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VALENTINA MARTELLI

FUTURE SCENARIOS FOR THE BRAZILIAN ENERGY ECOSYSTEM

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VALENTINA MARTELLI

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Dissertação de Mestrado apresentada ao Programa de Pós Graduação em Administração, Instituto COPPEAD de Administração, Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Mestre em Administração (M.Sc.).

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ABSTRACT

Martelli, Valentina. Future scenarios for the Brazilian Energy ecosystem. Rio de Janeiro, 2018. Dissertação (Mestrado em Administração) – Instituto de Pós Graduação e Pesquisa em Administração, COPPEAD, Universidade Federal do Rio de Janeiro, 2018.

The integrated Brazilian electricity network is one of the largest in the word and it is traditionally based on a centralized model. The operational integrated model allows for optimization whenever the generation of a certain source is available in a region and scarce in another one. The allocation of renewable energies (as wind and solar) posed the technical challenge on how to integrate intermittent sources within the existing system without compromising energy security and electricity prices. However, Brazilian policies on the matter still lag behind international references and serious regulatory obstacles have been delaying the development of the distributed generation and the smart grid integration.

This qualitative research is based on 15 in-depth interviews aimed at revealing the perceptions of the main actors playing within the business ecosystem. The analysis led to individuate the main forces acting in the market and to classify them as trends or uncertainties. Among the short-term (5 years) uncertainties, we identified country's industrial policies (importation vs local production), energy policies (taxation, incentives) and technical challenges due to the efficient allocation of renewable sources within the Brazilian energy matrix. In the long-term uncertainties' list, geopolitical dynamics and local effect of climate change play a role. The dependence of the energy governance on political instability emerged as one of the main warnings that investors perceive as the major risk of entering the electricity market.

Keywords: energy ecosystem, Brazilian energy sector, distributed generation

RESUMO

Martelli, Valentina. Cenários futuros para o ecossistema brasileiro do mercado da Energia, Rio de Janeiro, Ano. Dissertação (Mestrado em Administração) – Instituto de Pós Graduação e Pesquisa em Administração, COPPEAD, Universidade Federal do Rio de Janeiro, 2018.

A rede brasileira integrada da eletricidade é uma das maiores no mundo e é baseada tradicionalmente em um modelo centralizado. O modelo operacional integrado permite a otimização quando a geração de uma determinada fonte esteja disponível em uma região e escassa em uma outra. A introdução das energias renováveis (como a eólica e solar) levantaram o desafio técnico de integrar fontes intermitentes ao sistema existente, sem comprometer a segurança do fornecimento energético e os preços da eletricidade para o consumidor. Contudo, as políticas brasileiras encontram-se tecnicamente atrasadas internacionalmente e obstáculos regulatórios são empecilhos tanto para o desenvolvimento da geração distribuída como do *smart grid*.

Esta pesquisa qualitativa, baseada em 15 entrevistas em profundidade teve como objetivo identificar a percepção dos principais atores que atuam no ecossistema do negócio, permitindo elencar as principais forças atuantes e classificá-las como tendências ou incertezas. Entre as incertezas de curto prazo (5 anos), identificamos as políticas industriais do país (importação *vs* produção local), as políticas energéticas (tributação, incentivos) e os desafios técnicos devido

à integração eficiente de fontes renováveis dentro da matriz energética brasileira. Na lista das incertezas de longo prazo, a dinâmica geopolítica e o efeito local das alterações climáticas têm um papel relevante. A relação da governança de energia com a instabilidade política emergiu como um dos principais elementos de risco percebidos por atuais e potenciais investidores.

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Palavras chaves: ecossistema de energia, setor de energia brasileira, geração distribuída.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Several millions (or trillions) of species on earth have been struggling for survival in a very complicated equilibrium of exchange and interaction called ecosystem that evolves inside a finite planet, with finite resources and finite life-time. Continuously new species form and others go toward extinction, in a completely natural process. The evolution awarded us, so far, with the survival thanks to the role that along the last ~200000 years we found within such dynamic ecosystem.

Despite our insignificantly short time on Earth, we gave a name to this era, Anthropocene: the era of the humans. This is because of the impressive impact that we (as dominant species) have been having on the global ecosystem, especially after the industrial evolution. However, so far, humanity has failed to reconcile the industrial civilization and technological advancement with a sustainable development, as signals of a dangerous drift toward an inhospitable ecosystem are recognized in what is called climate change (IPCC, 2014). There is an almost unanimous consensus in the scientific community about the anthropogenic causes to the climate rapid drifts and irreversible consequences on some biological ecosystems (COOK ET AL., 2016). The resilience of our ecosystem, and so our survival, may be under threat when, for instance, critical values of biodiversity are lost (CARDINALE ET AL., 2012).

Climate change is ultimately an energy problem. Most of the greenhouse gases (GHG) emissions can be ascribed, directly or indirectly, to the use of energy and such consumption is currently increasing due to global population growth and increasing standards of living (IPCC, 2014). This fact is represented in Fig. 1.1 (OLIVIER, 2017), where the increase along the time of the global GHG emissions are reported, referring to the contributions coming from the different industries.

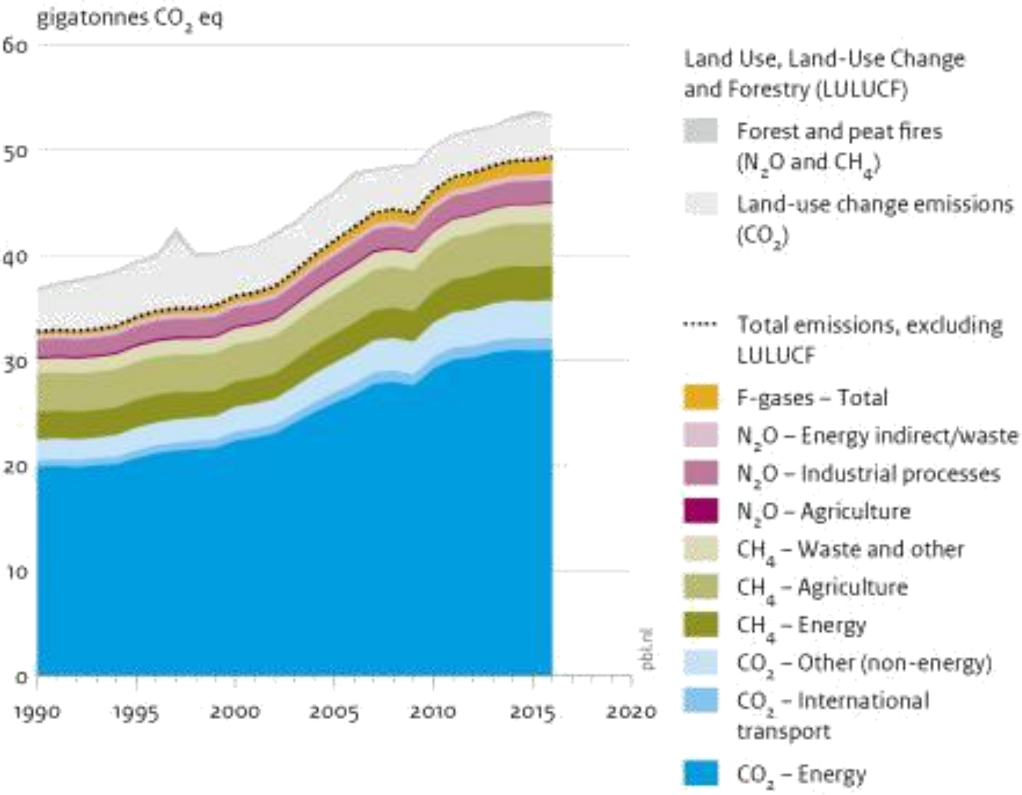

Figure 1.1 Emissions of global greenhouse gas, per type of gas and source, including LULUCF (Land Use, Land-Use Change and Forestry). (OLIVIER, 2017).

This evidence has very slowly led to a global race toward renewable (REN21, 2017) and low-emissions sources of energy (solar, wind, waves, geothermic, hydro) in an attempt to dump the disastrous effects of the fossil fuel usage. Observing Fig. 1.1, we can clearly see that the adoption pace of renewables has not been sufficiently fast, so far, given the gravity and the scope (global) of the problem. This is shown in Fig. 1.2, where we can see that in 2015 the global consumption was supported by renewables only for 19.3% (upper panel), whereas concerning to electricity this value reaches 24.5% (lower panel). Among the renewable sources of electricity, we find hydropower, wind, solar, biomass, and other emerging technologies. In this work, our interest was mainly devoted to solar generation and the reason for this choice of scope resides in the relevance and potential of this technology. Hydropower is not seen any more as a long-term viable alternative due to high environmental and social impact (this will be discussed in detail in the following). Excluding hydropower, 95% of the total global investment in 2016 (~250 billion USD) went for wind and solar, almost in the same proportion (REN21, 2017). In Fig. 1.3, the installed capacity of wind and solar of the last 10 years is reported (REN21, 2017). The reason why solar energy has being taking more a more a relevant role respect to wind is due to the scalability of the technology and to the rapid decrease of the production costs which could help a fast diffusion and adoption. This explains and supports the decision to focus this work on solar generation, though studying it within the energy market as a whole is necessary, as it is the general context.

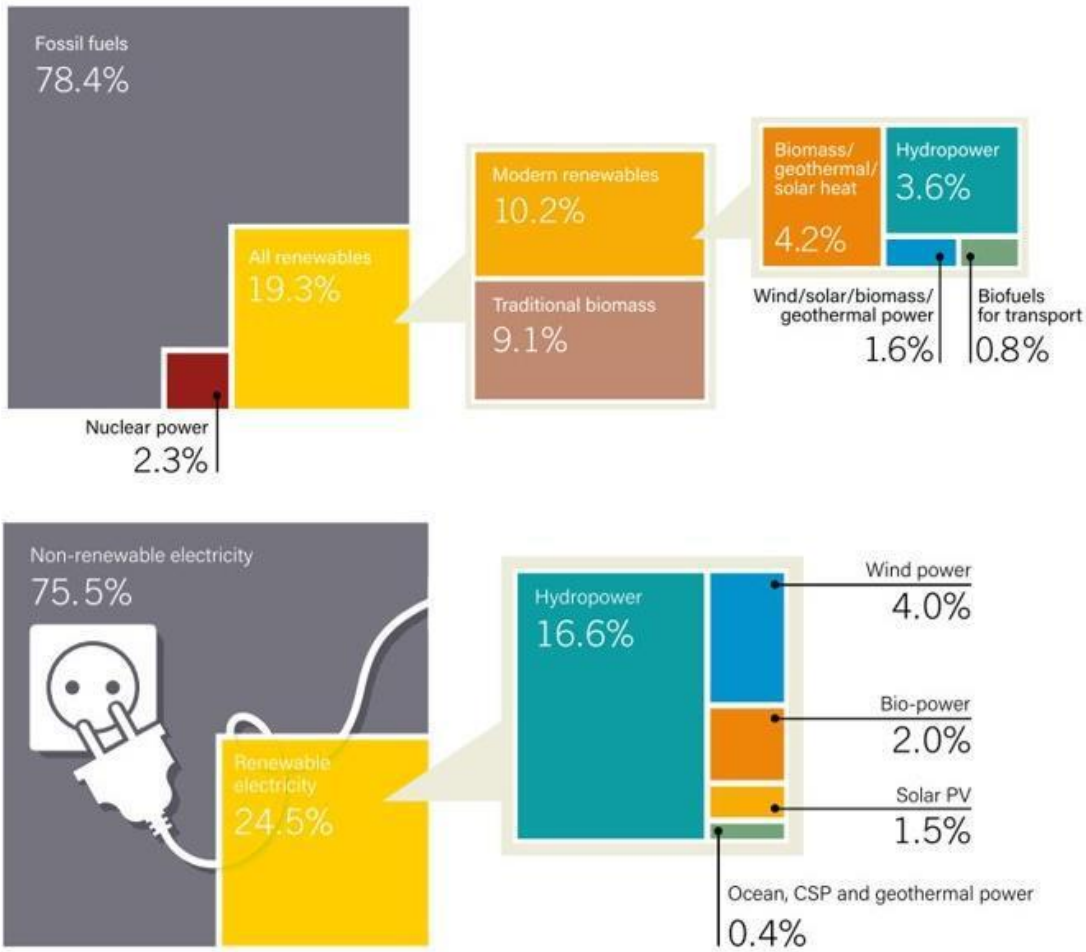

Figure 1.2 Upper figure: Estimated renewable energy share of total final energy consumption (2015). Lower figure: Estimated renewable energy share of global electricity production (End-2016). Both figures from (REN21, 2017).

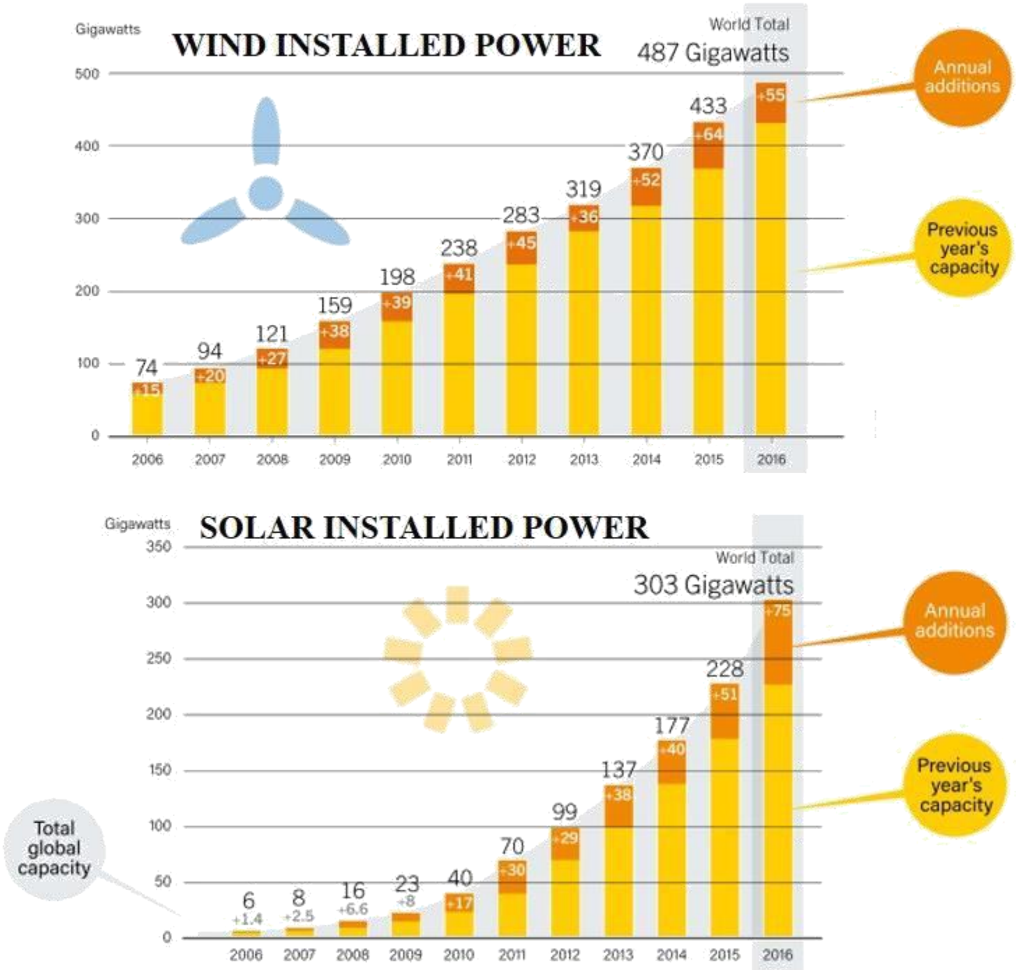

Figure 1.3 Wind and Solar installed power evolution between 2006 and 2016 (REN21, 2017). The exponential growth of the solar power is the key driver for this industry.

It remains open the question whether the solar energy based-technology will be one of the successful components to help addressing our global sustainability issues (DIAMANDIS, 2012) or it will be just another techno-fix[1] that will bring unintended consequences as the previous ones thus not bringing the expected long-term effects (HUESEMANN, 2011)? Although this question will not be answered here, it is fair to place the topic within the right framework that concerns not only a market with potentially huge financial opportunities but also a way to contribute to the open problem of the industrial sustainability.

Nowadays energy is a global business of over 1 trillion dollars and the renewable energies market is expected to be above 700 billions in 2019[2]. This impressive worth and the

[1] Techno-fix: a new technology that actually just fixes problems created by previous technology.

[2] http://www.researchandmarkets.com/research/nx5352/renewable_energy

potential impact of their massive application are so big to attract the interest of many research investigations other than, obviously, investors.

In this work, we focused on the energy market in Brazil, though global geopolitics dynamics will be also matter of discussion. Despite the very virtuous Brazilian energy matrix compared to other countries (counting on over 70% of electricity produced by hydroelectric basins), the solar component is still incipient, while wind has a relevant presence. In general, renewable sources present, at the current status of technology, an issue of intermittence. To guarantee energy security and, at the same time, to integrate solar and wind energy has, so far, an indirect impact in terms of both costs and emissions that batteries might help to address in the next future. Energy demand in Brazil grew constantly until 2015. Public auctions 'created' a demand for investors and, as long as the industrial growth was constant, that demand matched the real one. These mechanisms got stuck in the time of economic recession, to the point that, in August 2017, the government opened a "cancellation auction" where projects accepted in previous auctions could have been retracted[3].

In 2017, after the economic recession that has impacted Brazil and Brazilian industry, is not clear yet whether the real electricity demand (i.e., not only created by auction) will increase and, if so, in which time horizon. In fact, although the end of 2017 indicated positive signals of growth, they are still tiny to allow for predictions. It is clear that the country is facing a political and economic challenge and that the energy supply is a key point to guarantee the development of the Brazilian economy. In this situation of uncertainties, the country ratified the Paris agreement in September 2016 and commit to reduce greenhouses emissions that translates on two fronts: stopping deforestation and reducing active greenhouse gases emissions. Brazil, observed in the big picture as the country with the biggest rain forest, plays a fundamental and crucial role in the international panorama and the energy issue is a critical factor.

It is beyond the scope of this work to give an exhaustive analysis of this complex and fascinating issue, but it was necessary to place this research in the right context.

[3] http://www.aneel.gov.br/sala-de-imprensa-exibicao-2/-/asset_publisher/zXQREz8EVlZ6/content/mecanismo-de-descontratacao-de-energia-de-reserva-totaliza-183-2-mwmedios/656877?inheritRedirect=false

1.1. Objectives of the study

In this work, we aim at identifying the main forces acting on the Brazilian electricity market with a special attention to the distributed solar energy. The goal of this research is to bring insights starting from the perception of the significant actors playing within the ecosystem. Specifically, we aim at:

- Revising recent existing scientific literature regarding the topic not only about Brazil, but also about the international context;
- Performing a field research investigation based on in-depth interviews with the aim to understand the perceptions of the main actors;
- Individuating the main drivers of the energy market (trends and uncertainties), starting from the joint analysis of the literature review and the field work's outcomes.
- Building the electricity ecosystem based on the literature review and on field results;
- Constructing future scenarios based on the two most relevant uncertainties individuated during the analysis process.

1.2. Relevance and scope the work

The solar energy business is still incipient in Brazil despite the huge irradiation potential and despite the size of the business opportunity. Therefore, the lack of specific literature regarding this topic does not surprise and clearly offer an opportunity for investigation due the extreme relevance that clean power production has been playing globally.

The database used for the literature gathering process was SCOPUS as it is the biggest multidisciplinary base of scientific articles and only peer-reviewed English works were considered. Our research focuses on solar energy production, both on-grid and off-grid. Our key-word search is summarized in Fig. 1.4. The first Boolean chart shows as the literature on off-grid solar in Brazil is lacking; as already commented, this makes completely sense considering the stage of development of this market. In the second Boolean we can observe as in the case of the distributed energy generation the literature is already more relevant, though not abundant. The ANEEL resolution of 2012 (discussed in the next sections) stimulated the distributed production of solar energy, thus an increasing number of scientific works on this topic was expected. Those papers related to Brazil have been reviewed.

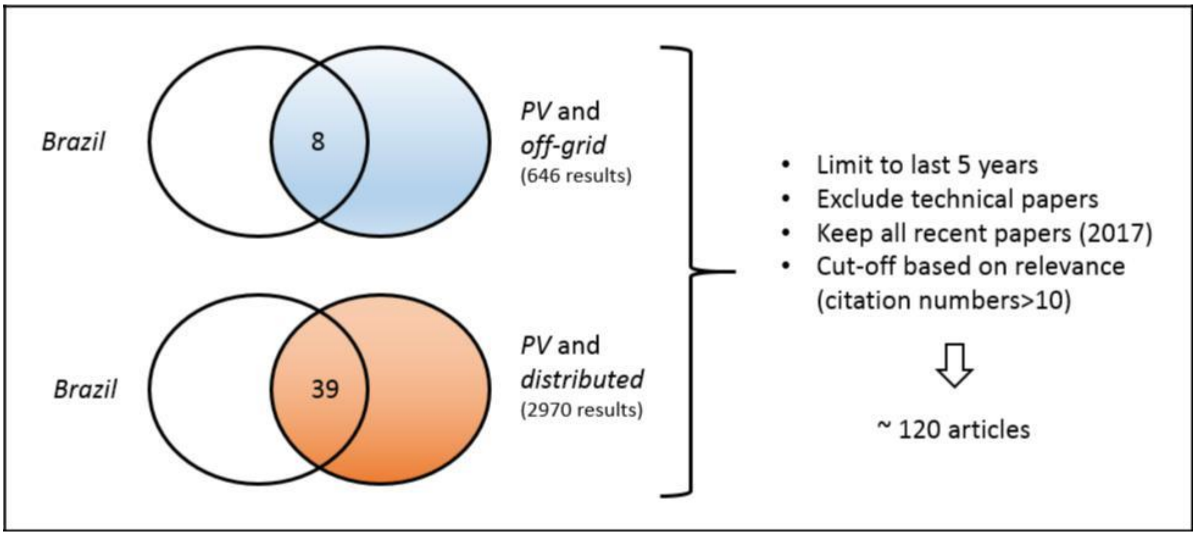

Figure 1.4 Schematics of the literature search process.

If we remove from the keyword search the restriction to Brazil, we obtain over 3000 articles counting both off-grid and on-grid solar. We limited the search to the last 5 years and we excluded all technical papers related to chemistry, materials science and other specific subjects. We reviewed all very recent papers (2017) that still do not have enough citation records, and, for the other years of publication, we took into consideration all papers that have more than 10 citations as criterion for relevance. Many of them revealed to be not relevant to the topic after a first screening, while other papers were included as interesting references found in the selected papers.

The method does not lead to a systematic literature review, but to an exploratory one that matches with the scope and goal. During the literature readings, it appeared necessary to integrate with official regulation documentation and magazine articles.

1.3 Organization of the work

The following part of this work (Chapter 2) covers the literature review, presents data from Brazilian public sector and regulators and also discuss the scientific literature on the topic. In Chapter 3, we present the methodologies and how they fit to the current investigation. Chapter 4 reports field research outcomes and analysis (business ecosystem, interviews and scenarios), and Chapter 5 reports the conclusions and suggestions of possible future investigations.

2. LITERATURE REVIEW

2.1 Brazilian Electricity Market

The electricity supply system in Brazil is mainly centralized and can be quite accurately represented by the schematics in Fig 2.1, as 99.3% of the total installed power is provided by centralized plants. In fact, of the ~160 GW[4] total installed capacity, only 240 MW[5] are provided by distributed generation (DG). Primary electricity voltage is generated in a power station, then the voltage is elevated above 50 KV to reduce losses along the transmission lines that distribute it all across the territory. After a first stage of transformation, medium Voltage (1 – 50 KV) is supplied to industrial customers and after a second transformation stage low-voltage (< 1 KV) is provided to, residential consumers.

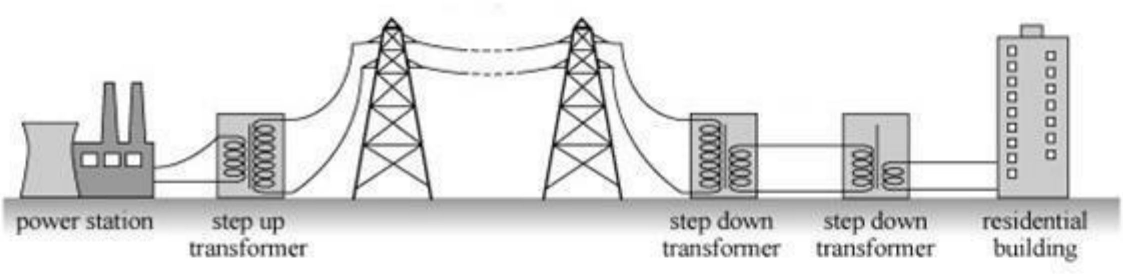

Figure 2.1 General schematics of centralized electricity supply (Source: hk-phy.org)

The Brazilian electric system is one of the biggest integrated supply network in the world. In fact, energy is produced in several power plants (Hydro, Thermal, Biomass, Wind, and Nuclear) that are distributed across the country due to the convenience of the location. The proportion of the different sources can be seen in the EPE (Empresa de Pesquisa Energética[6]) report (EPE, 2017) (Fig. 2.2).

4 http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

5 http://www2.aneel.gov.br/scg/gd/VerGD.asp

6 http://www.epe.gov.br/pt

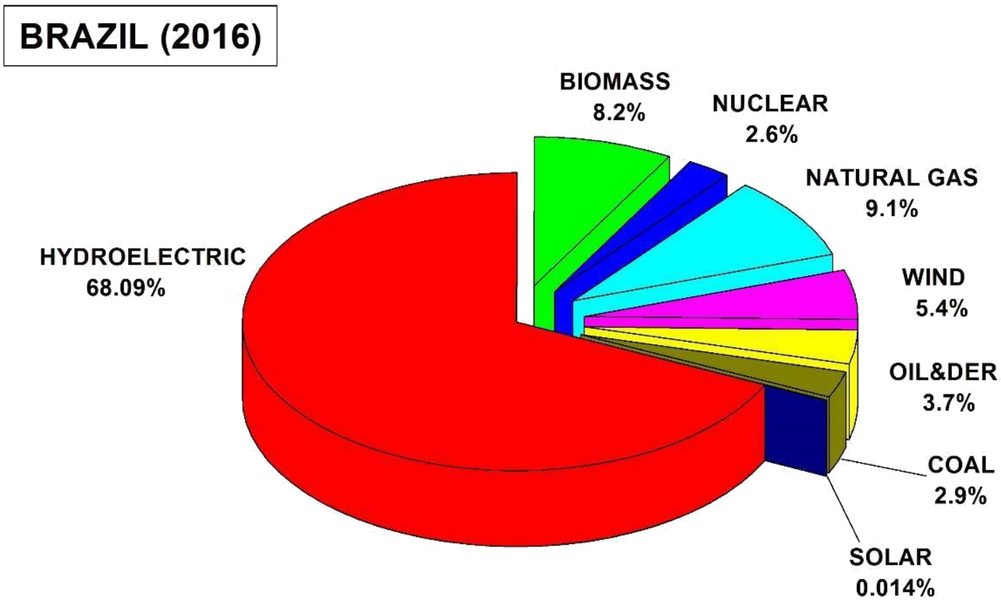

Figure 2.2 Brazilian Electricity Generation Matrix organized by source (EPE, 2017)

After the generation, electricity is then supplied to users through a complex network that is interconnected and controlled in a centralized way over all the Brazilian territory. The total length of the Brazilian transmission lines is more than 100,000[7] km that is roughly two times the equator line. Such a system presents amazing aspects like for instance to produce energy locally where wind or water are abundant at a certain point and then to transfer it to other geographical zones where it is scarce. The distribution of energy produced across a huge region is optimized according to the demand and the available resources using a sophisticated software. However, it has been recently seen as this type of system is subjected to limitation or even to disruption especially in the case of Brazilian reality for at least two reasons. First, the electricity matrix relies heavily on hydroelectric components; in case of droughts (SILVA, NETO, SEIFERT, 2016), hydroelectric input becomes insufficient and additional fossil-fuel based power plants have to be activated to feed the network. This has as a result to incur in additional costs for consumers and to increase greenhouse gases emissions, with no guarantee of fully meeting the national demand. Second, average losses along the transmission lines can amount up to about 14% (OLIVEIRA, 2012) accounting for ~7% of technical losses and 7% of non-technical losses.

[7] http://www.brasil.gov.br/infraestrutura/2011/12/rede-de-transmissao-supera-107-mil-quilometros

Taking into account the average expected technological development, the value of 7% is considered to be acceptable. However, the non-technical 7% losses level is extremely high, especially because there is a high variance among different transmission operators; some can count up to 30% non-technical losses. While those losses can be explained by social and historical reasons, companies don't work on frauds and thefts prevention, due to several reasons. It is clear as overall losses/disruptions can heavily affect the reliability of the supply network and the end-consumer prices.

If we look at data of losses estimated by the WorldBank (IEA, 2017), the figure is even worse (up to 16%) and it is interesting that an overall improvement of the performance does not appear (Fig. 2.3). From 1995, over 20 years, losses are roughly stable above 16%; thus, neither new distribution lines installation nor maintenance were enough to improve such feature due probably to behavioural and security reasons.

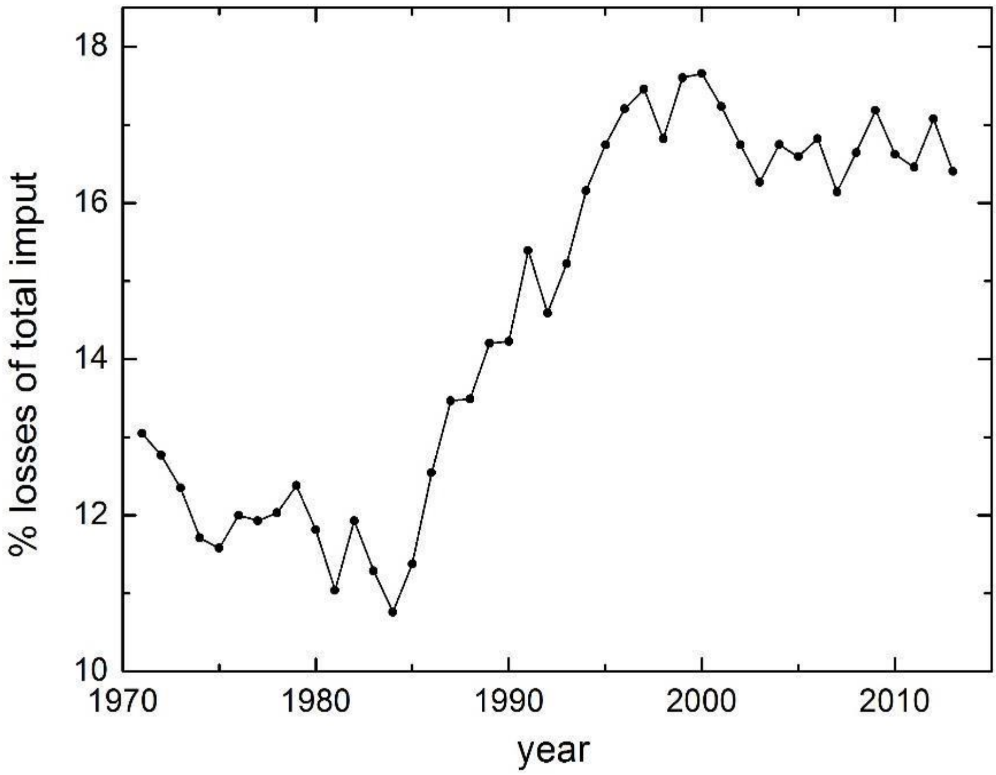

Figure 2.3 Electric losses through transmission/distribution lines (IEA, 2017)

2.2 Is the energy demand increasing?

Figure 2.4 shows the consumption of electrical energy in Brazil in 2015 per sector. We can see that residential, commercial, industrial and losses account for most of the electricity use (~75%). These percentages give an idea of the relevance of each sector in determining the demand as they are affected by slightly different factors although, obviously, general financial health of the country will affect all of them.

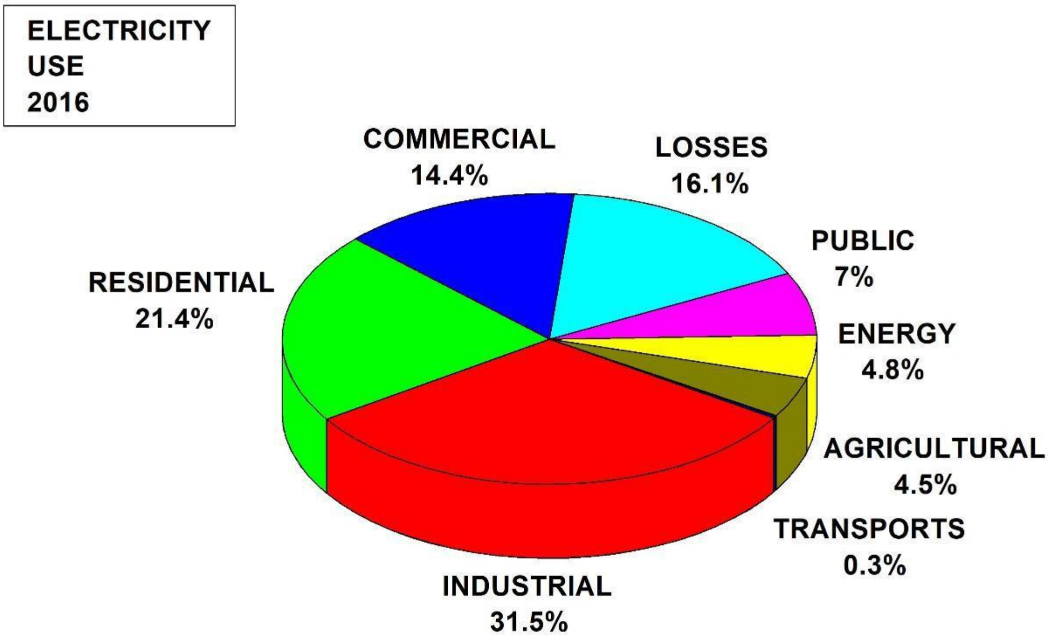

Figure 2.4 Electricity consumption per sector in 2015 (EPE, 2017)

Residential consumption, for instance, is affected by how many people, in total, will use the electricity. Brazil's population counts over 200 million people and this number is expected to grow at a rate lower than other developing countries. According to World Bank and United Nations databases, the Brazilian population growth will be 0.8% in 2017, 0.5% in 2030 and will reach zero growth around 2050 (UN, 2017) with the population size stable around 240 million people, not very far from the value of today. From this point of view, we would not expect a fast growing rate of energy demand. The other factor that might not lead to an increasing demand is that most of the residential population has already access to the electricity. In table 2.1, electricity access data are reported for Brazil, India and South Africa. Brazil is the country where both the percentage of total (99.5%) and of the rural population (97%) shows very high level of energy access. Probably this is due to the Programme "Light for all"[8] that,

[8] https://www.mme.gov.br/luzparatodos/Asp/o_programa.asp

from 2003, promoted investments in electricity in rural areas. Thus, demographic indicators do not indicate that a higher demand is expected.

ACCESS TO ELECTRICITY IN 2012	BRAZIL	INDIA	SOUTH-AFRICA
% total population	99.5	78.7	85.4
% rural population	97	69.7	66.9

Table 2.1 Access to electrification data for Brazil, India, and South-Africa (WORLD BANK, IEA, 2017).

In 2014, EPE (EPE, 2014) listed the uncertainties that might influence how the total energy demand (electricity is only one of the sources) will evolve in the next decades. The consumer behaviour is one of them and it could influence the electricity market especially in terms of distributed generation adoption, mobility standards, new technologies adoption. Beyond consumer behaviour patterns, other relevant factors might be the increase in the average per capita income leading to higher standards of living, the change in construction standards, and the economic competitiveness of new renewable sources. EPE supports the idea that an improvement in the efficiency of the production/transmission is a trend; however this is in contrast with data shown in Fig. 2.3 (IEA, 2017).

According to IBGE (Brazilian Institute of Statistics and Geography), from the second trimester of 2014 till beginning of 2017, the GDP (Gross domestic product) fell down 9.1%[9,10], representing one of the worst recessions since the 1947, when the PIB started to be measured and assessed. The impact of recessions is usually evaluated according to the duration of negative growth in terms of quarters or in terms of accumulated value lost in economic production.

Although it seems reasonable to expect a correlation between GDP growth and energy demand, especially for industrial and commercial sectors that together account for 46.7%, it is useful to report them in a plot for graphic comparison (Fig. 2.5). The blue line (right axis)

[9] http://www1.folha.uol.com.br/mercado/2017/03/1864296-populacao-brasileira-empobrece-91-com-recessao.shtml

[10] http://brasilemsintese.ibge.gov.br/contas-nacionais/renda-nacional-bruta

represents the Brazilian GDP, while the red circles (left axis) represent the total energy consumption in GWh. The energy consumption growth rate have been positive during most of the time and also we can notice an overall linear increase. Shaded regions A, B, and C were reported with the intention to individuate past recession times and see whether a correlation with energy use was observed. In Region A, the consumption shows a local reduction in the slope, but the rate was recovered after two years. The same effect, but more evident, can be seen in region B. However, the previous growth rate was recovered just in one year. Similar behaviour for region C. From the analysis of the historical data, we can conclude that there is short-term correlation between GDP and energy consumption, but in the past, after the economic crises, the energy consumption growth rate came back to be the same before the recession rather quickly. This was probably due to the inexorable growth of the country and the auctions' mechanism (will be discussed in the next section) that induced a mechanism of investments to provide regular energy offer growth.

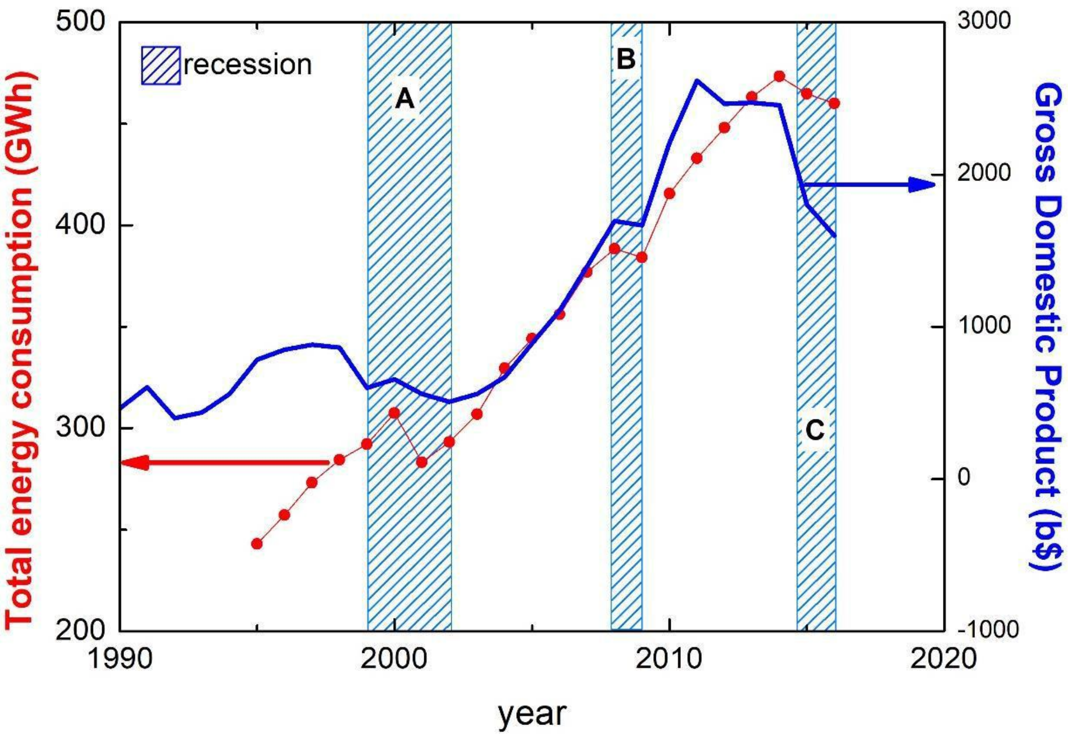

Figure 2.5 Historical values of total consumption in GWh (left axes) and GDP (right axes). Shaded regions A, B and C evidence GDP stagnations or reduction. Data were obtained from EPE official website[11].

[11]http://www.epe.gov.br/mercado/Paginas/default.aspx

Short-term forecasts based on development trends prior to 2015 might result inaccurate and currently there is not unanimous agreement whether Brazil will invert the trend during 2017. Analysts say the recession is going to finish in 2017[12], but the signals of the economic recovery at the end of 2017 were still tiny. Negative signs to investors have been given as, for instance the cancellation, in December 2016, of the auction for the generation of reserve energy[13]. Although the short-term forecast seems so uncertain, Fig. 2.5 may suggest that, if the economic crises will be promptly and properly addressed, the electricity consumption and demand will increase rather quickly, as happened in the past. However, this rational has a speculative nature.

It is quite clear that there is an uncertainty on the short/mid-term electricity demand, however in order to better understand the energy policies, we can investigate how Brazil was dealing with the demand till 2015. Figures 2.6 reports the percentage of the different sources of energy that composed the Brazilian electricity matrix in 2011, 2013, 2014, 2015 and 2016. Data of 2016 are reported for completeness, but we cannot forget that 2016 was a recession year with a lower energy consumption; therefore the matrix composition does not follow the development policies set by the country. Data were obtained from EPE reports (EPE, 2014; EPE-R, 2016; EPE, 2017). The two graphs represent the same data in linear (left panel) and logarithmic (right panel) scale, as this allows for different observations. Brazil is considered one of the most virtuous countries in the world in term of renewable sources. In 2011, over 80% of the electricity was supplied by hydroelectric plants. Between 2011 and 2015, we can see how the percentage of hydroelectric is falling down over time and this fact is even more relevant considering that the total supplied energy increased. In fact, three main factors limit the expansion of the hydroelectric participation in the matrix. First, stricter environmental protection rules make more difficult the installation of new dams (See, for instance all legal issues related to the case of Belo Monte); in fact, building big hydroelectric reservoirs implies flooding huge areas with strong environmental and social impacts for the indigenous habitants. Second, the biggest hydro-basins are basically already exploited (though only 30% of the total water potential is currently used); third, climate change is affecting the expected seasonal rainfalls leading to times of extreme droughts (SILVA, NETO, SEIFERT, 2016) that, as a

[12] http://oglobo.globo.com/economia/mesmo-com-fim-da-recessao-pib-do-brasil-ficara-na-lanterna-em-2017-21026310

[13] http://www.epe.gov.br/leiloes/Paginas/2%C2%BA%20Leil%C3%A3o%20de%20Energia%20de%20Reserva%202016%20-%20CANCELADO/Quedadedemandaporenergiael%C3%A9tricacancela2%C2%BALER2016.aspx

consequence, requires the use of other sources of electricity to meet the demand. As we can observe in Fig. 2.6, the missing part had been provided mainly by non-renewable sources such as coal, natural gas, and nuclear. Wind energy shows a growth trend while biomass maintains roughly the same share, while solar energy has not obtained yet a relevant portion of the matrix.

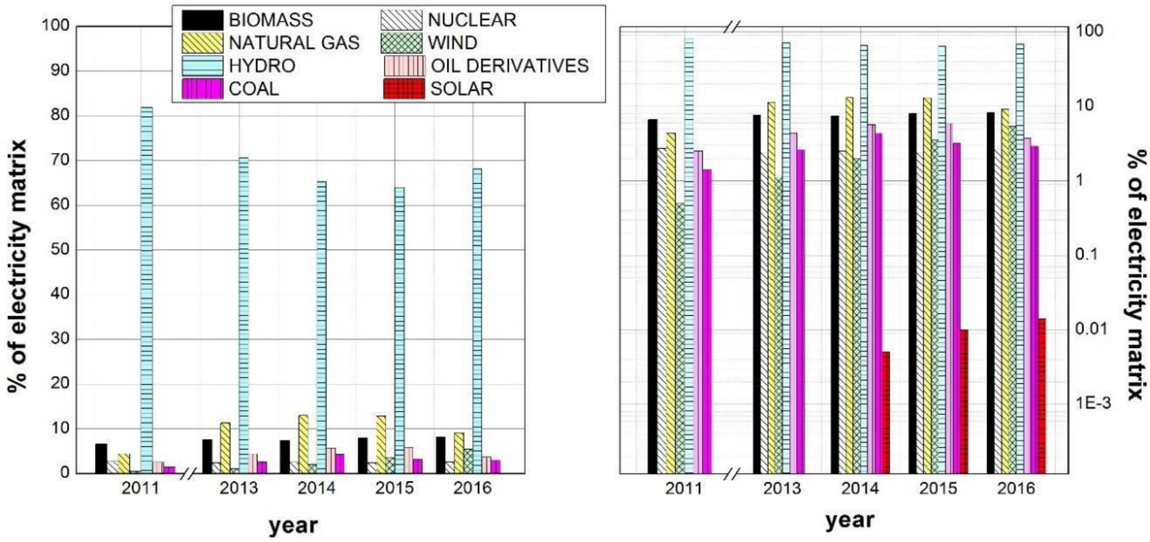

Figure 2.6 Brazilian matrix for electricity supply. Data are obtained by (EPE, 2014; EPE-R, 2016, EPE, 2017). Left and right panels display data respectively in linear and logarithmic scale.

Interestingly, if we look at the logarithmic graph (Fig. 2.6, right panel) we can learn something about the pace at which the percentages are changing over time. The wind energy percentage shows a very interesting trend, but more remarkable is the solar component figure that presents a very fast growth in 2014 and 2015, indicating a possible promising development in the next few years, though not presenting a relevant presence right now as net contribution. This trend is consistent with the analysis of Freire M. C. et al. (2015) that showed that investments in big power plants of renewable energy are already attractive given all financial, policies, local climate, and geopolitical aspects. The smoother growth rate of solar in 2016 can be ascribed to the financial recession.

It is noteworthy that all the sources reported in Fig. 2.6, included wind, solar and biomass, are located in the centralized schematics previously reported, thus subjected to the intrinsic weaknesses of the transmission infrastructures previously discussed (OLIVEIRA, 2012). In other words, distributed generation (DG) is not reported.

The development of the energy sector in Brazil is in principle constrained by the country's commitment towards international goals related to climate change mitigation. According to available data (CDIAC, 2017), Brazil emits about 2.5% of the world's carbon dioxide and other polluting gases and its overall emissions increased steeply from 2010 till today. This negative trend could be explained as follows: on the one hand emissions of gases from human activities actively contribute to the net GHG budget, on the other hand an uncontrolled raise in deforestation led to a weaker offset naturally coming from the Amazon forest. This last trend was ascribed to a lack of law enforcement on the Amazon forest (RICHARDS ET AL., 2017). In September 2016, Brazil ratified the Paris agreement (AGRICONE, 2016) committing to reduce emissions of 37% by 2025 and of 43% by 2030, based on reference values of 2005. Therefore, this ambitious goal should be reached working on the two sides of the problem: fighting deforestation and reducing emissions. The second point relates to energy, agriculture and industry and is meant to be focused on efficiency, technological improvements and policies that is the direct interest of this research.

Brazil is facing a very challenging problem: how to stimulate economic recovery providing electricity at an affordable price and, at the same time, reducing the greenhouses emission to meet international agreements.

2.3 Actors in the Brazilian electricity sector

In the previous sections, we analyzed the general structure of the Brazilian electricity system and supply matrix. The aim of this section is to describe the actors playing the roles described schematically in Fig. 2.1.

All the organizations/institutions operating in the electricity sector are regulated by the National Agency of Electric Energy (ANEEL)[14] since 1997. The main task of ANEEL is to regulate the production, transmission, distribution and commercialization of electric energy. Beyond that, it controls the concessions and permissions, establishes the electricity prices, mediates between providers and consumers, and promotes new concessions (by means of public auctions) on behalf of the Brazilian government, the latter being one central peculiar aspect of the Brazilian reality. Public auctions stimulated investments in all sectors of the industry

[14] http://www.aneel.gov.br/a-aneel

(generation, transmission and distribution), and it was a central engine to meet country's energy demand.

In November 2017, Brazil had 4,760 power plants in operation, providing a total installed capacity of almost 156 GW[15] and a transmission lines network of about 100,000 km[16].

Electricity is then distributed through a network provided by around 100 companies, both public and private (also called Utility companies). 51 of those distributors are organized in a consortium called ABRADEE [17] (Associação Brasileira de Distribuidores de Energia Elétrica) that serves almost all the Brazilian users (99.6%). ABRADEE is a not-for-profit organization that has as main goals[18]: to maintain the sustainability of the distribution business, to guarantee the investments required to increase the operational efficiency of the service, to improve the service to the final consumer, and to work for a fair tariff. It is worth spending a few words on the business model of the distributors. Their business is basically buy and resell energy to consumers. Distributors (or Utilities companies) have the right to receive 9.8% of the net income. One of the main operating costs is the maintenance of the infrastructure of transformation and distribution.

The National Operator of the Brazilian Electric System (ONS)[19] is the federal institution responsible to control and supervise the operations related to the installation of power generation and transmission/distribution lines within the National Interconnected System (SIN), which is an informatic system of operation that allows an automatic coordination of the energy distribution within the network. The ONS is a not-for-profit public organization that has as mission: to promote the optimization of the operations within the electric generation/distribution system, guarantee to everyone a fair access to electric power, and to guarantee that the SIN system (National Interconnected System) is improved at the minimum costs.

Another important organization is the CCEE (Câmara de Comercialização de Energia Elétrica) that provides support in the energy commercialization of generators, distributors and traders. CCEE is a not-for-profit institution that joins all public and private companies and

[15] http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm

[16] http://www.brasil.gov.br/infraestrutura/2011/12/rede-de-transmissao-supera-107-mil-quilometros

[17] http://www.abradee.com.br/index.php

[18] http://www.abradee.com.br/abradee/quem-somos

[19] http://www.ons.org.br/home/

institutions operating in the market. CCEE administrates all trading contracts in this market. The list of all energy traders can be found in the CCEE website[20]. At this point is important to distinguish between the so called regulated and free market in order to make clear where and when energy trading takes place.

A privatization process of the Brazilian energy sector has been started in 1996. However, most of the assets remains under the control of the Brazilian government. Starting from 2004, a new energy-trading model set the rules for the two markets: regulated and free (SILVA, NETO, SEIFERT, 2016). The regulated one undergoes auctions: companies can participate in public tender competing with the offered capacity and price and after winning the contract they provide the agreed supply in the network according to the auctions' terms. ANEEL can call for regular or reserve auctions. Regular auctions target the forecasted demand in the regulated market. Reserve auctions are meant to cover the energy need in case of emergency (e.g. in case of droughts) and the amount of reserve energy is set by the government through supply security criteria. Users of the regulated market buy the electricity at the cost established by ANEEL; in case of use of the reserve energy users will receive bills charged based on the "tariff flags"[21]. With green-flag the bill will not be -overcharged; with yellow-flag, red-flag1, or red-flag2 bills are surcharged, respectively, by +0.01R$, +0.03R$ and +0.05R$ for each consumed KWh) giving a variation of over 500%.

In the free market, users can in principle negotiate costs and conditions directly with the energy provider, but how can the final consumer act in this setting? How is possible to choose and negotiate directly with the energy provider? In practice, there are still restrictions on this issue and only under special circumstances a user can become part of the "free market", thus, benefiting from a free negotiation on the price/service directly with the energy provider. A user can enter in the free market if it belongs to one of these two consumption categories: (a) single or multiple users that together purchase >500 KW/h ("Consumidor Especial") with a tension of at least 2.3 KV; (b) single user purchasing >3,000 KW with a minimum tension of 2.3 KV. It is still necessary that the distributor serving the user agrees to stipulate a contract with the energy generator selected for the contract. 2.3 KV is classified as medium tension, then the free market is focused on commercial activities or group of private consumers, but generally not

[20] https://www.ccee.org.br/portal/faces/pages_publico/quem-participa/conheca_os_agentes?classe=2&modo=lista&letra=A&_afrLoop=206173050121325#%40%3Fletra%3DA%26modo%3Dlista%26classe%3D2%26_afrLoop%3D206173050121325%26_adf.ctrl-state%3Dh861un3aq_93

[21] http://www.aneel.gov.br/tarifas-consumidores/-/asset_publisher/e2INtBH4EC4e/content/bandeira-tarifaria/654800?inheritRedirect=false

single households. Instead, the user in the regulated market cannot negotiate the price or choose the provider and its electricity tariff will be set by the Brazilian Government and will take into account generation and distribution costs.

To complete the description of the context, it can be useful to look at the typical costs of electricity for the regulated market. The total cost reported in Fig. 2.4 includes: Generation-Transmission-Distribution (GTD), Taxes (state and federal), others (losses, flag-readjustments).

ITEM	**R$/MWh**	**%**
Generation/Transmission/ Distribution	298.45	59.2
Technical Losses	7.3	7.3
Charges	4.8	4.8
Flags	8.75	1.7
Taxes	135.87	27.0
TOTAL	504.00	100.0

Table 2.2 Average cost breakdown of the electricity provided by the Brazilian infrastructure during 2016 (FIRJAN, 2017).

From the investors' point of view, how much does it cost to produce energy from different sources? Which kind of new power-plant would it be worth investing on in Brazil? The answer is not straightforward as many factors play a role. Technology advancement is a relevant parameter to determine the amount of investment when renewable sources are involved. For all kind of sources, public policies (incentives, taxes, auctions) can heavily determine the final cost for the investors and they may vary over time. In table 2.3, the cost of electricity generation per source is reported and it refers to average values between 2005 and 2015 (SILVA, NETO, SEIFERT, 2016). The data are the most updated for our analysis, as the last auction focused on renewable resources took place in 2015; so far, solar and wind did not reach the competitiveness to be awarded in a regular auction (see last regular auction in 2016[22]).

SOURCE	FIXED COSTS (US$/MWh)			VARIABLE COSTS (US$/MWh)	TOTAL PRICE (US$/MWh)
	Average	Min.	Max.		
Hydro	34.45	19.07	50.62	-	34.45
Small hydro	52.37	41.51	67.65	-	52.37
Wind	45.49	28.59	59.60	-	45.49
Nuclear	52.91	-	-	7.08	59.99
Coal	48.76	41.16	66.01	59.92	108.68
Natural gas	54.92	33.74	91.00	79.78	134.70
Diesel	45.46	40.96	64.41	272.28	317.74
Fuel oil	45.46	40.96	64.41	178.2	223.66
Sugarcane refuse	51.98	43.59	68.87	68.97	120.94
Wood residues	52.89	44.28	67.75	68.97	121.86
Biomass (others)	53.32	33.47	91.00	68.97	122.29
Solar	97.66	70.30	99.84	-	**97.66**

Table 2.3 Costs of electricity generation for different type of source. Dollar trading on May 11, 2015 US$1.00=R$3.06. (SILVA, NETO, SEIFEIRT, 2016).

Generation costs depend on fixed costs (set during the auction, with the exception of nuclear energy) and on variable costs of generation (VCG). It is remarkable that solar, hydro and wind generation don't have relevant variable costs. So, we can expect the decreasing costs of the solar technology discussed in section 3.1 (reported in Fig. 3.3) to directly impact its value, although the final costs will also depend on the current policies’ framework.

Another relevant organization worth mentioning is the Brazilian Development Bank (BNDES - Banco Nacional de Desenvolvimento Econômico e Social)[23]. BNDES is not a for-

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[22] http://www.epe.gov.br/leiloes/Paginas/Leil%C3%A3o%20de%20Energia%20A-5%202016/Leil%C3%A3oA-52016viabilizaR$.aspx?CategoriaID=7049

[23] http://www.bndes.gov.br/wps/portal/site/home

profit bank, but a federal institution that offers financing and investment for projects with socio/environment/economical impact. BNDES is offering financing whenever specific local production requirements are satisfied. In the case of the solar energy, starting from 2014, according to its policies, solar panels must be assembled in Brazil; from 2018 on, all electronics, included inverters, must be produced in Brazil, and from 2020 all PV panels must be manufactured in the country. Although the idea of local production might have long term advantages and also financial returns for the local economy, it is at the moment a hurdle to boost the solar energy industry, already struggling to take off due to current policies. It is remarkable to point out that currently BNDES is offering the lowest interest rates for PV projects in the country, though under all described restrictions (MITCHER, LACCHINI, RÜTHER, 2015).

2.4 Distributed energy generation: on-grid

It is quite clear that centralization is a dominant characteristic of the Brazilian electricity supply structure. On the one hand, optimistic scholars claim that Brazil is moving towards full implementation of a smart grid, where utilities would find their financial survival preserved and where big renewable power plants could be the solution to fulfil the energy demand (SANTO ET AL., 2015). On the other hand, there exists an incipient market of distributed energy production that does not clash with the smart grid concept but nor necessarily support it.

Distributed means that users not only can generate and use their own energy produced through small-hydroelectric, wind or solar systems, but they can also inject in the network the excess they don’t need. In 2012, ANEEL for the first time formalized under which conditions users can produce and feed the network with their energy through a net-metering system (ANEEL, 2012). In the resolution, revised in 2015 (ANEEL, 2015), distributed micro-generation and mini-generation refer to systems respectively up to 100 KW and 1 MW[24]. The regulation states that users, which produce excess energy during the day, will accumulate an energy credit that can be used when needed, within a 60 months timeframe.

[24] http://www2.aneel.gov.br/aplicacoes/noticias/Output_Noticias.cfm?Identidade=8534&id_area=90

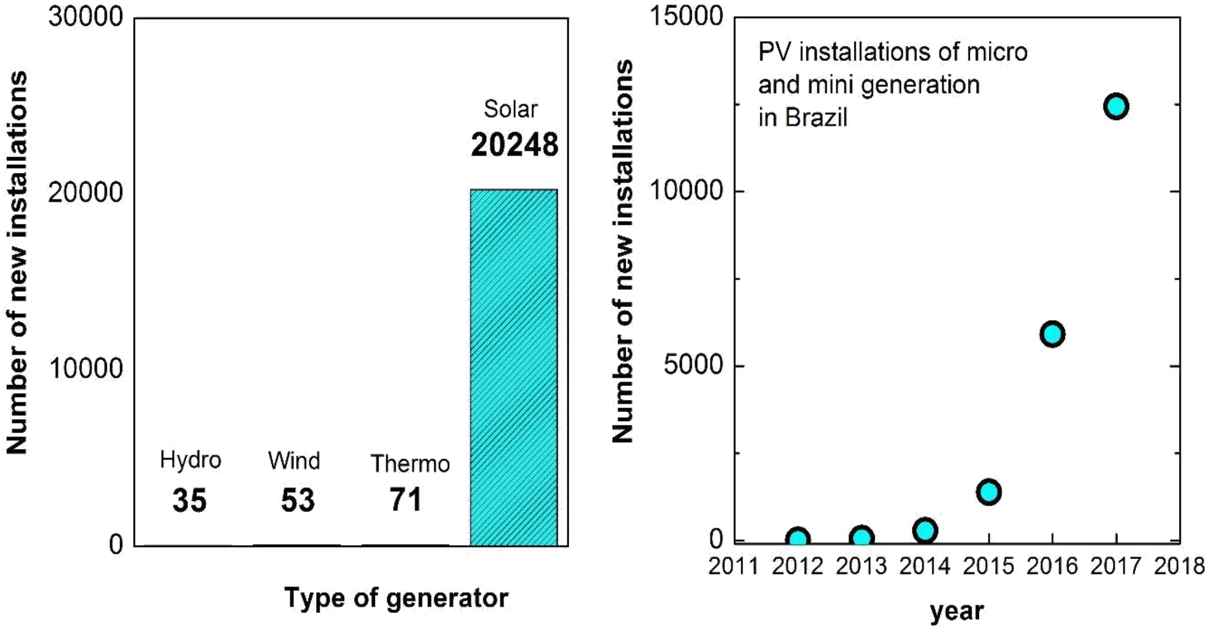

Figure 2.7 (Left-panel) Number of new installations per generator type from 2012 to 2017. (Right-panel) Number of PV installations per year (ANEEL Distributed generation, 2017)

Official data disclosed by ANEEL (ANEEL, 2017) show the total number of new installations of micro and mini-generation between January 2012 and December 2017 (Fig. 2.7). Almost 99% of the installations are photovoltaic-systems (PV-systems). This fact is explained by the relatively ease of installation and by Brazil's solar irradiation abundance (VILELA, DA SILVA, 2016). The relevance of PV respect to the other sources in the Brazilian market justifies why this research is focused only solar generation, when we come to talk about distributed generation. Remarkably, although the ANEEL resolution triggered a fast adoption of the PV distributed systems, Mitscher and Rüther (2012) demonstrated that already before 2012 a PV project would be financially interesting under low interest rate financing (~10%). This could suggest the insufficiency of the ANEEL policies and on the necessity to offer access to credit for residential users besides the one offered by the BNDES.

What does a consumer need to install her PV-system and where can she purchase it? A "solar-kit" is usually composed by the PV-panel, the inverter (it transforms current from DC to AC), cabling and monitoring electronics. A private user can purchase and install a complete solar-kit hiring a distributor that will buy (import) the PV panels and will install on the roof top of the house. In Brazil there is a platform called PortalSolar[25] where a consumer can check on

[25] http://www.portalsolar.com.br/fornecedores/empresas-de-energia-solar

the map all available distributors and choose the most suitable or the cheaper according to quotations that can be requested online (there are more than 900 service providers). In fact, PortalSolar tries to works as a platform, connecting possible users to distributors. On the webpage, we can find out that PortalSolar partners with Absolar (Associação Brasileira de Energia Solar Fotovoltaica) a not for profit association that promotes solar energy in the Brazilian matrix. There is not a specific focus on distributed generation, but rather a wider interest for solar. PortalSolar partners also with InterSolar (South America) that is part of Intersolar, the world leading organization in events to spread knowledge about the solar energy generation.

The decentralized model just described is an alternative that may induce important changes in the centralized model of power generation, transmission and distribution. Therefore, power generation, transmission and distribution existing infrastructures could be impacted by an abrupt market shift as an off-grid system is capable to produce/store energy without being connected to the power distribution network. In Brazil, off-grid systems are even more incipient than on-grid, due to the current limitations of energy storage devices. The Brazilian association of the distributed generation (ABGD[26]) listed 10 off-grid projects; however, they are mainly focused on energy supply to remote areas of the country.

2.5 Technology

2.5.1 PV Cells

The technological advancement is a key element for solar energy generation adoption not only in Brazil, but everywhere. In fact, although consumers can be positive toward adoption, if the technology is not efficient enough in terms of operations and investment, it will remain restricted to niche markets. As it is well-known, photovoltaic (PV) is the technology that directly transform sunlight into electricity, using semiconducting materials. The hardware elements that composes a complete off-grid PV system are: the PV panels, the electrical inverter (from DC to AC current), and the energy storage (the battery). Currently the most critical elements are the panels and the batteries, whereas the latter are still in an earlier stage on the market than the former.

[26] https://www.geracaodistribuida.org/editais-licitacoes

Figure 2.8 Comparison among the different type of PV cells. (NREL21, 2017)

PVs are commonly classified in first, second and third generation. First generation panels are considered the traditional ones and are made on silicon; they are so far the most widely used (90% of global production). Second generation PV are based on thin-films technology (as films based on Cadmium and Tellurium) and are gaining economic relevance. but their production is energy intensive and also relies on rare materials, making scalability a limiting issue. Third generation PVs are still in stage of emerging technologies and do not play yet any relevance in the market. They are based on a wide range of substances, mainly organic and they can range from multi-junction structures that are based on expensive designs to plastic solar cells that can be very cheap and present a great potential for future development.

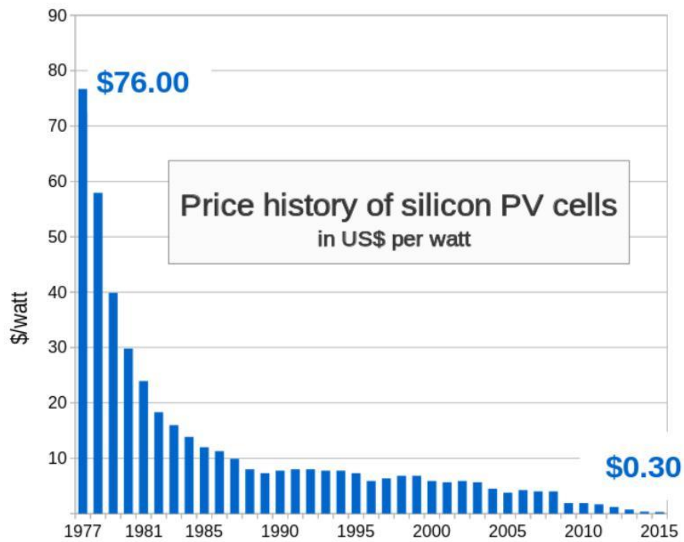

Figure 2.9 Price history of silicon PV cells (BLOOMBERG, 2017).

Figure 2.8 (NREL, 2016) reports the comparison of the cell-efficiency for different types. The efficiency refers to the physical performance of the cell, and it is interesting to notice that traditional crystalline Silicon cells are bound to 25% of efficiency (usually they are between 15% and 20%) that looks very low compared to the over 45% of a multi-junction structured cell.

Emerging technologies need time to escalate, along with public and private financial support and R&D development; in addition, scale is reached through the learning curve that can make an impact along the whole supply chain, from a zero marginal cost trend as it happens for traditional silicon chips. In fact, if we have a look to the price over time of those cells (Price history, 2017) we can see that price per Watt provided by silicon PV cells reduced from 76$ in

1977 to 0.30$ in 2015.

2.5.2 Batteries

The sunlight offers its maximum peak during the day and the energy, if not used or injected in the transmission network, is lost. This is why the other critical element for an off-grid PV system is the storage device: the battery that is still under way to reach scalability. As for the third generation of PV panels, there is a lot of attention from investors and research lab to design batteries based on organic matters in order to make the production environmentally sustainable and financially feasible[27] (Fig. 2.10). However, the batteries that are currently relevant are lithium-based and gained resonance in the media due to the advertised PowerWall produced by Tesla. Actually, there is a vivid debate about that. In Tesla's website consumers can request a quotation for the complete off-grid system including batteries, solar cells or roof, and controlling system.

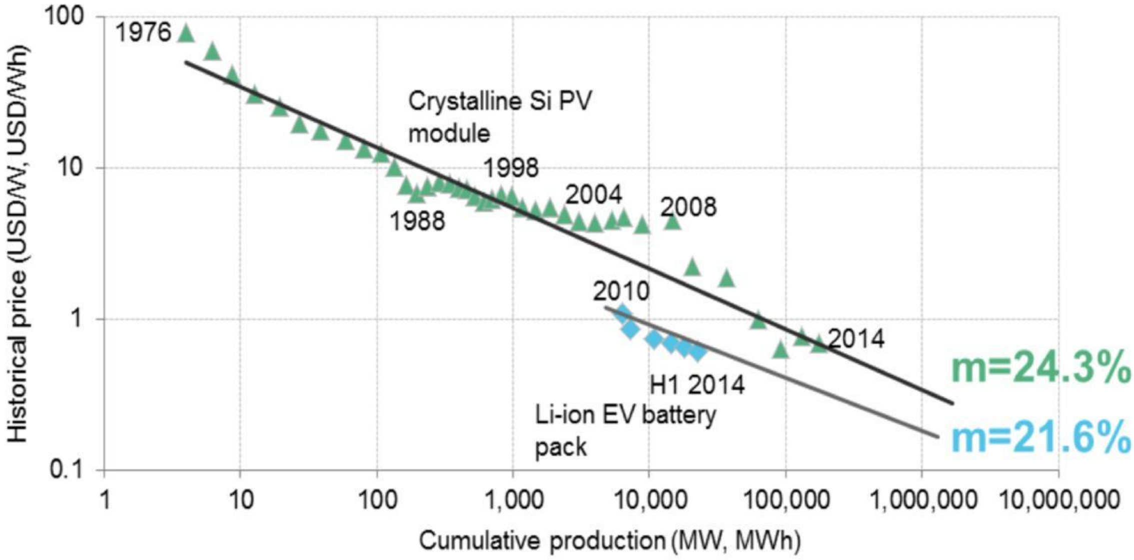

Figure 2.10 Learning curve: Historical prices of Lithium-based batteries vs cumulative production..

In general, the financial advantage that consumers can benefit from depends on government's policies (subsidies) on the subject and may substantially from one country to another. This indicates that this on the verge of transforming the electricity system but is still struggling. However, the Tesla's entrepreneurial initiative is creating infrastructures and awareness that entrepreneurs can profit from. It is noteworthy current studies of comparative financial assessments between stand-alone systems and a traditional utility configurations, and, so far, a financial benefit is not observed, especially when the life-time of the batteries is taken into account (UDDINE ET AL., 2017).

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[27] http://news.stanford.edu/2017/02/07/stanford-engineers-create-low-cost-battery-storing-renewable-energy/

Considering technology as one key point of the discussion makes a good sense, however is also important to keep in mind that policies and a good market supervision and integration can boost the connection between R&D and the market (ZOU ET AL., 2017). The fact that solar technologies are over a century old, can give an insight about this type of dynamic (GEOFFREY, BOUAMANE, 2012).

Interestingly, the exponential decrease of the price of Lithium-based batteries (Fig. 2.10) reminds the exponential patter of number of transistors on integrated circuits over time (Moore's law)[28]. That behaviour allowed to reach a zero-marginal cost in a short time and to allow a global diffusion of all transistor-based devices. From this analysis we can state that technology advancement is a trend and will help realizing favourable conditions for the development of this market.

2.6 Geopolitics

It can be very insightful to place the Brazilian energy market within the big global picture. A complete and exhaustive analysis of the global dynamics would go beyond the scope of this work. Nevertheless, this must be addressed because globalization and its effects are also main drivers that shape this industry.

As the sociology of globalization has discussed, global phenomena such as climate change, migrations, or market developments are events that may not be under the control of a national authority (ROBINSON, 2009). This does not mean, in general, that a country does not have power and relevance to induce and promote changes; on the contrary it does have, but the effects on other countries will show interconnectedness and this is especially true in the case of energy trading. The theory of methodological cosmopolitanism (BECK, 2003) was used by Souza et al. (SOUZA, 2016) to study the emergence of the PV market in Brazil. In this theory's framework, the distinction of "inside" and "outside" national borders are lost along with the mainstream research pattern of focusing just on technological deployment to explain adoption in a certain country. China's leadership in PV manufacturing goes back to 1987, when the government set up interest-free loans to promote local production (SONG, 2015), seeing the renewable energy (RE) markets as strategic in the long-term; indeed, in the long run, China could make the transition from "factory" to "tech hub". The long time in which China invested

[28] https://upload.wikimedia.org/wikipedia/en/9/9d/Moore%27s_Law_Transistor_Count_1971-2016.png

in this industry allowed to reach production scale, other than to improve through a constant learning curve. In addition, the favourable investment conditions offered by the Chinese government attracted a strong flux of foreign capital. In 2008, China shipped PVs for 26,000MW, 90% of those for Europe and North America (ZHANG, 2013). The consumer side saw pioneering countries like Germany, Italy and Spain promoting clean generation through favourable laws in order to meet the greenhouse emission reduction goals. The incentives (see e.g. Renewable Energy law 2000 in Germany) made PV generation cheaper than conventional sources and so, the Chinese panels found a flourished market and a very keen demand. On the global scale, Chinese panels have been cost competitive in comparison to European and North-American products mainly because of cheap energy availability in China (mainly coal) as PV production is energy intensive, representing up to 35% of their final cost (IEA, 2015). Ironically, the big 'green-rush' in the developed countries did not consider the full life-cycle assessment of the panels, produced from dirty energy. It is noteworthy to observe that Brazil, thanks to its energy matrix, could in theory produce PV-panels with a much lower environmental impact. Among other factors that will be discussed in the next paragraphs, the main limiting issue for local production in Brazil is the high cost of electricity.

After 2008, due to the global crisis, several PV producers in Europe and North-America went bankrupt because they could not compete with the Chinese. For this reason, European Commission set anti-dumping taxes of 47% on Chinese panels and US set taxes up to 250% to protect local producers (HUGHES, MECKLING, 2017). China, to place the overproduction promoted a national Programme to induce local market adoption. Hochstetler (HOCHSTETLER, 2015) investigated differences between China and Brazil in PV panel industry development and concluded that the outcomes can be ascribed mainly to institutional differences (Chinese state-owned businesses versus Brazilian public-private partnership) with trade-offs in both models.

From this short historical analysis, it is clear how the interconnectedness between global markets takes place. It should be also clear how the state actions can shape markets in the long-term and so the transition from fossil fuels to renewable sources is not necessarily a natural process but one that should be appropriately driven and stimulated.

Other scholars (DOWNIE, 2015) discussed the relevance and the potential of the BRICs countries in reshaping the global governance driven by the energy industry. In fact, China is the world's largest energy consumer (3,101 Mtoe in 2015 [29]) and India will drive the consumption increase from 2020 with its growing population; Brazil is expected to become a major exporter of oil and to be the world's 6th largest energy provider by 2035 (IEA, 2014). Although it might be difficult to exactly estimate the worth of this global industry, IEA estimates that, in 2015, $1.8 trillion were invested globally[30]. The impressive worth of this trade easily suggests that a shift in the global governance might soon happen and this could shape the way in which the energy market evolves.

Leader countries will also have an impact on the development of renewable sources and, as a consequence, on the management of climate change because at the end global warming is an energy problem as most of the greenhouse emissions are linked to direct or indirect use of energy (EPA, 2017). Climate change is a problem that is affecting and extinguishing several species and these anthropogenic dramatic consequences will threat several communities around the world soon in case we do not take serious counteractions. The scientific community of climate change works in a regular review of the available literature about the topic (every 4 years) and the error margin of drastic climate changes is being reduced (IPCC, 2014). It is very important to remark how there is basically a consensus in the scientific community about the anthropogenic origin of the climate shift, in fact more than 97% of the scientists active in the area and publishing on peer-reviewed journals, are in agreement about that (COOK, 2016). What is not clear is how those effects will exactly impact locally different communities and in which time horizon (IPCC, 2014), making them an intrinsic uncertainty for several countries especially the BRICS as they are still under development, though probably not in a time horizon shorter than 5 years, the time frame of this research. Brazil, relying heavily on water reservoirs for most energy supply, will be one of the countries mostly affected by climate change in a way that scientists are still trying to assess (MARENGO, TOMASELLA, NOBRE, 2017).

The acclaimed Paris agreement (UN, 2015) was not the first attempt of global agreement to preserve our biological ecosystem; it would be enough to mention the Kyoto protocol (KYOTO, 1997), that was even not ratified by US and Canada, among others. Furthermore, the scientific community showed as the Paris agreement, even if successfully implemented, will not be enough to prevent the global temperature to rise higher than 2°C (ROGELJ, 2016). The rapid shift to a sustainable model is urgent and necessary, but it will not happen without a global

[29] https://yearbook.enerdata.net/

[30] https://www.iea.org/newsroom/news/2016/september/world-energy-investment-2016.html

collaboration; so, it will be crucial to see how the global governance will be shaped and will act regarding to this topic.

Another interesting view about energy and globalization was offered by Overland (OVERLAND, 2016). He points out a research gap in energy industry studies on globalization and very interestingly, he suggests how the development of decentralized energy could even invert the globalization process itself leading to a more sustainable model in terms of environmental impact, through a process of de-urbanization (OVERLAND 2016).

2.7 Brazilian macroeconomics and energy supply

In section 2.2, we overview Brazil's energy consumption in the last years and the sources the country used to meet that demand. It was also briefly discussed the connection between GDP and energy demand and just observing those two parameters, a weak correlation could be observed but not enough clear to make statements about the future. In fact, the analysis between macroeconomics and energy demand/offer is more complex and requires to take into account several parameters, external and internal, that we are going to discuss in this section.

Among the external parameters negatively influencing not only the Brazilian economy but also the other emerging economies we can find: the low performance of the international trade, the low prices of commodities and the restriction of capitals' flux mainly due to the increased American interest rate (EPE-CM, 2016).

In Figure 2.11, the commodities' price index updated till February 2017 is reported. We can see that the after an almost flat trend between 2010 and 2014, the price falls till 2016 and correlates quite well with the Brazilian economic recession discussed in Section 2.2. It is interesting to observe that also other BRICS countries suffered a recession in the same time, especially Russia (GDP growth -3.7% in 2015) and China (GDP growth 7%, on of the lowest of the last years).

The US interest rates, after reaching a minimum of 0.25% in 2008, rose up to 1% in the beginning of 2017[31]. This fact might induce investors to keep capital in the US national market

31 http://www.tradingeconomics.com/united-states/interest-rate

instead of going for more risky emerging markets, as for instance Brazil. Thus, this trend might not favor capital flux into the country.

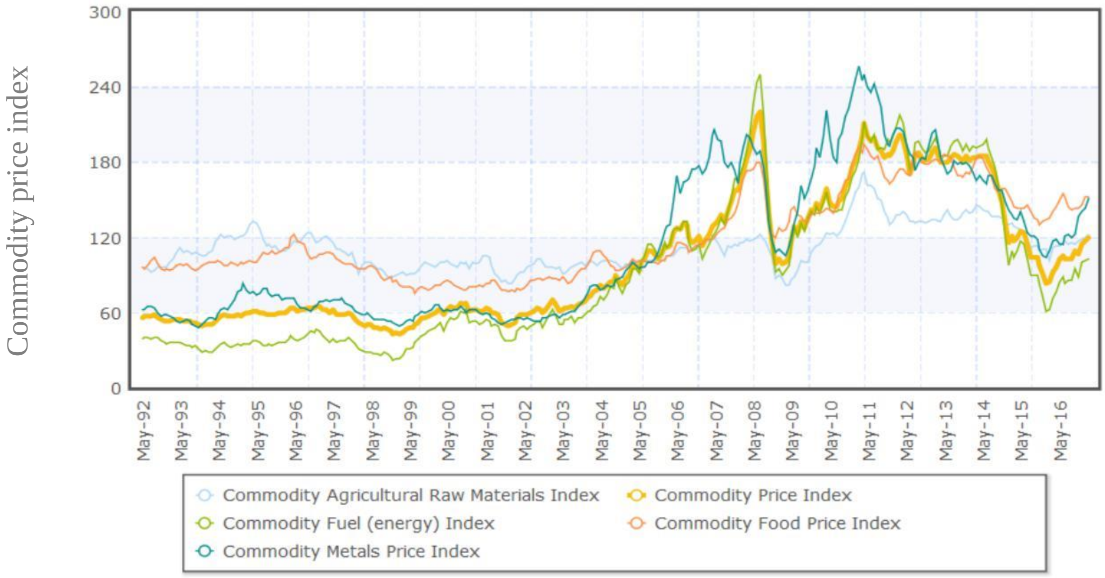

Figure 2.11 Commodities' prices index (average of a fixed set of relevant items) between 1992 and February 2017 (Source: http://www.indexmundi.com/commodities)

Among internal influencing factors we can mention: weak internal demand that leads to higher unemployment rate (11.5% in 2016, 8.5% in 2015) and also lower local consumption, inflation, and a low confidence of economic agents (investors, entrepreneurs, government, and banks). Inflation grew based upon price increase to consumers, electricity being one of those. This impacted the main official Brazilian index, IPCA (Índice Nacional de Preços ao consumidor) of 1.5 p.p (EPE-CM, 2016) despite the attempt to keep the prices artificially low in 2013[32] (Fig. 2.12). There, we can see that the reduction of 2013 did not prevent the increase in the next years. We have to shortly comment that cost of the electricity impacts the market on several fronts and in different ways. If from one side, there is a negative impact on established industries and consumers, there might emerge an opportunity for investors of different sources of renewable energy as those become competitive and offer, in the long run, a cheaper form of energy. Clearly, the dynamic is very complex, but it might open space for opportunities.

[32] https://www.congressonacional.leg.br/materias/medidas-provisorias/-/mpv/107292

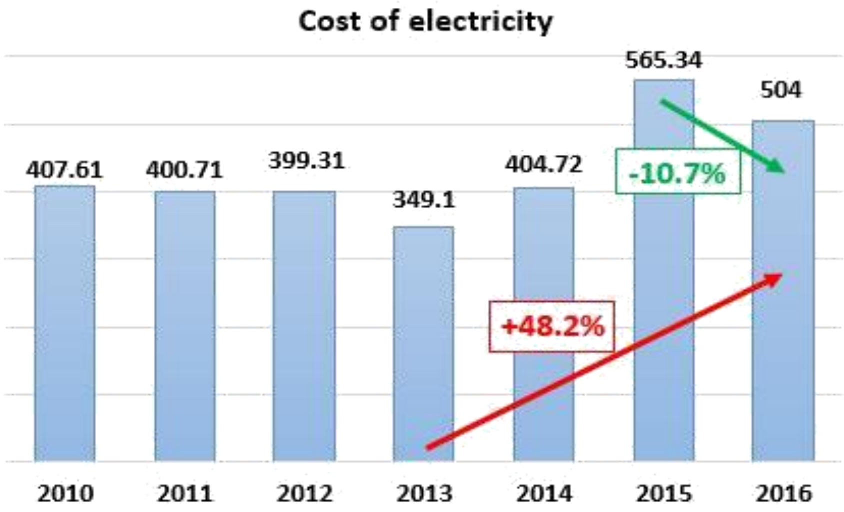

Figure 2.12 Total cost of electricity 2010-2016. Real valued devaluated by IGPM[33]*, according with ANEEL corrections, taking 2016=1. Red (+48.2%) and green (-10.7%) lines are guides for the eyes to emphasize, respectively, the electricity cost increase between 2013 and 2016, and, the decrease between 2015 and 2016. (FIRJAN, 2017).*

The central Bank reacted to the prices´ increase with a restrictive monetary policy increasing interest rates (up to 14.25% in 2015). This negative setting slowed down both import and exports, though the former with a higher rate than the latter, leading to a positive balance that in 2015 of 20 billion dollars.

Surprisingly, in the EPE report (EPE-CM, 2016), the role of renewable energies is not taken into account within the big macroeconomic Brazilian picture. Angstmann and De Souza (2016) have discussed the strategic relevance of a national scale for renewables and its impact on the Brazilian macroeconomics. They analyzed US and China, quantifying the economic benefits (as, for instance in terms of employment rate) that the countries expect to experience due to the renewable energy sectors. However, they point out favourable policies that help making renewable sources cheaper than conventional as, for instance, the Investment Tax Credit (ITC) that allows a tax reduction of 30% on the generation costs. Although this specific example refers to US and conditions might change under the new administration, it remains a good example of favourable policies boosting investment and adoption of renewable sources. It is widely believed that renewables are being held back not by technology or adoption behaviours, but rather by unfavourable regulations (PEARCE, 2016). This does not mean that a market has to be sustained by incentives, but that it should be supported in the initial phase of development.

[33]IGPM is an index used to readjust energy price increase (http://www.portalbrasil.net/igpm.htm)

Angstmann and De Souza (2016) claim that, due to its solar irradiation potential (one of the highest in the world, between 4,500 and 6,300 W/m^2 per day), Brazil expects to reach 3GW of solar energy generation and to offer between 20,000 and 60,000 related jobs. Actually, this figure refers mostly to the expansion of the concentrated solar plants (CSP); among already installed plants we find: Tauá (Ceara, 2011, 1MW), Tractebel (Santa Catarina, 3MW), Eletrosul (1WM), Estádio Mineirão (BH, 1.4MW).

National energy policies regarding renewables have been discussed on the international level. IRENA (International Renewable Energy Agency) performed an extensive econometric study on 164 countries, investigating the correlation between investment level on renewables and economic impact (IRENA, 2016). One of the general findings is that doubling of renewables share in the global energy matrix, GDP can increase of up to 1.1%, equivalent to 1.3 trillion dollars leading to over 24 million direct and indirect jobs by 2030 (respect to the conventional energy market). Clearly, there would be all the intangible benefits such as social and environmental positive impacts that cleaner energies bring. In the case of Brazil, the higher renewable share in the matrix would mean a lower dependence on importation of coal that, in turn, would also imply a higher energy security.

We can summarize saying that general industrial policies, set by the government, impact and influence the different industries in different way. The government's guidelines will set regulation (ANEEL) and financial access (BNDES) through policies of local production and employment, investment on specific technical education and so on. Given the centralized structure of the Brazilian government, policies are materialized directly on industrial development (Section 2.8) and indirectly on long term state financing (Section 2.9).

2.8 Public policies

> *If they do not have an economic advantage, renewable energy technologies will not be able to compete with the conventional resource technologies* (ABOLHOSSEINI, HESMATI, 2014).

Public policies and access to financing have been both determining and crucial aspects boosting the developing of the solar energy market in many countries.

Forms of financing can highly depend on policies in place, therefore we will discuss financing separately in the next section even if it is important to remember that they strongly depend on the context. It is also important to remark that, although here only PV related policies are discussed, they belong to a more complex system that concerns not only the energy supply but several other areas where more stakeholders exist, not only those that can be seen at first sight. Cheng and Yi (2017) point out how studying policies without regard of the wider context might lead to overlook the real size of the discussion and to obstruct substantial efforts to have a global impact on greenhouse gas emission.

Several works focused on assessing the financial parameters of such investments as for instance net present values (NPV), payback period and internal rate of return (IRR). Those calculations are usually based on scenarios and on several assumptions related to public policies, cost of electricity and local solar irradiation. Solar irradiation is probably the most independent parameter that can be included in the analysis (BAKHSHI, SADEH, 2016) and can even be compared among different countries. In this sense, Brazil enjoys a favourable condition of irradiation making it a natural incentive for its development.

Abolhosseini and Heshmati, (2014) reviewed the circumstances for renewables' development: there is general agreement among scholars about which ones should be adopted. Aquila et al. (2017) distinguished between a short-term or long-term government's strategies for the renewable sources: short-term are the ones that run out after the time of application, long-term strategies will continue to produce investments also after the implementation because they aim at constructing a market. Short term strategies include: direct subsidies (both for the investors and for the consumers), tax incentives, and extra-taxes for surpassing a certain value of emissions. Long-term strategies are considered: feed-in tariff (FITs), auctions, net metering, and the quota system. FITs mean that the energy producer can sell to the grid the excess of produced power, while net metering indicates a form of credit in terms of energy that a consumer injects in the network and can use later on.

How are the major markets for solar dealing with these issues? The systematic review of this issue would also require a longitudinal study as countries adopted different policies not only to cope with technological advancements but also with geopolitical configuration and local economic conditions. However, we believed that some useful insights could be taken away comparing what other countries did recently and the current Brazilian situation.

The three big geographic regions rushing into renewable energy are: Europe, US and China. Europe can be compared with Brazil in terms of population, though being the Brazilian population only one third is still in the same order of magnitude. US can be partially compared to Brazil (in the last two years) in terms of liberal economic approach, even with clear and substantial distinctions especially for what concern the energy market where state-owned companies have been a strong characteristic till the very recent privatization trend.

Ramírez et al. (2017) discussed how in Europe there was a race to renewables after the Kyoto protocol (KYOTO, 1997). A series of new policies were introduced to favor the development of renewable energies. However, this introduced also an imbalance in electric systems and also in electricity prices. Scholars tried to evaluate financial performance of a PV project considering FiTs, manufacturing costs, and costs of energy. In his recent work, Ramirez et al (2017) try to combine both FiTs and net metering to assess which combination could be more suitable for different countries. They also included in the analysis upfront costs of PV systems, electricity market prices, operational parameters and calculated NPV, IRR and payback time. Basically they took into account legal, financial, economical, technological and geographical aspects leaving excluded only the consumer behaviour. They calculated financial returns for Germany, Italy, UK, France, Spain, Belgium, and Greece and found that the most favourable markets are: Germany for the financial conditions and Italy, Spain and Greece for the solar irradiation. Interesting insights are that in case of Spain and Italy, due to the high cost of electricity, it could lead to a stronger interest from investors, but the right combination of FiTs and net metering policies is fundamental.

In Brazil, the joint condition of high solar irradiation together with the high cost of electricity might help developing the distributed solar power market. However, policies should be revised: net metering is the only benefit residential prosumers (producers-consumers) are receiving, while FiTs are only for mid and big investors that basically operate as power plants, preventing a capillary expansion of the real distributed generation.

The Brazilian policies might also reveal the influence of the utilities' lobby as a way to guarantee the financial sustainability of their previous investments, having as effect to damp the developing of a possible decentralized model. It is noteworthy that even where the is a wider acceptance from governments and their policies, there is a tendency of utilities to charge more for fixed costs due to the financial losses coming from an imposed net metering system (EID ET AL., 2014). This has two main consequences: first, it makes the investment from residential users less attractive thus not boosting a transition to a decentralized model, and second it is seen as less socially fair as the ones that cannot afford an investment on PV will be still affected by the tariff increase. Nevertheless, tariff increases can trigger the wider adoption of off-grid systems, whenever it would become cheaper than the conventional one.

Utilities' strategy of increasing fixed costs to mitigate losses can be observed in Italy. There, to comply with EU requirements established, FiTs policies (ORIOLI ET AL., 2016; ORIOLI, GANGI, 2017) induced investments on large-size solar plants, causing a grid congestion and not promoting the distributed business (LAZZERONI, OLIVERO, REPETTO, 2017). After 2013, together with the reduced PV prices (lower upfront investment), regulation changed on tax-discounts: 50% of the expenses before end 2014, 40% end 2015, 36% after 2015. The new resolution still allowed energy selling but only to single end-user located in the contiguous land parcel, with the aim of reducing network costs. Performing a quantitative evaluation on three different cities (Milan, Rome, Palermo) that have different radiation level, the study shows that the policies based on tax reduction are financially more effective than the FiTs. However, for a residential user the non-satisfactory financial performance is due to the change of the electric bills that increased over 50% the fixed cost for the grid connection, offsetting in the advantage for the prosumer to have purchased a PV system and in fact not using heavily the grid itself. For bigger plants trading energy with an industrial company, a financial benefits could still be found (LAZZERONI, OLIVERO, REPETTO, 2017).

Interestingly, Italy is the most profitable market in Europe for PV but policies have shown to be inadequate to sustain investment in the long way. A long-term growth of the PV market is not only guaranteed by the profitability of the PV business, but also by a proper regulation (BOECK, BRUECKER, AUDENAERT, 2016). Germany, nowadays with over 34% of renewable energy, over 6% coming from solar, employed complex multiple policies in order to guarantee sector's sustainable development (KIRSTEN, 2014), though not being the most profitable market for investors.

The US market confirms what we can observe in Europe. There, besides tax credits and net metering, the Solar Renewable Energy Credits (SREC) have been indicated as a powerful driver (BURNS, KANG, 2012). However, SREC may have a different impact from state to state but as their trading conditions vary in the time and from state to state, their impact can be very different. Burns et al. (BURNS, KANG, 2012) remark the potential of this tool to promote investments in this sector.

The way Chinese policies were developed has a completely different path, as they develop its domestic market to place in the excess products caused by export barriers from Europe and US (ZHANG, 2013). The generous Golden Sun Demonstration Program offered huge subsidies for PV systems revealed inappropriate to develop the on-grid distributed market (ZHANG ET AL., 2015). The rapid change to FiTs policies made not possible an effective response from the market and investors that were still moving along the 2009 policies. Those authors investigated how China, though being the world's manufacturing leader in PV and not having cost barriers (in comparison to other countries), delayed adoption on domestic market. They individuated other barriers to explain this: uncertain project returns and high perceived risk due to the FiTs policies, utilities companies seeing the distributed business as a threat as they expected increasing grid costs and reduced revenues, and also coordination between central and local governments.

Comparing these observations with distributed solar energy regulations in Brazil, we can individuate regulation as one of the main uncertainties for the market development. Aneel resolutions (ANEEL, 2012; ANEEL 2015) lag well behind international standards. Access to BNDES financing for DG imposes some degree of local production and focuses mainly on big investors; as the PV production in Brazil is incipient, this policy instead of stimulating the market, is halting it from start. This could be perceived as a financing problem, but is in fact a policy problem, as BNDES follows guidelines from the Mines and Energy Ministry. This completely differs from oil&gas policies - flexible and regulated under a special taxation and import regime[34].

2.9 Financing

Financing a solar system (PV panels or complete with batteries) is an obstacle even for consumers that are firmly convinced to change their energy sourcing, due to its high upfront investment and all risk that this implies.

Thus, envisioning new business models is fundamental to promote a transformation of the electric power industry (RICHTER, 2013). Huijben and Verbong (2013) investigated how distributed PV grew rapidly in the Netherland, finding that not only new business models were in place but also both national and local government were promoting suitable policies. Furthermore, they point out how the development of new business models is intimately connected to the existing regulation. So, the following discussion on which are the possible business models is in fact subjected to restriction due to a particular regulation. This means they may not apply to all markets.

34 http://www.repetroregime.com.br/

There are three main business models: customer-owned model, third-party model and community share model.

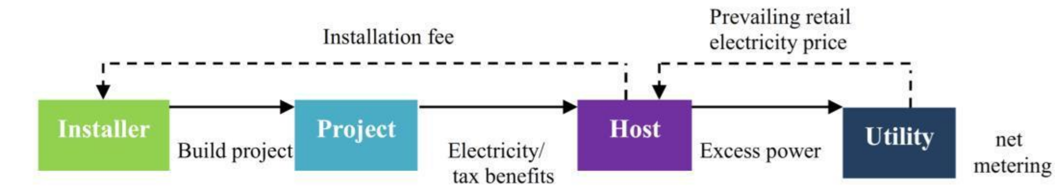

Figure 2.13 Customer-owned model (ZHANG, 2016)

Customer-owned model (Fig. 2.13) is based on the purchase of the PV system by the owner of the rooftop or land and the produced electrical power is mainly used by the owner that can benefit from possible tax benefits and from net-metering credit. The disadvantages of this solution are the upfront investment, the eventual poor performance of the system and the transaction costs related to grid connection. This business model is viable if the owner can self-finance the system (reduced target of the population) or in case there is access a favourable loan (SANDERS, 2013). The tax credit is a valuable tool in case the owner is sufficiently tax liable, otherwise she/he will not take full benefit from the policy.

Third-party ownership model (SolarCity model[35]): the upfront costs and risks are taken by a third-party instead of the host-customer (Fig.2.14). Here, the third-party deals with PV purchases, the installation project, service and maintenance. The third-party enters in a long-term agreement with the customer that will pay a fixed or variable monthly fee (LINDER, DI CAPUA, 2012). The consumer benefits from savings in the utility bill and the third-party, assuming the risks, can benefit from tax credit policies.

[35] SolarCity is an North-American energy and service providers in the solar energy market that offers a wide variety of products including solar batteries and rental options for PV solar systems.

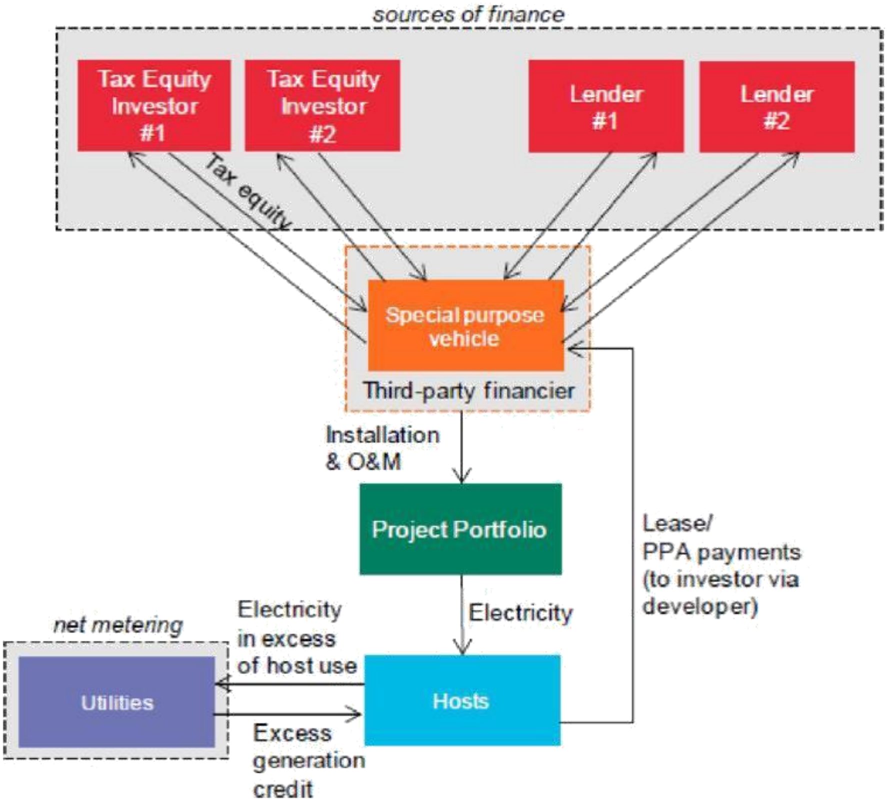

Figure 2.14 Third-party business model (SolarCity)

In the <u>community shared model</u>, multiple subscribers are connected to the utility grid from which they receive electricity. Subscribers can be both residential and commercial users, as well as non-profit or public buildings. The power plant is dislocated in the most suitable location and subscribers are also shareholders of this Special Purpose Entity (SPE). Several financing options under this configuration are reported in Fig. 2.15 (NREL, 2012), where utilities are also included as third-party.

	Utility	Special Purpose Entity	Nonprofit
Owned By	Utility or third party	SPE members	Nonprofit
Financed By	Utility, grants, ratepayer subscriptions	Member investments, grants, incentives	Memberships, donor contributions, grants
Hosted By	Utility or third party	Third party	Nonprofit
Subscriber Profile	Electric rate payers of the utility	Community investors	Donors, members
Subscriber Motive	Offset personal electricity use	Return on investment; offset personal electricity use	Return on investment; philanthropy
Long-term Strategy of Sponsor	Offer solar options; add solar generation (possibly for Renewable Portfolio Standard)	Sell system to host; retain for electricity production	Retain for electricity production for life of system

Figure 2.15 Financing schemes for community-shared model (NREL, 2012)

We can see how financing for DG is quite a weakness in Brazil, mostly because it is linked to old industrial policies and regulation, being a relevant uncertainty for investors. The lack of attractive tax credit benefits and lack of financing institutions restricts private users' adoption. The BNDES funds available require local production that is not available on an efficient basis. Finally, the current regulation allows the community shared model only under several limitations, making it often not viable.

Finally, Mitscher (2016) points out how the country's actual and perceived financial risks creates very high interest rates and turns loans a no-option for customers. He claims that the growth of the distributed generation stands below the expectations and potential. The creation and implementation of new business models is crucial to distributed market development.

2.10 Off-grid solar experiences

Stand-alone systems can work without the grid. They can be composed by PV panels, inverters, control systems and also include batteries for a complete standalone application. In developed countries and, actually, also in Brazil, most of the population is connected to the electricity grid and thus, receives the energy supply needed for the daily needs. This also true for the industrial users.

Switching from on-grid to off-grid is financially demanding and involves high risks for most people, though PV technology becomes more efficient and accessible. This is even truer in developing or under-developed countries. There, stand-alone systems have been thought to be used in rural zones where the grid connection was prohibitively expensive and thus a different financial rational applies. We can find several examples of PV installation to alleviate extreme poverty, but those projects have been designed for almost a pure humanitarian aid. What is more interesting is that recently, due to the drop in the PV systems' prices, financially sustainable business models are showing up and investments have becoming more attractive towards the population target commonly called BoP (bottom of the pyramid). As PV costs fall, BoP users might switch to pay something for having solar energy rather than rely on kerosene or diesel that turn out to be more expensive and unhealthy. Clearly, appropriate business model have to be devised, as this target cannot definitely afford the upfront investment required for PV. An interesting example is the experience of 'Off Grid Electric'[36] that showed that bringing energy to the BoP is financially feasible and also succeeded to attract strategic investors as Solar City. The fact that stand alone systems can be an attractive ground for investors was discussed also by Sen and Bhattacharyya (2014). Off grid became thus a way to bring energy to the poor and a viable model to provide electricity to communities, especially if combined with hydro and wind, as long as battery systems remain expensive. A similar approach was proposed by Hassan et al. (2016) discussing Iraqi rural communities.

We can find several works on rural communities of India, a country particularly subjected to climate change and the raise of floods that might lead to food supply disruption with extreme consequences for the population. Thus, climate change mitigation is a main concern. Kathaiyan (2015) discussed financial and social implication, and highlight how climate change mitigation would be fundamental for India and supportive policies for PV systems could bring a long-term benefit. Also Loka et al. (2013) raised the same issue: you need to involve authorities for the risk mitigation and financial benefits that investor might not see. These articles point out also another important aspect that is more connected with consumer behaviour: In order to design a functional and financially sustainable business model it is important to understand how the target populations live, which are their needs and in which forms and timings they need electric energy (STOJANOVSKI, THURBER, WOLAK, 2017).

[36] http://offgrid-electric.com/#home

Recently, even in developed countries, switching out of the grid becomes attractive for some users. In the previous chapters, we reviewed and discussed some of the policies related to the topic and it is quite clear that generalization on the financial advantage of a solution respect to the others cannot be made. However, the example of Tesla and its Power Wall is clearly challenging the current prevalent model on free markets. Kantamneni et al. (2016) performed a comparative study between stand-alone system and grid-connected for Michigan's houses. For some households it would be already cost effective to switch off-grid. The mechanism could trigger a virtuous (or vicious, depends from which point of view - renewable providers vs incumbents) cycle of increase of utilities' costs as a consequence of users leaving the grid, together with PV systems becoming cheaper. Kantamneni et al. (2016) suggest that utility companies and policy makers should take this fact into account planning their strategies. The North American experience is not an isolated one. Japan studies on energy independent households are carried out as a possible effective strategy for climate change mitigation (MIYAZATO ET AL., 2017).

Not all scholars agree on an off-grid trend. Khalilpour and Vassallo (2015) tried to answer the question: is really possible to leave the grid? They claim that battery costs still impede the transition and keep utilities' footprint. However, utilities should find other sources of revenues and not just increase user's tariffs.

2.11 Emerging technologies: incumbents vs newcomers

The analysis of the previous sections evidenced that the current Brazilian electricity market is centralized, mainly from policies' choices. Although new regulation has been created for distributed power generation, it still lags behind international standards and the development process looks slow and uncertain. It is not clear whether the incumbents (generation, transmission, distributors/utilities) are trying to find a new role in this paradigm shift or rather they are just resisting the change, protecting the status quo. Through the fieldwork, we expect to get insights about this point. From a theoretical point of view, a discussion of incumbents versus newcomers is appropriate.

The disruption in the electricity industry may come on two different levels. The first one could involve a new way of generating power through completely distributed power sources. This case would still see a relevant role of the utility companies as the grid would remain fundamental and options like smart-grid could be in place. In this scenario, conventional large power plants (mainly those based on fossil fuels) would be at risk. The second level would involve the disruption of the distribution and utility companies: if stand-alone systems could operate off-grid and guarantee an effective power supply to households and companies, both old plants, transmission lines and services would result outdated and not economically sustainable. So far, the evolution of PV systems and batteries are not indicating an abrupt disruption of the grid system. In Europe or US, the grid-connected systems have been supported by regulations and policies to make them financially viable. Brazil remains apart from this and could experience a shift towards the second level of disruption, as not many users are locked into a PV-grid-connected-system. On the one hand, Brazil presents unfavourable policies, on the other hand the low cost that PV is approaching could boost an even more dramatic shift. If PV systems (including batteries) become affordable for the population, they could shift to a stand-alone system, in order to get rid of the increasing electricity prices.

Schoemaker et al. (2000) discussed how an emerging technology enters the market and what are the usual reactions from incumbents. Here, we shortly review the main insights of their analysis and we discuss their framework in the Brazilian case. According to the authors, incumbent's disruption can be avoided when the need for change and adaption is recognized and well tackled. It is hard for them to realize that their assets could become irrelevant and in some occasions, liabilities. They usually have financial resources and a solid customer base, but the real (and perceived) risks coming from the uncertainties block most of them from acting. Therefore, most of the time the risk of disruption can remain overlooked, leading to even more catastrophic consequences. The main hurdles that incumbents have to overcome are: cope with uncertainty and complexity, develop new competencies, and be ready for an accelerating innovation.

If we look at the Brazilian case, we can observe those concepts in place. It is definitely true that the incumbents protect their market positions, by the regulatory framework. They do not fully commit to PV distributed business, although PV technology is mature enough to be marketable as in other countries already happened, but is in a stage of low marginal costs that would not even request a heavy R&D investment to make it financially viable. The resistance appears to be merely a protection of the status quo. Policies help them, with high import taxes for PV components and batteries.

What Schoemaker et al. (2000) suggest to an incumbent trying to not be disrupted is: adopt a different investment mindset and resource allocation - typically real options approach -

iterative and flexible decision making process, more suited for a dynamic business and flexible planning, collaborating with strategic partners.

What they also point out that there is not a recipe for dealing with disruptive innovation, but the first mover advantage has been observed as a crucial, though not sufficient: *Winners are often pioneers, but most pioneers fail*. In terms of the Brazilian ecosystem, we can say that most risks are related to business models rather than the technology. This way, the big competition could be among the incumbents to become the leader of the new transforming market. At first sight, observing the several incumbent consortia created for sustainability (e.g. ABRADEE for distributors) and the strong lobbying power clearly reflected in current policies, it seems that they don’t envision disruption.

All the traps for incumbents during a disruption process (SCHOEMAKER, GUNTHER, DAY, 2000) can be found in the Brazilian electricity ecosystem:

1. Delayed participation in committing to the new technology (more implementing, in this case)

2. Sticking with the familiar, for instance using renewable sources for big power plants instead of developing new business models for distributed generation.

3. Reluctance to fully commit and lack of involvements (and persistence)

From the field research, we will get incumbents’ vision on these topics, checking current assumptions and bringing new insights to complement our preliminary analysis based on the literature review.

From consumer’s standpoint discussion appears to be premature in the Brazilian market and it is kept out of our present scope. Nevertheless, there would be interesting market dynamics, as, for instance, the demand of low-consumption led lights instead of traditional light bulb that might influence the electricity ecosystem.

So far, PV systems in Brazil are unaffordable for the majority of the population and even when there is a positive attitude and intention, it lacks financing, therefore being restricted to a niche of users devoted to environmental sustainability. So, this is why the discussion focuses on policies and business models that could boost or drag PV adoption, rather than on consumer behaviour. In Fig. 2.16, we depict again Fig. 2.7 PV installations (right-panel) but on a logarithmic scale; there, we can observe PV system according to ANEEL official data (ANEEL, 2017).

As disruptive innovations usually behave exponentially in terms of adoption rates, a log-scale reveals how fast is the phenomenon, considering that a linear behaviour in a log-scale would indicate an exponential trend. In 2012, the first ANEEL resolution addressing PV was published and triggered the fast increase in that year and the following ones. At first sight, we observe a linear behaviour from 2013, however a closer analysis shows that the trend is slowing down in 2016 and 2017; this evidence could be ascribed to the economical recession and political uncertainties. Nevertheless, if we plot installed power, instead of total number of installations, we can see as the continuing linear behaviour (in log scale). This is a very relevant information and it brings two insights: First one: even under unfavourable policies and economic conditions the total number of installed DG-PV is exponentially increasing. Second one, as the number of total installations follows a slower rate respect to the total installed capacity, there is a shift towards installation of higher capacity units: less PV systems installed in households, more installations in small commercial activities requiring higher installed capacity. A further quantitative analysis of the available data would go beyond the scope of this work.

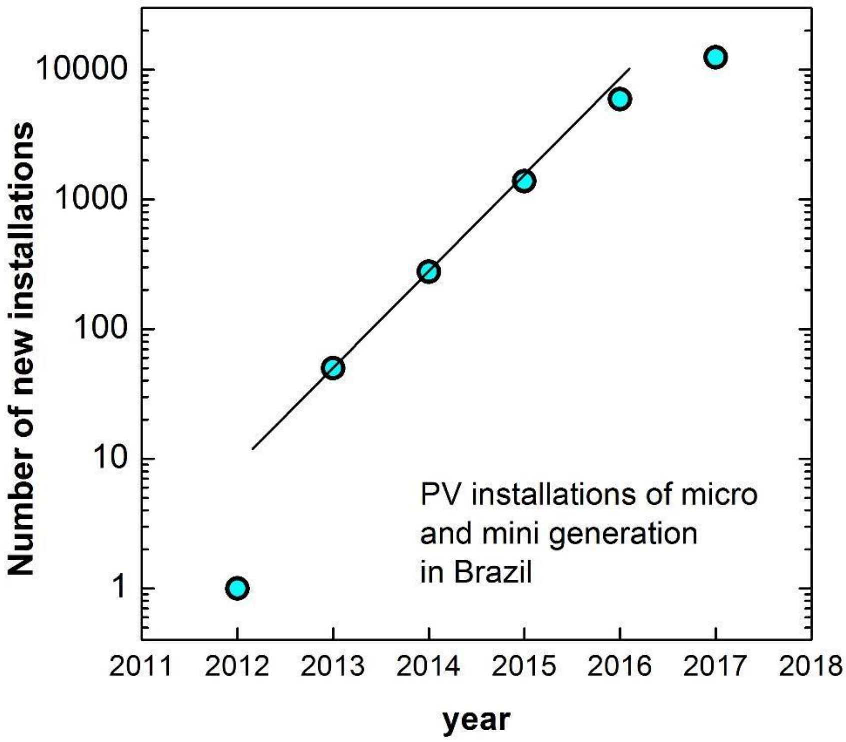

Figure 2.16 Logarithmic plot of data of new installation of distributed PV systems reported in Fig.2.7.

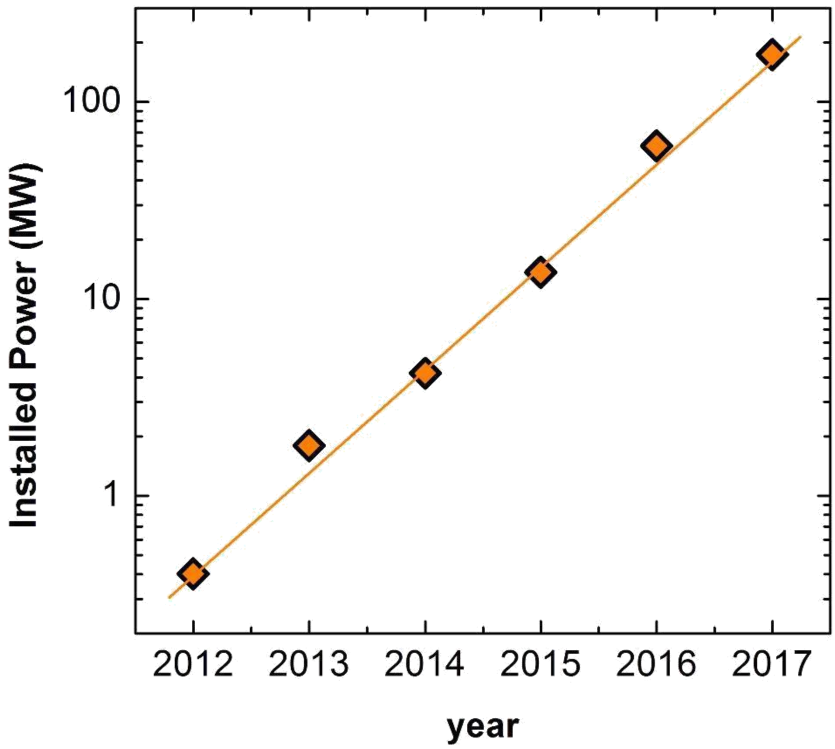

Figure 2.17 Logarithmic plot of data of installed power of distributed PV systems.

2.12 Research questions

The analysis of the literature brought to evidence the main drivers of the energy sector, summarized in Fig. 2.18 - uncertainties in grey rectangles and trends in white ones. Government's development policies (industrial) decisions coming from the government that affect the Brazilian market as a whole, and, as a consequence the, energy market. Development policies regard mainly importation vs local production policies and impact directly the PV market because most of the PV modules are currently produced in China and the Brazilian local production is incipient.

Energy and financing policies are set within the development's policies and so they take place within the same framework of government's guidelines. However, they are not a deterministic consequence of them: energy and financing policies can be set to favor/not favor the development of the DG industry (especially PV) on both scenarios of open or protected market. For this reason, the two uncertainties, energy and financing policies, are represented as separate items though being part of the same context. Those uncertainties may affect the market within a 5 year timeframe.

Geopolitics are also uncertainties, as the global dynamics about energy security cannot be easily predicted. Although a growing presence of Chinese investors in Brazil emerged as a trend, overall, geopolitical dynamics are uncertain and they can also have short and long term effects due to intrinsic complexity of decisions of several markets and countries (See Section 2.6).

Technology, instead, shows a clear cost reduction trend. In fact, the cost of PV panels is already competitive in comparison with other sources and the same is expected for batteries. What is not certain is the timeframe. Will this will happen within the next 5 years? Technological advancement can be classified more as a trend than uncertainty.

Climate change has a twofold feature because the global climate shift is a trend, but local implications for Brazil are uncertain especially due to the dependence of the energy sector on hydric resources (MARENGO, TOMASELLA, NOBRE, 2017).

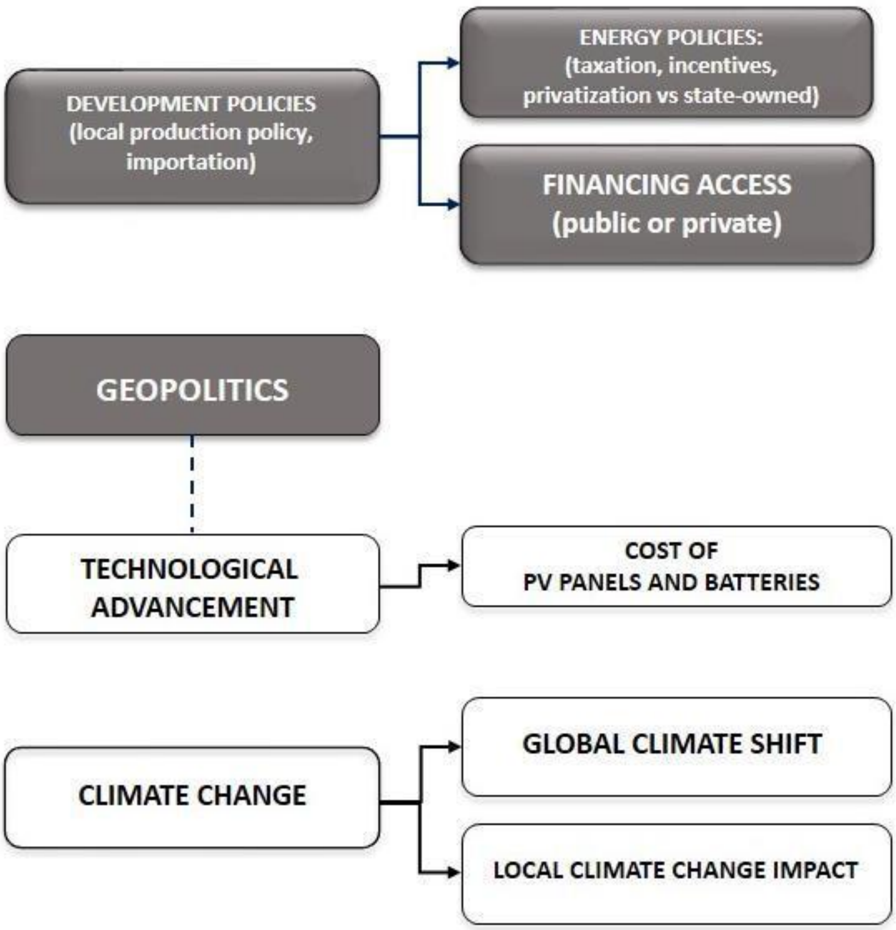

Figure 2.18 Uncertainties and trends in the Brazilian energy sector obtained from the literature review. Uncertainties are indicated in grey, trends in white.

The most relevant uncertainties and trends emerged from the literature review. The next step is to verify those elements in order to construct possible scenarios for the future electrical energy market, beside to chart the business ecosystem. Therefore, we land at our research questions:

RESEARCH QUESTIONS: How is going to look the Brazilian energy ecosystem in 5 years from now? Which will be the fate of the solar business? Which are the key uncertainties that might play a crucial role in shaping this sector?

3. METHODOLOGY

The energy sector has been traditionally investigated with a broad variety of quantitative approaches; technical studies and data about the technology and economics are largely present in literature. The development gap of PV market in Brazil respect to other countries, discussed in previous sections is not explained by the technological access that is quite deep in the country in other type of contexts. This apparent gap suggests that specific forces, which are not captured by quantitative indicators, are also playing a relevant role and we initially supposed that they may have a social and/or economic origin. Bento and Ferreira (BENTO, FERREIRA, 1983) suggests that an exploratory approach is appropriate in this case. Starting from observation, a researcher wants to begin an investigation on a phenomenon and only after carrying out this step, hypotheses can be formulated, and a more specific research can be conducted aimed at verifying selected aspects. The lack of specific scientific literature on this matter (See Section 1.2) reinforced the idea to carry out a qualitative exploratory approach (CRESWELL, 2013). We ultimately want to explore possible relationships of causality between forces acting on the market and the market itself.

Qualitative research methods give the researcher flexibility to shape the investigation’s design in order to match appropriately the investigation’s goals. Interviews with open-ended questions were the selected method.

The research was design so that the results, obtained from the interviews and the literature review are contextualized and discussed using ecosystem charting and scenario analysis frameworks. Ecosystem charting and scenario planning are becoming useful frameworks to discuss markets, as they offer visualization of complex ecosystems and dynamics, which would remain otherwise unappreciated.

Therefore, the research’s design was thought and developed as follows (Fig. 3.1):

- The analysis of the literature review offers a view on the most relevant actors of the market and the main forces acting within it. Forces can be classified as trends or uncertainties. A tentative ecosystem will be charted.

- In-depth interviews with relevant actors (covering basically all parts of the ecosystem) can confirm, clarify and detail roles, trends and uncertainties. Interviews also helped define the time-horizon and distinguish short-term and long-term.

- From the joint contribution of literature review and interviews, we can built the ecosystem’s final version and the scenarios.

- Additional papers were added to the literature review section whenever interviews were suggesting aspects that remained unexplored in the first phase. This iterative process accompanied this work till the final analysis.

Ecosystem charting and scenario planning can help to translate research outcomes into visual charts and to give insights to ecosystem's actors that are the ultimate goal of a management research.

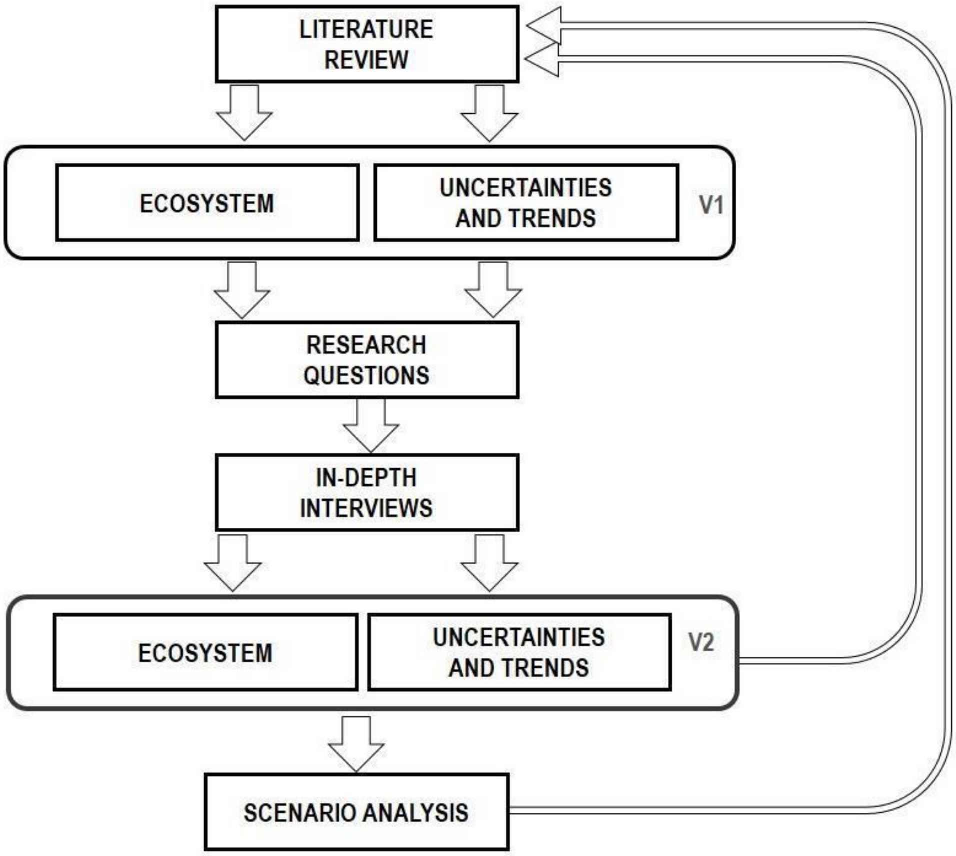

Figure 3.1 Diagram of the research design. Literature review was the first step of this work that led to build a tentative ecosystem and to individuate uncertainties and trends of the energy market. After this step, we could formulate the research questions that are meant to be answered through in-depth interviews with relevant ecosystem's actors. From analysis of the interviews, the ecosystem was build and uncertainties and trends based on the interviewees' perceptions were found. Those were compared with the results of the literature review to finally lead to the scenario analysis.

3.1 Ecosystem charting

An ecosystem is traditionally a biological complex system formed by several organisms occupying a habitat and coexisting within a certain equilibrium or hierarchy. Keeping the biological analogy, the word has been lent to business for the first time in 1993 (MOORE, 1993) and nowadays is part of the common business vocabulary especially for what concerns innovation. A business ecosystem represents the collection of the main actors (organizations and individuals) playing in a market set (that can range from a regional to a global one) and the connections among them. As in biology, a dynamic system can change over time, even abruptly. The connections among actors may change whenever a more suitable link can better serve the need of a single actor or of a part of the ecosystem. The strength of connection between two actors depend on many factors and on the type of interaction.

Ecosystem charting is a graphic tool that serves the goal to represent that network. Through this approach, we can visualize which actors have a central role, which may have a disruptive potential and if there are parts of the ecosystem that are still under way to be occupied.

In this research, we use ecosystem charting to represent the Brazilian electricity ecosystem. Connections are drawn based first on literature review then interviews' insights. The ecosystem and its discussion are reported in Section 4.1. The chart was obtained using the open source software Gephi[37], a free tool that allow for nice graphic visualization and analysis of complex networks.

3.2 In Depth interviews

The complexity of the energy ecosystem has already emerged from the previous sections. We aimed at integrating the available literature and official institutional material together with the perceptions of the Brazilian Energy Ecosystem key actors to reveal subtle aspects hardly quantifiable. For this purpose, script based in-depth interviews represent a natural fit to capture actors' perceptions, as the approach has the distinct characteristic to elicit views from the interviewees (CRESWELL, 2013). In fact, open-ended questions allow the free expression of the interviewees and relevant elements emerge, most of the time, spontaneously.

INTERVIEW PROTOCOL

We interviewed top executives from most of the relevant segments depicted on the Brazilian Electric Ecosystem (actors being organizations on: generation, distribution, transmission, regulation, services and research/graduate education). The interviews took in average 1-2 hours and were performed in Portuguese, using the script presented in Appendix,

[37] https://gephi.org/

were recorded and later transcribed by a professional. Transcriptions were carefully checked against the audio and then analyzed.

As part of the process, interviewees were guaranteed to remain anonymous together with their organizations or companies. Thus, to comply with that, but at the same time to bring useful information to the reader, we compiled a table with some basic information that can give a general context of the quotes that will be reported in the following sections. In table 3.1, the first column reports interviewee's assigned number, the second the segment where he/she worked or has been working and the last one reports the years of experience in the energy industry. Services refer to all activity that do not involve hardware parts, so it might include consulting and financial services. Regulation refers to regulatory agencies and external services that support companies regarding regulatory aspects. Generation refers to both centralized and decentralized and includes all kind of sources.

Interviewee reference number	Segment within Energy sector	Years of experience in the sector
1	Services	35
2	Regulation/Distribution Generation/Transmission	20
3	Services/Generation	35
4	Services/Regulation	10
5	Services/R&D	20
6	Education	25
7	Education/Generation/Transmission	>40
8	Regulation	15
9	Services/Generation	5
10	R&D/Regulation/Services	>35
11	Generation/Services/Distribution	>35
12	Education/Generation/Distribution Transmission/Services	>35
13	Service/Generation	5

14	Generation/Distribution/Services	>35
15	Services/Regulation	20

Table 3.1 List of the interviewees participating to the research.

LIMITATIONS OF THE METHOD

The choice of the language for the interviews is a crucial part of the research methodology design (TEMPLE, YOUNG, 2004). All interviews were performed in Portuguese to create the best conditions and to offer complete freedom of expression to the interviewees. However, Portuguese is not the interviewer's mother language. This might result in a possible limitation throughout the process. The supervision of the research group (advisors) helped to insure correct interpretations and to adjust misleading translations.

Another intrinsic limitation linked to the method is the number of the interviews. They were carried out till the interviewer perceived that only marginal insight was attained, the so called 'saturation limit'. However, it might be that a more extensive set of interviews could have brought new elements, especially given the large size of the ecosystem and the diverse type of players acting on it.

A further limitation that is intrinsic to the method (MYERS, 2013) is that the interviewees may or may not trust the interviewer, especially because of the request to record. As Brazil is a relational country and as the research is promoted by Coppead (known, recognized and with a wide network), all interviewees appeared very comfortable, open and collaborative. However, it is difficult to say whether given information are filtered and to which extent.

This methodology led to individuate the main drivers that shape the electric energy ecosystem, from interviewees' perception. Those parameters were checked against the reviewed literature and a final schematics of uncertainties/trends was built.

We have to point out that the interviewees are based and work in the cities of: Rio de Janeiro, Sao Paulo, and Brasilia. Conclusions, based on the results of those interviews, are reported in general terms referring to the country as a whole.

COMMENTS ON THE INTERVIEWS' PROCESS

In most of the cases, there was no need to ask all questions; rather the relevant elements emerged naturally from the conversation often after the first question where the interviewee was asked to talk about the professional trajectory.

Regarding the timeframe that we set for our research question, it is noteworthy that each interviewee had already in mind a timeframe although they were clearly asked otherwise, probably due to their experiences and views. Some were more inclined towards a short time frame (5 years) whereas others were focused on a long trajectory (15-20 years) and this is a very personal positioning and we had to take into account. We believe this is already a very useful insight and we use this information to further discuss uncertainties in short/long time horizon. For completeness, the discussion on long-term parameters will be reported in a separate section in the results section (See 4.7).

3.2 Scenario planning

Scenario planning is a virtual 'exercise' (GARVIN ET AL., 2017) that tries to foresee possible future scenarios and to imagine solutions that could properly deal with them. Scenarios do not have any type of predictive value; rather they are used to push the imagination in extreme direction to explore the effects of the main uncertainties and prepare plans for most of the circumstances.

The research question that we formulated at the end of Chapter 2 already set the stage for our scenario planning. The next step of this method consists in determining the main trends and uncertainties acting on a specific market. In our case, uncertainties and trends are provided by the analysis of the literature review and of the interviews.

The scenarios are constructed starting from the two uncertainties that are considered more relevant. The two more relevant uncertainties will set the two dimensions to construct a bi-dimensional graph (x-y plot, where the left and right extremes represent the two opposite directions where the uncertainty can lead to). The four quadrants that are obtained in such representation will be described with appropriate narratives. It is recommended to individuate so-called *early warnings,* critical parameters that can indicate the likely emergence of specific scenarios. Companies and policy makers can use them to readjust actively the adopted strategy.

4. RESULTS AND DISCUSSION

4.1 Analysis of the interviews

The analysis of the interviews was conducted on each transcription and in a comparative way. Common elements have been found across several interviews and they have been grouped and discussed in the next sections. In order to make a more straightforward connection with the literature review, the elements will be discussed in separate sections, directly referring to the literature review. Every element will be included or integrated in Fig. 2.18 (see pg. 59) step by step, to finally arrive to a complete chart that will represent schematically both literature review and field results.

4.1.1 State policies and energy governance

Development policies set by the state have been identified in the literature as one of the main drivers for the energy market and this, together with energy policies and financing access was confirmed in the interviews. The finding was supported by the field research, but with a caveat: there is also connection between political instability and bad energy governance, undermining stability in the long run. In the following, we explore this statement. Fig. 4.1 represents the set of drivers related to state policies (grey boxes indicate that they are classified as uncertainties).

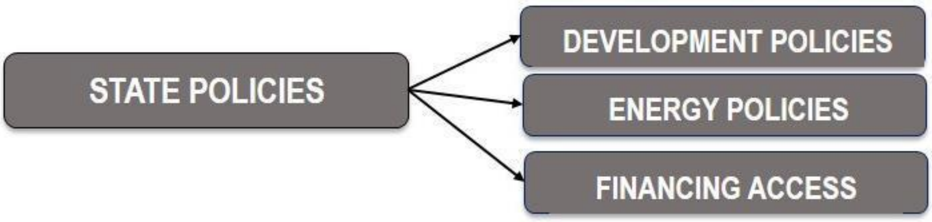

Fig. 4.1 Development and energy policies are often dependent on political stability/instability. It is lacking an independent energy governance that could guarantee continuity in energy policies and a higher stability to the market. Grey indicate that the drivers are considered as uncertainties.

Industrial policies suffer from the political instability

A general mistrust towards political institutions emerged in several interviews, and interviewees perceive as this impacts (mostly negatively) on the sustainability of Brazilian industrial policies.

"There is no alignment at all, no strategic axis, no sense, no positioning not even a direction, an objective to increase the GDP, or whatsoever, whatever thing. I might say that planning is missing, but what is missing is the country's project. The lack of governmental references is so obvious that the tasks of public institutions remain impaired" **#Interviewee1**

"Lula had leadership, but not a vision. Today is even worse because we don't have anyone, even with leadership" **#Interviewee10**

Energy governance does not have the required independency

It emerged a broad agreement that energy policies with all its manifestations (regulation, taxation, financial access, incentives, etc) would greatly benefit from a certain independence from short term political issues. Clearly, energy is paramount for a country's industrial policy, however interviewees think that there should be some degree of independence between energy governance and political governance.

"What I would recommend to the electrical sector is that there should be governance, and it should have an adaptive approach in the sense that should be clear who has to formulate a policy, who has to implement, and agents that should have a space to manifest their point of views. The government should be interested to hear feedbacks of its action, constantly working." **#Interviewee1**

"Brazil drifts according to the flavour of confused energy policies. The definition of an energy policy is not relevant, the important is to place a director in that institution that will support my political campaign… no one is worried with energy policy. It is not professionally managed. (…) We plan for 4 years because we never know what the next government will do. Governments' planning is based on divergent political interests. … EPE regularly publishes the PDE (decade planning for energy supply expansion). In 2014, there was the first solar auction… but by the end of 2013 EPE published a PDE where there was no solar expansion. Therefore EPE, the Brazilian planning institution, was not capable to foreseen what was going to happen one year ahead. Today EPE presidency is a political position. But independently on the politics EPE should go ahead in the same way." **#Interviewee2**

"If you don't have congress support, it is difficult to make changes in regulation. The government can produce ordinances… but big changes require laws, that necessarily the congress must approve. And energy policies were never unlinked from politics. (...) We are on a route towards improvements but at the same time we have the political problem… you can see how, in this country politics, technical aspects and management get confused a lot." **#Interviewee3**

"A wider governance would give bigger dynamics for this market, bigger agility […] *You don't need new institutions, it is just missing the articulation."* **#Interviewee4**

"Short-term decisions are in conflict with longer-term ones. This is not only in Brazil, but everywhere. A government in general think about the next 4/5 years. This produces sub-optimal decisions for the next 20, 30 or 50 years from now. We compare what would be the optimal decision model with the real one. The distance between them comes from a series of barriers, governance failures, partially explained by the legislation. [...] Europe suffered already, passed through wars…then they learned how to deal with that. Developing countries are really behind in terms of governance. This partially explains why you technically know how to fix a problem, and it ends up not happening." **#Interviewee6**

"We are in an unbelievable level of legal fights in the electrical sector; it is a sector that it should not be fragmented and it is totally fragmented. [...] Today political indication within organizations are huge. Look at the US. Try to remove the president of Tennessee valley[38]*, you cannot. He has a term. If Trump does not like him, he must wait until the end of the term. Here no. You remove a president because another political party indicated him and so on. A state institution should not be a government's tool, as a regulatory agency…managers should be removed only in case they make a serious mistake. Otherwise, they would not be useful to society."* **#Interviewee7**

"I don't know whether it should be the role of the State, but there should be more continuity. Actually, it is the Ministry of Mines and Energy that sets the guidelines. What happens is that first you have a group thinking in a way, but then a second group takes over, but with different positions. We are confused on how to deal with the new governance each time. For instance, we just came out from a centralized governance, now we are entering in a market oriented governance. … In Brazil we don't have an

38 https://www.tva.gov/

energy problem but a problem of energy governance. Depending on the current government, we go back and forth many times…wasting a lot of time. To improve governance we would need more specific knowledge, we have politicians that have no technical knowledge." **#Interviewee12**

"The problem of violence is a matter of education, which is something that will take time to improve, it has to do with the economic conditions of the country. It is missing a vision of the country's planning. Why? Because here we have a very party-oriented reality. It is does not exist something above the parties like –this is the energy policy we need for Brazil- when another government arrives everything changes. " **#Interviewee14**

There were two interviewees that expressed a different view about his point:

"The governance of the energy sector is stable. It is not perfect but has some ways of protection. Managers (or president) have 4 years term and the government cannot fire them. Surely you will never be director of one of those institutions without political support and…Clearly, the Ministry of Mines and Energy is relevant to establish the guidelines. ... In this sense it is true that governance is weak, it depends on the central power of the Ministry." **#Interviewee11**

"Electrical sector in Brazil has a good governance! It is a condominium governance, with a centralized distribution. […] It cannot lose this condominium vision. This is the point I would like to underline because we are living in a moment where some technologies point to individualism." **#Interviewee15**

Development policies affect the energy sector

The guidelines that the government will set as strategies for the country's industries, do influence the energy sector. This point reinforces the previous paragraph: as industrial policies are the main expression of the government, through them, market players strongly perceive the instability.

"Public organizations acting in the energy sector follow the government's guidelines." **#Interviewee5, #Interviewee11**

"BNDES acts according federal government's guidelines and might promote the development of one energy source rather than other one." **#Interviewee4**

"The regulatory agency ANEEL is responsible for keeping offer and demand equilibrium. They don't provide guidelines because those are part of Mines and Energy Ministry roles. The auctions are established by the Ministry. The proportion between hydroelectric, wind or solar is a decision that competes to the Ministry with the support of the EPE." **#Interviewee8**

Developement policies: local content vs imports

Industrial policies affect the so called 'national component' in the supply chain. In order to stimulate the development of a local supply chain and, thus, to induce development of technical capabilities and new jobs, government requires a certain level of local components supply for BNDES credit allowance.

Several Interviewees believe that local production of PV system would be possible, but it will take time to develop a local industry.

"Solar panels today… prices are much lower if you look into the Chinese market, out of Brazil. There are not conditions today to have a sustainable expansion of PV industrial manufacturing in Brazil. […] Prices are not competitive, but with government support, prices of solar components should reach competitiveness within 5-10 years."**#Interviewee3**

"There is still a very strong protectionism for local production. There still exist a vision to protect and develop the national industry, but at the end of the day, this should be better studied because it is an approach that is thought to protect, but end up not bringing development. Then, this middle term we have not found yet." **#Interviewee14**

"(Talking about PV Brazilian industry) *"The day that in Brazil we are capable of producing solar technology and be competitive to export, at least, to other South American countries, then I think it would make sense a strong industrial policy to attract manufacturers. But we know that we cannot be competitive because of "Brazil's cost: Manpower cost, absurd taxes, then we should give up from having local supply chain and let people import from China. If we forget about local supply chain and we think only to import, we should also, to take advantage from this global PV production, release the* *pressure on import taxes, all taxes that end up making PV very expensive. This is matter of industrial policy.* "**#Interviewee2**

Some have a more skeptical position about the fact that local production can play a role in future.

"*We are having a national discussion, because some investor say that there is no way to buy, to comply with this compromise to buy from the local supply chain. They are requesting an exemption from all this local content.* "**#Interviewee5**

"*Companies open subsidiaries in Brazil to access BNDES money. [...] If you talk to people that are constructing a power plant in Brazil they say: if you don't need to access BNDES financing, better you buy in China, it is cheaper than to buy in Brazil."***#Interviewee9**

"I don't know if local production will help. Brazil has a very low productivity, high inefficiency. There is a study showing that is cheaper to produce in US rather than in Brazil. In US, you pay more but the output is much higher. Workers are qualified and much more productive. You need in Brazil 100 people to make the job that in Germany you do with 20." **#Interviewee9**

There is the idea that a partial opening to favor importation from abroad could help the PV market to take off in the first stage, and gradually would make more sense to focus on local production.

Energy policies: taxation

Taxation regimes set by the federal government and by the states (each state independently) is a crucial point that affects solar market development. In fact, a certain taxation regime can turn unfeasible a business and this is especially true for the distributed solar energy that already struggles to take off.

"8% of Rio de Janeiro state income comes from ICMS (VAT at the state level) on electrical energy. It is the third major source. Can you imagine if everyone starts to produce his own energy? This source stops. The interest of the government is the money […] *they don't create incentives, Light and Ampla would see that as a loss of revenue."* **#Interviewee9**

"There is one more uncertainty related to distributed generation: taxation. Brazil has federal and state taxes, and each of them is applied independently. When we speak about Brazil we speak about 26 states that have total autonomy to decide on state taxation. […] A PV system can be financially viable in Rio and not in Minas Gerais. Furthermore, it might happen that in the same states two distributors applied the taxation in a different way and that does not make any sense. Every distributor does whatever it wants" **#Interviewee13**

"(About 482) Distributors are obliged to accept those new bidirectional connections…users accumulate credit and afterwards they can use it. As it was not energy trading but accumulated credit in a form of generated energy, it should not be taxable. But quickly State's Financial departments are deciding upon taxing, making unprofitable many DG projects" **#Interviewee4**

"The success of distributed generation will create an erosion of the fiscal income of the states and they have to fight that somehow." **#Interviewee15**

*"As soon as the distributed generation reaches a significant market penetration, you need to rethink the problem of taxation for the distribution sector."***#Interviewee8**

Energy policies: private vs state-owned

Privatization in the energy market is a trend. We observed that opinions about this issue were contrasting. For instance, some see this trend as positive:

"*Today Brazilian society is more open to discuss problems that were refused before, privatization as the villain*" **#Interviewee1**

"Brazil has a regulation that has to be improved, it still transforms losses in social terms, it still transforms gains in social terms, but it is changing fast. Like the Eletrobras privatization […] At the end, if an enterprise fails, let it break! Here it is not like this." **#Interviewee14**

Some others showed a more prudent position toward privatization as an effective tool for the long term interest of the country:

"*In the old state owned enterprises era, Eletrobras (EB) coordinated all the system in a way that though not being a company, all companies acted harmonically as* *if EB was an orchestra director. […] Companies were acting under the coordination of EB, but with the intention to do well. […] we lost this collectivism. Privatizing only led to an increase of the electricity price*" **#Interviewee7**

"I am skeptical about the free market model. Economists like a lot to say that the market will take care of (offer) expansion. I am skeptical about this. For me electricity is not a commodity like the others, it is a big driver in a developing country. In a country that has been constructing it is very risky to accept the market as a driver to fix all your problems." **#Interviewee12**

"Brazil had already experienced market freedom. It was because of that that we had the blackout in 2002, it happened for the lack of investments because the market was liberalized. Investors did not have motivation to invest in the electric sector. Since there, auctions have been introduced where you guarantee a financial return to investors. Just that maybe in this sense you are unbalanced towards investors. It is from that time that we thought that we cannot liberalize completely but you need some form of centralization. Today we re-discuss whether this model of centralization is really efficient." **#Interviewee13**

Energy policies: regulation is one of the sector's uncertainty

"When I started to work in this sector I asked where I could find all the market rules. It does not exist. Rules are dispersed in laws, decrees, resolutions, and administrative rules. Rules dispersed on four levels." **#Interviewee13**

Regulations are the way governments act directly and indirectly on a market. This is also true for the Brazilian government that, in the case of the energy market, acts through direct laws, or through the Mines and Energy Ministry. Once main guidelines are set, they are implemented in terms of operation by the ONS and in terms of regulation by ANEEL. The Brazilian political crises and uncertainty reflect on regulation and, as consequence, international investors perceive as a threat to their current or new businesses. On the other hand, public auctions have a timeframe of 20/30 years, so once they are set, they will follow rules in place in the time of the concession. Thus, a strong dichotomy of instability against long term fixed contracts is clearly witnessed:

"Looking at the electrical sector, I think we had big changes in the last 30 years but the biggest mistake to my understanding was that all those changes were done in local ways, always trying to fix a small problem without looking at the whole, without considering the impact on the whole, without what is called regulatory analysis. This got worse and sores in the time. […] Once I remember we compared 30 auction calls for energy generation… each of them ran under different rules. New auction, new government's rule. " **#Interviewee11**

"The political issue is messing up with everything… if you don't have the support of the congress it will be very difficult to have changes in regulation" **#Interviewee3**

"When a minister sets a direction this will affect the lifetime of all investment during the time of the concession. We are talking about 20 to 30 years. The rules will remain with the plant." **#Interviewee8**

Interviewees were basically unanimous about the role that regulation plays in the Brazilian energy market, and several points of view of the same issue emerged. First of all, we can distinguish between external and internal repercussions. The former concerns mainly to foreign capitals and investors. It is generally believed that Brazil represents the next big market for distributed generation expansion, especially to what concern solar energy. However, the real and perceived political instability impact on foreign investors' decisions and delay the development of a new business model (often a paralysis):

"If the regulatory agents resist, are inert, they prevent market development. They will not impede economy's internationalization, but they will delay it, compromising several financial interests. Nowadays the principal signal is not the lack of investments, but rather that people fear the lack of regulatory references that leads to lack of confidence." **#Interviewee1**

"Regulation about the generation segment needs to allocate risk, it is necessary a clearer risk matrix. We should redefine the prices. Today, the price is defined through a very complex model and it was criticized because was not transparent. If every agent could trade his own price, you would have less difficulties. […] We have to assess availability, flexibility (of renewable sources). To compensate those type of sources we end up creating externalities. The ideal would be all sources operating in the network to meet system's necessity, and to be remunerated for that." **#Interviewee8**

On the internal impact dimension, regulations impact the market in several ways. Some Interviewees perceive that regulation is not adequate. However, some think policies are already sufficient (as for DG), some not and there is also who believes a low level of subsidies makes the market evolve in a more solid way.

"If a person could sell his own energy and receive an immediate payment, then it could change the perception." **#Interviewee2**

"Only who has a demand above 500 kilowatts can go to the free market and between 500 KWatts and 3 MWatts can be incentivized energy. [...] Today, the prices of the free market are much cheaper than regulated market." **#Interviewee3**

"Although the Brazilian energy matrix is pretty much clean due to the hydroelectrics, I believe that solar and wind energy will take a more relevant role. In my opinion, the subsidies that these industries received have been more than enough to develop this new market. " **#Interviewee11**

"The national regulatory agency (ANEEL) must regulate somehow what you do with your spare energy, you need intelligent metering technology, to sell this energy, to give up energy in some time windows… This is a matter of time." **#Interviewee12**

"Subsidies are good because they create demand, they stimulate an industry. The problem is when support becomes artificial to the point that when you remove it the industry does not survive. For solar energy in Brazil, we did not have the subsidies that were given in Germany. This is good because, although the industry is very far from its potential, it is growing solidly." **#Interviewee13**

There is a shared perception that regulation (and enforcement) is not keeping up with the market evolution for what concerns distributed generation:

*"Regulation in Brazil does not help, it is very slow. For instance, the distributor (utilities company) charges for something unfair. Where am I supposed to complain?"***#Interviewee9**

"The intermittent nature of DG requires reserve energy from fossil fuels, gas, oil, diesel and other sources with rapid ramp up. This is loaded on the system and who is paying are people that do not have DG. Today we are discussing the separation between energy used and re-injected from residential users, the so called binomial energy. Today a user can completely offset the bill. This does not consider that the user used the distributor." **#Interviewee13**

"(About 482) 482 resolution is just a resolution, it does not have the power of a law, it does not have a power of a decree, it is very unstable, regulatory-wise is very unstable. [...] Today I see this point as one of the biggest risks for the sector, an industry growth based upon a resolution that does not have the power of a law…that can be changed anytime. This is a huge risk. In the time that the president changes, we can have a domino effect, he/she will nominate the heads of public institutions. If a new president has a different vision, he might terminate an entire sector that had just been created. " **#Interviewee13**

"Brazilian regulation is missing the concept that one thing is to have availability of energy there and something else is to consume that availability. They have different prices, binomial prices. This is under way to be worked in the temporary resolution." **#Interviewee14**

Finally, regulation appears inadequate to address carbon emissions that, theoretically, Brazil compromised to comply with on September 2016. It is proposed carbon credit as the way to enforce emission reduction:

"Oil industry is subsidized all over the world… in order to promote clean energy you should stop such subsidies, so the other sources could become competitive.." **#Interviewee5**

*"In Brazil you don't have a rigorous regulation like in Europe about energy efficiency [...], technically we know how to do but there is not enforcement, there is not legislation that forces compliance."***#Interviewee6**

*"Between energy and us, there exist that equipment. They have higher or lower efficiency. Policies in Brazil have been bad, it is very poor the way to think electricity in Brazil, especially electricity because always the focus was to increase the energy offer. Among the 23 bigger global economies, Brazil is the worse in efficiency."***Interviewee10**

*"When we talk about clean energy, carbon emission pricing will be fundamental…the only reason why today in Brazil our model chooses more thermic and coal and less solar is because it is perceived as the cheapest. The owner of a diesel car does not pay for the public health damage caused by this car emissions, then he understands that his car is cheaper… at a certain point we have to internalize the external environmental and social costs of fossil sources. "***Interviewee6**

Finally, it emerged a regulation void for what concerns emerging technologies (as electric cars and batteries). This happens in every country, so it is not a peculiarity of Brazil.

"About mobility (electrical vehicles)… regulation does not exist at all, how will it be regulated car batteries? Is it going to be a distribution issue?" **#Interviewee3**

In view of the interviewees' perceptions and previous analysis, we can consider "policies and regulations" as an uncertainty that could heavily affect energy market in general, and the solar one in particular within the next 5 years.

Financing access is another uncertainty for PV adoption

Several interviewees do not believe distributed solar adoption will be fast. Access to affordable money is perceived as one of the most critical uncertainties to the ecosystems' actors.

"*I bet whatever you want that solar energy supply won't reach 10 Giga in Brazil in the next 10 years, as the government claims. Money is Brazil is very expensive, therefore if you take a loan to purchase your PV system you will never pay back that loan with the saving on your energy bill. […] As long as the access to cheap money is not a reality, development of solar energy in Brazil will be slow.* " **#Interviewee9**

"I think it is very difficult that solar reaches in the next 15 years up to 10% of the Brazilian energy matrix." **#Interviewee15**

"What has not reached most of the population is a better way to finance your purchase of a PV system. I believe financing is a fundamental issue; if you take a loan, it will have a very high interest rate, making your solution much more expensive" **#Interviewee2**

"..therefore financing is an extremely relevant point to make all these investments viable and not only to approve it. There must be a financing model." **#Interviewee3**

Financing in the framework of PV industry is a big hurdle both for small investors and for private users, whereas big investors can access BNDES financial support for big projects (but under conditions of local components production). The nature of the distributed PV business requires capillary access to money at an affordable interest rate. There is a complete void on this issue. To fulfil this gap, government guidelines would be necessary and a new implementation should be devised. In fact, it is not trivial to understand which institution could be the best for the aim.

"For small companies, BNDES financing remains inaccessible. They will not even answer them. " **#Interviewee9**

"In terms of levelled cost, your self-generated energy is cheaper than the one supplied. However, the levelled cost assumes to have investment and in Brazil you don't have commercial banks that finance your PV. […] BNDES does not have structure to deal with projects of R$300K, for example. […] It should be maybe another bank working with retail, like for instance Caixa Econômica, Banco do Brasil or Correios, institutions with larger penetration. […] however it is complicated because you cannot oblige BB to do that and not oblige Bradesco or Itau… it would turn in an unfair competition." **#Interviewee6**

It was also pointed out as oil industry is more financially attractive because it has been historically supported by financial institutions.

"One of the most financially supported areas is oil&gas. At least in the last years, as investments are huge. **#Interviewee5**

4.1.2 Technology as a trend and as uncertainty

Technological advancement emerged from the interviews in different ways. First, we see the cost reduction trend of PV systems and batteries in other countries (China in particular). Second, the problem of intermittent energy sources (distributed network development) and its linkage to the current grid appears to be related to local R&D; interviewees did not show optimism on the timeframe where this might be solved.

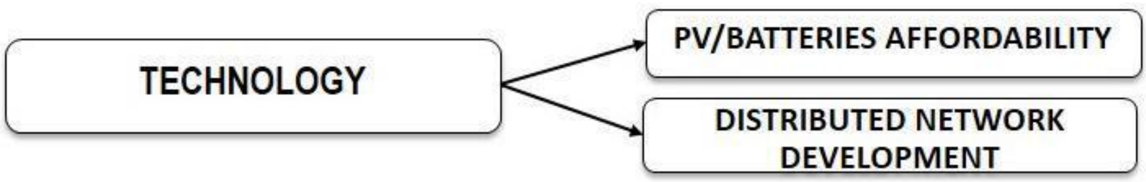

Fig. 4.2 Technological drivers in the energy ecosystem. The white rectangles indicate that the drivers are considered as trends.

Cost reduction of PV-systems (panel and batteries) is a trend

There is evidence that a rapid cost reduction of PV systems and batteries is expected, consistently with the literature review:

"Projections of cost reduction for PV panels as well as for batteries are impressive" **#Interviewee1**

"The breaking point of the distributed generation will be when the cost of batteries becomes much lower" **#Interviewee3**

Independently on the pace of the cost reductions of batteries, many do not see them crucial parameter for the development of the distributed generation, as big hydroelectric basis could work as energy accumulator, playing in fact their role.

"It might be that when batteries enter the market, when they will be cheap enough to keep at home as a refrigerator, you will be able to store energy during the day and even sell to the grid. Why not everyone agrees with that? We are a poor country, then for a reasonable time some could afford and some not. And this will not be so soon." **#Interviewee12**

"Batteries are an open question… I don't think we are close to a technological disruption in this sense." **#Interviewee15**

"Batteries… Brazil does not need batteries… we have big water reservoirs. Big reservoirs can play the role of batteries. The amount of people that could diminish the load on the network (with PV) and improve the situation of reservoirs is huge. Improving the situation of reservoirs you waste less thermal energy and price decreases. Have you seen any institution talking about that? On the contrary, they create obstacles!" **#Interviewee7**

"(Talking about solar/wind energy) As there is a variability out of the human control, there is a natural call for technologies and alternatives to compensate that variability. […] Some Brazilian reservoirs (of water) started to be called recently as 'accumulators of wind' to the extent that they can compensate the variance. […] There are several alternatives for energy storage… the solution will change from country to country. What fits better Brazil at first is a combined solution. " **#Interviewee1**

"To have more solar and wind energy, you need to have a more interconnected system. […] in Brazil, regions with higher solar radiation are in the northeast that also have a lot of biomass. We started to develop some prototypes of power plants together with

the Germans that combine solar with biomass. […] The future that we see is that, more interconnectedness, more energy storage. " **#Interviewee6**

Allocating intermittent sources is a challenge in Brazil

In the centralized and interconnected transmission and distribution system in Brazil, intermittent sources allocation is not a trivial technological and energy security problem. Some perceive that this should be done in a different way than it is currently.

> *"I think the incentives (for distributed generation and renewable sources) should be reduced because they are intermittent. They do not provide energy all the time and they are not centrally controlled. We will need huge water reservoirs and we need to get those started quickly. This has not been considered because if I need a thermoelectric then I will clean the matrix from one side and get dirtier from the other one. This cost has to be taken into account.*" **#Interviewee11**

> *"Technically, for the management of any electrical sector, you need to accommodate intermittent sources. Brazil has even an advantage in comparison to other countries using thermoelectricity - we have a hydroelectric base that allows for this arrangement. […] Thermoelectric input in Brazil increased; however, if we would have not included* renewable *sources, we would have got an even dirtier matrix. As long as Brazil or other countries are developing technologies to arrange intermittent sources, natural gas will remain relevant."* **#Interviewee4**

> *"It should be clarified to Brazilian society that having solar implies to have thermal and gas plants in standby. The day you don't have energy, you want to switch one of those plants - they could stay 1 year off and then work for 2 months to meet your demand, avoiding you to be trapped in the elevator. This has a cost."* **#Interviewee15**

4.1.3 Geopolitics

Brazil is subjected to geopolitical dynamics under several aspects. As discussed in the literature review, national policies can tackle geopolitical shifts and set regulations favouring the local development, however, given the protectionist attitude and the regulation behind international standards, it is likely that Brazil will undergo external events and pressures without being a main player. This view is shared among several interviewees, regarding both geopolitics in South America, and global as well:

"If Brazil does not assume a leadership (in South-America) in terms of regulation and as a reference for integration, other countries will take bilateral actions with a much smaller impact **#Interviewee1**

"The Brazilian economy is bigger than any neighbour countries. It is a country that should set guidelines, but it does not. Actually, you have Chile with a much more advanced market" **#Interviewee2**

"It is quite different to invest in solar/wind energy in Europe as their population is stable. […] How did Spain generate last week 90% of its energy from solar and wind? They did because they have the option of importing nuclear energy from France or Norway. In Europe people may be ambitious individually depending on renewables but they are still connected to the European grid […] Brazil cannot depend on Chile or Peru. We have to guarantee ourselves." **#Interviewee6**

Remarkably, it is clearly perceived that China became a central player in Brazil, despite all forms of protectionism, thanks to their long term strategy in this market.

"Chinese are big technology supplier for continuous current transmission and they are buying companies here in Brazil… […] they are buying in Brazil with an impressive ease. […] They are not buying more because they are careful, but they are studying Brazil since the 1990s. From 1990s, we have been welcoming Chinese delegations that went back and forth, every time with different people. They did that for 10 years and after that they started to buy. [...] The Chinese context brought not only technological advancement. Due to their leadership they win all public auctions for transmission - they offer better conditions and they have a broad experience. For the Chinese State Grid they prepare annually at their universities 100,000 electrical engineers. **#Interviewee1**

"The uncertainties related to solar generation in Brazil prevents investors to enter heavily in the Brazilian market; the ones that do, in my opinion, are taking a crazy step. If I were an investor, I would probably not do, but Canadian and BYD (Chinese), two important global players, did it **#Interviewee2**

“The growth of Chinese business in Brazil is scary. They tried to access the financial support of BNDES, but they did not want to comply with local content requirements. So they went for the transmission business.” **#Interviewee15**

Exchange fluctuation and dependence on commodities’ prices are also uncertainties generated by external dynamics:

“In Brazil, we are subjected to facts happening in the world, especially to what concerns oil prices” **#Interviewee5**

“You have to protect yourself from the currency fluctuation. It is up to the agents to mitigate this risk, not to the regulatory agency” **#Interviewee8**

“One improvement would be to link contracts to dollar value instead of Real” **#Interviewee13**

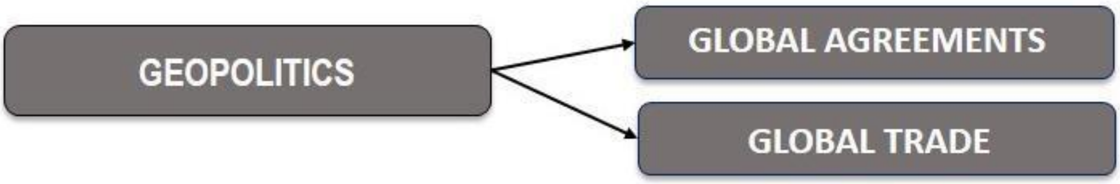

Figure 4.3 Geopolitical drivers. Grey indicates that drivers are classified as uncertainties.

4.1.4 Paradigm shifts in the energy sector

The two main shifts that we can individuate in this ecosystem are: the transition to low carbon sources and the distributed energy generation. They might lead to the partial ecosystem reorganization and maybe to disruptions.

Regarding the disruption of traditional sources, it is not a shared view that fossil fuels will be abandoned so soon:

“Still the expectation is that with the increase in global energy demand, even if we experience a relative decrease in the oil and gas demand, it ends up that in absolute values it will keep increasing for the next years. Although technology is advancing and will reach price parity, still the balance favours oil. In 2040; oil&gas will still occupy 50% of the energy matrix. […] Clean energies will not remove the oil supremacy.” **#Interviewee5**

"The country is manly hydroelectric and it will be still for the next 10 years. We have fantastic energy diversity, we have a lot of wind, sun…and we took advantage from developed countries in terms of technology and subsidies. […] Solar generation will reach 2GW in the next 5 years. There will be even more in future due to Brazil's irradiation potential. However, with DG we don't know how to do yet. About nuclear, I think it is an emotional issue - people are afraid of nuclear waste. Nuclear plants are expensive projects, capital intensive but with very low operating costs and very high intrinsic safety. For Germany was easy to deactivate nuclear, while keeping buying from France. They say Brazilian society would not accept, but society has not enough education to understand the issue." **#Interviewee12**

The advent of the distributed generation in a model like smart-grid could affect several players: traditional centralized generation, transmission and especially distribution. The advent of batteries could bring even a sharper transition, but, as discussed previously, the current costs keep it from happening so soon. Most of the interviewees mentioned the criticality that is going to affect the traditional distribution business and financial sustainability. There is general perception that centralized generation and transmission lines will keep a relevant role, the same happening to the distribution business if they reshape their role and function within the ecosystem; distributors will lose their stakes in the ecosystem if they keep the current resistive attitude. Several interviewees think that distributors should hurry up to disrupt themselves and re-invent their role:

"Solar decentralizes so much that is dismissing the traditional system." **#Interviewee1**

"Electrical energy as we think today is changing completely. We are having a very strong disrupting change in our model. Simply generate, transmit and distribute energy…this model is obsolete because you see strongly DG coming in, which is generation where the consumer (called prosumer) produces and consumes. This implies that distributors have to revise their business model. Today we pay both for the infrastructure and for the transformation… cash flow will remain only for the infrastructure." **#Interviewee2**

"This is a point of high complexity. Distributors are not thinking about that... it is not that they are not thinking…they are thinking very slowly. When you have clients migrating to the free market, they will still pay for the 'wire'. From the moment DG enters, theoretically you don't need any more energy from the distributors. ... Imagine

half of your clients quitting. The distribution business becomes unsustainable…. Therefore, they have to reinvent themselves. I witness today very strong in distribution enterprises the attempt to resists all events that are bringing in this direction of the market.” **#Interviewee3**

*“I believe in 5 years everything will change…the function of the distributors has to be changed.”***#Interviewee7**

*“Today you pay a price that represents energy and infrastructure (distribution), thus every time someone installs a distributed generation he stops paying for it. Who is going to pay for the infrastructure? In the moment that DG gets significant penetration, you will have to revise the way taxation is done in distribution. Infrastructure gives you energy during the night when you have PV. Somehow you have to pay for it.”***#Interviewee8**

“Distribution's value proposition has to change - all sector configuration. The big question is whether the regulatory agency is ready for this technological shift that is under way.”# **Interviewee11**

“(About DG) We don’t know yet what will be the successful business model, but we know that the client is going to have power in this industry. […] Thus, we have to increase our clients' pool, be close to them, offering services, solving their problems, like with DG, selling products, services, adding value.” **#Interviewee14**

“I am not a fan of disruptive technologies, because I am not linked to this vision. Some people value a lot the role of innovation as a growth factor. I give more value to institutions. DG has for sure a role, but it has to be organized DG not disorganized. I think DG offers possibility for local development. Therefore yes, DG will grow but it won’t be a panacea, I don’t think we are close to a technological disruption, I don’t share this view. I think DG should have a centralized governance that is compatible with DG […] Distributors should have a central role in DG, they should not see DG as a threat and they should contribute to guarantee that solar grows in an ordered way. They should provide certificates, like certificated providers that users can trust if they want to install.” **#Interviewee15**

Some Interviewees made explicit that most of the distributors are not assuming a new role, but rather showing active resistance to the shift, while just a few are trying to reposition themselves within the ecosystem:

"For how the distribution business model is today, improving energy efficiency means to lose money, from a distributor's standpoint." **#Interviewee14**

"Distributors of electrical energy have to invest up to 1% of their net operating income in R&D for energy efficiency and development. ... Distributors have not presented enough projects to reach the minimum legal of 0.5%. ... There are some that comply with that and even propose a bigger number of projects, but on average they stay under. They maintain a conservative profile on technological advancement." **#Interviewee4**

"(About the mandatory investment R&D distributors should do) If you take 20 years at 0.5% of net operating income, you obtain approximately 10 billion Reais. If they had invested those in R&D, we would have a completely different distribution sector nowadays. [...] It is not a matter of money amount - it is just bad use. National congress should enforce that." **#Interviewee11**

"In the moment you put a PV system in your roof, you are stealing market from the distributors. Those are strong actors in the ecosystem. Therefore, they will have to reinvent themselves... so I believe that part of the regulatory delay on this matter is due to distribution lobbying. .. Technologically, I don't think there will be any disruption." **#Interviewee12**

"Today there exist two distributor profiles. The first fears and tries to prevent the advent of DG. The official position of ABRADEE is of resistance. The second profile has a completely different attitude and prepares to enter the market. They will offer services, rents and whatever else in DG. Most of those are international companies." **#Interviewee13**

"It is not possible to block this change. Better be part of it instead of risking the business. There are distributors that are lobbying hard to block that trend." **#Interviewee14**

Mobility emerged when DG is debated. There is a consensus that electric vehicles will be part of this paradigm shift. Beside the clean energy issue, electric vehicles represent a huge business opportunity. They are a perfect substitute already widespread in developed countries and in some developing countries. In the interviews, we did not find strong indications that mobility will be a DG driver in Brazil, possibly because it is still incipient. However, several interviewees mentioned it as a natural consequence of DG and it is expected that electric mobility actors will play an active role in the electric energy ecosystem.

*“Distributed generation is a matter of market liberalization…there is not yet something solid so far, even regulation does not exist on this matter.”***#Interviewee2**

*“Cars are rarely used for more than 10% of their lifetime. Most of the time cars are not useful. You could have, for instance, connected to the grid, in such a way that when is windy or sunny, you can store the energy in the car battery, or to inject energy into the grid. ”***#Interviewee6**

*“I think there is no way to escape, it is a global trend. Probably we will have electric cars. ”***#Interviewee7**

*“(Talking about cars fueled with ethanol) I think this technology sets Brazil among countries that pioneered fuels with lower greenhouse gas emissions, competing with electric cars. This is a peculiar Brazilian characteristic that is different from US and Europe where the absence of low emission cars brought much faster the electric ones.”***#Interviewee10**

*“I think electric cars are a trend for big cities.”***#Interviewee11**

“Electric cars are a strong trend in big cities, because with your car you can have both energy generation and storage. And it is clean because you dislocate energy generation punctually, not inside the city.” **#Interviewee14**

DG and its consequences are a reality for most of the Interviewees - more than any other points reported in this section. However, DG is not a driver per se, but rather a consequence of all elements discussed till now. DG can be considered as an expression of technological advancement, favourable development and energy policies, energy scarcity, emission reduction, electricity cost, etc. The model transformation from centralized to decentralized involves incumbents and newcomers, just like Shoemaker presented (SCHOEMAKER, GUNTHER, DAY, 2000) Distributors enjoy a favourable position in the ecosystem and own enough cash to enable them to disrupt their current business models and become leaders in the new model. However, this is initially costly, and for most interviewees, they will resist the change.

4.1.5 Trends and uncertainties in the energy sector

Figure 4.4 summarizes the literature review and the field investigation findings. We did not find contradictions between the two approaches, and we merged both.

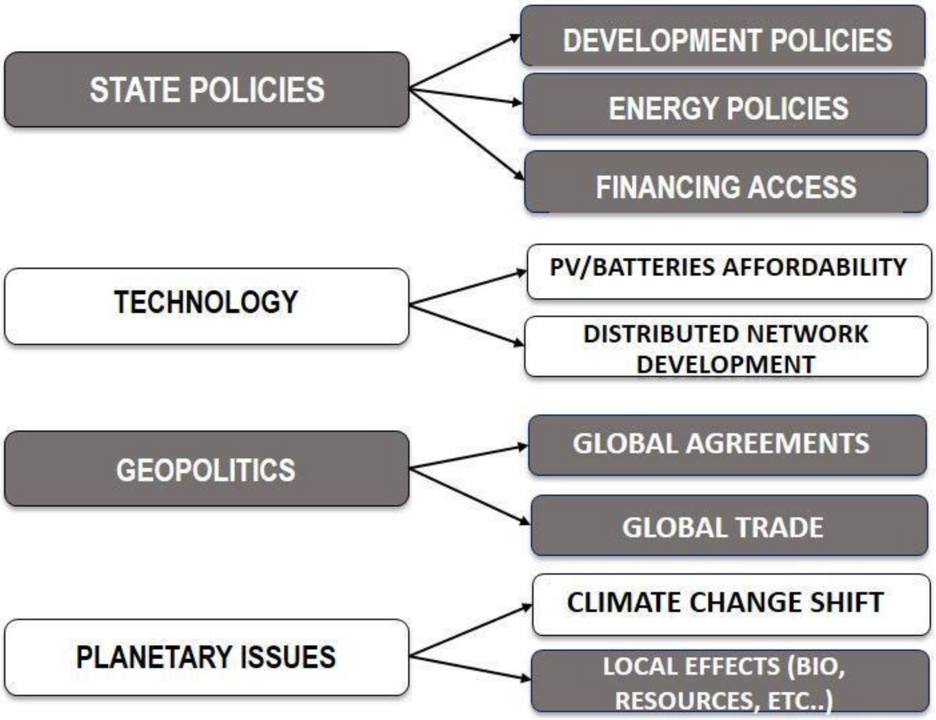

Fig. 4.4 Schematics of the drivers acting on the Brazilian energy sector. Both literature review and interviews results are here included. Drivers are indicated in white, when trends, and in grey, when uncertainties.

4.1.6 Long term drivers

Most of the interviewees referred to long-term issues, as education in a broad sense, societal and cultural aspects. This time frame (>5years) goes beyond the scope of this dissertation but, as they were recurrent, we decided to bring them to the analysis in order to inspire further research.

We have to keep in mind that all the 15 interviewees were Brazilian, placed in top management positions, and also belonging to the middle-high income class group.

We talked about technical education in the section of technology (Section 4.2.2). Here education is meant in a broader sense and refers to all economic classes, clearly, in different ways: from the resistance of higher-income classes to question historical privileges to lower-income classes not politically positioned (through vote) due to lack of basic education.

"Energy sector can contribute to a project for a different country. In the long term, like 2050, we should focus in fundamental stuff as education. Brazil never decided to have a good public education. [...] In Brazil, we never overcame the idea that education is a privilege, not a right. [...] In the best case, people send children to private school when they can afford. There are several private schools that you can see they are a closed world.
[…] *From the colonialism, what you have in Brazil's mentality? You have social classes separated by privileges, there is a huge gap. I am very pessimistic on this matter. In other countries (like Japan or Korea) you have an elite that perceives that they won't have competitiveness without education. However, once you are under this way, it is clear you break structures. And privileged people will lose their privilege at certain points."*
#Interviewee10

"You can name the possible future Brazilian president. They are all not ok. A country that is not capable of having leadership! 200M people and you don't have anyone. What does this tell us? We left behind the relevance of leadership. We got used to have a dancer or a football player. Popularity is a usual starting point for political career"
#Interviewee1

Lack of trust in institutions

The disappointment is expressed as a lack of trust towards institutions and a sense of unsuitability.

"In my opinion, one of the best indicators of maturity in a society is the consistency of its institutions. Corruption always happened in Brazil and also happens in any other country of the world… However, we were too much permissive, we left this phenomenon take huge dimensions and we live with that. [...] Brazil accepted it and closed the eyes for many years. [...] Nowadays we have a bad political class. [...] what is the message they send to society? ...that key positions in education, healthcare, justice, can be occupied by persons not necessarily qualified and that this does not have a cost for the Brazilian society." **#Interviewee1**

"The problem of corruption destroyed companies. Actually, investigations brought uncertainties. Everything would continue as before if there would not be the oil price collapse. It would continue to provide revenues for everyone and no one would complain.

Where is my share? That brought friction between the different agents and that brought to investigations that led to uncertainties. And uncertainties led to paralysis." **#Interviewee5**

"(Talking about violence and UPPs) There are areas where I cannot enter to cut power connections (of people that did not pay their bills). [...] In this country, there is still a social problem that has not been solved, that is crime. The regulatory model attributes this risk to the distributors, and those are negatively affected. You can treat this problem by regulation, but that means to hide the reality under the carpet. The honest consumer pays for the dishonest. In the Rocinha favela, 80% of electricity is not paid for." **#Interviewee14**

"Brazil is a country were you are cheated a lot. To buy a PV system at R$ 60K that does not work as promised costs you a lot. People do it both intentionally and also because of incompetence. Therefore, people don't trust anybody." **#Interviewee9**

This feeling can be understood in the crisis context being experienced. During the interviews we explored this disappointment in order to identify underlying factors for this mistrust.

Cultural and societal factors

Cultural and societal factors emerged in most interviews, many interviewees appeared highly critical towards the society and some attitudes.

There is a trend to maintain the status quo (generational and economical)

"Our age pyramid is not a pyramid, is an hourglass… there are young people in the middle (squeezed) and at the top a bunch of sixties. Therefore is difficult. It is natural in life that a person turns more conservative. " **#Interviewee1**

"A friend of mine was saying (and I share his view): capitalism in Brazil has not worked because it was never actually tried. In my opinion, all that a Brazilian entrepreneur does NOT want, is capitalism. Capitalism is a matter of risk, Brazilian entrepreneurs do not want risks. [...] Entrepreneurs and investors love when the government awards 30 year contracts adjusted for inflation. Where is the risk for the entrepreneur? No economy can support that. What is the problem to allocate risk in this industry? It is a business like others, but unfortunately that attitude is deeply rooted in the Brazilian culture." **#Interviewee11**

Several interviewees expressed highly critical about attitudes and behaviours of the society, indicating those as sources of unreliable institutions. Permissiveness with wrong behaviours, corruption, intolerance and the lack of hope towards improvements are factors that keeps society as it is.

"Brazil is a country that does not miss the opportunity to miss an opportunity. When we miss an opportunity is because we believe that actually is not going to be the last." **#Interviewee1, #Interviewee7**

"It is very difficult to deal with conflicts. It is a Brazilian thing; people do not want to hear that they don't agree with. ...you foreigners see all Brazilians as kind, friendly. We have a writer, Sérgio *Buarque de Holanda, talking about the kind Brazilian man (homem cordial) as result of the colonial time. This kind man is one that accepts to lose rights because he knows he can get those back later in another way. He accepts to be cheated because he cheats. This is Brazilian spirit. It is unbelievable. ... Our laws are unprepared for the degree of permissiveness that what Brazilians are used to."* **#Interviewee7**

"(Talking about indigenous populations) Brazil is a homogenizer society. Although it might look that a Brazilian is kind, he is not. Brazilian is intolerant with differences. Brazilian does not support the idea that there exists another language inside Brazil. […] It is part of the indigenous resistance to have schools where you have both languages. It is just a resistance. The official federal policy is very strong in terms of having an uniform country" **#Interviewee10**

Interviewee#1 found the "human aspect" of tolerance as positive one, if correctly addressed.

"We have to use our values, our strengths with consciousness. Brazil is a relational country, this is a very important value for the future of humanity, but it is not possible to just stick with it. Optimistically speaking, it is easier to bring institutional way from Europe or US rather than to export the Brazilian human way." **#Interviewee1**

Lack of technically skilled HR

The lack of technically skilled workers has been brought to the discussion as an element that does not favor the solar business development. Interestingly, this deficiency is not exclusive of basic technical jobs, but also of specialized ones. This aspect can be considered as an uncertainty or a trend for the future, but, as education is a long term issue even if correctly addressed, the improvement of workers' technical skills might or might not play a role in the 5-years time frame that we are interested in (we discuss further on long term drivers in Section 4.2.6).

> *"All PV panel installations requires manpower that does not need to know a lot, it is a low-skilled job"* **#Interviewee7**

> *"To have qualified workers is a matter of culture too. Brazilians are often lazy, not committed, gets lost at work, without considering the lack of qualification that generated the necessity to re-do the work. This led to the fact that on each dollar you spend you generate less output. […] I don't know how we can address the cultural problem, but it would be already a big advancement to reach a basic level of technical qualification. […] How do you teach someone to install a PV system if he did not have even basic education? This is difficult. In the moment to talk about basic geometry, like a triangle, he is lost."* **#Interviewee9**

> *"There are few universities in Brazil with undergrad programmes in Energy studies. I don't know why… probably because electric engineering is a traditional course coming from Europe and US that have typical curricula from year to year about power supply systems."* **#Interviewee12**

> *"Today in Brazil there are some courses starting to integrate renewable energy sources, but not yet in the MSc level, as can be seen in Europe."* **Interviewee13**

Perceptions on environmental issues

Environmental protection issues regard Brazil especially because of the Amazon forest. There is a wide perception that big hydroelectric projects have been damaging the environment and local communities, but also that they are a powerful way to reduce GHG climate change. Some believe big hydroelectric should not be further constructed:

"In the North we don't have enough reservoirs because of the environmental issues. So you build big hydroelectric plants without reservoirs and you generate from the water flow. You throw away a lot of water because you don't have reservoirs. These projects are condemned in this country because of global problems about the environment. Amazon belongs to the world not to Brazil…" **#Interviewee3**

"Public opinion nowadays does not accept big projects of hydroelectric plants. That is curiously leading to a contradiction in the electric sector about the so called climate change. There is a trend in the Brazilian electric sector to go more and more for sources that emit carbon. Coal, natural gas… Exactly for the troubles to construct big hydroelectric that would bring environmental impact." **#Interviewee6**

"In Brazil, carbon emissions are increasing. We have several independent causes for it. The first one is deforestation. Amazonia deforestation has to do with how Brazil plans to occupy and use that territory. […] Deforestation is the result of that process. To fix that you should have governance and law enforcement. Big land owners do not have any responsibility towards preservation. When you talk with indigenous population you see that they are aligned to the preservation because they get their survival out of the forest. ... Thinking about preservation, there is no possible agreement with the big owners. The second cause for GHG increase comes from the energy sector. I don't believe we should offset one with the other one, they should be treated independently. In case of Brazil, hydroelectric plants contributed a lot to have a poorer country. Is it really a clean matrix? Why? Because it does not emit CO_2? There are plenty of things that do not emit CO_2 and are the worst for humanity. What are we talking about? Richness of the country? Among the richness you have cultures, languages, knowledge. If those disappear, the country gets poorer." **#Interviewee10**

"Imagine to inundate 8,000 hectare: That man that always lived there, that church there for many years, you terminate all of that. The social impact of huge hydroelectric, our company is not going to do it any longer". **#Interviewee14**

Some think that, despite the high impact, hydroelectric is still worth because of the low GHG emissions, in case it is done in the proper way. Some interviewees think that the public opinion is so hard towards new hydroelectric plants because of some bad examples in the past that biased their perception:

"The construction of big reservoirs was traumatic because it was done during the dictatorship...Brazilian rivers stay in a plateau…if you make a dam, it turns to be a big thing. This should be natural, it should be done in another way…removing people…nothing was done this way. First, they constructed the plant, only afterwards they took care of the existing cities. " **#Interviewee7**

"In Amazonia is not possible anymore to make big water reservoirs… as it is very flat. To have a reservoir you need to build a big dam. Then, whatever we do in Amazonia all the world is watching us. They do not help to avoid fires but they love to block dams.
[…] *Nowadays hydroelectrics have been demonized. They became the big villain because they cause floods, they need reservoirs, they inundate big territories from agriculture. Sometimes is easier to obtain a license for a thermoelectric than to have for a hydroelectric. No one can be against solar and wind"* **#Interviewee12**

"(Talking about Belo Monte) It was a very complex project, with a remarkable level of investment, international polemics about the environment and so on, the project has been stigmatized. From my point of view, unfairly stigmatized; I don't want to defend it because it is not my role, but it is a project that Brazilian society should discuss better, with more rationality […] Now Brazil cannot have any more big reservoirs, because society does not accept that any longer. Therefore our model is hydro-thermal. It was hydro and now it became hydro-thermal." **#Interviewee15**

Climate change awareness

Once more, we remark how scientific community is in agreement about anthropogenic causes to the climate change manifestations (COOK, 2016). All interviewees have good education and work in the energy sector so they are closely exposed to that thematic. Some of them agree, some not and also some believe that academia is divided on the issue.

"I am not from the group believing in greenhouse effect induced by humans. I think assumptions are wrong, humans are not capable of that change… it might be locally, in cities. Clean energy matrix is important for our well-being, to have nicer places for us. Pollution is a poison for us but I don't believe this will have a big impact. We are not capable of geologically modify our planet. I read counter-arguments about climate change, scientists change… there are scientists in disagreement." **#Interviewee5**

"There is a school of thought in academia that say that we are experiencing a climate change. It is observed. Higher temperatures, severe droughts, abundant rains. ... there is another part that say that this is a part of a climate cycle. What academics told me is that academia is divided. " **#Interviewee12**

"The drought of São Francisco (river) has been lasting since the last 10 years, this breaks all paradigms. 2000 years of the Nile can be a reasonable time when you think that plenty of social integrations happened around that river. Now if we take São Francisco river, Amazon forest, we don't have 2000 years and we are devastating, making a mess." **#Interviewee1**

*"A series of climate accidents are calling our attention. Unprecedented droughts, heat waves in Siberia, in France in 2005/2006 that cost 10,000 lives, Venice under the water… maybe not everything is climate change…I am not cheering for it, but unfortunately we would probably need a higher rate of natural disasters to get governments of relevant countries more aware that we cannot play with that. ... You need a society honest enough to think beyond their own life of their children's. […] I won't be alive in 2100, but my grandchildren will… so we are talking about people that are sharing the life with us. It is difficult to convince governments, Rio state is broke today. Imagine to talk with Crivella (Rio's mayor) about 2050, they don't even know how to pay salaries at the end of the month. "***#Interviewee6**

The perception about climate change evidences and causes is sometimes misleading and worrying; the scientific community should seriously question the effectiveness of the way they communicate research results. This could have a huge impact on the decision making process of policy makers and responsible investors.

We close this discussion on long-term factors, adding education to the trends and uncertainties chart education. Education is meant as the set of tools that make citizens aware about their decisions' impacts.

We believe the following chart (Fig. 4.5) can summarize the main results of this research. All connections should be further explored and tested with other research methods properly focused. The exploratory nature of this study and the time restriction of this work did not allow to further test these hypothesis, so Fig. does not aim to be any theoretical generalization.

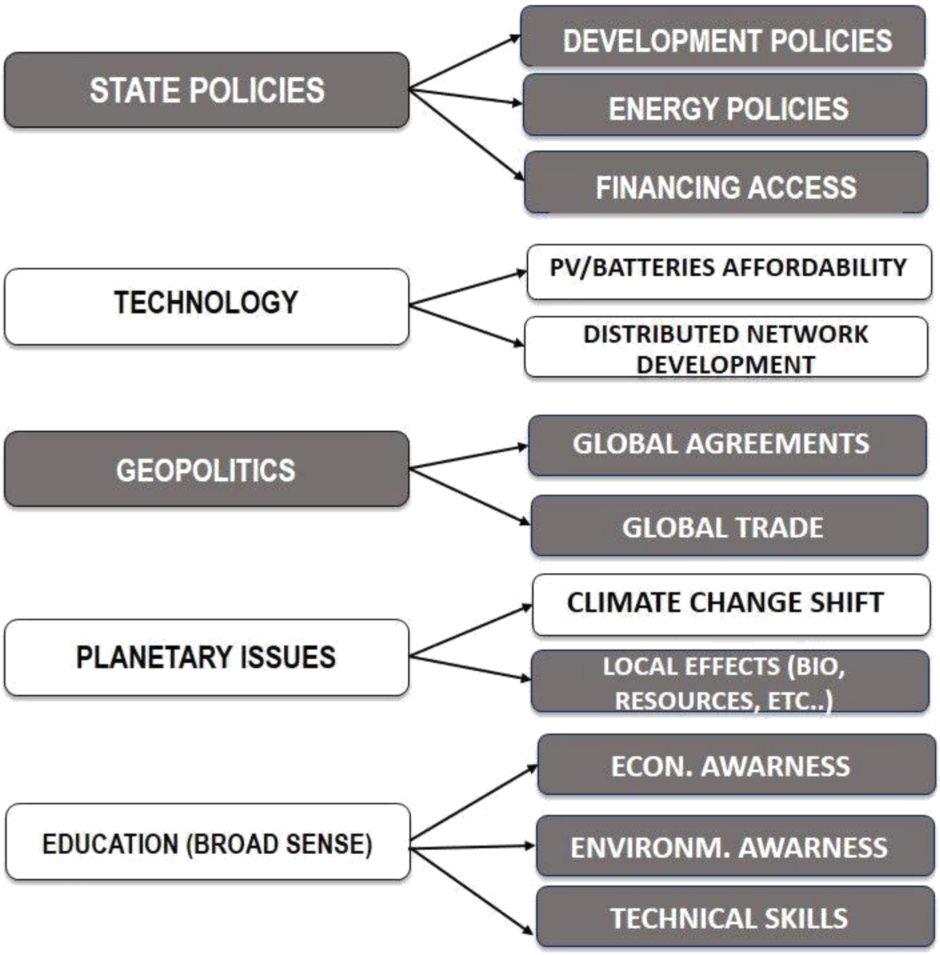

Fig. 4.5 Short-term and long-term drivers acting on the Brazilian energy ecosystem.

4.2 Brazilian Energy ecosystem

The Brazilian electricity ecosystem is reported in Fig. 4.1. The chart represents the most relevant connections that emerged from the literature review and the field work. The colours of the circles are assigned according to the degree of connections between one actor and another one: the darker is a circle more connections it represents. We can see that 'darker' circles are related to governmental institutions: ONS, ANEEL, BNDES. Following we find distributors (Utilities) and transmitters. Users are essentially passive elements, and service providers as PV installers do not play a central role, so far.

In the event of traditional sources disruption but with a smart-grid system, distributors and transmitters would preserve their role, although they could lose profitability, as it would become less evident how to capture value from the market. This last solution would not fix the problem of the low efficiency along the transmission lines that would still play an important role. It is interesting to observe that as PV system prices fall, Brazil could face a fast transition to a decentralized system where generators, transmitters and distributors could be disrupted. How is going to look this ecosystem in 5 years from now? What could happen with PV business in Brazil?

According to the literature review, we found out that the main uncertainties are development policies, energy policies and financing access, geopolitics, and compliance to international climate change agreements. Trends are: technological development that allows cheaper PV and batteries systems, increasing electricity prices and climate change awareness. Our analysis also showed that a direct comparison between Brazil and other countries is not so simple, as we can find completely different geographic configuration, geopolitics, population size and income. For this reason, we believe that a field investigation through interviews with key actors in the ecosystem could confirm or replace the literature findings and also generate insights to complement those. We aim at investigating which are the main uncertainties that are perceived by the actors and from those, proceed to a scenario planning and analysis.

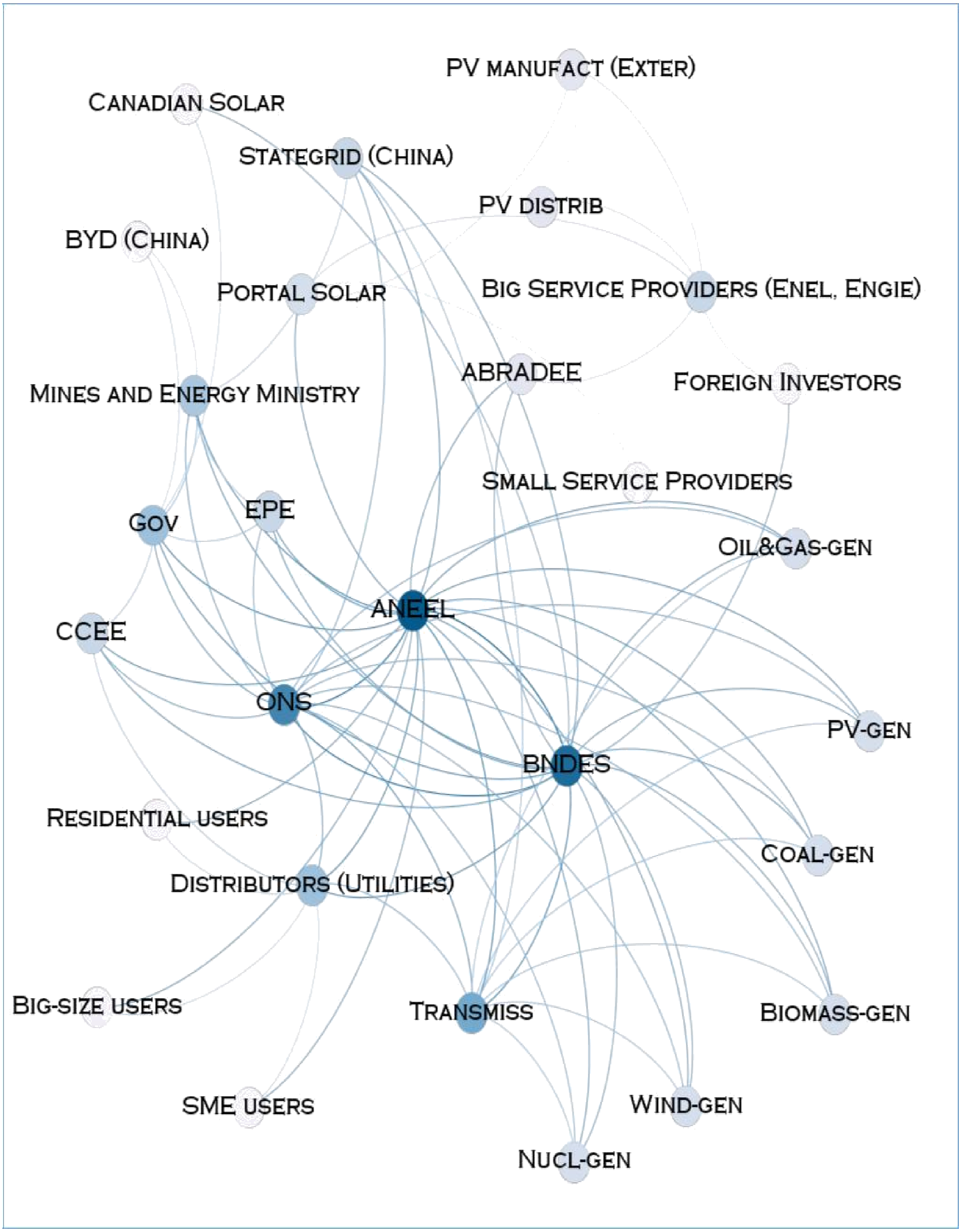

Figure 4.6 Brazilian electricity Ecosystem. A table with all connection is reported in Appendix-B.

4.3 Scenario analysis

The literature review and the field work led to construct the schematics reported in Fig. 4.5. From our analysis and from the perception of the interviewees, the most crucial uncertainties within the time horizon of 5-years resulted to be: development policies and energy policies. The choice was done based on the relevance and potential impact in the period set for our analysis that was reported in detail in the previous section.

According to the scenario planning method, the two most relevant uncertainties are used as the two dimensions (x and y) of a two-axes chart, representing schematically the possible scenarios. In reality, uncertainties are never completely independent, but the discussion in the previous sections has shown as we can consider them as independent with a quite good degree of approximation. In fact, an extreme tendency on one of the two does not imply the change of the other one. Development policies can point towards an open world market or to the protectionism, so that the two extremes would translate in make or buy scenarios. Fig. 4.7 reports our four scenarios according to that choice. Energy policies could, on left side, keep protected the traditional centralized market or to create conditions for alternative business models.

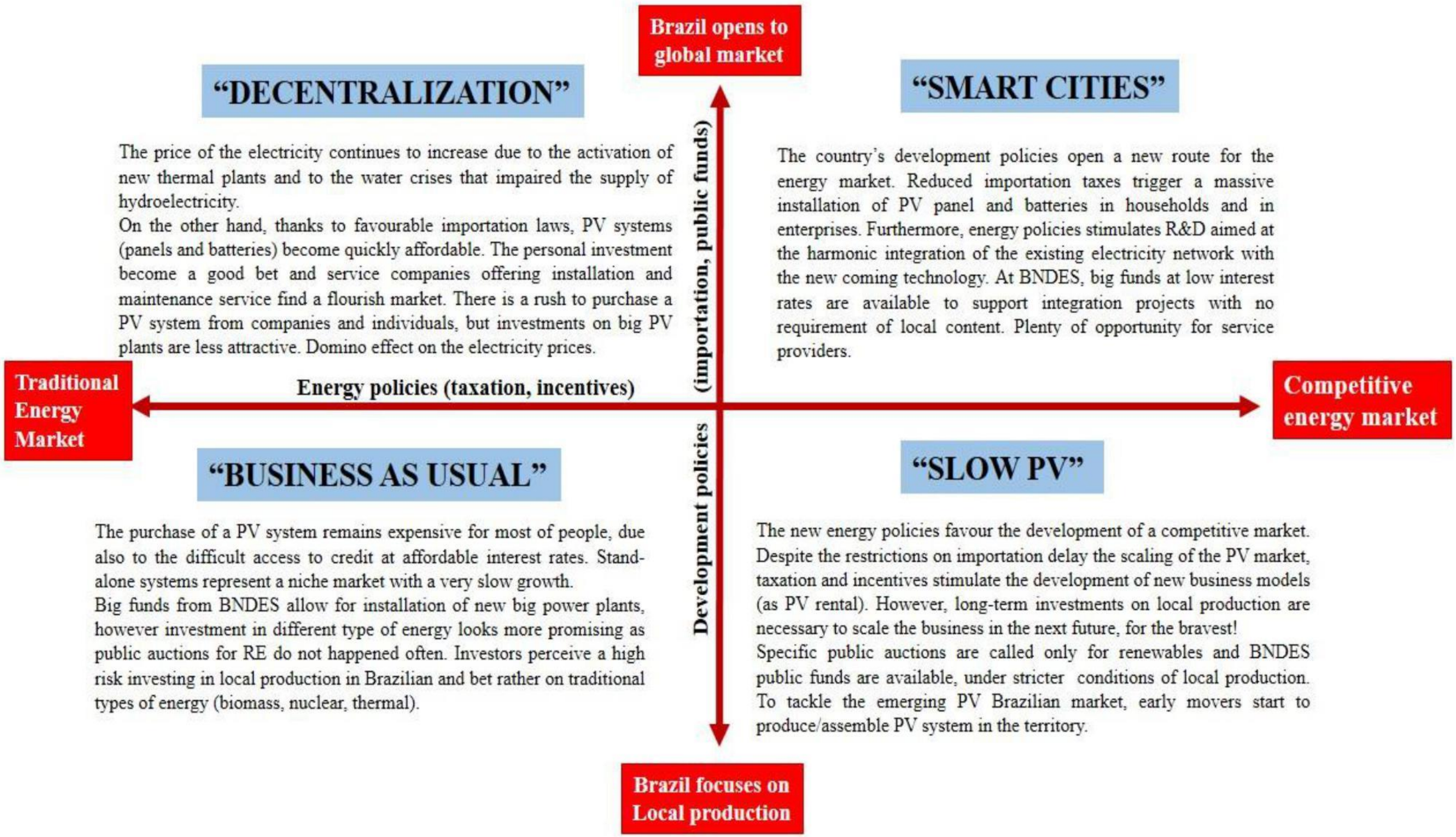

Figure 4.7 Futures scenarios of the Brazilian energy ecosystem based on interviews' analysis.

The four narratives (included in the chart) are also hereafter reported for clarity:

SMART CITIES

The country's development policies open a new route for the energy market. Reduced importation taxes trigger a massive installation of PV panel and batteries in households and in enterprises. Furthermore, energy policies stimulates R&D aimed at the harmonic integration of the existing electricity network with the new coming technology. At BNDES, big funds at low interest rates are available to support integration projects with no requirement of local content. Plenty of opportunity for service providers and big investors.

DECENTRALIZATION

The price of the electricity continues to increase due to the activation of new thermal plants and to the water crises that impaired the supply of hydroelectricity.

On the other hand, thanks to favourable importation laws, PV systems (panels and batteries) become quickly affordable. The personal investment become a good bet and service companies offering installation and maintenance service find a flourish market. There is a rush to purchase a PV system from companies and individuals, but investments on big PV plants are less attractive and the supply network does not find a harmonious development, giving rise to a rapid DG adoption. Domino effect on the electricity prices.

BUSINESS AS USUAL

The purchase of a PV system remains expensive for most of people, due also to the difficult access to credit at affordable interest rates. Stand-alone systems represent a niche market with a very slow growth. Big funds from BNDES allow for installation of new big power plants, however investment in different type of energy looks more promising as public auctions for RE do not happened often. Investors perceive a high risk investing in local production in Brazilian and bet rather on traditional types of energy (biomass, nuclear, thermal).

SLOW PV

The new energy policies favour the development of a competitive market. Despite the restrictions on importation are delaying the scaling of the PV market, taxation and incentives stimulate the development of new business models (as PV rental). However, long-term investments on local production are necessary to scale the business in the next future, for the bravest! Specific public auctions are called only for renewables and BNDES public funds are available, under stricter conditions of local production. To tackle the emerging PV Brazilian market, early movers start to produce/assemble PV system in the territory.

Possible *early warnings* are: the introduction of a special taxation regime for importation, the announcement of tax-detraction policies for private users purchasing a PV system, the introduction of FIT policies. We expect to see some indications in this sense as a public consultation was opened in July 2017 [39] and there is high expectation towards a regulatory reform in the energy sector especially for what concerns distributed generation.

Having a closer look to the secondary data that we found in the ANEEL website and that were discussed in section 2.4 (Fig. 2.7), we believe that there are already signals of an early warning, driven by technology. Reporting in Fig. 4.8 again the number of new installation of distributed power systems (micro and mini), we can see that the number that showed till 2016 an exponential growth, it started to saturate. At first sight, it might look that the diffusion of DG is slowing down. However, reporting instead the total installed power (Fig. 4.8, right panel), we can observe that the exponential pace is maintained. This is a clear early warning, especially considering all the unfavourable regulatory conditions. We could explore further the secondary data, for regions or for power range of the systems, but such analysis would go beyond the scope of the work. It is enough to support our claim that we are leaving the current scenario "business as usual" and we are moving towards one of the others quadrants (see Fig. 4.7).

[39] http://www.mme.gov.br/web/guest/consultas-publicas?p_p_id=consultapublicaexterna_WAR_consultapublicaportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&_consultapublicaexterna_WAR_consultapublicaportlet_consultaId=33&_consultapublicaexterna_WAR_consultapublicaportlet_mvcPath=%2Fhtml%2Fpublico%2FdadosConsultaPublica.jsp

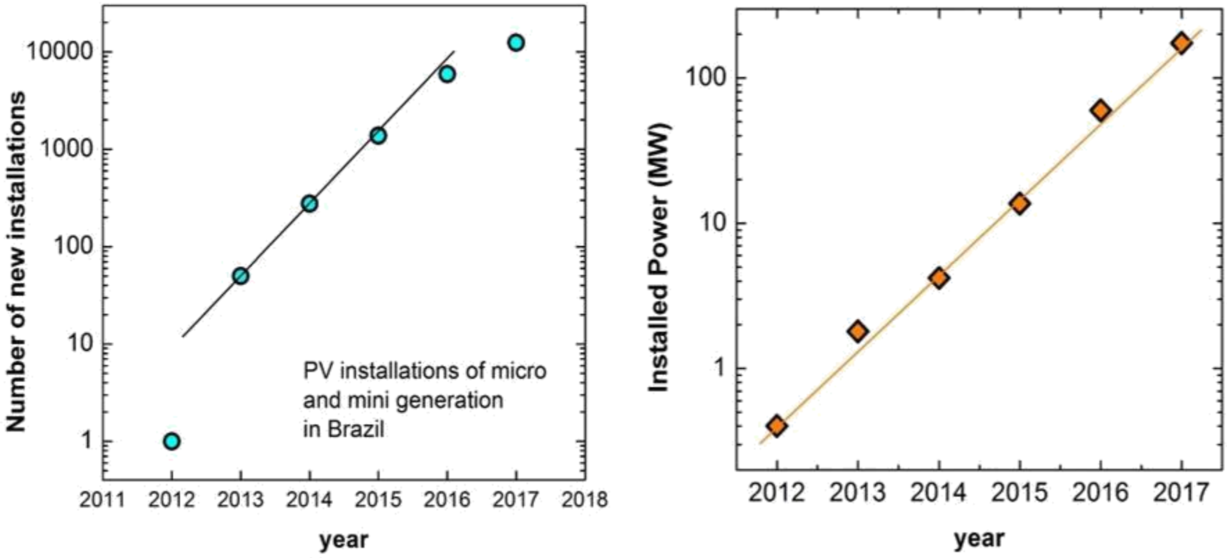

Figure 4.8 Early warning: (left panel) new installations of solar distributed generators; (right panel) Installed power of the new distributed plants.

5. CONCLUSIONS

5.1 Summary of the main findings

The Brazilian electricity system is one of the largest integrated energy networks in the world. It is traditionally and structurally a centralized system: electricity is generated in different points in the territory and then distributed to the users (commercial and residential) through an extended transmission system. The steady economic growth of the country (till 2015) required to plan the expansion of the energy sources to keep up with industrial development. External and internal circumstances brought to change the energy matrix composition along the time leading to a higher participation of fossil sources. On the other hand, renewable energies (as solar, wind and biomass) started to have a relevant component thanks to the lower costs of new technology. Distributed generation (mainly PV) has been regulated in Brazil since 2012, however its diffusion lags still behind international references despite the huge solar irradiation potential that the Brazilian territory enjoys. A recent "public consultation" called for opinions on this matter and it is widely believed and expected that a deep regulatory change is going to give a new route to the sector. In this framework, policy makers, incumbent, newcomer, investors and also consumers (commercial and residential) could have been affected by such regulatory change in a favourable or unfavourable fashion. On the other hand, rapid shifts in markets may occur and this work aimed at depicting possible scenarios so that each actor could "play" imagining how to deal with different configurations and how to prepare to mitigate risks and to tackle market's opportunities.

In order to build and construct such future possible scenarios for such complex market, we design a qualitative methodology in order to answer the research question: How is going to look like the energy ecosystem in 5 years from now? Which will be the fate of the solar business in the Brazilian reality? Which are the key uncertainties that might play a crucial role in shaping this sector?

To answer that question, the objectives listed in the introductory chapters have been first addressed:

- revising recent existing scientific literature regarding the topic not only about Brazil, but also about the international context, performing a field research investigation based on in-depth interviews with the aim to understand the perceptions of the main actors,

- individuating the main drivers of the energy market (trends and uncertainties), starting from the joint analysis of the literature review and the field work's outcomes,
- building the electricity ecosystem based on the literature review and on field results;
- Constructing future scenarios based on the two most relevant uncertainties individuated during the analysis process.

In the literature review, we individuated the aspects that play a relevant role on the electricity sector. Development policies (importation vs local production), energy policies (taxation, regulation, incentives), and technological advancement are the main drivers of the market. Aiming at revealing forces that are less quantifiable with quantitative methods, we designed a qualitative research based on open-ended questions. 15 in-depths interviews were carried out, interviewing key actors in the electricity ecosystem. The outcomes of the analysis of the results helped to build an ecosystem chart and to verify (and to complete) the driving forces, distinguishing them between uncertainties and trends. We individuated the two most critical uncertainties (development policies and energy policies) and we build four scenarios, which can serve managers and policy makers to envision the emergence of possible futures and to prepare to mitigate risks under different circumstances.

The scenario planning is a powerful tool because of its versatility in the application. In fact, after building the scenarios, virtually any possible actor can imagine to be in one of them and to envision strategies for the future. It is clear that to discuss the position of each player in the scenarios and discuss possible strategies would go beyond the scope of this academic work, as it is more a management tool rather than a rigorous research framework. However, to show to the reader the power of this approach we will discuss it for one of the player. One of the biggest risk of disruption that can affect the electricity ecosystem is the abrupt advent of distributed generation. Utility companies (distributors) are the incumbents that are most subjected to this shift as their current business model clashes with the DG, therefore we are going to discuss scenarios for distributors.

In Fig. 4.9, we reported again the four scenarios. The lower left panel (business as usual) represents closely the current situation. Therefore, how a traditional distributor can prepare for the other possible three scenarios? As we discussed previously, there are already signal of shift towards those scenarios, although interviewees perceived utility companies resisting this change rather of envisioning a new opportunity. There is a common perception that they should revise their business model in order to not be disrupted with the emergence of the DG market. Working constructively toward a new business model might help them to land to scenario “smart cities” (or “slow PV”, but in a longer time frame), where there is a lot of room for development of services as installation, metering, maintenance, monitoring, and even more promising all mobility sector, still incipient in Brazil. The distributors’ resistance can only lead to approach “off-grid” scenario that would be much more worrying for them, as beside installation, there is not much space for market development. Distributors, to guarantee their survival and financial health in the long term, should develop strategies to restyle their business model that is inevitably shifting toward a service provider rather than just infrastructure provider and sell/buy energy dynamic.

The same type of approach could be apply to policy makers, with the question: which strategies should we apply to guarantee our relevance in regulating this market and, at the same time, to guarantee an efficient and reliable service to the citizens and infrastructure for industrial development? Same for newcomers, how to enter the market considering restrictions and constrains in the different quadrants of the scenarios. As already said, the scenarios discussion for each player would go beyond the scope of this work.

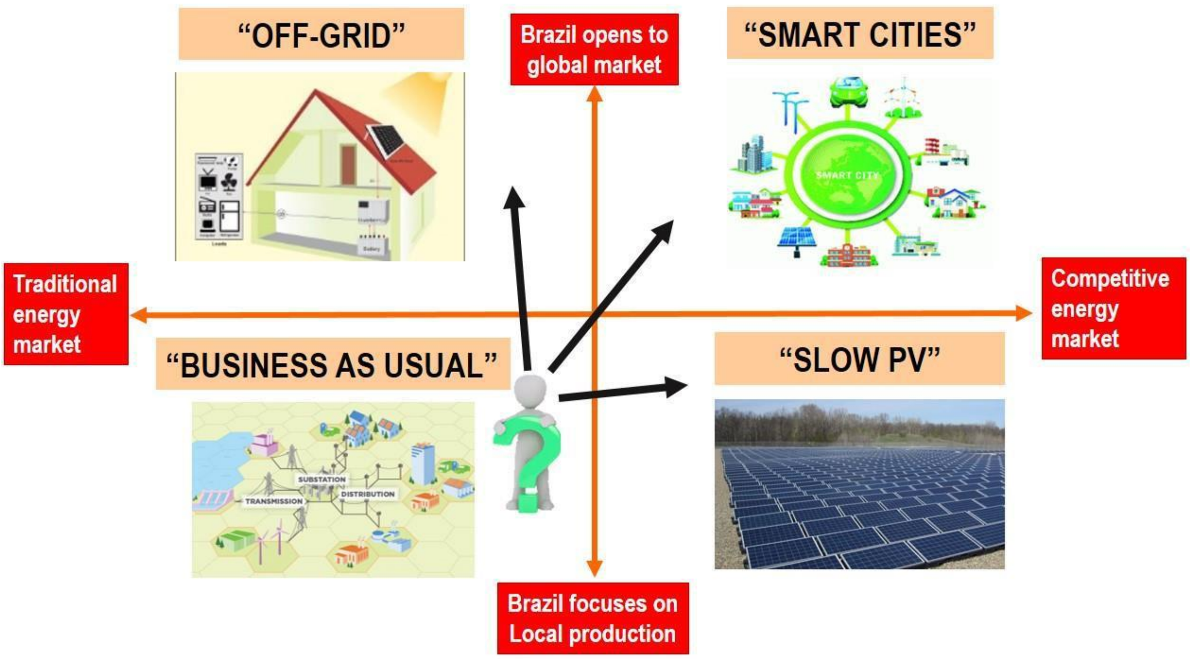

Figure 4.9 Scenario analysis application. How an actor in the energy ecosystem is going to deal with market shifts represented by the 4 scenarios. The „business as usual“ scenario represents quite closely the current situation.

Beside scenarios discussion, one of the most relevant insights emerged from the interviews regards the lack of independence between political governance and energy governance. Although it is clear that energy sector is strategic for a country, many actors complained of sector's lack of authonomy and the impacts of political instability. These circumstances don't allow for a long term planning and also are perceived as a big risk for new prospect investors, thus delaying the natural development of the electric sector respect to international standards.

Interestingly, long-term elements emerged from the interviews: education, cultural aspects and awareness about climate change. They were reported and discussed, though they did not enter in the scenario analysis as they are expected to become relevant in a longer time horizon. The discussion of those elements should be particularly of the interest of policy makers.

5.2 Suggestions for further research

The exploratory essence of this research naturally brings to a set of new research questions that can inspire further investigations.

Fig. 4.5 reports our tentative scheme of forces that play a role in the Brazilian electricity market. All those connection should be tested and explored more in depth, for instance, focusing on a specific part of the ecosystem. A study focused on the group of distributors would be very intriguing as they are in the focal node of the paradigm shift. Among newcomers, Chinese manufacturers and investors are entering the local Brazilian market. Specific case studies could bring relevant insights to further explore the role of geopolitical dynamics in shaping the Brazilian energy market. Among the limitations of the study, we mentioned the lack of contextualization in terms of territorialities. Scenarios were constructed based on interviews with people based in Rio de Janeiro, Sao Paulo and Brasilia. We are aware that conclusions won't catch regionalisms and a new study could be dedicated to explore how the scenarios could be reshaped due to different boundary conditions.

We mentioned already in the introduction that this exploratory study did not include directly energy users (residential and industrial). Indirectly, each interviewee is also an energy user, but the his/her role as consumer was not the focus of the interview. Therefore, there is room to explore the perception of the consumers and to understand how they can trigger market shifts. Although this aspect was out of the scope of this work, it would deserve further investigation.

The long-term uncertainties that emerged from the research go beyond the interest of a management study and rather enter in the field of sociology and economy. However, as this study has already a multidisciplinary flavour, it is fair to close these conclusions with open questions about this point. In addition, qualitative method see an active role of the researcher in the process as the worldview in which the research takes place plays a central role; therefore (the scientific background of the researcher induced the following inquiry).

About the anthropogenic origin of climate change, it emerged a worrying mismatch between what the scientific community is showing as evidence and what people perceive. As the perception about this topic might be impactful in terms of personal decisions (and in terms of consumption patterns and energy use) and also professional (in terms of responsible investments), the misleading conviction could lead to negative consequences. What are the reasons for this communication’s failure? How does this impact the society in terms of consumption patterns and energy use? To address sustainable development is an impelling topic for our society and future generations and we believe that these last questions deserve further attention.

APPENDIX-A

INTERVIEW’S SCRIPT

After a short introduction on the area of the research, we reminded the modality of the interview about recording and about the confidential and aggregate use of the data.

- I would like to hear something about your professional trajectory
- Thinking about your trajectory in the (energy) sector, would you identify any relevant shift?
    - Explore the origin of the changes raised in the previous question
- What is the mission of your company?
- Who are its customers/users and how does your company relate to them?
    - Explore the business model (if relevant)
- Who are the main suppliers? And competitors?
    - Explore other ecosystem’s actors and stakeholder.
- Thinking about the future of the electricity sector, which relevant trends could you foresee in the next 5 years?
    - Explore technology, consumer behaviour, regulation, financing.
    - Explore new source of energy (Wind, solar, ..)
    - Explore the distribution model
    - Explore markets’ newcomers or relevance shift of some actors within the ecosystem
- What could completely change the electricity sector in Brazil in the next years?
- How is your company/organization preparing for the future?
- If you could start a new organization/company from scratch, what would you do?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1.ANEEL		x	x	x	x	x	x	x	x	x	x	x	x	X	x	x				x				x	x	x	x		
2.BNDES			x	x	x	x	x	x	x		x	x	x	X	x	x							x	x					x
3.ONS				x	x	x	x		x	x	x		x	X	x	x								x					
4.EPE					x	x																							
5.Mines and Energy						x																		x				x	
6.Gov										x																		x	x
7.Distributors									x	x															x	x	x		
8.ABRADEE																						x							
9.Transmiss											x	x	x	X	x	x								x					
10.CCEE																													
11. Oil&Gas-gen																													
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13. Wind-gen																													
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18.PV distrib																													
19. Portal Solar																					x	x							
20. Small Service																					x	x							
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22. Foreign Investors																							x						
23. Stategrid (China)																													
24.PV distrib																													
25. Big-size users																													
26.SME users																													
27. Residential users																													
28.BYD (China)																													
29. Canadian Solar																													

Figure A.1 Connections used to construct the ecosystem reported in Fig. 4.6; the numbers on the upper raw refer to the same actors indicated to the column on the left.

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