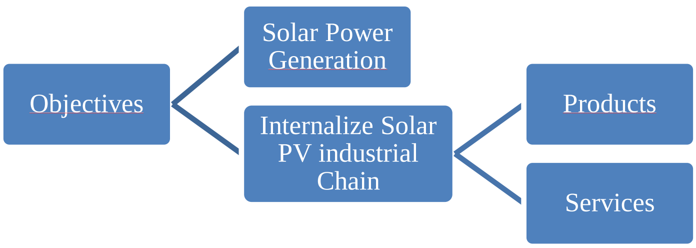

Figure 5 - Possible objectives of the solar PV expansion - Brazil - 2013-2017

Source: own elaboration

A possible revision would be to focus on assembly and installation of modules as the local content initial incentive, as it is a far less technological demanding step but an

[34] In 2013, the northeastern state of Pernambuco promoted a state auction for solar. It contracted five projects, including the ones which are currently the only utility-level deployments of solar PV in Brazil: Fontes Solar I and Fontes Solar II (Governo de Pernambuco, 2013). They were built by ENEL near its first wind project, therefore cutting costs related to the connection to the grid, and were inaugurated in 2015 (Enel Green Power, 2015b). However, both projects were not considered an expansion of the grid regarding power plants by ANEEL (2017b).

important one: in Europe, a large portion of the aggregate value is added on site[35]. According to EPE (2012b), about 50% of the aggregated value of a PV system corresponds to electromechanical components, engineering, assembly and margins of the vendors, added at the installation site. A focus on services as the authorization criteria could be a possibility to make the expansion of solar PV likely to happen while internalizing to some degree parts of its value chain[36]. The fact that PV panels are becoming less expensive[37] every year only contributes to this.

BNDES[38] needs to revise its methodology. First the objectives regarding the expansion of solar PV in Brazil must be more clearly defined, and then the methodology (specially the access criteria) must be changed accordingly. If the objectives and mechanisms ignore the fact that solar PV has its own features and traits unlike those of other sources, the expansion will be jeopardized. Similarly, in the case of incompatible objectives and mechanisms.

7 Conclusion and policy implications

The Brazilian case for solar shows that appropriating for solar an incentive mechanism tailored for wind, even with both sources being intermittent RES, can lead to problems, as the failing of the financing mechanism (part of the incentive framework) shows. An incentive mechanism heavily inspired by the wind case and not crafted for the specificities and characteristics of the solar PV technology has led to delays and uncertainty.

A feasible expansion can be made possible by congruity between (short- and long-term) objectives, mechanisms (including the local content policy and access criteria for public funds) and the technical and economical specificities and characteristics of the source. Brazil cannot disregard the specificities of solar, especially because of its failures regarding technologies and capital markets, which makes a technology-specific mechanism more cost-effective than a technology-neutral or a “technology-unspecific”. Furthermore, the success of wind and its technology-specific incentive mechanisms is an example of the possibilities of the solar PV expansion if its mechanism was tailored for the technology and proposed in accordance to feasible objectives.

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[35] As an example, in the largest European solar PV power plant, located in France, most of the investment went towards services (assembly, engineering services, irradiation measurement services, etc.), as the CEO of the company responsible for the enterprise, Neoen, Xavier Barbaro states (Reuters, 2015).

[36] We acknowledge that most if not all services must be done inside the Brazilian Territory, what would automatically met local content requirements. It would solely act as an authorization criteria, incentivizing the services related to solar PV and, consequently, this source. It would also bypass the hindrances discussed without foregoing completely of an authorization criteria, which could be revised. Afterwards, the internalization of other parts of its value chain could come into place.

[37] There are a great number of authors and reports on the subject. We recommend IEA (2015), MITEI (2015), and IRENA (2016) for more information on the matter.

[38] We do not address the overreliance of companies on the Finem fund. We stress the problems related to the financing of infrastructure and renewables in Brazil addressed by Tomelin (2016). For more information on the matter, we recommend Vazquez et al (2016).

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