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Towards a smart grid power system in Brazil: Challenges and opportunities

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ABSTRACT

The prospects for a smart power system have been widely discussed in the global electricity sector. Decarbonization, Digitalization and Decentralization are considered the main key drivers for this power system transition and Brazil is no exception to this universal trend. A search of the literature revealed few studies which attempt to address the main challenges and opportunities towards a smart grid power system in Brazil. This paper provides an up-to-date assessment of the present and potential capabilities of existing and future technologies, regulations and policies and attempts to identify how these elements are interrelated. Our findings add to a growing body of evidence suggesting that policies for Distributed Generation (DG), Demand-Side Management (DSM) and new tariff schemes are on a path of accelerated deployment in the country. The deployment of storage technologies, however, is at a slow pace of growth. We highlight the need to further develop new business models to address the various decentralized energy technologies and services that are emerging in the sector. The current net-metering system is considered a key issue to be addressed as this regulatory structure may shift the costs from DG to non-DG users.

1. Introduction

The growing demand for electricity over the past few decades is unquestionable, especially due to the growth of emerging economies, challenges brought by environmental issues and the constant search for the improvement of the quality of life, provided mainly by new technological processes (PCE, 2015). Energy issues, together with other infrastructure sectors contribute significantly to the economic, technological and socio-environmental development of a country and present strong synergy and interdependence (Santos et al., 2018; Reis and Santos, 2014). The increasing restrictions related to the use of fossil fuel resources and the challenges of exploiting the remaining hydropower potential are primarily because of the need for mitigating the climate changes impacts and reducing the social and environmental impacts related to the construction of new hydropower sources with large reservoirs, respectively. The need for substituting fossil-based energy fuel with more sustainable sources has been progressively growing due to global concerns about climate change and the use of Renewable Energy Sources (RES) have emerged as a high-priority solution for a sustainable, cost-effective and environmentally friendly energy system for the future (Abu-Taha, 2011). The growth of population and the cities expansion brought about a set of new challenges associated with the increasing energy use. The emergence of smart grids, however, may provide a wide range of benefits particularly for the population of developing countries which includes the reduction of power outages (proved to be costly for local economies) and also reducing the levels of CO_2 emissions. In addition to lowering bill costs, improving energy efficiency and increasing the reliability of the power system, the use of smart grids may also promote the optimized utilization of renewable energy and reduce the system losses (Moretti et al., 2017; Hossain et al., 2016). The combination of RES and energy efficiency measures are considered to be the main pillars of the energy transition towards a sustainable energy future (IRENA, 2018). The expected result of this energy transition is the contribution for decarbonization of its energy matrix. However, for the Brazilian electricity sector, the result might not be what is expected. This is mainly because the Brazilian hydropower regularization capacity has been decreasing considerably over the last decade and this has led to increased use of thermal electricity (Dranka and Ferreira, 2018). New Brazilian government policies have been stimulating the insertion of Distributed Generation (DG) from RES, such as the case of the Normative Resolution (in Portuguese, RN) nº 687/2015 (ANEEL, 2015) which is an improved version of RN nº 482 (ANEEL, 2012a), created in 2012, which

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regulates the grid connection of DG in the country. Over the past few years, the Brazilian government also proposed different tariff schemes focusing on household consumers. Traditional measures of energy conservation and efficiency have been also applied in the country, such as the National Electrical Energy Conservation Program (in Portuguese, PROCEL).

In addition to the large-scale hydropower system, several other paradigms shift have been verified over the past years in the Brazilian electricity sector which pose important challenges for the energy decision making process towards a sustainable and resilient power system. This includes new government policies on renewable energy incentives (ANEEL, 2015; ANEEL, 2012a); an increasingly volatile consumption profile (Eid et al., 2016; Kopiske et al., 2016); the possibility for the prepayment of electricity (ANEEL, 2014); changes in electricity tariff composition (ANEEL, 2014; ANEEL, 2016); the increasing environmental restrictions (Strantzali and Aravossis, 2016); the falling cost and the increasing insertion of DG (ANEEL, 2012a; ANEEL, 2017); the high level of uncertainty brought by intermittent sources (Kopiske et al., 2016; EPE, 2017); the prospect of conscious consumption (Tsarenko et al., 2013); the prospect for Demand-Side Management (DSM) strategies and storage technologies (EPE, 2017; Paterakis et al., 2017; Blanco and Faaij, 2018); the new commercial and regulatory trends (ANEEL, 2012a; ANEEL, 2017; Dantas et al., 2017); the developing and disseminating of smart grids and inserting electric vehicles (Dantas et al., 2017; Carvalho, 2015); among others.

The adoption of these new technologies, e.g., DG, DSM, electric vehicles and smart grids are likely to happen not only due to direct financial gains for consumers but also considering the consumers' preference (e.g. behavior and socio-cultural factors (EPE, 2018)), which goes beyond the classical economic rationality mindset (EPE, 2017; MIT Energy Initiative, 2016). The current public policies for a smart power system in Brazil is addressed and evaluated in (Dantas et al., 2018). This last study also suggested the most promising public policies for the country based on the successful experiences of several developing countries.

Therefore, the future trend is the establishment of several new complex features for the Brazilian electricity sector which requires an in-depth discussion in order to provide a high level of energy security and reliability (Santos et al., 2018; Dantas et al., 2017). Although recognizing several technical and economic problems related to the high penetration of RES, it is also important to identify the great opportunities that are emerging for the electricity sector. As a result of this complex set of changes expected for the future, in this paper, we address a lively discussion related to the main issues involving the opportunities, challenges, trends and latest developments of the Brazilian power sector towards a smarter grid structure. A search of the literature revealed few studies (such as in (Dantas et al., 2017; Dantas et al., 2018; Di Santo et al., 2015)) which attempted to address the main prospects, challenges and opportunities towards a smart grid power system in Brazil. Our purpose is to provide an overview of how these features are interrelated and how it might affect the future of the power sector. This paper addresses the challenges and opportunities of a smart power system for the specific case of Brazil through a qualitative assessment approach. The literature review includes not only scientific papers but also reports, legal texts and other publications from government institutions and organizations of the sector. The strengths and innovative aspects of this study include an in-depth analysis of the new regulatory structure and its interdependence, which represents a fertile field for research in which technological development may go hand in hand with energy policy making. Moreover, given the still relative immaturity of smart grid technologies and related concepts, the benefits of this analysis largely extend beyond the case addressed as the identified challenges, opportunities and policy implications can provide valuable lessons for other electricity systems.

The remainder of the paper is organized as follows. Section 2 presents an overview of the main drivers of power system evolution worldwide. Section 3 addresses the main characteristics of the Brazilian electricity system and the future projections regarding the overall installed system capacity. Then, in Section 4, the new trends for the Brazilian power sector are presented. Section 5 presents a comprehensive concept map of the new technologies and its associated regulations for the Brazilian electricity sector. Section 6 draws the main conclusions of the paper, identifies relevant policy implications and outlines the possible avenues for further research.

2. Main drivers of power system evolution worldwide

Recently, literature has considered Decarbonization, Digitalization and Decentralization the three main drivers of power systems evolution worldwide (Luisa et al., 2018). Fig. 1 illustrates these main drivers and its associated elements based on (IRENA, 2018; Blanco and Faaij, 2018; Luisa et al., 2018; MCTIC, 2018; Zhang et al., 2017; Löbbe and Hackbarth, 2017; Cigre, 2016). The concepts illustrated in Fig. 1 may be interrelated to each other. For example, the renewable energy integration of DG is strongly associated with the concept of Decentralization but is also related to Digitalization (e.g. the deployment of smart meters) and low-carbon systems (i.e. Decarbonization).

Smart grids are fundamental for this energy transition and it can be used to support different policy goals. As reported by (Zhang et al., 2017), "*Smart grids are among the most significant evolutionary developments in energy management systems because they enable integrated systems, including decentralized energy systems, the use of large-scale renewable energy and major improvements in demand-side-management*". Therefore, smart grid deployment is at the heart of the power system evolution as it is inherently related to new technologies and intelligent energy management through the entire value chain from the generation to the consumers. The main impacts of a digitalized industry 4.0 on renewable energy systems is addressed in Scharl and Praktiknjo (2019) for a case study in Germany. Recently, the concept of Energy 4.0 has appeared in literature which is strongly related to the Industry 4.0 concept. Energy 4.0 refers to the digitalization of the energy sector which includes the use of advanced energy management systems and control algorithms. The transition to Energy 4.0 is considered a challenge for energy companies and the government worldwide.

In order to achieve a full-scale decarbonized energy system, the use

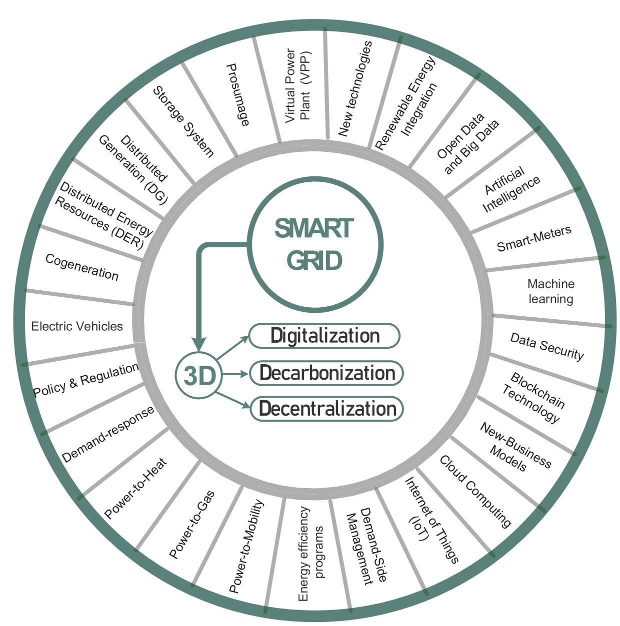


Fig. 1. Main drivers of power systems evolution worldwide (IRENA, 2018; Blanco and Faaij, 2018; Luisa et al., 2018; MCTIC, 2018; Zhang et al., 2017; Löbbe and Hackbarth, 2017; Cigre, 2016).

of RES together with Energy Efficiency Measures (EEMs) have been widely proposed in the literature (IRENA, 2018). Additionally, the entire world has been experiencing new opportunities through the 4th industrial revolution thanks to digitalization (Luisa et al., 2018). This latter concept would strongly impact the utilities through the new market models that are emerging for the sector such as the blockchain-based energy market models (Löbbe and Hackbarth, 2017). The blockchain technology in the energy field has recently emerged as a new market and business model such as discussed in (Merz, 2016). Last but not least, decentralization of energy systems appears as a growing need primarily given the increasing growth of demand. The concept of decentralization (Luisa et al., 2018) is strongly "*linked to decarbonization and digitalization since the most of the generation units are RES-based plants that must be coordinated in order to achieve security and efficiency*". The importance of both concepts, i.e., decentralization and decarbonization of the power sector are also highlighted in (McLellan et al., 2015).

For the next two decades (2020–2040) two possible potential trajectories for network development would appear namely larger networks (bulk) and smaller networks (micro) (Cigre, 2016). The need for both interconnecting large centralized renewable energy sources and connecting different countries and energy markets are related to the bulk power system development model whereas the distributed generation together with storage (i.e. *prosumage*) and the active customer participation are considered the main characteristics of the micropower system model. A mix of large and small networks is considered by literature (Luisa et al., 2018; Cigre, 2016) a more promising future regarding the development of the power system models. Luisa et al. (2018) highlights that different approaches for development models have been proposed by different regions such as the USA, EU and China, concerning the future configuration of its power systems.

Fig. 2 presents respectively the classical (centralized and unidirectional power system structure) and the future model (distributed and bidirectional power system structure) of the electricity system (Critchlow, 2015). For the future model, there is a major paradigm change towards customer-centricity. This concept focused on consumer protagonism has been changed recently from "*prosumer*" (**pro**ducer + con**sumer**) to "*prosumage*" (**pro**ducer + con**sum**er + stor**age**), representing a consumer with both energy generating capacity and energy storage capacity (Fikru et al., 2018; Green and Staffell, 2017; Von Hirschhausen, 2017). This type of consumer has some economic choices among self-supply, utility supply or partial utility and self-supply. According to (Luisa et al., 2018) "*the end users will play a crucial role as prosumers and as a provider of regulation services also through new business models empowered by digitalization*".

The main drivers of power system evolution worldwide presented along with this section aimed to illustrate a brief overview of these relevant issues. The following sections attempt specifically to address the new directions for the case of Brazil. The new trends proposed by the government will be presented and discussed in order to develop a clear argument based on the carried out literature review.

3. Brazilian power sector

The aim of this section is two-fold. First, a brief overview of the main characteristics of the Brazilian electricity system is presented. Second, the future projections regarding the overall installed system capacity are outlined together with some barriers and challenges associated with the future system expansion. Since the creation of the Energy Research Office (in Portuguese, EPE) in 2004, the Brazilian power sector has faced a new phase. The coexistence between state-controlled and private companies and competition in generation and commercialization sectors can be considered the main characteristics of this new model structure for the power sector.

Brazil is considered one of the leading countries in installed renewable energy capacity in the world. The overall installed capacity in Brazil reached 162.8 GW in 2018 (EPE, 2019), of which 83.3% are from RES. According to the Brazilian Energy Balance (in Portuguese, BEN), in 2018, electricity generation was primarily composed by RES including 66.6% of hydropower; 8.5% biomass; 7.6% wind and 0.5% from solar power (EPE, 2019). Fig. 3 presents the overall Brazilian installed power capacity in 2017 (ANEEL, 2018) and the predictions for 2026 (EPE, 2017), 2040 (IEA, 2016) and 2050 (PCE, 2015) according to studies of different energy research institutions. According to (EPE, 2019), the Brazilian electricity consumption in 2050 is expected to increase by approximately 300% compared to 2013, which justifies the growing trend of the sector.

Hydropower largely covers the overall renewable electricity production in the Brazilian power system. Although the hydropower is forecasted to remain the main power source in the future, the overall hydropower capacity (in terms of percentage), however, is projected to be lower for 2026, 2040 and 2050 comparatively to the current installed capacity (see Fig. 3). This decrease in the hydropower share is primarily due to environmental restrictions for constructing new hydropower plants with large reservoirs in the future. The high dependence on rainfall and climate conditions can also severely affect the future hydropower expansion and their role in electricity production (Santos et al., 2018). The high hydropower regularization capacity in Brazil is able to provide balancing services to allow higher integration of RES such as wind and solar power systems. Fig. 4 illustrates the historical values for the Brazilian maximum storage capacity in GW (left axis) and

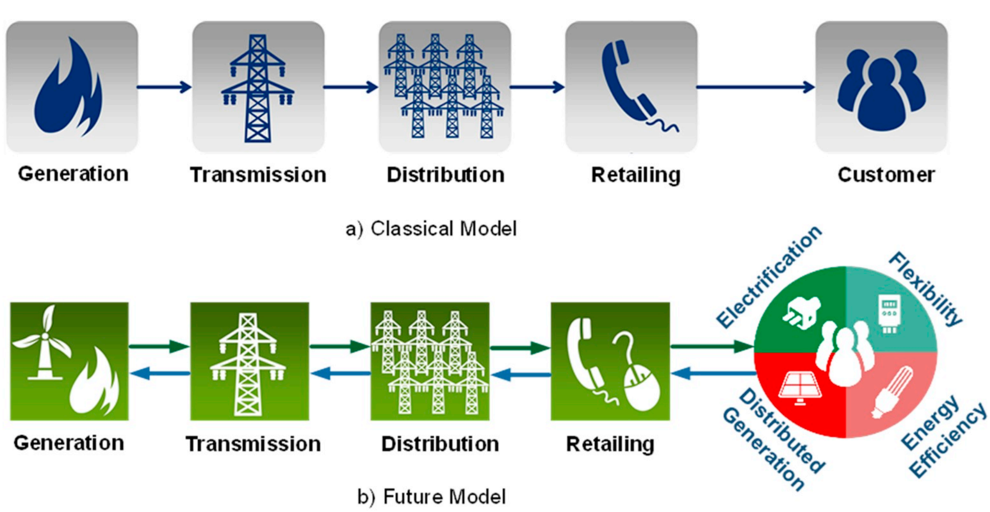


Fig. 2. Classical and future model of the electricity system (adapted from (Critchlow, 2015)).

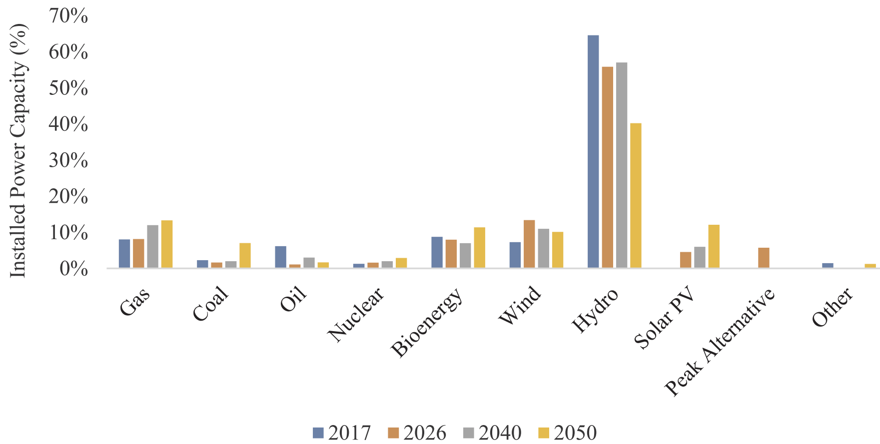


Fig. 3. Brazilian installed power capacity (%) by source for 2017 and projections for 2026, 2040 and 2050 (PCE, 2015; EPE, 2017; ANEEL, 2018; IEA, 2016).

the regularization capacity in months (right axis) between 2001 and 2017. Although the maximum hydropower storage capacity (in Portuguese, EAR) increased (in absolute terms) in the last years, the Brazilian hydropower regularization capacity has been decreasing considerably over the last decade as illustrated in Fig. 4 (ONS, 2019).

In 2001, for example, the regularization capacity was slightly higher than 6.2 months. This means that considering the full availability of the reservoirs, the stored capacity would be able to supply the load for this period of time (6.2 months) without the need for other power sources. The regularization capacity decreased by about 30% between 2001 and 2017 (from 6.2 months in 2001 to 4.4 months in 2017) (ONS, 2019), which is mainly explained by the demand increase but also because of the growth in the overall installed capacity of run-of-river power plants. This trend is set to continue since the current and the future hydro projects will be dominated by run-of-river hydropower plants with limited reservoir capacity (Firjan, 2013; Falcetta, 2015). Thus, the challenge for the future is to provide a high level of flexibility from other power sources and from energy storage technologies that might be capable of linking geographic and temporal (daily, weekly and seasonal basis) gaps between energy supply and demand (Child and Breyer, 2016).

The high share of several complementary non-hydro RES is expected also to diminish the dependency on hydropower and leading to a least-cost solution (Barbosa et al., 2016). Hydropower is also considered a well dispatchable power source. Therefore, the Brazilian power system is not yet experiencing large frequency problems. However, as the wind and solar generation technologies grow up together with the decreasing storage capacity (see Fig. 4) there would be some major problems related to the system frequency regulation. According to the decennial plan 2026 (in Portuguese, PDE) (EPE, 2017), the wind power capacity is projected to increase from 7.3% (2017) to 13.4% (2026) and solar photovoltaic (PV) is forecasted to have a significant increase from 236 MW (2017) to 9660 MW (2026). Assessing individual results for the PDE 2026 it is worth mentioning the contribution of "peak alternative" sources (5,74%), composed mainly by open-cycle thermal power plants, pumped hydroelectric, battery storage systems and the contribution of DSM measures. To meet the load during peak usage hours, the expansion proposed by PDE 2026 is primarily in the Southwest region and on a small scale in the South region of the country.

Supplementary planning studies related to the transmission interconnection system between Brazilian subsystems are required to improve the power system security and reliability. The possibility of future deployment of Time of Use (TOU) tariffs for electricity to reduce the peak demand can also lead to reductions in the current expansion requirements, especially between 2022 and 2026 (EPE, 2017).

For the future, the volatility of the demand together with uncertainties in fluctuating generation from RES will tend to increase in most countries, and Brazil is no exception. Consequently, thermal power plants are expected to develop a key role not only for baseload generation but also for flexible generation and system provision in the country (Kopiske et al., 2016). In the case of Brazil, their role will be particularly relevant mainly between September and December, due to the lower hydropower storage level (EPE, 2017). Thermal power plants already provide some system services, such as inertial response to maintain system stability in times of sudden generation loss or network fault. Additionally, the technological developments of thermal power plants will be needed to include new flexibility requirements, e.g., reduced startups and shutdowns, increased ramping rates, reduced minimum generation, and capacity to adapt to frequent load changes (Deetjen et al., 2017). The Brazilian power sector is discussed with more details in (Dranka and Ferreira, 2018) in which renewable scenarios are compared for technical, cost, emissions and risk parameters. This last study outlines the importance of seasonal complementarity of hydro and wind power for the future and also point out the determinant role of solar power, expected to moderate considerably the thermal generation in 2050 in the country.

Therefore, for the next years, it is expected a paradigm shift in the Brazilian power operation and planning that might be well discussed in order to provide a high level of energy security and reliability. In this context, the next section will discuss with some details the last developments and the new trends for the Brazilian power sector.

4. New trends for the Brazilian power sector

The aim of this section is to provide a broad picture of the last developments in the Brazilian electricity sector including the main technical and regulatory advances. A qualitative methodological approach (Saunders et al., 2016) is considered to explore the current and future challenges and also the opportunities of the power sector by using an archival and documentary research strategy. A three-step research process is followed in order to identify the new trends, challenges and opportunities for the future of the Brazilian power sector. The methodology approach is illustrated in Fig. 5 which includes an (1) in-depth systematic literature review analysis[1] in order to identify the research gap followed by the screening phase; composed by the (2) selection and eligibility and (3) the evaluation of the included papers.

Based on our systematic literature review, Fig. 6 is proposed which

[1] The systematic literature review includes a comprehensive analysis of the main papers in the field but also consider the last published legal texts (i.e. laws, decrees and regulations) for the Brazilian power sector.

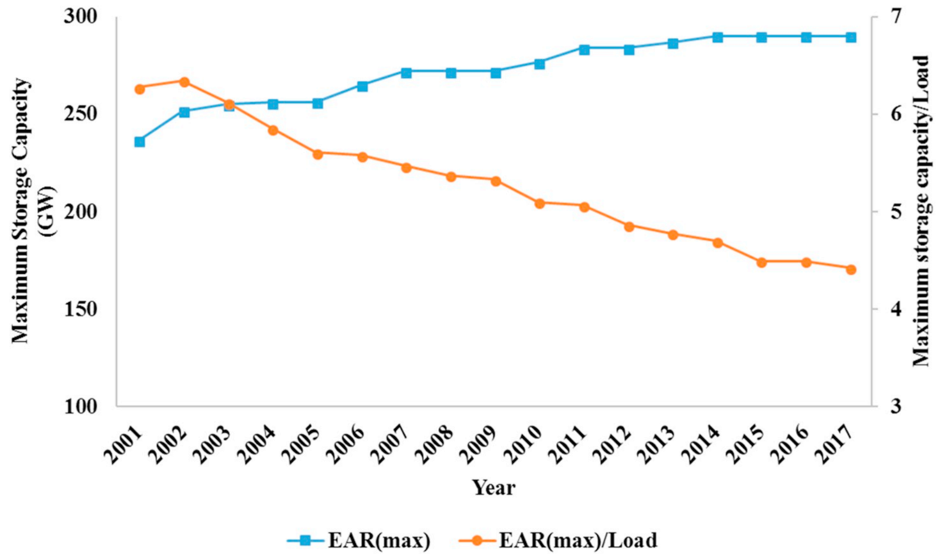


Fig. 4. Brazilian maximum storage capacity in GW (left axis) and the regularization capacity in months (right axis) between 2001 and 2017 (ONS, 2019).

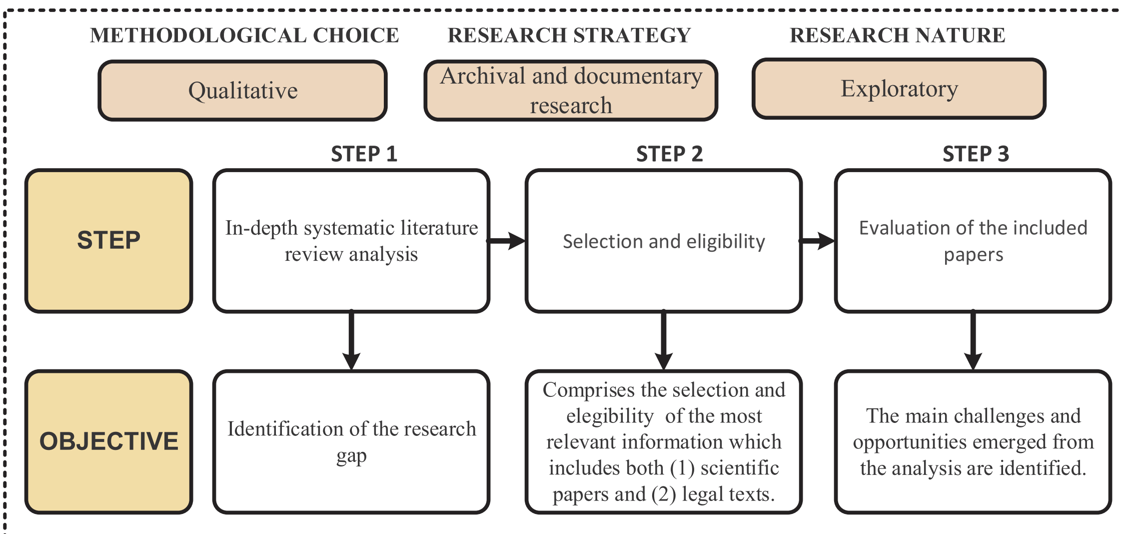


Fig. 5. General methodological approach of the research.

illustrates the chronological flowchart of the prospective evolution of the main Brazilian technologies and regulations towards smarter grids.

The Geographic Information System (GIS) was proposed in 2008 to store and manage electrical, topology and structural parameters of the utilities. In addition to managing outages and then improving consumer's satisfaction, this system also reduces information asymmetry. Further, in 2009, the Power Line Communication (PLC) technology started being implemented to support the future deployment of the smart grids in Brazil. According to (Zafar et al., 2017) "*Power Line Communication (PLC) is a communication technology in which bi-directional communication can be done using existing power lines*".

The consumer was also targeted within this power system evolution. The small-scale DG was firstly introduced in the Brazilian power system through the RN nº 482/2012 (ANEEL, 2012a). Brazil's new smart metering regulation was set in 2012 by the RN nº 502/2012 aiming to support the deployment of smart grids. In order to foster the potential of Demand Response (DR) and minimize the differences between costs and revenues of the utilities (Lima et al., 2017), the Tariff Flag System (TFS) was implemented through RN nº 547 in 2013 (ANEEL, 2013). Driven by the possibility of reducing electricity distribution losses and operational costs, improving utilities collecting revenues and reducing fraud, ANEEL approved the RN nº 610 in 2014 (ANEEL, 2014) regulating the electricity prepayment for a specific group of consumers. In 2015, ANEEL approved RN nº 687 (ANEEL, 2015) which is an improved version of the RN nº 482/2012 which has as its main goal to reduce some barriers for the development of DG in the country. The White Hourly Tariff (WHT) was further proposed by ANEEL in RN nº 733/2016 (ANEEL, 2016) and it is currently being implemented in the Brazilian electricity sector for household electricity consumers.

By 2000, in order to support Research and Development (R&D) and energy efficiency (EE) programs, through the Law 9,991/2000 (Law 9991/2000, 2000), the Brazilian government regulated the minimum level of investments that should be financed by the utilities for R&D and EE (Zorzo et al., 2017). The "*Energy Efficiency Law*" was settled in the Brazilian power sector in 2001 through Law 10,295/2001 (Law 10, 295/2001, 2001) which established, based on technical parameters, the minimum levels of energy efficiency for appliances and machines (Goldemberg and Lucon, 2007). Further, in 2016, Law 9,991/2000 was amended by Law 13,280/2016 (Law 13,280/2016, 2016) which established that 20% of the fund for energy efficiency must be designated to

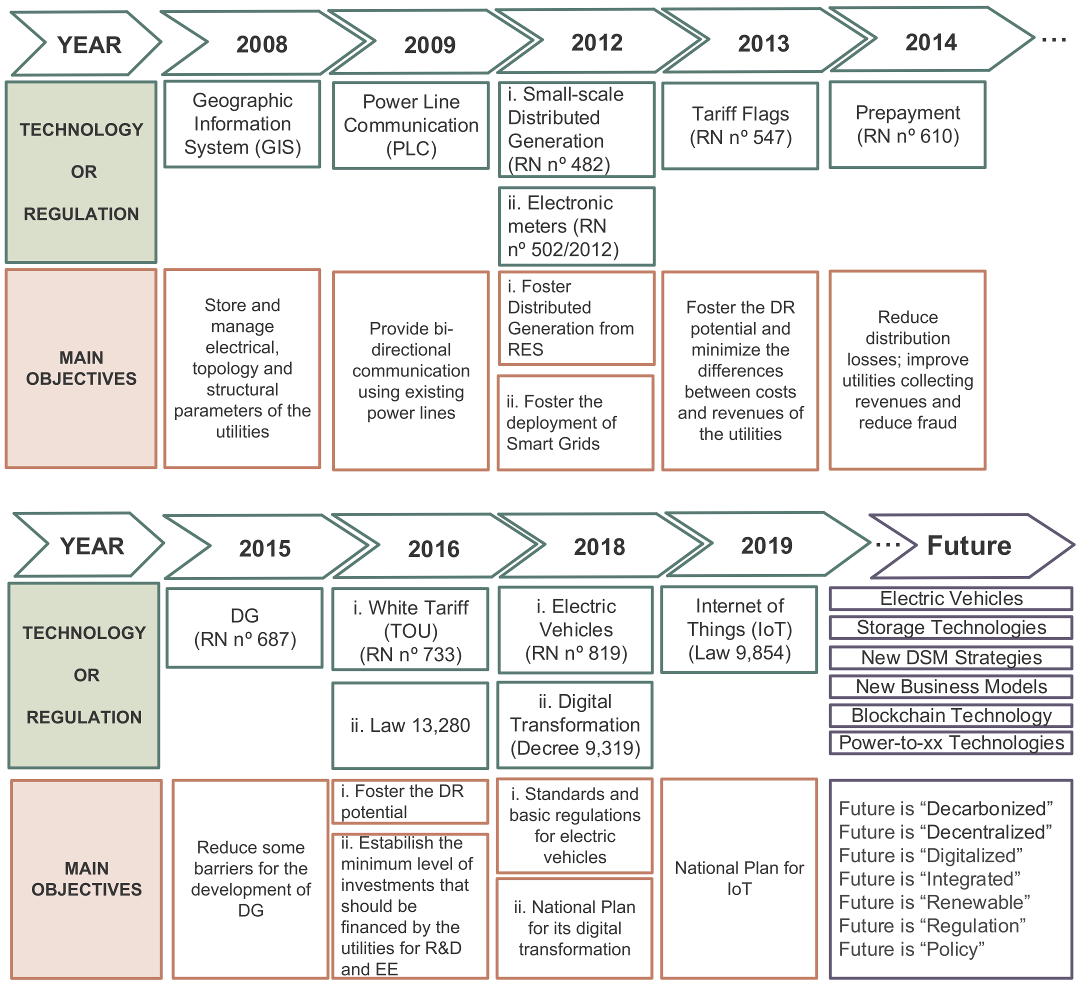


Fig. 6. Chronological flowchart of the prospective evolution of the main Brazilian regulations towards a smart grid power system.

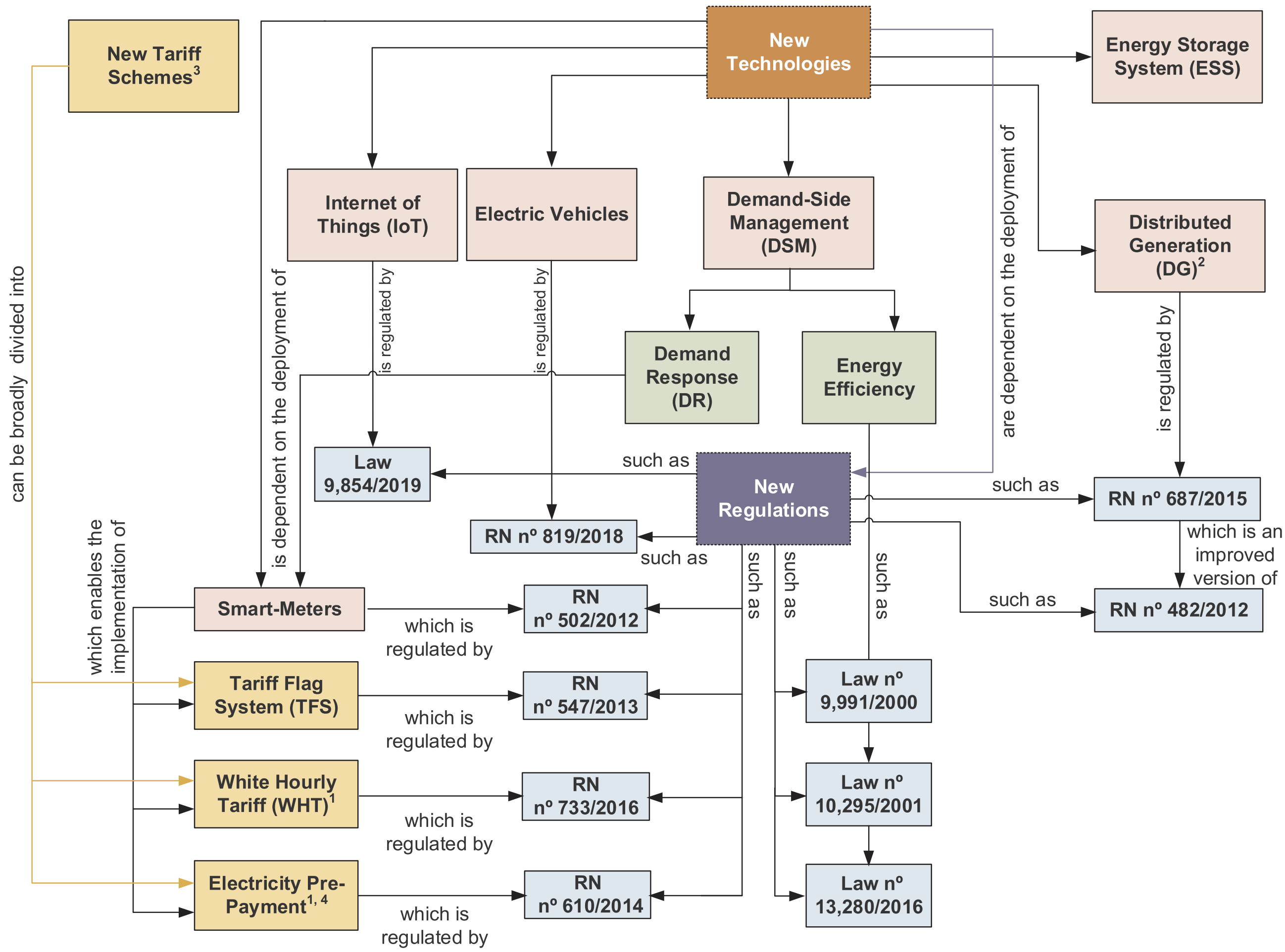
PROCEL. The legal requirements (RN nº 819/2018 (ANEEL, 2018a)) regarding the charging for electric vehicles in the Brazilian power sector was recently (June 2018) approved by ANEEL and it is considered the first published normative resolution about EVs in the country. Also, in 2018, the National Plan for Digital Transformation of Brazil was proposed through the Decree 9,319/2018.

The growth in influence of the IoT (Internet of Things) worldwide stimulated the Brazilian government to implement its first regulation on this important topic through the Law 9,854/2019 (Law 9,854/2019, 2019) which set the national plan for IoT in the country. This regulation is focused firstly on the industry, city, health and rural sectors. It is important to highlight that these IoT actions should be developed in agreement with the guidelines presented by the Decree 9,319/2018 (Law 9,319/2018, 2018) which presents the Brazilian strategies for its digital transformation and highlight the energy sector as one of the main pillars of the IoT regulation (MCTIC, 2018). Further information about this plan can be found in MCTIC (2018).

In order to obtain tangible policy implications for the Brazilian electricity sector, we have developed a comprehensive concept map, illustrated in Fig. 7, regarding the new technologies and its associated regulations. The concept map presented in Fig. 7 briefly describes how the new technologies are connected with the new regulations/laws. To give a well-known example for the sake of clarity, distributed generation is regulated by RN nº 687/2015 which is an improved version of RN nº 482/2012. New tariff schemes are particularly illustrated by a new category by using a different color and they are broadly divided into the TFS, WHT and electricity prepayment which are regulated respectively by RN nº 547/2013, RN nº 733/2016 and RN nº 610/2014. Next subsections (4.1–4.8) will describe with some details these last developments in the Brazilian electricity system regarding the new normative resolutions and its expected impacts on the power sector.

4.1. *Tariff Flag System (TFS)*

The Tariff Flag System (TFS) proposed by the Brazilian government aims to be threefold. First, it attempts to foster the potential of DR by increasing electricity tariff (Lima et al., 2017). Second, it aims to optimize the electricity system and energy resources usage (Charfuelan Villareal et al., 2016). The TFS would also minimize the differences between costs and revenues of the utilities in the Brazilian power sector (Lima et al., 2017). This system was proposed by the Brazilian Electricity Regulatory Agency (ANEEL) in 2013, and it is regulated by the RN nº 547 (ANEEL, 2013), although the starting point of its implementation is dated to 2015. The main objective of the TFS is to reflect monthly the real cost of electricity in order to promote consumer awareness (Di Santo et al., 2015; Corrêa Da Silva et al., 2016). Therefore, the TFS might be considered a short-term signal which reflects the current power generation costs, which is strongly related to the thermal power plant dispatch (Lima et al., 2017; Fossati et al., 2016). Before the existence of the TFS, the cost of electricity purchased by the utilities was computed annually and consequently, the tariff adjustment took effect once a year. For the TFS scheme, the generation costs of electricity are monthly flagged to consumers, giving them the opportunity to adapt their electricity consumption. Basically, the monthly flag is defined considering the overall required thermal power dispatch, according to the hydropower storage availability (de Jong et al., 2017). The monthly signals are triggered



[1]These tariff schemes are dependent on the deployment and availability of smart meters.

[2]DG in Brazil was implemented using the net-metering system.

[3]The new tariff schemes created by ANEEL aims to foster DR.

[4]Consumers who adopted the WHT or those who have a micro or mini DG system connected to the grid are not allowed to adopt the prepayment system.

Fig. 7. Concept map of the main Brazilian regulations toward smarter grids.

TARIFF FLAG	CONDITIONS	INCREASE IN THE TARIFF
GREEN	"LOW COST" TO PRODUCE ELECTRICITY	NO INCREASE
YELLOW	"MEDIUM COST" TO PRODUCE ELECTRICITY	INCREASE OF R$ 1.50 FOR EACH 100 kWh CONSUMED
RED BASELINE 1	"HIGH COST" TO PRODUCE ELECTRICITY	INCREASE OF R$ 4.00 FOR EACH kWh CONSUMED
RED BASELINE 2	"HIGH COST" TO PRODUCE ELECTRICITY	INCREASE OF R$ 6.00 FOR EACH 100 kWh CONSUMED

Fig. 8. Characteristics of tariff flags scheme for the Brazilian electricity sector ((ANEEL, 2013; ANEEL, 2019a), values established in 2019).

based on the Difference Settlement Price (in Portuguese, PLD) which corresponds to the spot price in the Brazilian electricity market (Lima et al., 2017). Thus, the TFS might be considered as warning signals to consumers (Zurn et al., 2017).

The flags are divided into Green, Yellow and Red types. Since its implementation in 2015, the costs for the yellow and red flags have been changing over the years. Recently (May/2019), ANEEL improved its calculation methodology of the monthly flags by also including the Generation Scaling Factor (GSF). The green flag represents no additional costs in the final electricity tariff whereas the yellow flag represents an increase of 0.015 R$/kWh. The red flag is divided into two baselines, representing an increase of 0.040 R$/kWh (baseline 1) and 0.060 R$/kWh (baseline 2) as summarized in Fig. 8.

Moraes (2018) evaluated the economic impact of the TFS for both the Brazilian utilities and the consumers. The work addressed in (Lima et al., 2017) performed a comprehensive analytical review of the TFS program. The authors analyzed qualitatively and quantitatively the expected results of this mechanism for both utility companies and consumers from different perspectives. The new risk-averse methodology was employed by the authors using real information on the Brazilian electricity system. The simulation results allowed to conclude that the TFS would promote a reduction of thermal dispatch, an increase in the overall storage level and the reduction of the overall operating system cost (Lima et al., 2017). From the point of view of utilities, a loss of revenue is expected due to the reduction in the overall electricity consumption.

4.2. White Hourly Tariff (WHT)

Some pricing mechanisms have been proposed by ANEEL, expecting that different rates at different times can effectively drive desired end-user consumption behavior (Stuart, 2013). For open-loop price-based control strategies, it is expected that higher electricity prices lead to lower consumption at peak demand times. For large consumers (supply voltage equal to or greater than 2.3 kV), TOU rates have already been implemented (called blue and green tariffs) promoting a positive impact on shifting peak load. Critical Peak Pricing (CPP) and Real-Time Pricing (RTP) has not yet been implemented in the Brazilian electricity market.

The White Hourly Tariff (WHT) was created by ANEEL through RN nº 733/2016 (ANEEL, 2016) and it is under implementation in the Brazilian electricity sector for household electricity consumers based on the calendar defined in (ANEEL, 2019b). This new tariff scheme might be considered the first hourly tariff ever implemented for this type of consumer in the country (ANEEL, 2016). The WHT is optional for household electricity consumers and results on different electricity prices throughout the day as shown in Fig. 9 (Di Santo et al., 2015; ANEEL, 2019b).

The WHT is divided into on-peak period (3 h per day on weekdays), intermediate period (an hour before and after the one-peak period) and off-peak period (composed by the remaining hours of the day plus the weekdays and holidays). The WHT results then on three price levels as shown in Fig. 9 (ANEEL, 2016; Di Santo et al., 2015; ANEEL, 2019b) comparatively to the conventional flat tariff.

The main reason for implementing this new rate regime (i.e. WHT) is to encourage household electricity consumers to reduce their consumption, especially during peak demand periods (between 06 p.m. and 10 p.m.) and thus optimize the generation and transmission investment decision-making process (ANEEL, 2016; Di Santo et al., 2015; de Jong et al., 2017). The possible benefits of the WHT should be well presented to consumers, giving them the possibility to choose or not to choose this new rate regime considering their load profile and consequently getting economic advantages from its choice.

4.3. Electricity prepayment

The prepayment system has been implemented in develop and developing countries, primarily motivated by the possibility of reducing electricity distribution losses and operational costs, improving companies collecting revenues and reducing fraud (Telles Esteves et al., 2016). From the consumers' perspective, experiences show that they feel empowered to manage and control billing cost and consumption using the electricity prepayment system.

In addition to the TFS and the WHT schemes, ANEEL approved the RN nº 610/2014 (ANEEL, 2014) regulating the possibility of electricity prepayment for a specific group of consumers (mostly focused on household electricity consumers) in Brazil (ANEEL, 2014; ANEEL, 2017a). The electricity prepayment system is supposed to offer advantages for both consumers and distribution companies. From the consumers' point of view, the electricity prepayment allows them to better control their budget, promotes a better quality of life and social inclusion and it might also reduce the risk of disconnection. The avoidance of debts and fees is considered an additional benefit for consumers. Higher consumer satisfaction, reduction of operational costs and billing reclaims, the anticipation of revenues and decrease of non-technical losses are considered the main advantages of the electricity prepayment system from the utilities' point of view.

In Brazil, the utilities are supposed to provide all the prepayment meter acquisition costs (ANEEL, 2014). The shift from the post-payment to the prepayment system is voluntary and free of charge for consumers (ANEEL, 2017a). Additionally, consumers can freely migrate between systems, i.e., prepayment and post-payment system (ANEEL, 2014). The

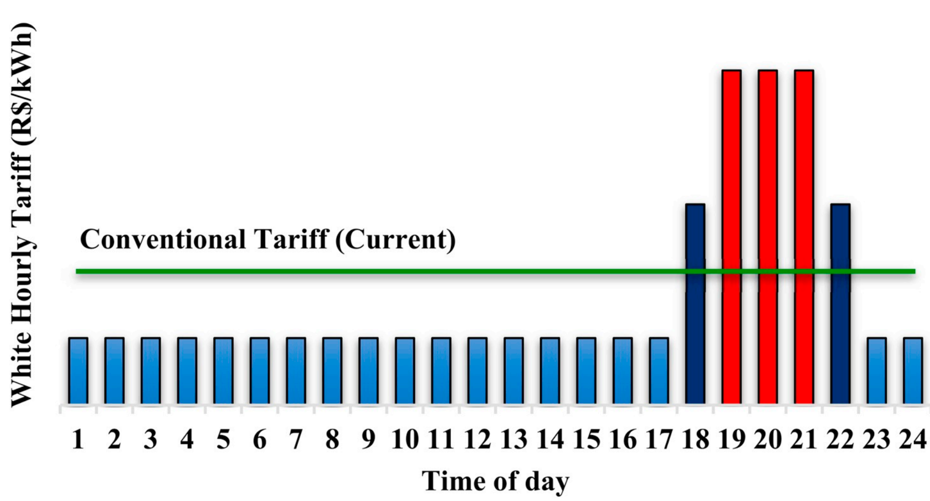


Fig. 9. White hourly tariff versus conventional tariff (ANEEL, 2019b).

importance of defining the group of consumers that can adopt the prepayment system is highlighted in (Telles Esteves et al., 2016), especially due to the high level of investment costs. In this sense, in the case of Brazil, some type of consumers are not allowed to adopt the prepayment system, e.g., consumers that adopted the WHT or those who have a micro or mini DG system connected to the grid (ANEEL, 2014). The electricity prepayment and the WHT are dependent on the deployment and availability of smart meters. Therefore, the next subsection will present a brief review and the current state of smart metering deployment in the Brazilian electricity sector.

4.4. Smart metering

Although there have been some advances in the Brazilian regulatory structure, many gaps still stand as a barrier to the development of smart grids. Smart grids are expected to be at an intermediate level of development in Brazil by 2030 (Carvalho, 2015). A disruptive project towards a smart grid power system has been recently proposed by a state-controlled electricity company in the country (in Portuguese, Companhia Paranaense de Energia – COPEL). This project is based on the implementation of an Advanced Distribution Management System (ADMS[2]) which will support the optimization of the distribution grids of the Paraná state by also enabling the self-healing process. The implementation of this project is projected to start in 2019 and it is designed to last about three years (COPEL, 2018). A set of other pilot programs regarding the implementation of smart grids in Brazil is better described in Ponce-Jara et al. (2017).

Ponce-Jara et al. (2017) reviewed the experiences of developing countries towards a smart grid power system which included particularly the analyses of Brazil and India. Concerning the case of Brazil, the authors highlighted the efforts of the Brazilian government to enable the deployment of smart grids since 2008. The authors also pointed out the main challenges of the country which are reinforced by its continental dimensions which would difficult the smart grid deployment in remote areas such as in the Amazon and rural areas. The problem of illegal connections and the lack of regulation in the sector are also considered additional barriers to the smart grid deployment.

The deployment of smart meters is a fundamental step in the deployment of smart grids. Smart metering is considered an emerging and current development technological system in Brazil and the main challenges related to its implementation mostly rely on technical and regulatory aspects (Carvalho, 2015). ANEEL edited the RN nº 502/2012 (ANEEL, 2012b) which regulates the energy metering systems for consumers of group B (e.g. household electricity consumers). Two types of smart meters were proposed by ANEEL. The first one is targeted for those consumers who chose the WHT scheme. In this case, the smart meter should be installed at no initial costs to consumers. The other type of smart meter presents additional functionalities and provides access to specific information to consumers. Consumers that chose this latter smart meter have to pay a price difference between this one and the former (ANEEL, 2012b). Smart Meter deployment is considered an important enabler to the adoption of new tariffs, e.g., Time-Of-Use (TOU), Critical Peak Pricing (CPP) and Real-Time Pricing (RTP). TOU rates have already been implemented in the Brazilian electricity market (e.g. WHT). However, CPP and RTP have not yet been implemented in the Brazilian electricity market.

A comparative analysis regarding the smart meter policies in Europe and Brazil was addressed in (Carvalho, 2015). The authors suggest that Europe policies consider the multiplicity of stakeholders involved in the technology, creating better conditions for investments and consumer engagement, differently from Brazil, in which only the electricity regulator takes the decisions by itself. Findings of this study also suggest that Brazil's government might present an economic assessment to guide the technology deployment of smart meters and then providing consumer engagement. Therefore, smart meter adoption for household electricity consumers in Brazil is a difficult task to predict due to limited consumer knowledge and awareness. Regardless all the benefits related to the development of the smart meters, the lack of support, incentives and proper information dissemination about the possible benefits of the smart meter technology might not result in the expected benefit for both consumers and utilities (Carvalho, 2015). Literature also supports the need for a general assessment framework to evaluate the economic benefits brought about the use of the smart meters (Carvalho, 2015; Dantas et al., 2018). These uncertainties also cause difficulties for distribution utilities, mainly because they need to make the initial investments in the smart meters (Carvalho, 2015). Chou and Yutami (2014) studied the smart meter adoption in Indonesia and concluded that the critical determinants of consumer acceptance of smart meters were mostly related to its usefulness and ease of use.

Utility companies of the Brazilian sector might also develop policies and strategies for the dissemination of the smart meter technology. Currently, the use of smart metering in Brazil is restricted to pilot smart grid projects of specific distribution utilities. Future studies should focus on measuring consumer propensity to adopt smart meters in residential buildings and investigate the perceptions and behaviors of electricity consumers with regard to the potential deployment of smart meters in the country.

4.5. Distributed Generation (DG)

New Brazilian government policies have been stimulating the DG from RES (although the current insertion of DG is still relatively small in Brazil), primarily since the creation of RN nº 482/2012, which regulates the grid connection of DG in the country through a net metering system (ANEEL, 2012a). There are several factors that have been contributing to the DG evolution in the Brazilian electricity sector, e.g., the increasing demand for electricity, restrictions for constructing new hydropower plants with large reservoirs, concerns about climate changes, regulatory incentives, e.g., RN nº 482/2012 (ANEEL, 2012a) and RN nº 687/2015 (ANEEL, 2015), cost reduction in solar PV and wind systems and also the electricity tariff increase over the past years.

Recently, ANEEL approved RN nº 687/2015 (ANEEL, 2015) which is an improved version of RN nº 482/2012, reducing some barriers to the development of DG in the country. These changes include a larger range over the installed capacity (i.e. between 75 kW and 5 MW); increased validity of credits from 36 to 60 months; and two new business models were created namely the possibility of shared generation between consumers and the possibility of installing DG in apartment complexes. RN nº 687/2015 also made a set of adjustments in the procedures of utilities for connecting the DG to the grid in order to make the process faster and simpler to consumers. Regarding the future projections for micro DG, a significant increase in the number of new consumers that will adopt micro DG in residential and commercial sectors is projected reaching up to 886,700 new consumers and a total installed capacity of 3.2 GW in 2024 as illustrated in Fig. 10 (ANEEL, 2017).

DG has been implemented in the Brazilian electricity sector using the net-metering system in which the electricity injected into the grid is valued the same as the electricity consumed from the grid (ANEEL, 2012a). The net-metering system together with the use of the monomial tariff might bring a problem for the balance of electricity tariffs for utility companies (EPE, 2017). By 2024, EPE projected a decrease in revenues of approximately 1.1% for distribution utilities in comparison to 2016 due to the DG insertion. According to Brazilian utilities, there is no adequate incentive to modernize distribution networks or even investing in new technologies considering the current sector regulation (ANEEL, 2018b). In this sense, structural changes in the distribution

[2] ADMS is composed by a set of subsystems namely, Energy Management System (EMS), Supervisory Control And Data Acquisition (SCADA), Distribution Management System (DMS), and the Outage Management System (OMS) (Software, 2018).

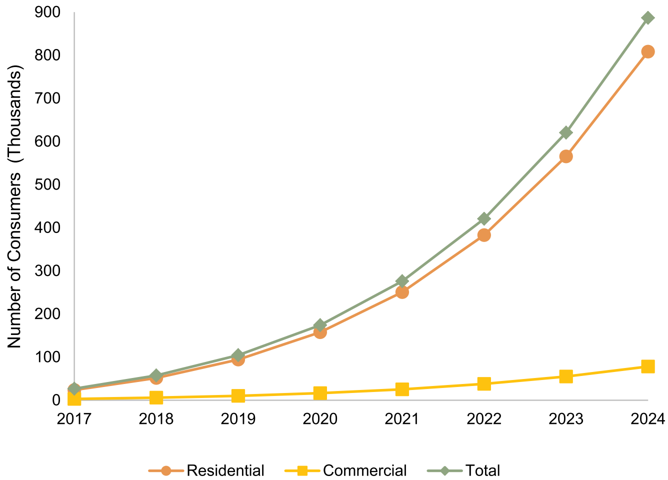


Fig. 10. Distributed generation projection for the period 2017–2024.

sector are projected for the near future in order to minimize the economic problems brought about by the DG insertion. The growth of DG in the Brazilian electricity sector is expected also to affect the electricity supply quality of distribution utilities and consequently its operational costs. It is worth mentioning that the quality of the grid supply can be severely affected by voltage and frequency fluctuations produced in power systems with high levels of RES penetration (IRENA, 2017).

4.6. Demand-Side Management (DSM)

Along with this subsection, the concept of DSM will be broadly used to refer to both energy efficiency measures and strategies that affect the resources on the demand-side. This last concept is mostly related to Demand-Response (DR) measures. As reported by (Meyabadi and Deihimi, 2017), "*the implementing of managerial measures to produce the resources on the demand-side by influencing the load demand*" can be defined as DSM. DSM strategies have been developing overtime to deal with the economic and environmental challenges brought by the expansion of supply-side energy resources. It is worth mentioning that the low DSM contribution of the Brazilian electricity sector aggravated and extended the energy supply crisis in 2014 due to the severe drought occurred in the country leading to a significant increase of generation from thermal power.

DR aims primarily to encourage end-users to reduce electricity usage by certain incentive schemes, especially when electricity prices are high (Zhang et al., 2016). According to the U.S. Department of Energy, DR can be defined as "*changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*". Dranka and Ferreira (2019) reviewed the different categories of DR potentials and concluded that there is a lack of understanding among literature regarding these different categories and proposed the unification of these different classifications.

In Brazil, the potential of DR is considered by authorities an important variable to delineate the medium and long-term electricity expansion planning (EPE, 2017). It is worth mentioning that changes in tariff schemes promoted by ANEEL may considerably motivate price-based DR programs in Brazil. Paterakis et al. (2017) emphasize the great potential of Brazil for wider penetration of DR programs in the future. The Brazilian Electricity Regulatory Agency (in Portuguese, ANEEL) implemented a DR pilot program for large industrial consumers located in the North and Northeast of the country in 2017 (ANEEL, 2017b). For this DR program, the consumer decides about the time and the amount of load reduction bids and load recovery (Saebi et al., 2010).

Additionally, considering the high demand increase and consequently the new projected generation power sources that should be installed in the future, DR might bring a significant positive impact on the Brazilian power system, by contributing to reducing the overall installed capacity projected by official Brazilian institutions and enhancing the power system security and reliability. In fact, most future projections do not consider the DR contribution. Finally, it can be concluded that many challenges and barriers associated with DSM deployment still exists although many advances have been observed over the past years. The outcomes of this review also lead to the conclusion that there is a significant gap between the current levels of DSM and the total potential available in Brazil.

4.7. Storage technologies

The future of RES-based systems deployment is strongly linked to energy storage options and consequently to decentralization and decarbonization policies (Luisa et al., 2018). Much of the attention in previous research has been to consider different methodologies for coupling RES and storage systems such as in (Barelli et al., 2018) and (Hemmati, 2018). Some of the problems brought by the increasing RES-based systems with great unpredictably and variability, e.g., frequency regulation, can be smoothed by the support of fast-responding storage technologies (e.g. hydro-pumping power stations, which are considered the most common storage technology across the world). On the other hand, hydro-pumping power stations might not be considered well suited to the DG model since it cannot be deployed in urbanized areas (Luisa et al., 2018).

Currently, Brazil has one of the highest capacity ratios for Hydropower/Renewable and Renewable/Electricity generation in the world. Therefore, Brazil reached a high share of RES (mostly based on hydropower) without significant problems on its power system operation. This fact can be explained by the high degree of flexibility offered by natural gas power plants. Thus, currently, there are quite a few operational storage projects in the Brazilian power system (Silvera et al., 2018) and few studies which address this issue. Therefore, the deployment of storage technologies is at a slow pace of growth in the country. However, the significant changes expected for the near future, such as the new market structure and the decreasing of storage capacity (see Fig. 4) would require substantial changes and new frameworks to support the increasing share of renewables, e.g., the deployment of fast energy storage resources such as batteries and flywheels. Silvera et al. (2018) addressed the role of storage technologies for the case of the Brazilian power system and concluded that the most promising technologies are batteries, pumped hydro-storage, flywheel and compressed air energy storage.

There is also a historical lack of funding in storage technologies research in Brazil mostly because of its high hydropower system. However, in order to foster investments in storage technologies, ANEEL proposed a Research and Development (R&D) program in 2016. This R&D program is focused on Battery Storage Energy Systems (BESS) technologies and 23 proposals were approved from different distribution companies of the country (ANEEL, 2017c).

4.8. Electric Vehicles (EVs)

The transition towards a sustainable future is strongly related to the deployment of smart technologies (e.g. smart charging for electric vehicles) (IRENA, 2018; Li et al., 2016). Following this idea, the Brazilian government approved RN nº 819/2018 (ANEEL, 2018a) which establishes the legal requirements regarding the charging for electric vehicles in the Brazilian power sector. This is considered the first normative resolution about EVs ever implemented in Brazil. RN nº 819/2018 aims to reduce the uncertainties to entrepreneurs who wish to invest in the development of the infrastructure for charging electric vehicles. This new normative resolution also enables to the utility distributor installing in its area of concession electric vehicles charging stations. Therefore, public or private EV charging stations are allowed in RN nº 819/2018 to transfer electricity to the battery of EVs. It worth mentioning that RN nº 819/2018 does not allow the bidirectional power flow between the battery of the EV and the power grid as well as the participation in the electricity compensation system, regulated by RN nº 482/2012 (ANEEL, 2018a). The number of recharging points shall be equivalent to the maximum number of electric vehicles that can be connected and charged simultaneously in each station (ANEEL, 2018a).

5. Summary and discussion

It is well known that the global electricity sector has been witnessing a significant share of innovations together with a high increase in renewable energy, and Brazil is no exception. Decarbonization, Digitalization and Decentralization of the energy sector will be the main three key drivers of the power system evolution. These main drivers would also promote important benefits for the country, but it requires potential changes in the current structure of the electricity sector. This section aims to present a lively discussion and some of the main policy implications regarding the prospects for a smart power system in Brazil.

The shift towards low-carbon economies throughout the integration of renewable energy is intensifying the disruption of traditional utility business models. For the future, utilities would change its traditional business models by providing ancillary services to end-users through innovative contracting offers, e.g., smart contracts which could include the energy price, quantity and date of delivery. Therefore, the development of innovative approaches to fulfill this new market would be required. This coming up future would be also disruptive from the point of view of the Distribution System Operators (DSO) and Transmission System Operators (TSO), affecting substantially its role, since new actors would appear on the energy market due to the new business models. It is worth mentioning that in agreement with (Tayal, 2016), the shift towards low-carbon economies throughout the integration of renewable energy is intensifying the disruption of traditional utility business models.

The economic and risk analysis of small-scale PV systems in Brazil was recently addressed by Dranka et al. (2018). Dranka et al. (2016) assessed the impact analysis of wind power mini-generation for industrial consumers considering different tariff modalities in Brazil. The role of DG for the different stakeholders (e.g. consumers and distribution companies) has received increased attention in recent years in Brazil. Understanding the complexity of the trade-offs of increasing DG is vitally important. Specialists have been criticizing RN nº 687/2015 since it does not foresee the possibility of the energy commercialization, but it rather defines a "sharing" mechanism. The possibility of trading the excess of electricity produced by DG systems could help to pave the way towards potential new business models that would make DG more competitive in Brazil. Recently (2018), ANEEL collected a set of contributions through a public consulting process (CP nº 10/2018) which aimed the enhancement of the current DG regulation established firstly by RN nº 482/2012. One of the most significant current discussions is related to the need for changing the current net-metering system. For the most part of consumers which already have a DG system installed, the maintenance of the current regulation should proceed, driven by the benefits brought about this technology to the society. On the other hand, from the non-DG users' point of view, the current regulatory system shifts the costs to them, and this is not considered a sustainable measure for the long-term. The Brazilian government, through ANEEL, has been evaluating five different alternatives for the current net-metering system by looking at two sides (ANEEL, 2018b). The first side refers to the consumer who still has or intends to install a DG system and the second side refers to the non-DG users. Findings of ANEEL (2018b) revealed that non-DG users would pay a higher share of the overall costs in the case of maintaining the current net-metering system. The general issue of cross-subsidization has been also discussed by literature such as in (Tomain, 2014) and (MIT, 2016). MIT (2016) highlight the problem brought about the net-energy metering system "*leading to cross-subsidization of DG network users by customers without DG*". This problem could be surpassed by using hourly tariffs. However, for the case of Brazil, this is not yet a reality and other solutions should be found to address this problem at least for the short-term. Viana et al. (2018) analyzed the use of a price-based demand response program together with photovoltaic distributed generation and concluded that regulatory changes would be necessary in order to stimulate the use of DR with these DG systems. Viana et al. (2018) also highlight that the simultaneous use of a price-based DR program with a photovoltaic distributed generation system may not be economically attractive for the WHT non-flat tariff. Therefore, improvements in the current DG regulation were also proposed.

The deployment and dissemination of DG, DSM strategies and storage systems are expected to reduce the need of consumers to be supplied by the network grid and are expected to play a growing role in balancing electricity demand and supply in the future. DSM has become a key instrument available to the electricity sector and has the potential to postpone capital investments to expand primarily distribution and subtransmission systems. The new tariff schemes created by ANEEL (e.g., tariff flag, WHT and the electricity prepayment) aim to foster the potential of DR and specifically may motivate price-based DR programs in Brazil. The development of smart grids enables the implementation of DSM measures. The smart meter deployment is also considered essential to enable the implementation of the WHT scheme. Given the increasing electricity demand growth rates and consequently the new projected power sources that should be installed in the future, DSM might significantly contribute and affect positively, reducing the total installed capacity projected by Brazilian institutions and also enhancing the power system security and reliability. In fact, most part of future projections does not consider the DSM contribution. Thus, the future projected installed capacity might be oversized.

The delay in smart meter deployment affects considerably the development of the new tariff schemes and consequently underusing Brazil's DSM potential already available. As discussed earlier, for those consumers who adopted the WHT, the utilities should install the smart meter with no initial costs for the customer. This smart meter, however, has only a few functionalities. We highlight the potential that should be achieved, mostly from the customer point of view, if a modern smart meter would be installed and thus allowing them to manage their energy consumption profile more efficiently. It is worth mentioning that this smart meter is already available, but the customer should pay the difference between this smart meter and the conventional one.

New technologies are also gaining considerable attention worldwide such as power-to-gas, power-to-heat and power-to-mobility, but they are not on a path of accelerated deployment in the case of Brazil (Blanco and Faaij, 2018; Barbosa et al., 2016). The new trends and regulatory aspects that have been proposed for the Brazilian electricity sector are correlated and occasionally mutually dependent as detailed in Table 1 which summarizes the last Brazilian regulations concerning the electricity sector and the main future trends expected to be implemented in the country. A set of highlights are presented aiming to discuss the main aspects of each trend considering the studies addressed by literature and the expected time horizon of each trend. Most of these highlights can be seen not only as challenges for the stakeholders of the power sector but also as important academic problems to be addressed in future research targeting Brazil and other countries moving towards smarter electricity systems.

6. Conclusion and policy implications

The transition towards a more sustainable energy system is a challenge for the Brazilian power sector and essential structural and regulatory changes (e.g. new business models) would be necessary to support this transition. The main challenges towards a sustainable and full-decarbonized energy system rely on increasing the power system

Table 1
Summarize of the smart grid trends and prospects for the Brazilian electricity sector.

Technology/New Trend and Regulation	Time-horizon[a]	Highlights	Literature
TARIFF FLAG SYSTEM (RN nº 547/2013)	Already implemented (Regulated in 2013 and implemented effectively in 2015)	▪ The main aim is to reflect the real cost of electricity generation and promote consumer awareness. ▪ The monthly flag is defined considering the required thermal power, according to hydropower availability. ▪ It attempts to foster the potential of DR by increasing the electricity tariff and also minimize the differences between costs and revenues of the utilities. ▪ TFS would promote a reduction of thermal dispatch, an increase in the overall storage level and the reduction of the overall operating system cost. ▪ A loss of revenue for utilities is foreseen due to the reduction in the overall electricity consumer's consumption. ▪ The costs for the yellow and red flags have been changing over the years and currently, the calculation methodology includes the Generation Scaling Factor (GSF).	(Di Santo et al., 2015; Lima et al., 2017; ANEEL, 2013; Charfuelan Villareal et al., 2016; de Jong et al., 2017; Zurn et al., 2017; Lino et al., 2011)
WHITE HOURLY TARIFF[b] (RN nº 733/2016)	Short-term (available since January 01, 2018)	▪ The WHT is a type of TOU rate in which electricity tariffs are differentiated along the day in on-peak, intermediate (mid-peak) and off-peak periods. ▪ This new tariff scheme is considered the first hourly tariff ever implemented for household electricity consumers in Brazil. ▪ The main reason for implementing this new rate regime is to incentive household electricity consumers to reduce their consumption, especially during peak demand periods (between 06 p.m. and 10 p.m.) ▪ The possible benefits of the WHT should be better presented to consumers, giving them the possibility to choose or not to choose this new regime rate considering their load profile. ▪ This new tariff scheme might optimize investments in generation and transmission in the future.	(ANEEL, 2016; Di Santo et al., 2015; de Jong et al., 2017; Zurn et al., 2017; ANEEL, 2019b)
ELECTRICITY PREPAYMENT[b] (RN nº610/2014)	Short-term (1–5 years)	▪ Prepayment system is supposed to offer advantages for both consumers and distribution companies. ▪ The system has been primarily motivated by the possibility of reducing electricity distribution losses and operational costs, improving companies collecting revenues and reducing fraud. ▪ From the consumers' perspective, experiences show that they feel empowered to manage and control billing cost and consumption using the electricity prepayment. ▪ In Brazil: I Companies are supposed to provide all the prepayment meter acquisition costs; II Consumers can freely migrate between systems (i.e. prepayment and post-payment); III The shift from the post-payment to the prepayment system is voluntary and free of charge for consumers. IV Some group of consumers is not allowed to adopt the prepayment system, e.g., consumers that adopted the WHT or those who have a mini or micro DG system connected to the grid; V There are some technical constraints mainly related to the lack of standardization that should be better addressed in the future.	(ANEEL, 2014; Telles Esteves et al., 2016; ANEEL, 2017a)
SMART METERING (RN nº 502/2012)	Short-term (1–5 years)	▪ Smart metering is considered an emerging and under development technological system in Brazil. ▪ Currently, the use of smart metering is Brazil is restricted to pilot smart grid projects of specific distribution utilities. ▪ The deployment of smart meters is a fundamental step for the deployment of smart grids in Brazil. ▪ The smart meter deployment is considered essential to enable the implementation of the WHT system. ▪ Smart meter adoption for Brazilian residential buildings is a difficult task to predict due to the limited consumer knowledge and awareness. ▪ The lack of support, incentives and proper information dissemination about the possible benefits of the smart meter might not result in the expected benefit for both consumers and utilities.	(Carvalho, 2015; ANEEL, 2012b; Chou and Yutami, 2014)

(*continued on next page*)

Table 1 (*continued*)

Technology/New Trend and Regulation	Time-horizon[a]	Highlights	Literature
		▪ Utility companies of the Brazilian system might develop policies and strategies for the dissemination of the smart meter technology. ▪ Although there have been some advances in the Brazilian regulatory structure, many gaps still stand as a barrier to the development of smart grids. ▪ Future studies should measure consumer propensity to adopt smart meters in residential buildings and investigate the perceptions and behaviors of electricity consumers with regard to the potential deployment of smart meters in the Brazilian electricity sector.	
DISTRIBUTED GENERATION (RN nº 482/2012 and RN nº 687/2015)	Short-term (already available since 2012)	▪ Solar PV represented 99% of total mini and micro DG already installed in Brazil up to 2017. ▪ The overall installed small-scale DG energy systems is relatively small compared to Brazil's potential. ▪ The forecast for 2024 is a total amount of 886,700 new consumers and an overall installed capacity of 3.2 GW for DG. ▪ The net-metering system together with the use of monomial tariff might bring a problem for the balance of electricity tariffs for utilities. ▪ By 2024, EPE projected a decrease in revenues of approximately 1.1% for distribution utilities in comparison to 2016 due to the insertion of DG. ▪ According to Brazilian distribution utilities, there is no adequate incentive to modernize distribution networks or even invest in new technologies. ▪ There is little emphasis on previously published works related to social impacts and benefits of distributed technologies.	(ANEEL, 2015; ANEEL, 2012a; ANEEL, 2017; EPE, 2017; ANEEL, 2018b)
DEMAND RESPONSE	Medium to long-term (5–20 years)	▪ The deployment of DR programs has been seen as an alternative to generation and transmission expansion. ▪ Peak demand reduction is considered one of the main goals of DR. ▪ DR might be used to contribute to power system regulation capacity in order to promote wind power integration, mainly in the Northeast region of Brazil. ▪ The potential of DR in Brazil is considered by authorities an important variable to delineate the medium and long-term electricity expansion planning. ▪ The most part of studies so far addressed by literature worldwide regarding DR role has been focused on power system operation and emphasize that the effects of DR should be considered in power system planning. ▪ The changes in tariff schemes promoted by ANEEL may considerably motivate price-based DR programs in Brazil. ▪ There is a great potential in Brazil for the wider penetration of DR programs. ▪ The new tariff schemes created by ANEEL (i.e. TFS, WHT and the prepayment system) aims to foster DR.	(EPE, 2017; Paterakis et al., 2017; Blanco and Faaij, 2018; de Jong et al., 2017; Zhang et al., 2016; Dranka and Ferreira, 2019; Fotouhi Ghazvini et al., 2017; Rathore and Roy, 2016)

[a] The time-horizon was established consider the first consumers' adoption of the new technologies but also based on the conducted literature review.
[b] Both have been already regulated but are under practical implementation.

flexibility while at the same time maintaining its reliability.

Our findings suggest that DG, DSM and the new tariff schemes are on a path of accelerated deployment in the country due to the new policies and regulatory frameworks proposed by the government, mainly in the last five years. Outcomes of this paper lead to the conclusion that there is a great potential for the wider penetration of DSM programs in Brazil but there is a significant gap between the current levels of DSM and the overall potential available. The main part of new normative resolutions proposed by the Brazilian government (e.g., WHT and electricity prepayment) are mostly related to household electricity consumers and to a somewhat lesser extent for commercial consumers. This fact can be explained mostly because the residential and commercial sectors are the main contributors at times of heavy demand or peak usage (between 06 p.m. and 10 p.m.). Our findings also imply that the WHT should be better presented to the Brazilian consumers, giving them the possibility to choose or not to choose this new rate regime, considering their load profile and consequently getting economic advantages from its choice.

The economic impact of DG growth is considered one of the most important issues presented by utilities. Also, the transformation of the regulatory structure and the habits of consumption, together with the commercial feasibility of technologies and human resources training, appear as additional challenges for the sector. New business models have been proposed to address the high insertion of DG in the Brazilian electricity market such as the ones proposed by RN nº 687/2015. However, we highlight the necessity to further develop other new business models to address the various decentralized energy technologies and services that are emerging in the sector, as for example, the ones related to the so-called "*prosumage*" concept. Education activities that simultaneously clarify the new regulatory framework to consumers and its possible benefits are considered actions to be taken in order to encourage them to adopt or not to adopt the proposed new tariff schemes (i.e. WHT and the prepayment system).

In light with the results, the following policy-related recommendations are proposed. First, the deployment and dissemination of DG projected by the national authorities of the power sector in Brazil together with the intermittent nature of RES enforce the need for new policy designs for both the utilities and consumers and this can be considered a key issue to enable the ambitious transition toward RES based systems. Additionally, policy designs should find the optimal balance between investments to update the current energy system (and thus take the advantages of the smart grid model) and other climate-policy related investments. In this sense, the regulatory framework, primarily including new network grid codes, grid investment incentives, market design and environmental regulation will have a key role in the future of the Brazilian electricity sector.

Second, the digitalization process can be seen as a key opportunity for the utilities reducing both technical and non-technical grid losses. This would also enhance the potential for new business models, promoting non-regulated services to the consumers, e.g., helping them to understand and manage their energy profile consumption. The cognitive patterns of the electricity consumers would also impact the future of the electricity sector and this is considered another key factor to be further evaluated.

Third, the creation of positive inducements related to the insertion of RES and the importance of diversifying the electricity supply mix in order to ensure not only financial savings but also energy security and reliability of the electrical power system is an important tag in the Brazilian power sector. Therefore, we highlight the need for the government to develop flexible regulatory frameworks in order to address the disruptive models that may become available in the power sector in the years to come. The diversity amongst distribution companies and the trade-off between affordable tariffs and technological advances also open up important avenues for further research.

Fourth, we believe that greater attention should be performed from policy-makers to the implementation of effective demand-side measures. The new policies may have a great potential to change business models among Brazilian utilities and this should be further evaluated. The policy implications of the analysis carried out in this paper, include that we have learned that the integration of DR resources into the Brazilian electricity market requires a set of regulatory changes. We have shown that policies are needed in order to foster the introduction of DR measures. These new regulatory changes may have a positive influence on the potential benefits of DR usage for almost all stakeholders.

The creation of additional indicators that can measure the impact of the integration of DG in the future scenarios; the use of a parameterization of measures to represent the environmental, cultural and social externalities related to each option and also the technological competitiveness of electric vehicles over time are some of the aspects that should be included in future works. Regulation for electrical vehicles is still emerging in the country, e.g., through RN nº 819/2012. However, its impact on the power grid is not yet assessed and this aspect is a future key regulation that should be addressed. In (Zhang et al., 2018), for example, the use of the EVs for system frequency regulation is addressed and give useful insights into the technical impacts of EVs on the power grid. All these aspects offer important problems for the industrial and scientific community and for which a multidisciplinary perspective would benefit energy systems research beyond the Brazilian case. We also highlight the need of system integration and sector coupling which is also considered a key point to be addressed by the Brazilian government towards a full-scale decarbonized energy system, but this would require a long-term political framework.

Although there have been some advances in the Brazilian regulatory structure, many gaps still stand as a barrier to the development of the electricity sector. The integration of the new aspects discussed in this paper remains a difficult and complex endeavor for several reasons. There are several uncertainties that might cause difficulties for utilities, e.g., the net-metering system together with the use of monomial tariff might bring a problem for the balance of electricity tariffs. Conclusively, considering the review analysis proposed in this paper, we believe our results offer insights into the future trends for the Brazilian electricity sector which allowed to highlight the important role of smart grid technologies for the creation of a more efficient grid and for the intelligent management of the entire energy system. This would also allow households to manage their electricity needs, having a more active behavior in electricity management. Although simplified, our review analysis brings some light on the main barriers, challenges and opportunities towards a smart power system in Brazil and contributes to a better understanding regarding the trade-offs of the power sector.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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