3rd International Conference on Public Policy (ICPP3)

June 28-30, 2017 – Singapore

Panel T01P10 Session 2

Systems Theory and Modelling for Public Policy: System Dynamics, Agent-based Models, and Other Approaches

Title of the paper

The relationship between finance and industrial policy in the promotion of renewable technology: an agent-based model for the challenges to promote photovoltaic in Brazil

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Date of presentation

2017-06-30

The relationship between finance and industrial policy in the promotion of renewable technology: an agent-based model for the challenges to promote photovoltaic in Brazil

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Abstract

From the notion of "lock-in / lock-out" of Arthur, and through the theoretical reference of the Dynamic Capabilities of Teece, Pisano and Shuen, we try to verify the lock-out of the photovoltaic generation in Brazil, simulating a possibility of agents learning. In the country, there are two mechanisms for an expansion of the installed capacity of centralized generation: auctions for the contracting of power plants; and public financing offered by the National Development Bank (BNDES). Particular attention is given to the role played by BNDES, currently generating obstacles for companies that depend on it to complete their works. Dependence on the bank is common in the sector: around 60% of the works completed after a reform of the Brazilian electricity sector (SEB) were financed by BNDES and 90% in relation to wind. An agent-based model is used. The possibilities of learning are extracted from the simulation: firms in relation to obtaining new forms of financing; and BNDES in relation to the change in its methodology. The concepts are applied in relation to the Brazilian electric sector by analyzing the lock-out of centralized photovoltaic generation.

1. Introduction

Solar PV is a renewable source that utilizes sunlight to produce electricity, without noise or negatively impacting upon the wildlife (unlike wind, an important renewable source) and without emitting greenhouse gas or pollutants (unlike fossil sources, such as gas and oil). Brazil is a country with a largely clean and renewable electricity mix, i.e., its installed capacity. The hydro source is historically important in the country (until the

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early 2000's, over 80% of the mix was composed by hydro), however, a sustainable expansion of hydro plants (with dams) is unfeasible because of environmental problems. Since mid 1990's other sources have begun to grow, however, until mid 2000's, most of this non-hydro expansion was based on fossil-fueled power plants. Afterwards, biomass power generation started to be reasonably introduced into the mix. The Brazilian electricity mix should grow accordingly to the growth in demand for electricity. Moreover, its growth is not only expected but planned by State.

Since the late 2000's, there has been a great expansion of wind power generation in Brazil, planned by the State and performed by private companies. The country successfully inserted wind power generation into its electricity mix, alongside with a reasonable internalization of its value chain. The other important new renewable source, solar PV, should currently be undergoing its first steps towards a similar expansion in the country, according to State planning. Therefore, the same was expected for solar: to be inserted in the mix; while internalizing its industrial chain.

Brazil aims to foment solar farms taking advantage of its high potential for solar energy and the institutional importance of the National Bank of Development[1] (BNDES) regarding the funding of infrastructure projects. The development of new industrial chains is institutionally tied (through the traditional mechanism) to the development or insertion of the source in the mix. However, most of the Brazilian solar expansion currently has low viability, especially in regards to the schedule and construction rhythm of its already contracted solar farms. Most are not currently under construction, some projects are halted and the few being constructed are actually importing solar PV panels, bypassing the traditional mechanism and not internalizing an important and advanced value chain.

The scope of this work refers to centralized solar photovoltaic (PV) power generation, also known as utility-level solar PV. Brazil relies heavily on a traditional model of generation with large centralized power plants. Moreover, the main objectives of grid-connected centralized and distributed PV generation are different: centralized power generation aims to generate and transmit energy from the power plant to the consumer; whereas distributed power generation aims to reduce the dependence on the grid or the consumption of electricity (from the grid) through self-production and self-consumption. Distributed solar PV involves more types of agents, more complicated mechanisms and tools. Lastly, distributed solar PV is expected to grow at a lower rate and to a lower capacity than its centralized counterpart.

Therefore, we analyze the reasons behind the Brazilian impaired solar PV expansion. As such, this article is divided in five sections, apart from this introduction. In the first section we analyze the technical and economical differences between solar and wind power generation. We then analyze the framework for deployment of renewables in the country. Then we investigate the evolution of solar developments. We then analyze the compatibility between financing mechanisms and financing objectives

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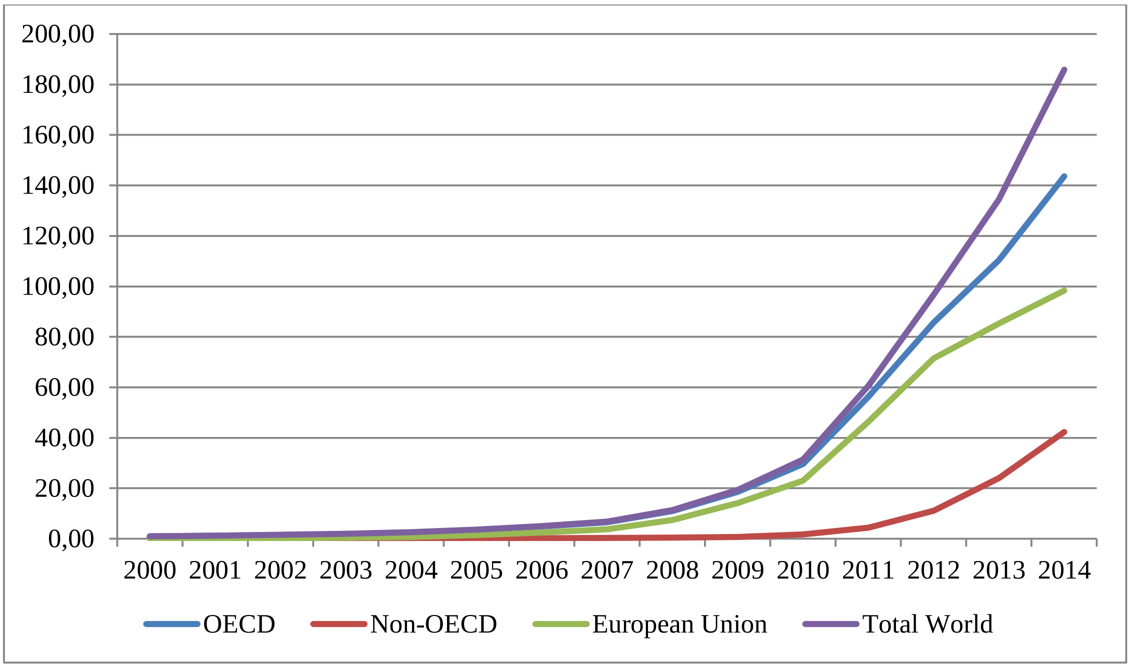
[1] "Banco Nacional de Desenvolvimento Econômico e Social" in portuguese

in regards to the internalization of the chain and the current events. Lastly, we present our closing remarks.

2. Current utility-level PV generation lock-out situation in Brazil

Solar Photovoltaic (PV) transforms sunlight (diffuse horizontal irradiation) into electricity. This process happens in the solar cells, which can be made of silicon (about 90% of the industry) or other materials (e.g. thin film). Distributed solar PV is common; however, utility-level solar PV has economies of scale and scope related to it, as well as a larger output. This source is also intermittent, producing no noise but having a large variability: its output varies 50% to 70% in between 2 to 10 minutes of production. Like wind turbines, geographic dispersion and interconnections can reduce this problem. Its industrial chain is highly concentrated, having few companies capable of refining solar-grade silicon (over 99.9999% purity) and also few capable of manufacturing solar modules. Its patent filings exceed those of all other renewables worldwide and in the most important offices, however, there's no clear technological path defined for solar PV. There's a smaller concentration of patent in the top 20 patent owners than in wind. Solar PV is not considered a mature industry (ABSOLAR, 2016; Baker et al., 2013; Cleantech Group, 2016; EPE, 2012; Eurostat, 2017; Green and Staffell, 2016; GTM Research, 2016; Helm et al., 2014; IEA, 2015, 2015; Jannuzzi, 2009; MITEI, 2015; Pepitone, 2016; Tolmasquim, 2016; UNEP and EPO, 2014).

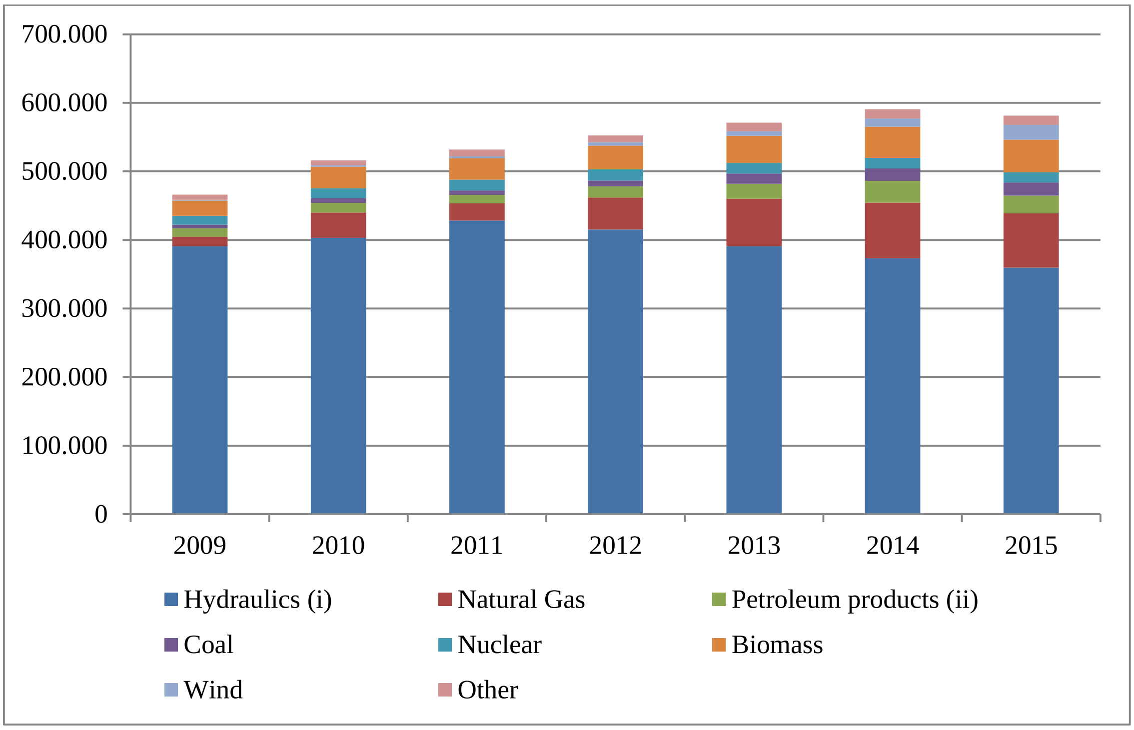
Graph 5 – Solar PV power generation – TWh – World – 2000-2014



Source: Own elaboration based on BP (2015)

Worldwide, solar PV started a sustained growth in the late 2000's, albeit at lower values than wind. In 2014 it reached 185.9 TWh of output worldwide (143.6 TWh in the OECD). Since 2010 solar PV has experienced exponential growth, lead especially by OECD countries, notably by the European Union countries. Since 2013 the non-OECD countries have started to generate exponentially larger outputs of solar PV electricity (BP, 2015; IEA, 2015).

Graph 2 – Power generation according to source – GWh – Brazil – 2009-2015



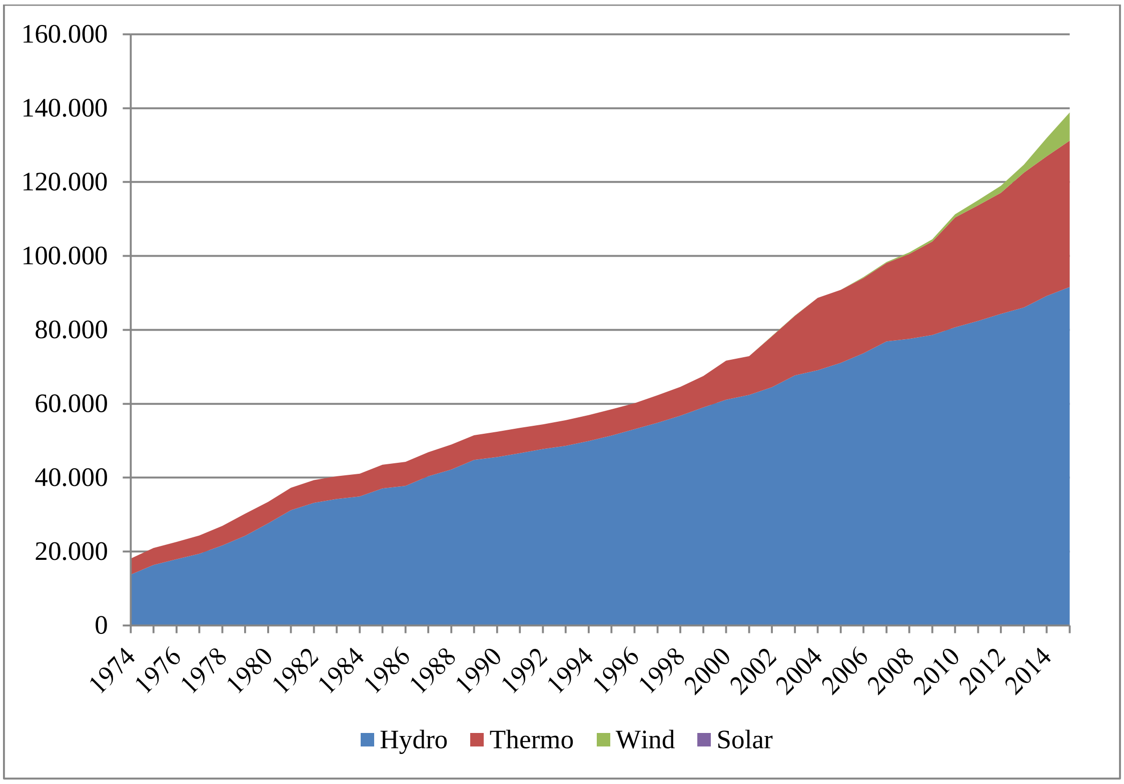
(i): including autoproduction

(ii): diesel oil and fuel oil

Source: Adapted from EPE (EPE, 2014a, 2016a)

Europe has a large share of distributed solar PV, which is not the case for Latin America. Utility-level solar PV was instead preferred because of ease of planning and deployment related to a centralized decision framework. Brazil has favorable potentials and deployments for most renewable sources: it largely uses hydro power; and it is promoting wind power generation in a rapidly growing context (EPE, 2014a, 2016a; IEA, 2015; Joskow, 2008; Martins and Pereira, 2011). Since 2012 Brazil has been planning to start deploying solar PV power plants to take advantage of its enormous solar potential (EPE, 2012, 2014b, 2016a; GTM Research, 2016; IEA, 2015; Martins and Pereira, 2011, 2011).

Graph 3 – Power capacity according to source (hydro, thermo, wind and solar) – MW – Brazil – 1974-2015



Source: Adapted from EPE (2016a)

Regarding both the capacity and the generation, it is clear that solar is still an incipient source in the country, as shown by table 4. The solar PV capacity is of only 23 MW as of 2017, and it generated 0.59 TWh in 2015, having less than 0.1% of capacity and output (ANEEL, 2017a; EPE, 2016a).

Table 1 – Electricity generation by source – TWh – Brazil – 2009-2015

TWh	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Renewables	364	393	390	415	437	463	456	438	432	430
Biomass and others	14.77	18.01	19.52	22.64	31.55	32.24	35.29	40.47	46.38	49.03
Wind	0.24	0.66	1.18	1.24	2.18	2.71	5.05	6.58	12.21	21.63
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06
Hydro	349	374	370	391	403	428	415	391	373	360

Source: Adapted from EPE (2016a)

We now analyze the planned expansion for solar PV in Brazil.

2.1. The planned expansion

Regarding capacity, solar is extremely underdeveloped. It has currently 23 MW of capacity in the country, with most plants being off-grid or micro and mini-generation applications. There are only two plants with a utility-level capacity: Fontes Solar I and

Fontes Solar II, both with 5 MW of capacity (ANEEL, 2016a, 2017a). 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, 2014b).

Externalities, a type of market failure, validate the use of support schemes or incentive frameworks because in its presence, there are incomplete (goods without markets) and imperfect markets (there is no full disclosure): we have goods without prices. Under this assumption, market equilibrium becomes not necessarily feasible and, if so, may not produce Pareto optimal outcomes (Kreps, 1990; Mas-Colell et al., 1995).

Renewable sources have its externalities: environmental costs and benefits; costs of electric power system integration; and costs related to energy security (Gawel et al., 2017; Gillingham and Sweeney, 2010; Lehmann and Söderholm, 2016). In its presence, an incentive framework becomes a necessity. Furthermore, according to Lehmann and Söderholm (2016)[2] and Gawel et al (2017), technology-specific incentive mechanisms or frameworks become cost-effective if: the financial markets are imperfect or faulty (related to the financing and funding of enterprises); and if there is asymmetry between the different technological learning rates and externalities (related to the cash flow of enterprises).

Brazil has severely faulty financial markets, similar to other Latin American countries (IEA, 2015; Vazquez et al., 2016). The asymmetries between technological learning rates and externalities are also facts well established and well known through the world (Anadon et al., 2016; Baker et al., 2013; Heal and Millner, 2014; Helm et al., 2014; Huenteler et al., 2016a, 2016b; Huntington et al., 2017; Neij et al., 2017; Peters et al., 2012; Prado and Trebilcock, 2009; UNEP, 2015, p. 2015) and in Latin America (EPE, 2012; Hochstetler and Kostka, 2015; Nascimento, 2015; UNEP and EPO, 2014). 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). Therefore, the use of an incentive framework for solar is validated and it needs to take into account the specificities of solar PV technologies.

Solar was supposed to enter into the traditional incentive framework for deployment of renewables, similar to wind power generation since 2009[3] (IEA, 2015). This framework is composed of: an auction mechanism related to tenders, through which capacity is contracted through a known price; and a public financing mechanism, through which the National Bank of Development[4] (BNDES) finances the investment

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[2] A preliminary version of the article is available as Lehmann and Söderholm (2015).

[3] Prior to this, wind was unsuccessfully promoted in Brazil through two programs. For more information on the matter we recommend Kissel and Krauter (2006), Olz (2003), Wachsmann and Tolmasquim (2003), Silva (2013) and Dutra and Szklo (2008).

[4] "Banco Nacional de Desenvolvimento Econômico e Social" in Portuguese.

with subsidized funds at below-market interest rates (BNDES, 2014a; Ferreira, 2013; Hochstetler and Kostka, 2015; Podcameni, 2014).

Regarding the mechanism that is related to the cash flow of companies, since 2004 the new regulated market is primarily expanded through auctions (auction mechanism). 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[5]), in which the safety of supply is increased. All types encompass long-term PPAs. 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 introduced in the auction mechanism. Therefore, the scheme in response to cash-flow problems in Brazil for wind is an auction mechanism with related long-term PPAs (tenders) (ANEEL, 2016b; Dutra and Menezes, 2005; Held et al., 2014; Pinto Junior, 2007; Podcameni, 2014; Porrua et al., 2010).

Solar PV 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 support scheme for resolving problems related to the cash flow of solar PV companies is an auction mechanism with long-term PPAs (EPE, 2012; SITAWI and CEBDS, 2016).

Regarding the mechanism related to the financing of enterprises, the National Bank of Development[6] (BNDES) is an important player in the financing of energy and infrastructure, including the recent wind power generation. Therefore, 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 (Ferreira et al., 2014; Ferreira, 2013; Hochstetler and Kostka, 2015; Juárez et al., 2014).

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 through its methodology, similar to wind power generation. Once more, similar to wind, the support scheme for solving the problems related to the financing and funding of solar PV power plants is a public financing mechanism utilizing BNDES' funds (BNDES, 2012, 2014a, 2014b, 2017a; Reuters Brasil, 2017a).

Regarding the role of public organizations, public authorities and policy makers, we highlight the organizations: BNDES; the Energy Research Company (EPE[7]); and the Regulatory Agency for electric energy (ANEEL[8]). The role of BNDES regarding the funding and financing of infrastructure and energy in Brazil is well established,

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[5]Acronym for "Leilão de Energia Reserva" in portuguese.
[6] "Banco Nacional de Desenvolvimento Econômico e Social" in Portuguese.
[7] Acronym for "Empresa de Pesquisa Energética" in Portuguese.
[8] Acronym for "Agência Nacional de Energia Elétrica" in Portuguese.

especially regarding novel energy sources: 90% of the recent growth of wind power generation in Brazil[9] was financed by the bank (BNDES, 2014b; Ferreira, 2013; Hochstetler and Kostka, 2015; IEA, 2015; Mazzucato and Penna, 2015, 2016; Podcameni, 2014; Tomelin, 2016). EPE and ANEEL are responsible for the auction mechanism: ANEEL operates the auctions and contract the capacity, stipulating an auction-agreed price for the MWh; whereas EPE analyzes the necessity of auctions and provides information and data regarding the Brazilian energy sector.

The auction mechanism and the public financing mechanism (or BNDES' financing mechanism) compose the incentive framework for deployment of renewables in Brazil. We now analyze the attempted solar expansion.

2.2. The attempted expansion

Regarding the auction mechanism, solar farms are currently in an undeveloped state. Specific solar auctions are considered a necessary, but not sufficient[10] incentive in the promotion of solar source generation (Jannuzzi, 2009; Sekiguchi, 2014) (ABSOLAR, 2016; 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, 2012; 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, the four main companies together have 52.12% (49 plants) of all solar power plants and 54.13% (1,419.9 MW) of all installed capacity. Those are: the Italian group Enel; Canadian Solar Inc; Lintran do Brasil 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, 2016b; Reuters Brasil, 2016a).

Table 2 – Contracted capacity of Solar PV at LER Auctions – MW, %, R$ 1000 - Brazil - 2015-2016

Companies	Plants	Potency	Investment in

[9] Alongside China and India, Brazil is one of the countries in which this source is growing faster (GWEC, 2017).

[10] According to Moreno and Weiss (2016), the solar source in Brazil is currently one of the less competitive generation sources. This is due to the high internal costs of its components and to a still low capacity factor.

	Units	%	MW	%	Apr. 2017 US$ (i)
					$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

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

Source: Own elaboration based on ANEEL (2016b)

Therefore, between 2014 and 2015, solar PV was successfully inserted into the auctions in Brazil, selecting winners (at reasonable and competitive prices). 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, 2016b, 2016a).

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 canceled, because of a decrease in the demand for electricity. Therefore, the auction tool, regardless of an initial success in contracting solar capacity, is currently in an uncertain situation (EPE, 2016b, 2016c).

Regarding the financing mechanism, in April 2017, the first disbursements of BNDES towards solar PV were analyzed. 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. The plant is expected to enter into operation barely on schedule: August 2017. 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 analyzed by ANEEL (2017b). 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 (BNDES, 2017b; Reuters Brasil, 2017b).

The public funding of power plants is linked to the internalization of its industrial chain[11]. 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, i.e., the factory located in Sorocaba, São Paulo (southeastern region) is able to provide modules that could be financed by the bank. Completed in December 2016, it is able to produce up to 350 MW of solar modules per year, which will be used solely in its own projects for the first six months of production. Afterwards, 250 MW will be reserved for the company's projects and 100 MW will be allocated for other developers. 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. If the local content requirements are then increased (which is currently under analysis of BNDES), the economical viability of the facility will be highly jeopardized: without subsidy, the domestic panels are at least 15% more expensive than Chinese panels. Therefore, the current situation of the traditional financing mechanism is highly uncertain and deficient (Bloomberg, 2016; BNDES, 2014b; Canadian Solar Inc, 2016; PV Magazine, 2016; Reuters, 2016; Reuters Brasil, 2016b, 2017a; SITAWI and CEBDS, 2016).

Therefore, both mechanisms of the incentive framework appear to not be working properly. Now we analyze the numbers and figures for the impaired expansion. According to the auction's results, up until September 2016[12] there was 2652.8 MW contracted for commercial operation beginning in 2017 and 2018. However, the figures clash with the planned expansion and the insertion of solar in the Brazilian electricity mix has failed (ANEEL, 2015, 2016c, 2016b, 2016d, 2016e, 2016f; Hochstetler and Kostka, 2015).

Table 3 – Forecast for entry into operation – 2017-2019 – Brazil

	2017		2018		2019	
	No restrictions	Some restrictions	No restrictions	Some restrictions	No restrictions	Some restrictions

[11] According to Hochstetler and Kostka (2015) and EPE (2012), 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.

[12] From September on there were later auctions, but none had solar farms as winners(EPE, 2016c, 2016b).

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	580.00	-523.47	0.00	-835.66
	%	139.31%	-100%	-	-5.63%	-	-39.45%

Source: Own elaboration based on ANEEL (2016a, 2017c)

Regarding the viability of enterprises, tables 3 and 4 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. This accounted for 202 MW out of the 2,953.1 MW expansion expected for 2017-2019 period. According to the 2016 forecast, all remaining capacity had some restrictions to enter into operation when scheduled (ANEEL, 2016a).

Table 4 – Total Forecast for entry into operation – 2017-2019 – Brazil

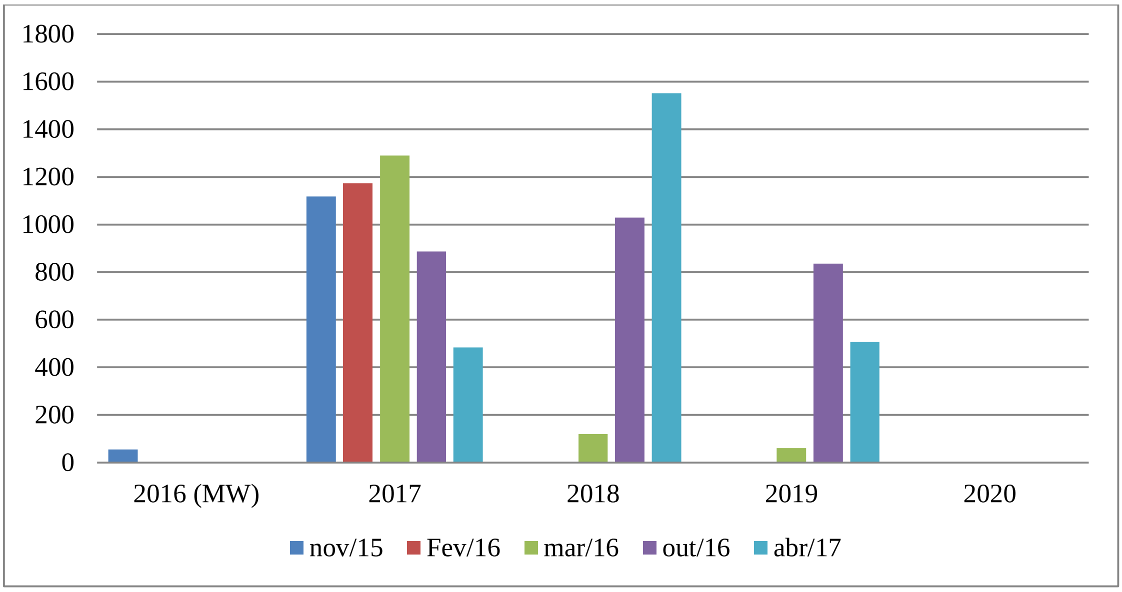
		No forecast Severe restrictions	2017 Total	2018 Total	2019 Total	Total
Capacity (MW)	2016 Forecast	0.00	1087.99	1029.47	835.66	2953.12
	2017 Forecast	439.66	483.40	1551.46	506.00	2980.52
Difference between both years	Δ	439.66	-604.59	521.99	-329.66	27.40
	%	-	-55.57%	50.70%	-39.45%	0.93%

Source: Own elaboration based on ANEEL (2016a, 2017c)

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: from 202 MW to 483.4 MW. 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. Therefore, there are still problems in solar PV as of the 2017. For 2018, the capacity with no restrictions forecasted to enter into operation accounted for 580 MW of solar capacity likely to enter into operation when scheduled. 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. The capacity with severe restrictions, 439.66 MW, has no forecast to enter into operation (between 2017 and 2020) and accounts for 14.75% of all solar PV capacity. In 2016 there was no solar PV without forecast to entry into operation, nor any solar PV capacity with severe restrictions to enter into operation when scheduled (ANEEL, 2016a, 2017c)

ANEEL (2015, 2016e, 2016f, 2016d) analyze 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).Analyzing the commitment to schedule and the progress of construction of the Brazilian solar plants, the numbers are concerning: until October 2016 there were no plants with an advanced schedule; and until the same month there were no plants under construction (ANEEL, 2016a, 2016f).

Graph 6 – Solar Farms entry forecast – MW – November 2015 to April 2017 - Brazil

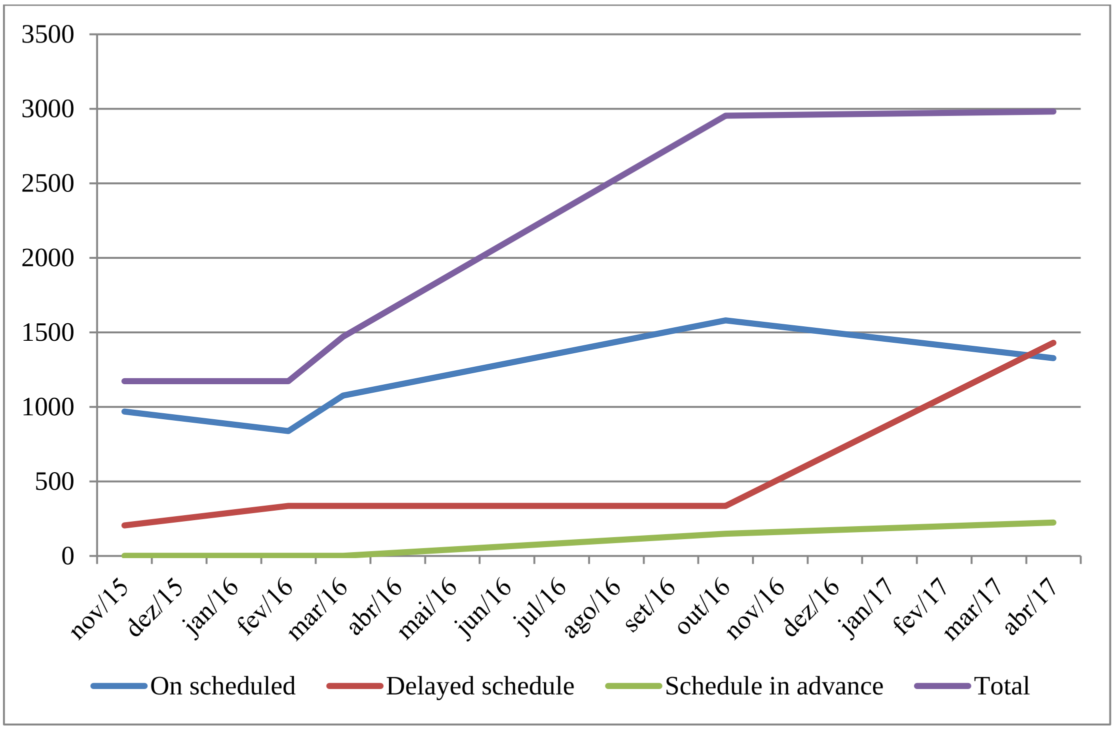


Source: Own elaboration based on ANEEL (2015, 2016d, 2016e, 2016f, 2017b)

At November 2015 the review appointed that there were 55 MW scheduled for commercial operation in 2016 (ANEEL, 2015). All the capacity was revised to enter operation in 2017 as of the February 2016 report (ANEEL, 2016d). At the October 2016review (ANEEL, 2016f), there were 9 plants under construction (270 MW total), with only 6 of them also with high viability (180 MW) and only 5 also with an advanced schedule (150 MW): before, no plants were under construction. All 9 plants 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 are still the majority, with 86 plants (1917.15 MW) (ANEEL, 2017b). From table 3 and graph 8 it becomes clear that the solar PV capacity is being consecutively postponed on each review.

Out of the 2.9 GW of planned installed capacity expansion only 9.14% were under construction (8.91% of all planned solar farms) as of October 2016. In contrast with wind power generation, in October 2016, 2,910.4 MW or 34.78% of the capacity were under construction (34.82% of plants, or 49 wind farms) and 15.61% of the plants had an advanced schedule. In April 2017, out of the 3 GW planned expansion, only 35% were under construction, however, 60.22% of all solar PV capacity had a delayed schedule. Again, 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, 2016g, 2016f, 2016a, 2017b, 2017d).

Graph 7 – Solar PV capacity regarding its schedule to enter into operation – MW – November 2015 to April 2017 – Brazil



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

From graph 7 it is clear that, even if the number of power plants (and capacity) is rising, schedule is becoming problematic. For the first time, the number and capacity of solar PV power plants with a delayed scheduled has surpassed the power plants on schedule: as of April 2017, the solar PV capacity on schedule and with a delayed schedule are 1326.36 MW (36 plants) and 1430.16 MW (44 plants) respectively. This tendency has no reasonable signs that it will stop in the near future (ANEEL, 2017b). Therefore, the construction risk appointed by Gatti (2013) is present: most projects are have a delayed completion.

In conclusion, the investments in solar farms are falling short in regards to their viability, commitment to schedule and prevision of the 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 the 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.

3. Framework of the agent-based model

Agent based models (ABMs) is a methodological approach which permits: rigorous testing, with possibilities of refinements; and a deeper understanding of fundamental causal mechanisms in the analyzed systems (multi-agent systems). It studies system that have two properties: interactions between agents; and the emergence of novel properties. In ABMs, autonomous but interacting agents, identical or not, singular or millions, interact in space and time. Traditional mathematical analysis (e.g. econometrics) are typically very limited when the object of analysis is a system in which the interaction of agents is non-ergodic, i.e., when history matters (path dependencies arise). Utilizing assumptions about agents, their interactions generate outcomes, generally through computer simulation: they have rule-based behaviors rather than utilities that need to be maximized. Therefore, learning (enhancing) and adapting behaviors is an important part of ABM (Axelrod and Tesfatsion, 2006; de Marchi and Page, 2014).

ABM can be compared to the two traditional scientifically methods: deduction and induction. Unlike deduction, it does not prove theorems with generally, generating data suited for an inductive analysis. However, the fact that the simulated data comes from a rigorous set of assumptions rather than direct measurements of the real world distances ABM from induction. Simulation and ABM therefore differ from traditional induction and deduction by its assumptions, implementation and goals. These can be divided into four specific goals: empirical; normative; heuristic; and methodological. The empirical goal aims to ground the causal explanations in repeated inteactions and outcomes related to realistic albeit not directly drawn from reality. The normative goal relates to the correlation between interactions and the emergence of properties. The heuristic goal relates to the emergence of patterns, i.e, the anticipation of effects from pre-conditions. Lastly, the methodological goal aims to better suit researchers with ABM tools and methods (Axelrod and Tesfatsion, 2006).

There is an important division between the learning rules, as they can be: individual-based learning rules; or population-based ones. The latter are more akin to evolutionary games. According to De Marchi and Page (2014), richer and more convoluted problems will likely need the analysis of an ABM rather than a mathematical analysis of game theory or an econometric approach. Game theory, according to the authors is more robust to analyze the outcomes of problems which involve equilibrium. Regarding problems that have non-equilibrium, ABM is a more robust tool, especially because Game theory is more rigorous.

There is a clear limit to realism: too many analyzed domains and the analysis of variables may become too difficult to understand. There needs to be a balance between the analyzed domains and the level of intricacy of an ABM. Furthermore, equilibria is not an assumption of ABMs, as the focus in on the dynamics of the system. It goes beyond the equilibrium approach, producing a variety of outcomes and possible phenomena such as: randomness; patterns; complexity; and path dependence. Lastly, it utilizies rule-based computer code to interpret the plays of agents (Axelrod and Tesfatsion, 2006; de Marchi and Page, 2014).

In the ABM produced for the analysis of the impaired Brazilian solar expansion, we consider a complexity approach to economics. As suggested by De Marchi and Page (2014), complexity is a possible phenomenon of ABM. According to Arthur (2013), complexity is the study of interactions and its consequences: the emergence of patterns (phenomena) from interactions among elements (in our case, agents). It essentially analyzes the propagation and robustness of change through interconnected behavior. This analysis is essential in systems without equilibrium.

Complex entities are: interdependent; connected; adaptive and diverse. Their interaction in time and space produces phenomena which in return affect time and space. This feedback process happens constantly. Phenomena are: spontaneous; unpredictable; temporal (it emerges and happen within time, as opposed to equilibrium, which is a timeless state); meso-level (neither at the individual or micro level, nor at the aggregate or macro level); phase transitory (time only flows in one direction, i.e., it is impossible to go back to a previous phase); robust; novel; related to large events; and related to emergent properties. Furthermore, the behavior related to ABM is understood as algorithmic rationality: algorithms are inducted from environment and are adapted to the changes that the agents are exposed to. Algorithms are tested and can spread (Arthur, 2013; Elsner et al., 2015).

Non-complex analysis, specially the traditional equilibrium approach of economics restrains economical phenomena to negative feedbacks (e.g. diminishing returns), which is the main cause for the convergence to equilibrium. Nevertheless, systems with only positive feedbacks (e.g. increasing returns of adoption) gives way to explosive non-equilibrium, inhibiting the analysis of the emergence of patterns and behaviors. Both negative and positive feedbacks need to be addressed, being a defining property of complex systems, leading to: multiple attractors, unpredictability; lock-ins processes; possible inefficiencies; and path-dependencies. This complex analysis is therefore richer than the standard analytical process, emphasizing contingency, indeterminacy, sense-making and openness to change (Arthur, 2013).

First, we acknowledge the pre-conditions for the model (question and hypothesis). Setup and entities are described in the next section, as well as the steps of the model

3.1. Question and hypothesis

The central question of this ABM is, given the context, are agents (companies and/or BNDES) capable of learning how to be better adjusted to its environment? Therefore, we model if companies faced by negative conditions (lack of financing) expand its capabilities towards the neutralization of this negative conditions. We also model if a central agent not involved directly the profit process but responsible for *ex-ante* financing of the enterprises is capable of better adjusting its relevant variable (the local content minimum requirements) to the necessities of companies.

Our hypothesis is positive: agents are capable of learning and better adjusting to its environment. We hypothesize that companies are capable of enhancing its capabilities, as well as BNDES is capable of adjusting its minimum local content requirements.

3.2. The model

The ABM produced for this case study is composed of four main time periods and an *ex-ante* period for the insertion of inputs and definition of parameters. The model utilizes the theoretical groundwork of dynamic capabilities, as defined by Teece, Pisano and Shuen (1997) and Teece and Pisano (1994), which encompasses elements drawn from Arthur (1988, 1989) and North (1990): lock-in processes; and path dependencies, respectively.

In the *ex-ante* period, the companies, divided into two categories, define its capabilities. The division is between companies: capable of utilizing other financing sources for their enterprises beyond BNDES and its funds; and companies that are incapable of utilizing other funds that not the Finem fund from BNDES. Respectively, companies that are not restricted by the functioning of the public financing mechanism and companies that are restricted by its correct functioning. In the case study, one company (Enel Green Power) is capable of accessing other funds besides the finem fund, whereas the other companies are not. This is apparent from the fact that ENEL's power plants are being build and the rest of the other companies' plants are not (ANEEL, 2017a, 2017d; SITAWI and CEBDS, 2016).

The dynamic capabilities framework draws inspiration from various streams and theories, specially: behavioral economics; organization theory; transaction cost economics; evolutionary economics; and institutional economics. The zero-profit condition of traditional neoclassical equilibrium in economics has been defied since it was first established. According to Teece and Pisano (1994), dynamic capabilities are non-imitable and non-replicable capacities that business enterprises possesses to shape, reshape, configure and reconfigure its assets in relation to technologies and markets in order to escape the zero-profit condition. Therefore, dynamic capabilities are directly linked to Schumpeterian rents: without dynamic capabilities, firms with ressources and/or competences are restricted to Ricardian quasi-rents in the short-term and no rents at all in the long-term.

In our case, we consider two dynamic capabilities: the commercial capability; and the state capability. Both capabilities relate to the capability of interacting, respectively: with the market (banks, companies, etc.); and the government and State (e.g. public banks). We are not concerned about the division between processes, positions and paths, as elucidated by Teece, Pisano and Shuen (1997): this approach is preferred because of its theoretical and modelling simplicity.

The definition process of capabilities for companies is expressed in the equations 3.1, 3.2 (type 1) and 3.3 and 3.4 (type 2). First, the input parameters are defined: the total number of companies; the percentage of type 1 companies; the specialization of best capability; and the specialization of the worst capabilities. Respectively, these parameters are: N; percent1comp; spec_best_cap; spec_worst_cap. The parameter N is an integer number that ranges from 0 to 100, whereas the parameter percent1comp is a percentage (being a real number) which ranges from 0 to 1. The parameters spec_best_cap and spec_worst_cap are real number which range from 0 to 100 and represent respectively: the minimum value of the best capability (commercial capability for type 1 and state capability for type 2); and the maximum value of the worst capability (state capability for type 1 and commercial capability for type 2). Type 1 companies have a better capability to relate to the market than type 2, whereas type 2 have a better capability to relate to the Brazilian state. Random capabilities inside the defined range are associated with up to 100 companies, with some companies being type 1 and the rest type 2 companies

$$(\mathbf{3.1}): Comcap_1 = Random[spec\_best\_cap, 100]$$

$$(\mathbf{3.2}): Statecap_1 = Random[0, spec\_worst\_cap]$$

$$(\mathbf{3.3}): Comcap_2 = Random[0, spec\_worst\_cap]$$

$$(\mathbf{3.4}): Statecap_2 = Random[spec\_best\_cap, 100]$$

In the *ex-ante* period (T_{-1}), the BNDES defines its minimum local content requirement: *min_local_content* accordingly to the equation 3.5. The bank first decides if it will ignore or not the specificities related to solar PV: the parameter *BNDES_ignor_spec* is assigned a value 0 (in which the bank respects the characteristics of solar PV) or 1 (in which the bank does the opposite). If the bank ignores the specificities of solar PV, i.e., if *BNDES_ignor_spec* is equal to 1, then the bank simply chooses a random value for *min_local_content*, ranging from 0.4 to 0.8. These are the values for the minimum local content first established by BNDES in its 2014 methodology for solar panels (BNDES, 2014c). However, if the bank chooses to consider the economic and technical characteristics of solar PV, then it simulates commercial and state capabilities for enterprises, after which, the bank will assign an average risk premium (parameter av_risk_prem ϵ [-100,100] $\subset$ R) for the average combination of commercial and state capabilities, according to the equations 3.6 and 3.7. The only variable in them is min_local_content, which BNDES adjusts to achieve the desired average risk premium, which is equal to the profit of the companies (variable profit ϵ [-100,100] $\subset$ R).

To find the average capabilities, BNDES utilizes the same process through which actual capabilities are attached to companies albeit with random variables. The randomness of prevision of BNDES is controlled through with a parameter responsible for the power of prevision of the bank (prev_BNDES ϵ [0,100] $\subset$ R): where 0 means that the bank predicts correctly; higher values represent less correct previsions; and 100 means that the bank has no clear prediction despite the actual parameter. The predictability is inserted into the prevision of the best and worst capability, as shown by equations 3.8 and 3.9. In them, BNDES predicts both parameters, deviating from reality according to its power of prediction. The equations 3.9 and 3.10 assign random expected capabilities for a type 1 company, whereas the equations 3.11 and 3.12 assign random expected capabilities for a type 2 company. This process happens N times: *percent1comp*N times* for type 1 companies; and *(1-percent1comp)* times for type 2 companies.

$$(\mathbf{3.5}): \min\_local\_content \; \epsilon \; [0,1] \subset R$$

$$(\mathbf{3.6}): average\_risk\_prem = v(\min\_local\_content)$$

$$(\mathbf{3.7}): av\_risk\_prem = profit = comcap_{average}^{e^{\min\_local\_content}} * statecap_{average}^{e^{(1-\min\_local\_content)}} - 100 * \min\_exp$$

$$(\mathbf{3.8}): spec\_best\_cap^{e} = Random[max\{0, espec\_best\_cap - prev\_BNDES\}, min\{espec\_best\_cap - prev\_BNDES, 100\}]$$

$$(\mathbf{3.9}): spec\_worst\_cap^{e} = Random[max\{0, espec\_worst\_cap - prev\_BNDES\}, min\{espec\_worst\_cap - prev\_BNDES, 100\}]$$

$$(\mathbf{3.1.10}): Comcap_{1}^{e} = Random[spec\_best\_cap^{e}, 100]$$

$$(\mathbf{3.1.11}): Statecap_{1}^{e} = Random[0, spec\_worst\_cap^{e}]$$

$$(\mathbf{3.1.12}): Comcap_{2}^{e} = Random[0, spec\_worst\_cap^{e}]$$

$$(\mathbf{3.1.13}): Statecap_{2}^{e} = Random[spec\_best\_cap^{e}, 100]$$

The average commercial capability and state capability are found through a simple algebraic average, as shown by equations 3.14 and 3.15. This process assures that, for the average company, its profit will be equal or approximate to the risk premium defined by the bank, i.e., the average profit.

$$(\mathbf{3.14}): comcap_{average}^{e} = \sum_{i=1}^{N} comcap_{i}^{e} \Big/ N = \sum_{i=1}^{percent1comp*N} comcap_{1_i}^{e} + \sum_{j=1}^{(1-percent1comp)*N} comcap_{2_j}^{e} \Big/ N$$

$$(\mathbf{3.15}): statecap_{average}^{e} = \sum_{i=1}^{N} statecap_{1,2_i}^{e} \Big/ N = \sum_{i=1}^{percent1comp*N} statecap_{1_i}^{e} + \sum_{j=1}^{(1-percent1comp)*N} statecap_{2_j}^{e} \Big/ N$$

Therefore, in the *ex-ante* period, companies assign values to its capabilities and BNDES defines its min_local_content, by simulating an outcome related to the actual model or through simple speculation.

In the first period (T_0), both the capabilities and the minimum local content are applied to the environment by the companies and the bank, respectively. This first period situates the agents in time and space, as companies are bound to *x* and *y* coordinates in the Cartesian plane and the minimum local content is disclosed.

In the second period (T_1), the landscape takes form. A 3D representation of the landscape encompasses: commercial capability or comcap (*x* axis); state capability or statecap (*y* axis); and the profit (*z* axis). It is represented by the equations 3.1.16 and 3.1.17 below. Equation 3.16 establishes that profit is a function of the capabilities of enterprises. Equation 3.17 establishes that the commercial capability is more important than the state capability for min_local_content > 0.5: the more restrictive the local content policy, the better chance to find financing elsewhere, i.e., in the market.

However, for lower than 0.5 minimum local content requirements, state capability is more important, as the access to public funds is less restrictive and is more certain than market interactions (while having lower interest rates). Both variables have diminishing returns, albeit at different rates for all values of min_local_content with the exception of 0.5.

$$(\mathbf{3.16}): profit = f(comcap, statecap)$$

$$(\mathbf{3.17}): profit = comcap^{\min\_local\_content} * statecap^{1-(\text{min\_local\_content})} - 100 * \text{min\_exp}$$

In the third period (T_2), the companies gross profits (positive *profits*) or endure losses (negative *profits*). For simplification, at the end of the period cycle, all profits or losses are neutralized: profits are consumed; and losses are passed on. This is a simplification.

In the fourth period (T_3), the companies reinvest part of the profits (if positive) on its capabilities and BNDES compares the consequences of its local content requirements to the market to its expectations, making adjustments if necessary.

$$(\mathbf{3.18}): Comcap_{1,2_{i_{t+1}}} = c(profit, comcap_{1,2_i}, \min\_local\_content)$$

$$(\mathbf{3.19}): Comcap_{1,2_{i_{t+1}}} = comcap_i * \left(1 + (\alpha/100)^{1/2+\min\_exp}\right) |\, profit > 0, \alpha = profit * success\_rate_{i_{t+1}} * \%\_profit\_reinvest * h_{1,2}(\min\_local\_content)$$

$$(\mathbf{3.20}): statecap_{1,2_{i_{t+1}}} = s(profit, statecap_{1,2_i}, \min\_local\_content)$$

$$(\mathbf{3.21}): statecap_{1,2_{i_{t+1}}} = statecap_i * \left(1 + (\beta/100)^{1/2+\min\_exp}\right) |\, profit > 0, \beta = profit * success\_rate_{i_{t+1}} * \%\_profit\_reinvest * (1 - h_{1,2}(\min\_local\_content))$$

$$(\mathbf{3.22}): h_1(\min\_local\_content) = \min\_local\_content^{(1+pref\_cap*con\_c\_v\_reinvest)^{-1^{norm\_or\_mirror}}}$$

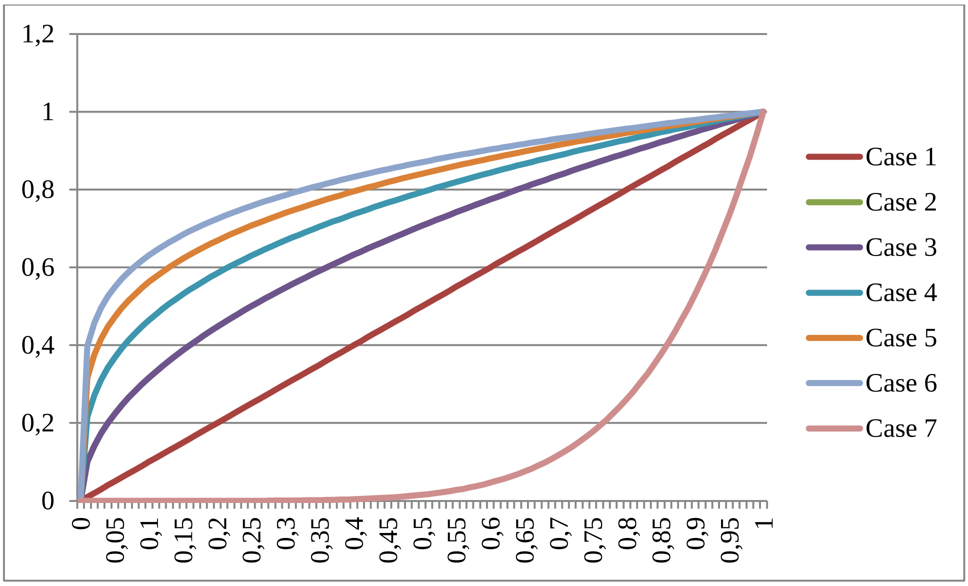
$$(\mathbf{3.23}): h_2(\min\_local\_content) = \min\_local\_content^{(1+pref\_cap*con\_c\_v\_reinvest)^{-1^{(1-norm\_or\_mirror)}}}$$

Both reinvestment equations produce the next period capability (*$comcap_{t+1}$* and *$statecap_{t+1}$*), which are a function of profit and their respective capability: the prior state of the capability defines how much it can grow in accordance to the profit, according to equations 3.18, 3.19, 3.20 and 3.21. However, not all profit is reinvested, there are four parameters that give the total profit reinvested successfully: the successs rate of the investment, which is a random integer number between 0 and 1 (*$success\_rate_{i\ t+1}$* ϵ [0,1] ⊂ R); the percentage of profit allocated to reinvestment in both capabilities (*%_profit_reinvest* ϵ [0,1] ⊂ R); and the actual allocation of profit to each capability.

This last parameter is achieved through a function of minimum local content as shown by equations 3.1.22 (for type 1 companies) and 3.1.23 (for type 2 companies).

The function $h_{1,2}$ returns integer valuables between 0 and 1 ($h_{1,2} \in [0,1] \subset R$). It means the percentage of profit allocated to commercial capability of type 1 companies (h_1) and type 2 companies (h_2). The percentage of profit allocated to state capability is found through the complimentary to its functions ($1 - h_{1,2}$). In them, the minimum local content is elevated to the power of one plus the preference for certain capability (*pref_cap* $\in \{0,1\} \subset N$) times the concavity of convexity of reinvestment function (*con_c_v_reinvest* $\in [0,5] \subset R$). The parameter *pref_cap* is an input that determines if the companies have a clear preference for some capability (if *pref_cap* = 1) or not (if *pref_cap* = 0). The input parameter responsible for determining if the reaction to reinvestment is normal or mirrored (*norm_or_mirror* $\in \{0,1\} \subset R$ inverts the reaction of companies if its equal to 1. The normal reaction for type 1 companies is to invest more on its commercial capability (its best capability), whereas the normal reaction for type 2 companies is to invest more on its state capability (its best capability). In the mirrored case, the reactions are inverted.

Graph 8 – Variation of $h_{1,2}$ according to different parameters



Source: own elaboration

Essentially, $h_{1,2}$ allocates part of the profit to both capabilities as according to graph 8 and table 5, which depict an example for h_1. By them, we can understand how the parameter *con_c_v_reinvest* distorts the function away from the diagonal (in which the parameter *pref_cap* is equal to zero) in direction to the edges and how the *normal_or_mirror* parameter can invert the graph.

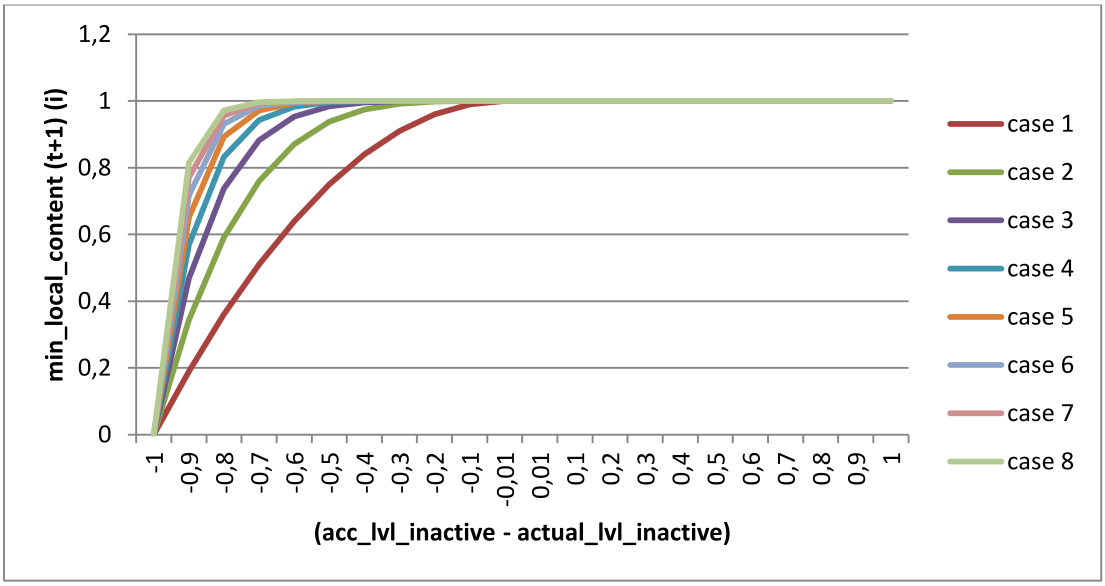
Table 5 – Parameters for the different cases presented at graph 8

Case	*pref_cap*	*con_c_v_reinvest*	*norm_or_mirror*
1	0	1	0
2	1	1	0
3	1	2	0
4	1	3	0
5	1	4	0
6	1	5	0
7	1	5	1

Source: own elaboration

After the companies attempt to reinvest, BNDES analyzes the market to understand the effects its simulated or randomly generated minimum local content requirements had upon the companies. Equations 3.24 and 3.25 depict this analysis. Equation 3.24 determines that the local content requirements for the next period will be a function of the current minimum local content requirements and of the difference between the accepted level of inactive companies and the actual level of inactive companies. The higher this difference, the higher change to the requirements are made, as depicted by graph 9.

Graph 9 – Relation between $min\_local\_content_{t+1}$ and (*acc_lvl_inactive* – *actual_lvl_inactive*)



(i) : we have determined *min_local_content* = 1 in this example. For a general purpose, the limit is equal to the defined variable, i.e., in the limit it does not change.

Source: own elaboration

$$(\mathbf{3.24}): \min\_local\_content_{\ t+1} = g(\min\_local\_content, (acc\_lvl\_inactive - actual\_lvl\_inactive))$$

$$(\mathbf{3.25}): min\_local\_content_{\ t+1} = min\_local\_content * min\{1, 1 - (acc\_lvl\_inactive - actual\_lvl\_inactive)^{2*revision\_lvl*(1+BNDES\_ignor\_spec)}$$

Graph 9 depicts the fact that, the higher the difference between the accepted and actual level of inactive companies (in negative terms), the higher the change in minimum local content requirements. This means that, if the accepted level of inactive companies is too high in comparison with the actual level, then BNDES will choose to diminish its minimum local content requirements. In the case 1, depicted in graph 9, BNDES has a low revision level (*revision_lvl* = 1), which rises in further cases. Higher *revision_lvl* mean that BNDES will only revise the minimum local content requirements at successively larger differences of accepted and actual level of inactive companies. All cases depicted in the graph 9 show BNDES not ignoring the characteristics of solar PV. If he does so (*BNDES_ignor_spec* = 1), the first case would be similar to case 2: BNDES takes longer to revise its minimum_local_content, keeping it the same for larger differences of inactive levels.

The highest possible difference (-1) only happens if the accepted level of inactive companies is zero (*acc_lvl_inactive* = 0) and the actual level of inactive companies is equal to 1 (*actual_lvl_inactive* = 1). This situation is only possible in the case in which BNDES acknowledges the specificities of solar PV, because otherwise the bank simply chooses a random number between 0.4 and 0.8. Therefore, the situation in which BNDES simply abandons the local content requirement is highly improbable: this great difference between accepted and actual inactive levels should not happen given the fact that the bank simulates a *min_local_content* suited for the necessities of the companies. This is a simplification: BNDES does not change its input accepted level of inactive companies, rather changing the local content requirements. Nevertheless, this complies with the fact that BNDES executes order from policy makers, which would settle an accepted level of inactive companies rather than a minimum local content requirements.

In the next period, the model goes back to a similar state as the initial phase (T_0), albeit with possibly new capabilities (for the companies who were able to reinvest) for companies that might be confronted by a new minimum local content requirement (if BNDES revised its prior stipulation). The system does not go back to the same phase as before and it is not static: the landscape might change, and the positions of firms in it may also change from one cycle to the other. There is a clear simplification that the capabilities of firms do not decrease. This is done for simplicity of simulation and argument, and also because the focus of analysis is on the growth of capabilities and in the learning, not on the possibilities for a decline in capabilities or in the oblivion regarding the evolution of this system.

The fact that agents and landscape change complies with the complexity approach to economics as well as the usage of ABM. Furthermore, it is clear that agents are not maximizing any type of function: they have well established behaviors (improve capabilities if possible and decrease requirements if needed). Nevertheless, the interactions between agents is still oversimplified, as the actions of companies do not affect directly each other, only through BNDES: too much inactive companies have no direct effect upon active companies (and vice-versa), however, if BNDES decreases the minimum local content requirement, then the inactive companies have indirectly affected the whole system. Further developments of the model could better simulate interactions between the two groups or, better yet, between all agents.

4. Expected outcomes

EPE (2012) states that there are three basic conditions for a reasonable promotion of centralized solar PV: specific auctions for this source, more suited contracts; and best suited technical accreditation requirements for PV panels and related equipment. Essentially, its differences and specificities need to be taken into account in order for it to become a viable power source. Without it, solar PV power generation will remain uncompetitive. The institutional learning acquired by the bank in its previous financing of wind power generation (successful regarding the viability of the market and the internalization of parts of the industrial chain) was put to use in the methodology for the financing of solar PV (BNDES, 2014a). However, it can be appointed as problematic: it does not acknowledge most differences regarding the characteristics of both sources. This financing mechanism, part of the incentive framework, is not technology-neutral, however, it neither is specific for solar: the mechanism borrowed elements from the previous technology-specific mechanism for wind (Gawel et al., 2017).

EPE (2012) clearly predicted the growth of solar PV based on the success of the prior success of wind power generation. Similar to BNDES (BNDES, 2014a), EPE (2012) was optimistic about the solar expansion in the country, drawing conclusions (and in the case of BNDES, policies) from the prior success of wind power. Although both sources are renewables, the differences between them are enormous and to adapt a methodology from one source to other (with little similarities) made little sense. Furthermore, since the beginning, the deployment of solar PV was linked to a development of a solar PV value chain in Brazil, which is not a feasible short-term objective for solar, unlike wind (Gawel et al., 2017; Huenteler et al., 2016b).

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, 2016c, 2016f, 2016b, 2016a, 2017a; Hochstetler and Kostka, 2015; Reuters Brasil, 2017b, 2017a; SITAWI and CEBDS, 2016).

The incentive framework, especially the financing mechanism for promotion of solar was inspired by its wind counterpart, as stated by BNDES (2014a) however, both technologies have little in common. 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 eight years after the first incentive program for wind (PROEÓLICA in 2001), whereas the methodology for solar was implemented in the same year that solar PV capacity was first contracted[13]. 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 solar capacity established. Therefore, time is not an issue, as well as flexibility: the institutional learning acquired by the bank permitted it to developed more flexible methodologies. The methodology for solar panels is more flexible than the methodology for wind turbines, which is already more flexible than the index of internalization. Furthermore, the methodology for solar panels was implemented much earlier than the methodology for wind turbines, regarding the evolution of each source's capacity and output in the country (ANEEL, 2016b; BNDES, 2012, 2014c, 2014a; EPE, 2016a; Podcameni, 2014).

At last, it is important to understand that the auctions have sanctions and penalties for companies that do not commit to the schedule and fail to deliver its power plants in time. Therefore, the contracted solar PV capacity expected to enter into operation when scheduled: it counted on the correct operation of the incentive mechanism, i.e., of both the auction mechanism and the financing mechanism. The capacity is contracted at reasonable prices, which means that the auction mechanism is operational. The incentive mechanism for the failures of the spot market, which is the role of the auction mechanism, is correctly working. The mechanism that seems faulty is the public financing mechanism. This is incentive mechanism responsible for promoting the source despite the problems in the stock and capital markets. The contracted capacity took four years to have its first 150 MW financed by the bank. This mechanism, in relation to the financing mechanism for wind: shared the same fund (Finem fund); had a more favorable conditions for financing (higher participation of the bank, larger amortization period); and had a more streamlined and flexible methodology

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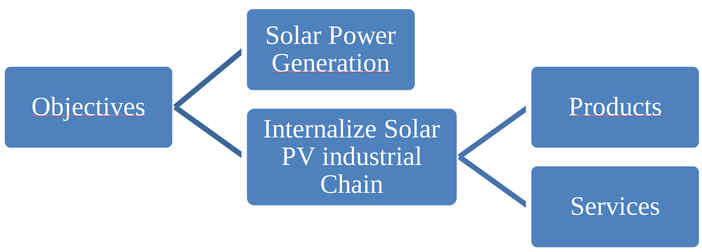
[13] In 2013, the northeastern state of Pernambuco promoted a state auction for solar. It contracted five projects, including the ones which are currently the only utility-level deployments of solar PV in Brazil: Fontes Solar I and Fontes Solar II (Governo de Pernambuco, 2013). They were built by ENEL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

(BNDES, 2012, 2014c, 2014a; Dutra and Menezes, 2005; Dutra and Szklo, 2008; Vazquez et al., 2016).

Moreover, the Brazilian exchange rate grew steadily since the first auction[14] (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. That changes the outcome of the scenario, as there would probably be more plants under construction, albeit it does not change the fact that the mechanism is not working: it simply would imply a bypass of the faulty methodology. Additionally, even if most auction winners are foreign companies, the traditional mechanism is the bank, 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). Furthermore, the fact that 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 (e.g. Enel, EDF, Solairedirect) during the same period Brazil struggled to finance its already contracted capacity is a sign that the cause for the impaired Brazilian solar expansion is internal (Cleantechies, 2016; EDF Energies Nouvelles, 2015; Enel Green Power, 2015b; GTM Research, 2016; IEA, 2015).

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. Defining its objective, Brazil can start to work on mechanisms that go accordingly to it and to the technology to be internalized.

Figure 1 – Possible objectives of the solar PV expansion - Brazil



Source: own elaboration

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

To keep both objectives, BNDES would need to seriously revise its methodology and its access criteria. That would probably incur in the reduction of the N factors and in a large revision of periods. A possibility 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 important one: in Europe, a large portion of the aggregate value is added on site[15]. According to EPE (2012), 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. The fact that PV panels are becoming less expensive every year only contributes to this. A focus on services could be a possibility to make the expansion of solar PV likely to happen while internalizing to some degree parts of the value chain related to the source.

The expected results of the simulation, utilizing ABM and complexity should corroborate this discussion. The actual case indicates that BNDES ignored the characteristics of solar PV in T_{-1} (*BNDES_ignor_spec* = 1) and that all type 2 companies were incapable of collecting profits, which lead to them being unable to reinvest into their capabilities. Furthermore, BNDES failed to revise is minimum local content requirements, which means that it is only willing to do so in case the difference between the accepted and actual level of inactive companies (*acc_lvl_inactive* – *actual_lvl_inactive*) is extremely high (in negative terms) and probably have a very high *revision_lvl* parameter. The model corroborates the fact that, given the current situation, without a decrease in the minimum local content requirements, BNDES will probably be unable to finance the solar expansion in Brazil alongside an internalization of this industrial chain. Furthermore, models that simulate requirements for processes and services would enhance the understanding that BNDES failed to acknowledge the differences between wind and solar.

In conclusion, BNDES[16] needs to revise its methodology. However, 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 to them. If the objectives and mechanisms ignore the fact that solar PV has its own features and traits unlike those of wind power generation and other sources, the expansion will be jeopardized. Likewise, if objectives and mechanisms are not compatible, it will be also jeopardized. Therefore, a feasible expansion can only be made possible by congruity between objectives (short-term and long-term), 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

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[15] 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).

[16] 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).

a technology-neutral or a “technology-unspecific”. Furthermore, the success of wind and its technology-specific incentive mechanisms is an example of the possibilities a Brazilian solar expansion could have reached if its mechanism was tailored for the technology and proposed in accordance to feasible objectives.

5. Conclusion

The two tools for promoting renewables in Brazil (auctions and BNDES’ financing) are not being capable of successfully promoting the expansion of centralized PV generation in the country. There is currently contracted capacity; however, these power plants are not under construction. The incentive mechanism is not working properly.

Analyzing the several differences between the two sources and addressing the fact that the financing mechanism for solar power generation was heavily inspired by BNDES’ prior successful funding of wind farms, the reason of the outcome becomes clear. By not fully acknowledging the many differences between both sources, BNDES underestimated this challenge.

We understand that BNDES’ objective with its subsidized financing of investments, in this case, is actually two: the promotion of the source in the country; and the internalization of certain parts of the industrial chain. Tackling such challenge with a mechanism heavily influenced by the severely different wind power generation only increased the difficulty.

However, possible solutions for this incompatibility between objective, mechanism and technology can be proposed. BNDES can decide to tackle the hardest challenge that is internalizing a very concentrated industrial chain, requiring a reimagining of this mechanism and the combining of others tools, such as R&D policies[17]. However, this would probably take more time than planned for the expansion of centralized PV generation in Brazil. If promoting and supporting solar farms is considered the most important objective, then a different shift in the mechanism is needed: imported solar panels will have to be financed to keep schedules intact.

Nevertheless, not all is lost for local content, for, even with imported solar panels (or panels with significantly less local content requirements regarding items), there are ways of promoting income generation in the country and some internalization of the value chain. In Europe, most of the added value comes from services performed at the site of installation: assembly, cabling, engineering services, miscellaneous services, irradiation measurement, etc. For a Brazilian solar PV value chain to flourish, it does not need to necessarily start from either the manufacturing of solar-grade silicon or from the manufacturing of solar modules. A more feasible possibility is to first promote this internalization process through specialized services as means for maturing

[17]As some countries did to internalize wind turbine industrial chains.

the solar PV market in the country. With a more mature market in Brazil, the country may then (if coherent with the previously defined objective) start to internalize the industrial chain through progressive local content requirements (regarding items) truly suited for the specificities of solar PV. However, to start this process with a severely underdeveloped solar PV market and an unsuited methodology for the technology is bound to have its problems, as evident from the current status quo. Moreover, the fact that, since 2015, no additional solar capacity was contracted intensifies and corroborates the problem.

The most important conclusion to be drawn from the analysis is that if BNDES and the policy makers persist with their current objectives and mechanisms, the planned expansion of the solar power generation, and in consequence, the implantation of a national industry in this industrial chain will remain highly jeopardized. Brazil has to decide its short-term and long-term objectives for solar and adapt its mechanisms and tools to them while taking into account the specificities of different technologies.

6. References

ABSOLAR, 2016. Energia solar fotovoltaica: potencial, oportunidades e desafios.

Anadon, L.D., Baker, E., Bosetti, V., Aleluia Reis, L., 2016. Expert views - and disagreements - about the potential of energy technology R&D. Clim. Change 136, 677–691. doi:10.1007/s10584-016-1626-0

ANEEL, 2017a. Banco de Informações de geração.

ANEEL, 2017b. Acompanhamento das Centrais Geradoras Fotovoltaicas Abril 2017. Acompan. Centrais Geradoras Fotovoltaicas.

ANEEL, 2017c. Resumo geral das usinas.

ANEEL, 2017d. Acompanhamento das Centrais Geradoras Eólicas Abril 2017. Acompan. Centrais Geradoras Eólicas.

ANEEL, 2016a. Resumo geral das usinas.

ANEEL, 2016b. Resultado dos Leilões.

ANEEL, 2016c. Novos empreendimentos (implantações e ampliações) decorrentes de leilões de geração (2005 a 2016).

ANEEL, 2016d. Acompanhamento das Centrais Geradoras Fotovoltaicas Fevereiro 2016. Acompan. Centrais Geradoras Fotovoltaicas.

ANEEL, 2016e. Acompanhamento das Centrais Geradoras Fotovoltaicas Março 2016. Acompan. Centrais Geradoras Fotovoltaicas.

ANEEL, 2016f. Acompanhamento das Centrais Geradoras Fotovoltaicas Outubro 2016. Acompan. Centrais Geradoras Fotovoltaicas.

ANEEL, 2016g. Acompanhamento das Centrais Geradoras Eólicas Outubro 2016. Acompan. Centrais Geradoras Fotovoltaicas.

ANEEL, 2015. Acompanhamento das Centrais Geradoras Fotovoltaicas Novembro 2015. Acompan. Centrais Geradoras Fotovoltaicas.

Arthur, W.B., 2013. Complexity economics: a different framework for economic thought. St. Fe Inst. Work. Pap. 2013-4–12, 24.

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-in by historical events. Econ. J. 99, 116–131.

Arthur, W.B., 1988. Competing technologies: an overview, in: Dosi, C. (Ed.), Technical Change and Economic Theory. Pinter Publishers, London.

Axelrod, R., Tesfatsion, L., 2006. Appendix A A Guide for Newcomers to Agent-Based Modeling in the Social Sciences, in: Handbook of Computational Economics. Elsevier, pp. 1647–1659. doi:10.1016/S1574-0021(05)02044-7
Baker, E., Fowlie, M., Lemoine, D., Reynolds, S.S., 2013. The Economics of Solar Electricity. Annu. Rev. Resour. Econ. 5, 387–426. doi:10.1146/annurev-resource-091912-151843
Bloomberg, 2016. Brazil to Boost Funding for Solar, Cut Loans for Coal, Gas. Bloom. Mark.
BNDES, 2017a. BNDES Finem – Geração de Energia.
BNDES, 2017b. BNDES aprova primeiro financiamento para geração de energia solar, no valor de R$ 529,039 milhões. BNDES Notícias.
BNDES, 2014a. BNDES Define Condições de Apoio a Vencedores de Leilão de Energia Solar E Cria Metodologia Para Fomentar Conteúdo Nacional. BNDES Notícias.
BNDES, 2014b. Perspectivas da Energia Solar e o Apoio do BNDES ao Setor.
BNDES, 2014c. Metodologia Para Credenciamento E Apuração de Conteúdo Local de Equipamentos Fotovoltaicos No Credenciamento de Fabricantes Informatizado – CFI Do BNDES.
BNDES, 2012. Anexo 1: Etapas Físicas E Conteúdo Local Que Deverão Ser Cumpridos Pelo Fabricante.
BP, 2015. Statistical Review of World Energy.
Canadian Solar Inc, 2016. Canadian solar opens brazil’s largest capacity solar module manufacturing facility. Can. Sol. Inc News Release.
Cleantech Group, 2016. Clean energy patent growth index (CEPGI): 2015 year in review.
Cleantechies, 2016. Engie, Solairedirect To Develop 400 MW Solar Power Projects In Chile. Cleantechies.
de Marchi, S., Page, S.E., 2014. Agent-Based Models. Annu. Rev. Polit. Sci. 17, 1–20. doi:10.1146/annurev-polisci-080812-191558
Dutra, J., Menezes, F., 2005. Lessons from the Electricity Auctions in Brazil. Electr. J. 18, 11–21. doi:10.1016/j.tej.2005.10.009
Dutra, R.N., Szklo, A.S., 2008. Incentive policies for promoting wind power production in Brazil: Scenarios for the Alternative Energy Sources Incentive Program (PROINFA) under the New Brazilian electric power sector regulation. Renew. Energy 33, 65–76. doi:10.1016/j.renene.2007.01.013
EDF Energies Nouvelles, 2015. EDF Energies Nouvelles enters the Chilean market with a first 146 MWp solar plant project. EDF Energ. Nouv. Press Releases.
Elsner, W., Heinrich, T., Schwardt, H., 2015. The microeconomics of complex economies: evolutionary, institutional, neoclassical, and complexity perspectives. Academic Press, Amsterdam ; Boston.
Enel Green Power, 2015a. Enel Green Power puts online first hybrid plant in Brazil. Enel Green Power Press Release.
Enel Green Power, 2015b. Enel Green Power begins construction of chile’s largest photovoltaic plant. Enel Green Power Press Release.
EPE, 2016a. Balanço energético nacional 2015.
EPE, 2016b. 1º LER 2016 contrata 180,3 MW em 30 projetos de PCHs e CGHs. EPE Imprensa.
EPE, 2016c. Queda de demanda por energia elétrica cancela 2º LER 2016. EPE Imprensa.
EPE, 2014a. Balanço energético nacional 2013.

EPE, 2014b. Plano decenal de expansão de energia 2024.
EPE, 2012. Análise da Inserção da Geração Solar na Matriz Elétrica Brasileira. Nota Téc. EPE.
Eurostat, 2017. Eurostat Database.
Ferreira, A.C., Blasques, L.C.M., Pinho, J.T., 2014. Avaliações a respeito da evolução das capacidades contratada e instalada e dos custos da energia eólica no Brasil: do PROINFA aos leilões de energia. Rev. Bras. Energ. Sol. 5, 82–91.
Ferreira, W., 2013. O estado atual e os incentivos ao desenvolvimento da indústria eólica brasileira: o caso da política de conteúdo local do BNDES (Master's thesis). Universidade Federal Fluminense, Niterói.
Gatti, S., 2013. Project characteristics, risk analysis and sectors, in: Project Finance in Theory and Practice: Designing, Structuring, and Financing Private and Public Projects. Academic Press, Amsterdam ; Boston, pp. 43–76.
Gawel, E., Lehmann, P., Purkus, A., Söderholm, P.A., Witte, K., 2017. Rationales for technology-specific RES support and their relevance for German policy. Energy Policy 102, 16–26. doi:10.1016/j.enpol.2016.12.007
Gillingham, K., Deng, H., Wiser, R., Darghouth, N., Nemet, G., Barbose, G., Rai, V., Dong, C., 2016. Deconstructing Solar Photovoltaic Pricing. Energy J. 37. doi:10.5547/01956574.37.3.kgil
Gillingham, K., Sweeney, J.L., 2010. Market Failure and the Structure of Externalities, in: Harnessing Renewable Energy in Electric Power Systems: Theory, Pratice, Policy. John Hopkins University Press, Washington, D.C., pp. 69–91.
Governo de Pernambuco, 2013. Pernambuco promove primeiro leilão de energia solar do País, que atrai investimentos de R$ 597 milhões. Notícia Site Gov. Pernamb.
Green, R., Staffell, I., 2016. Electricity in Europe: exiting fossil fuels? Oxf. Rev. Econ. Policy 32, 282–303.
GTM Research, 2016. Latin America PV Playbook: Q2 2016 Market Update.
GWEC, 2017. Global wind statistics 2016.
Heal, G., Millner, A., 2014. Reflections: Uncertainty and Decision Making in Climate Change Economics. Rev. Environ. Econ. Policy 8, 120–137. doi:10.1093/reep/ret023
Held, A., Ragwitz, M., Gephart, M., De Visser, E., Klessmann, C., 2014. Design features of support schemes for renewable electricity. Ecofys Task Rep. 2.
Helm, S., Tannock, Q., Iliev, I., 2014. Renewable Energy Technology: Evolution and Policy Implications - Evidence from Patent Literature. WIPO Glob. Chall. Rep.
Hochstetler, K., Kostka, G., 2015. Wind and Solar Power in Brazil and China: Interests, State–Business Relations, and Policy Outcomes. Glob. Environ. Polit. 15, 74–94. doi:10.1162/GLEP_a_00312
Huenteler, J., Ossenbrink, J., Schmidt, T.S., Hoffmann, V.H., 2016a. How a product's design hierarchy shapes the evolution of technological knowledg —Evidence from patent citation networks in wind power. Res. Policy 45, 1195–1217. doi:http://doi.org/10.1016/j.respol.2016.03.014
Huenteler, J., Schmidt, T.S., Ossenbrink, J., Hoffmann, V.H., 2016b. Technology life-cycles in the energy sector — Technological characteristics and the role of deployment for innovation. Technol. Forecast. Soc. Change 104, 102–121. doi:10.1016/j.techfore.2015.09.022
Huntington, S.C., Rodilla, P., Herrero, I., Batlle, C., 2017. Revisiting support policies for RES-E adulthood: Towards market compatible schemes. Energy Policy 104, 474–483. doi:10.1016/j.enpol.2017.01.006

IEA, 2015. Renewable energy medium-term market report 2015: market analysis and forecasts to 2020.
IPEADATA, 2017. Ipeadata database.
IRENA, 2016. Renewable energy benefits: measuring the economics.
Jannuzzi, G.M. (Ed.), 2009. Sistemas fotovoltaicos conectados à rede elétrica no Brasil: panorama da atual legislação. Unicamp, Campinas.
Juárez, A.A., Araújo, A.M., Rohatgi, J.S., de Oliveira Filho, O.D.Q., 2014. Development of the wind power in Brazil: Political, social and technical issues. Renew. Sustain. Energy Rev. 39, 828–834. doi:10.1016/j.rser.2014.07.086
Kissel, J., Krauter, S.C.W., 2006. Adaptations of renewable energy policies to unstable macroeconomic situations—Case study: Wind power in Brazil. Energy Policy 34, 3591–3598. doi:10.1016/j.enpol.2005.07.013
Kreps, D.M., 1990. Chapter six: Pure exchange and general equilibrium, in: A Course in Microeconomic Theory. Princeton University Press, Princeton, N.J, pp. 187–233.
Lehmann, P., Söderholm, P.A., 2016. Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes. UFZ Discuss. Pap. 1.
Lehmann, P., Söderholm, P.A., 2015. Technology-neutral or Technology-specific? Designing Support Schemes for Renewable Energies Costeffectively. Energy Forum Antalya Special Issue 2015, 13–15.
Martins, F.R., Pereira, E.B., 2011. Enhancing information for solar and wind energy technology deployment in Brazil. Energy Policy 39, 4378–4390. doi:10.1016/j.enpol.2011.04.058
Mas-Colell, a., Whinston, M.D., Green, J.R., 1995. Externalities and public goods, in: Microeconomic Theory. Oxford University Press, New York, pp. 350–382.
Mazzucato, M., Penna, C.C.R., 2016. The Brazilian Innovation System: A Mission-Oriented Policy Proposal, Temas estratégicos para o desenvolvimento do Brasil. Brasília.
Mazzucato, M., Penna, C.C.R., 2015. The rise of mission-oriented state investment banks: the cases of Germany’s KfW and Brazil’s BNDES. Work. Pap. ISI Growth 2015/1.
MITEI, 2015. The future of solar energy: an interdisciplinary MIT study.
Moreno, R., Barroso, L.A., Rudnick, H., Mocarquer, S., Bezerra, B., 2010. Auction approaches of long-term contracts to ensure generation investment in electricity markets: Lessons from the Brazilian and Chilean experiences. Energy Policy 38, 5758–5769. doi:10.1016/j.enpol.2010.05.026
Nascimento, P.A.M.M., 2015. Considerações sobre as indústrias de equipamentos para produção de energias eólica e solar fotovoltaica e suas dimensões científicas no Brasil. Rev. Radar 39.
Neij, L., Heiskanen, E., Strupeit, L., 2017. The deployment of new energy technologies and the need for local learning. Energy Policy 101, 274–283. doi:10.1016/j.enpol.2016.11.029
North, D.C., 1990. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge. doi:10.1017/CBO9780511808678
Olz, S., 2003. Evaluation of market, regulatory and policy barriers to the use of wind energy in Brazil. (Master’sThesis). University of London.
Pepitone, A., 2016. Energia solar amplia a característica sustentável da matriz elétrica do Brasil. Cad. Opinião - FGV Energ.

Peters, M., Schneider, M., Griesshaber, T., Hoffmann, V.H., 2012. The impact of technology-push and demand-pull policies on technical change – Does the locus of policies matter? Res. Policy 41, 1296–1308. doi:10.1016/j.respol.2012.02.004
Pinto Junior, H.Q.P., 2007. Capítulo 3: Economia da indústria elétrica, in: Economia da energia: fundamentos econômicos, evolução histórica e organização industrial. Elsevier, Rio de Janeiro, pp. 129–229.
Podcameni, M.G., 2014. Sistemas de inovação e energia eólica: a experiência brasileira. (PhD Thesis). Universidade Federal do Rio Janeiro, Rio de Janeiro.
Porrua, F., Bezerra, B., Barroso, L.A., Lino, P., Ralston, F., Pereira, M., 2010. Wind power insertion through energy auctions in Brazil. IEEE, pp. 1–8. doi:10.1109/PES.2010.5589751
Prado, M.M., Trebilcock, M., 2009. Path dependence, development, and the dunamics of institutional reform. Univ. Tor. Law J. 59, 341–380. doi:10.3138/utlj.59.3.341
PV Magazine, 2016. Canadian Solar to invest $23m in 350 MW Brazil module fab. PV Mag.
Reuters, 2016. Usinas solares pedem à Aneel para adiar entrega de energia em 2 anos. O Globo.
Reuters, 2015. New French solar farm, Europe’s biggest, cheaper than new nuclear. Reuters.
Reuters Brasil, 2017a. Plano do Brasil para energia solar avança devagar e faz BNDES estudar mudanças. Reuters Bras.
Reuters Brasil, 2017b. BNDES analisa financiamentos para projetos de energia solar. Reuters Bras.
Reuters Brasil, 2016a. Francesa EDF compra 80% de usinas fotovoltaicas da Canadian Solar em Minas Gerais. Reuters Bras.
Reuters Brasil, 2016b. BNDES prevê mais 3 fabricantes de painéis solares no Brasil até o final do ano. Reuters Bras.
Sekiguchi, P.M., 2014. Análise das barreiras para inserção da geração fotovoltaica centralizada na matriz elétrica brasileira (Specialization Monograph). Universidade de São Paulo, São Paulo.
Silva, N.F., Rosa, L.P., Freitas, M.A.V., Pereira, M.G., 2013. Wind energy in Brazil: From the power sector’s expansion crisis model to the favorable environment. Renew. Sustain. Energy Rev. 22, 686–697. doi:10.1016/j.rser.2012.12.054
SITAWI, CEBDS, 2016. Financiamento à energia renovável: entraves, desafios e oportunidades.
Teece, D.J., Pisano, G., 1994. The dynamic capabilities of firms: an introduction. Ind. Corp. Change 3, 537–556.
Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strateg. Manag. J. 18, 509–533.
Tolmasquim, M., 2016. Energia renovável: hidráulica, biomassa, eólica, solar, oceânica. EPE, Rio de Janeiro.
Tomelin, A.C., 2016. Necessidade de adaptação dos instrumentos de financiamento de energia renovável (Master’sThesis). Universidade Federal do Rio Janeiro, Rio de Janeiro.
UNEP, 2015. Climate change mitigation technologies in Europe - evidence from patent and economic data.
UNEP, EPO, 2014. Patents and climate change mitigation technologies in Latin America and the Caribbean.

Vazquez, M., Hallack, M.C.M., Queiroz, R., 2016. Condicionantes institucionais à execução de projetos de infraestrutura: financiamento de longo prazo. Texto Discussão IPEA 2266.
Wachsmann, U., Tolmasquim, M.., 2003. Wind power in Brazil—transition using German experience. Renew. Energy 28, 1029–1038. doi:10.1016/S0960-1481(02)00212-4