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Scenarios for Ceará's electricity generation matrix in 2050

Cenários para a matriz de geração de eletricidade do Ceará em 2050

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RESUMO

A partir da proposição de cenários de matrizes energéticas a nível mundial para 2050, o objetivo do presente artigo é apresentar cenários de geração de eletricidade para o estado do Ceará em 2050, mostrando a participação de fontes já usadas na matriz elétrica do estado e acrescentando novas. O artigo propõe três cenários: um conservador, onde é mantida a proporção atual das fontes de geração de eletricidade do estado, um de transição, com 50% da geração de energia elétrica oriunda de fontes não renováveis e os outros 50% provenientes de fontes renováveis, e um 100% renovável, sem o uso de combustíveis fósseis ou nuclear. As estimativas para 2050 no estado são obtidas através de extrapolação de dados de geração de 2011 a 2017, alcançando um valor estimado de 94.775 GWh. No cenário conservador, observa-se que metade dessa geração é realizada por termelétricas e a outra metade por parques eólicos. No cenário de transição, dominado pelo uso do gás natural, destaca-se o crescimento exponencial da geração fotovoltaica. No cenário 100% renovável, dominado por parques eólicos, além do crescimento semelhante da geração fotovoltaica como no cenário de transição, destaca-se a utilização dos resíduos sólidos urbanos e de centrais solar térmicas de concentração.

Palavras-chave: Cenários energéticos; Planejamento Energético; Ceará 2050

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ABSTRACT
Based on the worldwide proposition of energy matrix scenarios for 2050, the objective of this article is to present scenarios of electricity generation for Ceará in 2050, showing the participation of sources already used in the state's electric matrix and adding new ones. The article proposes three scenarios: a conservative one, where the present proportion of electricity generation sources of the state is maintained, a transition one, with 50% of electricity generation from non-renewable sources and the other 50% from renewable sources, and 100% renewable, without the use of fossil or nuclear fuels. Estimates for 2050 in the state are obtained by extrapolating generation data from 2011 to 2017, reaching an estimated 94,775 GWh. In the conservative scenario, it is observed that half of this generation is made by thermoelectric plants and the other half by wind farms. In the transition scenario, dominated by the use of natural gas, the exponential growth of photovoltaic generation stands out. In the 100% renewable scenario, dominated by wind farms, in addition to the similar growth of photovoltaic generation as in the transition scenario, we highlight the use of urban solid waste and solar thermal concentration plants.
Keywords: Energetic scenarios; Energy planning; Ceará 2050

1 INTRODUCTION

For the 2050 horizon, the world energy sector probably will face challenges such as the increase in demand and problems related to current sources of electricity, especially considering environmental aspects. At the global level, the current electricity production is based mainly on fossil sources (38.4% coal, 3.7% oil and 23.2% natural gas (NG)), non-hydro renewables and waste (8.0%) , nuclear (10.4%) and hydroelectric plants (16.3%) (IEA, 2018). This set of sources may become unviable within a few years due to problems such as pollution, greenhouse gas emissions (GHG), depletion of water sources and land use, which may even make it impossible to continue using them. As a result, the use of alternative renewable sources has proved to be an interesting option, both because they are able to supply the growing energy demand and are sources with lesser environmental impacts. Several studies of energy planning have been carried out worldwide aiming to show the need to change the current energy matrix to one based on renewable sources (MOREIRA et al, 2015), such as solar and wind.

(Prasad et al., 2014) review the literature on the complex aspects involved in energy planning with a focus on the associated risks, errors and uncertainties of the area. Initially, the authors emphasize the importance of the activity, arguing that "an energy plan must always aim to support sustainable development". Three sustainable development criteria are discussed: environmental, economic and social. The environmental criterion is generally associated with the reduction of GHG, air pollution and depletion of natural resources. The economic criterion considers the reduction of dependence on fossil fuels and the increase of local investment in renewable energy and energy efficiency projects. The social criterion aims at improving human health, creating jobs, providing greater comfort and involving citizens in decision-making processes. In addition, the authors include two criteria to be considered in energy planning: technical and geopolitical aspects. As an important global trend in recent decades, the authors analyze that the demand for renewable energy is increasing and new markets and investments are increasingly shifting to developing countries, despite economic and political uncertainties.

Despite the progress of the sector worldwide, studies applied to Brazil (BR) and Ceará (CE), in particular, are scarce, making it difficult to draw an energy scenario for 2050 due to the lack of data and studies developed. Considering CE's context, (Costa et al., 2018) analyze the behavior of sustainability indexes for the electricity generation sector of the state. According to the proposed methodology, CE's electricity generation sector in 2017, based mainly on thermoelectric (TEP) and wind power plants, has a sustainability index of 1.351, which is 2.2 times above BR's sustainability level (index of 0.614). A high sustainability indicator shows low sustainability of the electricity generation matrix.

Aiming to contribute to the discussion, the present paper initially discusses what has been studied regarding the estimates of the energy sector for 2050. In a second stage, the paper presents proposals of scenarios for CE's electricity generation matrix in 2050.

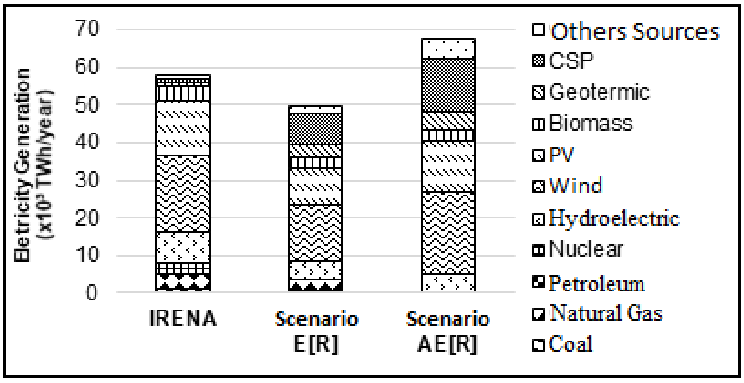
2 ENERGETIC SCENARIOS

2.1. World energetic scenarios to 2050

The International Renewable Energy Agency (IRENA) analyzes the global energy scenario between the years 2016 and 2050, showing that the sector can be sustained by the large-scale deployment of renewable energy and by increasingly flexible energy systems, supporting a profitable integration. According to the scenario proposed by IRENA, the share of renewable energies in the energy sector would increase from 25% in 2017 to 86% in 2050. This transformation would depend on new approaches to market planning, system and operations, regulation and public policies (IRENA, 2019). Looking at the 2016 hydro, solar photovoltaic (PV) and wind data, there is a generation of 3,970 GWh, 418 GWh and 737 GWh, respectively. Observing the data foreseen in 2050 for the same sources, there is, respectively, a generation of 7,882 GWh, 14,808 GWh and 20,236 GWh; in addition, Concentrated Solar Power (CSP) will generate 766 GWh in 2050.

Another analysis is carried out by Greenpeace for the world energy supply until 2050. One of these scenarios, entitled Energy [R]evolution (E[R]), projects a more optimistic and viable path for a widely decarbonized energy system until 2050, but that still has fossil fuels in the energy matrix in this horizon, such as coal and NG. The second scenario, entitled Advanced Energy [R]evolution (AE[R]), is more ambitious and projects a total decarbonization of the energy system (with a 100% renewable matrix) by 2050, that is, no fossil source will be used for the generation of electricity. According to this study, there are no major technical or economic barriers to achieving a 100% renewable energy matrix by 2050, and this scenario is the only alternative for the world not to undergo catastrophic climate changes (GREENPEACE INTERNATIONAL, 2015). Comparing IRENA and Greenpeace scenarios in 2050, and considering only the common sources in all scenarios, Graph 1 shows that renewable sources have the largest share in the world electrical matrix, with emphasis on PV (26%, 20 % and 21%, respectively) and wind (35%, 31% and 34%, respectively).

Graph 1 – Share of the main sources of electricity generation in the world in 2050 in the IRENA and E [R] and AE [R] scenarios



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2.2 BR’s energetic scenario to 2050

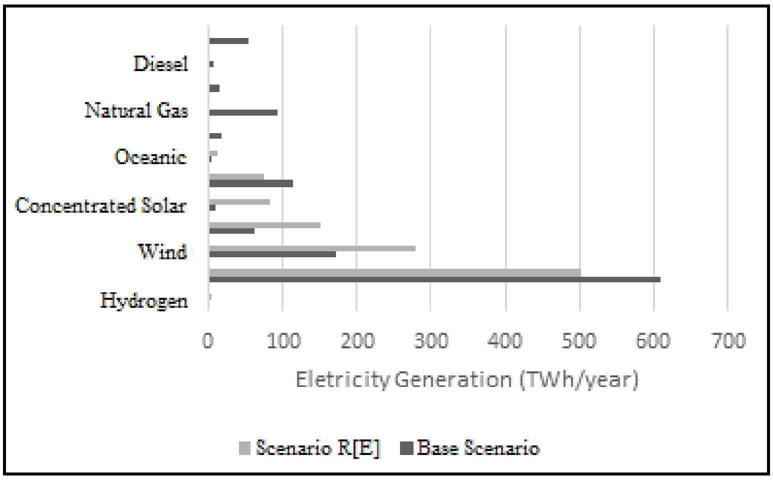
BR’s electric matrix has a predominantly renewable basis, with emphasis on the water source, which accounts for 65% of the domestic supply. Water, biomass and wind, together, are responsible for approximately 80% of Brazil's internal electricity supply (EPE, 2018). Thus, Brazil is the only country in Latin America with great prominence in the global generation of electric energy through renewable sources, not including hydroelectric, occupying the 7th place in the world with 4% of the total production (EIA, 2014). This base, mostly hydro, tends to decrease, due to issues such as reduced rainfall, long distances between generation sites and consumption centers, and social and environmental restrictions. Despite this, the main problem ends up being the reliability of electricity generation, due to periods of little rain, making it necessary to use TEP, which generate the base load. Additionally, the South and Northeast regions are the best areas in the country for the use of wind energy (MOREIRA et al., 2015).

In this context, Greenpeace elaborates, presents and compares two scenarios that show forecasts for the BR’s energy matrix in 2050. The so-called “Base scenario” reflects the continuity of the Brazilian government's policies for the energy sector. The so-called “Energy [R]evolution scenario” is a projection that considers the potential of the country to use renewable energy to reach 100% of its matrix clean with zero GHG emissions (GREENPEACE INTERNATIONAL, 2016).

According to the “Energy [R]evolution scenario”, in order to achieve a 100% renewable energy matrix, BR must gradually give up fossil fuels until 2050. For electricity generation, the use of coal must be stopped by 2030 and the oil in 2040. NG can be used as a transition fuel until it is no longer used in the middle of the century, and there should be a transition to the use of electricity and biofuels mainly in the transport sector and industry. In the generation of electricity, the expansion of wind and solar (PV and CSP) reaches a 46% share, more than double that predicted by the “Base scenario”. Thus, the installed capacity of renewable energies goes from the current 106 GW to 349 GW in 2050, a growth 48% higher than that predicted in the “Base Scenario” (GREENPEACE INTERNATIONAL, 2016).

According to the “Base scenario”, BR’s electricity consumption in 2050 will be 921 TWh, with 11% of this total coming from fossil sources. In the “Energy [R] evolution scenario”, consumption will reach 864 TWh in this year, with a large share of solar and wind energy, which will be responsible for 430 TWh per year or 39% of the BR’s total electricity generation. CSP plants, which are not used currently in the country, and PV generation, with activity still in the beginning, will reach 83 TWh and 150 TWh per year, respectively, in 2050, representing 22% of the total generation. Wind energy will continue to grow and will represent 280 TWh per year (GREENPEACE INTERNATIONAL, 2016). Graph 2 compares the electricity generation according to the two scenarios mentioned.

Graph 2 – BR’s Electricity generation by source in 2050



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Also according to Greenpeace, there should be a diversification and decentralization of BR's electricity generation, with a small expansion of hydroelectric plants (45% of generation), while wind generation grows to 25% and solar generation (PV and CSP) to 21%. Biomass remains with 7% of generation, and other sources, such as ocean and hydrogen, together represent 2%. In addition, there is a change in the current logic of production, since most consumers start to generate their own electric energy, with PV plants in homes, businesses, and industries, sending electricity to the grid (GREENPEACE INTERNATIONAL, 2016).

From an economic point of view, the end of the use of fossil fuels, which today feed TEP, will allow great cost savings. In 2050, electricity generation in the "Energy [R]evolution scenario" will cost R$ 209 billion per year, against R$ 254 billion in the "Base scenario". This annual savings of R$ 45 billion means a significant gain for the country and for consumers (GREENPEACE INTERNATIONAL, 2016).

2.3. CE's energetic scenario to 2050

The main forms of electrical generation in CE currently are wind and TEP using NG and coal. On the other hand, CE's annual solar irradiation is higher than the irradiation in several states of the country and provides a competitive scenario for PV and CSP (IPECE, 2018). Over time, many energy programs and measures have been designed and consolidated in CE, causing the energy matrix to grow and transform, following the national and world panorama. The main initiatives are:

•1987-1990: creation of CE's Energy Balance, Energy Diagnostic and Energy Potential.

•1991-1994: treatment of the energy sector. Increased efficiency in the electrical distribution system.

•1995-1998: Pluriannual Plan, with the recovery and increase of the capacity of the electric sector, the dissemination of renewable energies and the use of alternative energies.

•1999-2002: adoption of thermal solar systems in industry, application of biomass and biodigesters and continuity of wind energy programs.

•2001: creation of the ATLAS OF BRAZILIAN WIND DEVELOPMENT.

•2003-2006: search for self-sufficiency in the generation of electric energy and diversification of the energy matrix, from TEP and wind generation.

•2007-2014: expansion of the electric energy service in urban and rural areas. Creation of a state program to support the dissemination of the use of wind and solar energy. Bioenergy policy, with an emphasis on biodiesel.

•2015-2018: State Energy Plan, with an overview of the current situation of the actions and works of CE's Basic Network.

To prove the state's rapid energetic transformation, in 2001 CE imported all the electrical energy it consumed from other states. In 2017, TEP production reached 11,600 GWh and the production of wind farms reached 5,242 GWh, totaling 16,842 GWh (ANEEL, 2018). In addition, the state has shown decentralization of its electricity production: TEP production is more concentrated in the Metropolitan Region of Fortaleza, the greatest potential for PV generation is located in the regions of the Central Sertão and Canindé and good anemometric conditions are found on the coast and on the plateaus (IPECE, 2018).

Thus, the strategy outlined in the early 2000s by CE's government, which sought self-sufficiency in the generation of electric energy and diversification of the energy matrix, was successful. All this thanks to the set of public policies, investments and incentives mobilized in this direction. This success was even more valued as 33.6% of CE's total electricity production in 2016 came from clean renewable sources.

Despite the positive aspects mentioned, it must be recognized that negative points still persist in the segment. One of these points concerns the fact that two thirds of CE's electricity production, TEP based, use fossil fuels, causing atmospheric pollution. Thus, it is necessary to expand the use of renewable sources, a policy that has been implemented by CE's government in recent years. Under this perspective, by the end of 2019, the state foresees the addition of 1,076 MW in the generation capacity, from a project under construction and thirty-six others of construction not yet started (BIG ANEEL, 2019).

However, this growth can only exist if there is a change in technological innovation policies, aiming at facilitating contracts with companies that distribute and produce electricity that use clean renewable sources. Technological innovations in the electricity sector require regulatory innovations, in order to enable new business models associated with new products and services, which will be increasingly available to consumers (IPECE, 2018). On the other hand, it is possible to associate this process of construction of a new technological paradigm to the existence of public policies that encourage the development and diffusion of innovative activities, as well as consumer preferences and their different income levels, given the economic heterogeneity of the electricity market (CASTRO et al, 2019).

3 CE'S ENERGY SOURCES: CURRENT STATUS AND PERSPECTIVES

3.1. Coal, NG and diesel based TEP

In 2019, BR has 12 TEP based on coal for electricity production, with a total installed capacity of 3.21GW. Of these, two are in CE: Porto do Pecém I and II, in São Gonçalo do Amarante, which put the state in the 1st place in installed capacity in the country, with 1,085 MW (EPE, 2016). The first generator unit of Porto do Pecém I started the commercial operation in December 2012 with an installed capacity of 360 MW. The second generator unit, also of 360 MW, started operations in May 2013, totalizing 720 MW of installed capacity (ANEEL, 2019). The expansion project for a second stage, Porto do Pecém II, started operations in October 2013 with 365 MW. The coal used is imported from Colombia and discharged at the Port of Pecém; then, it is transported 12 km by covered conveyor belt and stored in the TEP. The plant has the capacity to store coal for 30 days of operation. In the current context, the TEP are responsible for 64% of CE's electricity generation (BEN 2016, 2017).

The use of TEP in CE has motivated polemics due to associated environmental impacts. As basic principle of operation of TEP based on coal, the process uses water to move the turbines and in the cooling phase (OLIVEIRA, 2009). Considering that CE has a low water availability and there is a great concurrence for its use in agriculture, livestock, industrial process and human consumption, operation of TEP based on coal becomes restricted, decreasing the reliability of the electricity supply of the state. Additionally, CE has Fortaleza and Termoceará TEP with installed capacity of 326 MW e 220 MW, respectively. Termoceará operates with NG as well as diesel (PETROBRAS, 2014). In addition, the state energy matrix has Maracanaú I TEP with 168 MW, that uses fuel oil and is operating since 2010.

3.2. Wind

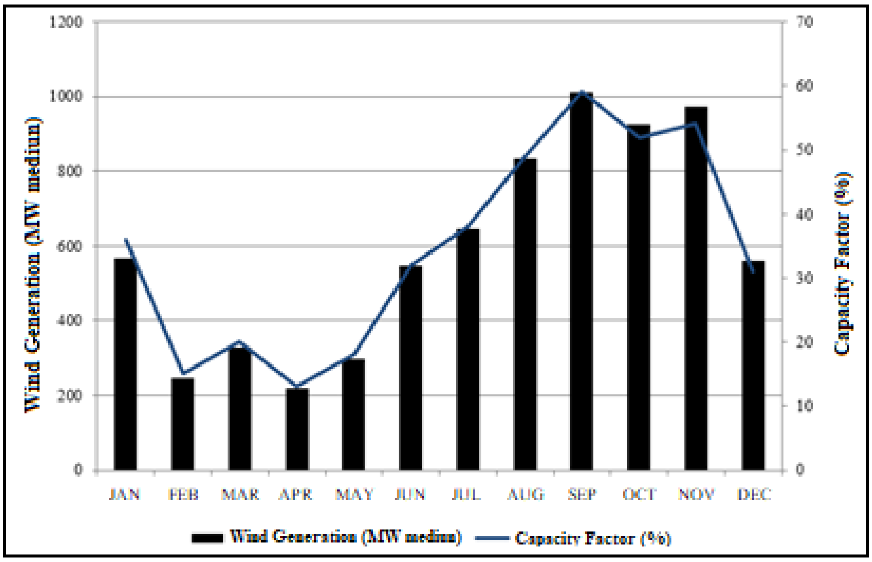
CE's winds are more intense and constant during the day, between the months of August and December, exactly in the periods of drought, when the reservoirs show low capacity (CEARÁ, 2001). The history of the use of wind energy in BR is directly related with CE. In 1993, towers were installed for prospecting wind potential by COELCE and CHESF; in 1996, the first BR's wind project on the coast: Mucuripe wind farm (Fortaleza), with 1.2 MW of capacity. In 1999, Taíba wind power plant on the west coast, considered the first independent producer of the country, with an installed capacity of 5 MW, and Prainha wind power plant on the east coast, with a capacity of 10 MW (CEARÁ apud GORAYEB; BRANNSTROM, 2016, p.105). In addition to the coast, one of the strategic points for the sector are the plateaus, mainly Apodi and Araripe (CERNE, 2018).

According to Environmental Impact Reports submitted to CE's Superintendence of the Environment, there are several models and manufacturers of wind turbines in CE. The gearbox models are present, for example, with the 2 MW G-87 model and the 2.1 MW S88 model, in the Dunas de Paracuru parks and in the Icaraí park. Among the models without gearboxes, the 2 MW E-82 models and the 1.5 MW Vensys 77 model, in the Cataventos Acaraú and Quixaba parks (AMPLA ENGENHARIA, 2011; GEOCONSULT CONSULTORIA, 2011; AMBIENTAL CONSULTORIA & PROJETOS, 2012 ; VENSYS, 2019).

CE is the third state in BR concerning wind power generation, behind Rio Grande do Norte and Bahia (ANEEL, 2018). Currently, wind represents 46.36% of the

State's electric matrix, with a total of 2.05 GW of installed capacity, with 81 projects in operation, 1 project under construction of 19.2 MW and 12 projects with not started construction of 315 MW (ANEEL, 2019). According to the National Electric System Operator (ONS), in 2018 CE reached a minimum capacity factor of 13% in April and a maximum of 59% in September, resulting in an average annual factor of 34.75%, higher than the world average (around 25%), as shown in Graph 3 (ABEEÓLICA, 2019).

Graph 3 – CE's Electricity generation and monthly capacity factor in 2018



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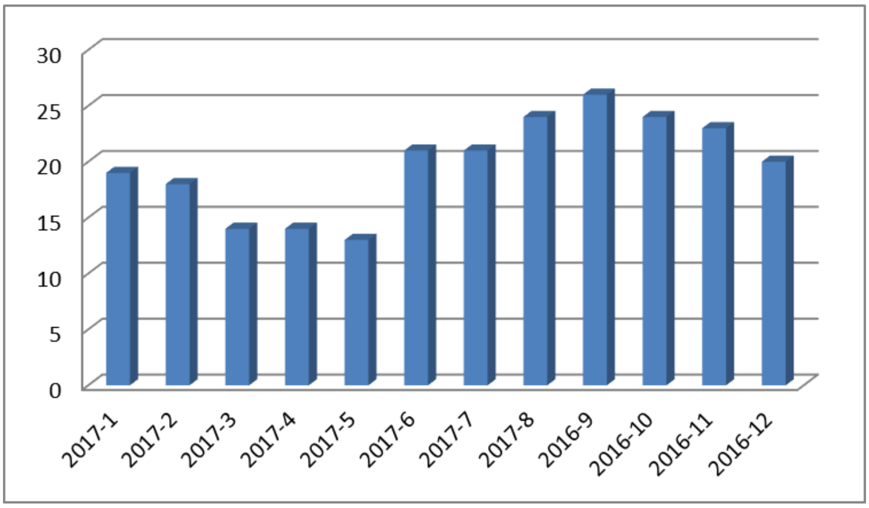
3.3. Photovoltaic

CE has been a pioneer in the use of PV plants in BR, both in autonomous systems and in grid connected plants. Considering autonomous units, between 1998 and 2002 the German Agency for International Cooperation (GTZ, currently GIZ), started the Photovoltaic Pumping Irrigation Pilot Project program, where 90 PV systems were installed in Brazil, Jordan, Indonesia, Argentina, Philippines and Zimbabwe, totaling 180 kWp. In BR, one of the places where these systems were installed was the CE's rural area (COELCE / DFACE, 1995). Considering the connection to the grid, CE's first PV system started operation in 2011. The plant was installed in a rural area of the state, with a power of 1 MWp, using 4,680 PV modules in an area of about 12,000 m^2 (MPX, 2013).

CE's territory has 35.2 MWp in installed power of distributed generation, occupying 8th place in the ranking of the states and 1st in the northeast region (ABSOLAR, 2019). CE already has 180 MWp contracted (5.6% of BR's total) and there is also the prospect of transferring another 90 MWp already contracted, which may increase the percentage to 8.4% of the contribution to the national energy matrix (CIN, 2019).

Graph 4 shows the capacity factor measured from a 1.5 kWp PV plant installed at the UFC's Laboratory of Alternative Energies (LEA - UFC) in Fortaleza, CE. The data, measured from September 2016 to August 2017, reveal the local climatic conditions: most of the rain occurs in the rainy season (first half of the year) and very little during the rest of the year. An average factor of 20% is calculated for the analyzed period (CARVALHO et al., 2018).

Graph 4 - Capacity factor of a 1.5 kWp PV plant in Fortaleza, CE



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3.4 Concentrated Solar Power (CSP)

CSP makes use of reflective surfaces to concentrate solar irradiation in a receiver that has a working fluid. According to Atlas (2017), the Northeast is the BR's region that has the best levels, presenting the highest daily irradiation on an inclined plane (average of 5.52 kWh / m2) and the lowest interannual variability. For this reason, this region, in particular its semi-arid portion, where high irradiation is associated with the occurrence of low precipitation and cloud cover throughout the year, is credited with being the priority destination for investments in electricity generation from the solar source, as already observed in ANEEL auctions.

CE has an area of 13,474 km² with normal direct annual irradiation above 2,000 kWh / m² (Burgi, 2013). Table 1 shows values for Fortaleza, CE, based on GIS (Geographic Information Systems) for the application of the minimum area requirement criteria, in addition to other analysis results such as electricity generation, capacity factor and water consumption. All the configurations of analyzed CSP plants have a humid cooling system.

Table 1 - Indicators for Fortaleza-CE for different types of CSP plant technology.

Fortaleza			
Indicators	PC	PC (6 hs)	ST (7.5 hs)
Multiple Solar	1.40	2.58	3.27
Total Area (km²)	3.29	6.07	9.16
Water Consumption (m²)	700.896	1272.043	1207.792
Annual Generation (MWh)	160.232	310.474	330.151
Capacity Factor (%)	18.3	35.5	37.7

PC - Parabolic cylinder; PC (6 hs) - Parabolic cylinder with 6 hs of thermal storage; ST (7.5 hs) - Solar tower with 7.5 hs of thermal storage.
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3.5. Urban Solid Waste (USW)

Biomass is derived from living matter and can be found in the form of urban, animal, vegetable and industrial waste; biomass can be used in three different ways: liquid (like ethanol), gaseous (like biogas) and solid (like firewood) (BORGES NETO & CARVALHO, 2015). Analyzing CE's climatic conditions, it is possible to conclude that the use of biomass related to direct burning and production of liquid fuel is impracticable, due to the indisposition of the territory for the planting of raw material, such as sugar cane.

An alternative for the state is the use of USW, an energy resource widely used for electricity generation in developed countries. Considering the Northeast production of USW (ABRELPE, 2017), it is estimated that the CE produces around 9 thousand tons per day. With the constant production of waste, which is mostly collected and taken to landfills, controlled landfills and dumps, selective collection and use as a source of biogas generation can be performed. The use of USW is broad and can be used to generate electricity through incineration, use of waste gas, anaerobic digestion and combined cycle. In CE biogas has already been produced through anaerobic digestion of USW since May 2018. The material is collected in Fortaleza and taken to Caucaia, generating 80,000 m³ of biomethane, and production is expected to reach 150,000 m³ / day. The biogas generated can be converted into vehicular NG and can be used to generate electricity (CICLOVIVO, 2018). In CE, collection services are performed directly in 43 municipalities, outsourced in 133 and mixed in 8.

3.6. Hydrogen

CE has several researches related to the inclusion of hydrogen in the energy matrix of the state in a clean way, using solar and wind energy, as an alternative to the use of fossil sources. Sacramento (2008) applies a mathematical model of solar and wind hydrogen for CE, prospecting for the reduction of fossil fuel emissions. In the study three long-term simulations are developed: the first scenario (non-introduction of hydrogen), the second (considering the slow introduction of hydrogen) and the third (rapid introduction of hydrogen in the state matrix). In the case of no introduction of hydrogen, the study predicts that by the year 2070, the state will emit 40 million tons of CO_2 per year; with the introduction of hydrogen this value would drop to 25 million in 2040 and with the rapid introduction of hydrogen it would drop to 20 million already in 2035, reaching a zero value in 2055.

Patrício (2012) develops a mathematical model to predict how the generation of electrolytic hydrogen with the aid of wind turbines can influence the energy matrix to replace the NG in use in CE. This model verifies the behavior of some variables, such as the net gain between hydrogen and NG, Gross Domestic Product (GDP) and energy price. Three scenarios were considered for the application of the model: Fast introduction, slow introduction and without introduction of hydrogen. For a gradual transition, it is initially considered to transport it together with NG, taking advantage of the existing infrastructure. In the scenario of rapid introduction, the demand for hydrogen transported together with NG is about 0.023 EJ around 2035; in the slow introduction scenario, a peak of around 0.027 J will be reached in the same year. When the NG is gradually replaced by hydrogen around 2070, this value reachs 0.046 EJ.

Sacramento et al., (2013) analyze the transition to a hydrogen economy in CE to replace fossil fuels. A mathematical model is applied to introduce the hydrogen obtained through the electrolysis of water, using solar and wind energy in two scenarios: slow and fast introduction. The study shows that the demand for energy in the scenario of slow and rapid introduction of hydrogen in the first year is equivalent to 0.17 EJ, while fossils represent 0.0505 EJ of this total. According to the slow introduction scenario, the demand for fossil energy grows until 2040, with a value of 0.334 EJ; after that year it starts to fall, reaching zero in 2065, when the hydrogen supplies all the needs for fossil fuels, reaching a peak in 2095, with the value of 0.50 EJ.

Esteves et al. (2015) analyze the feasibility of ammonia production as the main component for the synthesis of nitrogen fertilizers in CE. The potential for the production of ammonia via Haber-Bosch process with wind and solar electrolytic hydrogen is described with maps showing data per area unit in each municipal division of the state. With the occupation of only 12.5% of the area of a municipality, it is possible to produce fertilizer using ammonia synthesized from renewable hydrogen, supplying CE's demand and even exporting, resulting in an increase of local GDP.

3.7. Nuclear

According to the Nuclear Industries of Brazil, the main BR's reserves are found in Bahia, CE, Paraná and Minas Gerais, with an average of 309,000 tons in U3O8 reserves; from this total, 240,000 tons are found in Santa Quitéria, in CE's countryside. Thus, Brazil occupies the seventh position worldwide in ore reserves, but it is estimated that this value is even higher, since less than a third of the national territory was the target of searches (INB, 2017).

Discovered in 1976 by Nuclebrás, Santa Quitéria's deposit became part of a uranium and phosphate exploration project. Due to the presence of these two elements, it is estimated that the Santa Quitéria Project, when finalized, will quadruple the production of uranium concentrate for the production of nuclear fuel and increase the BR's production of phosphates by 10% (INB, 2017).

In addition to the potential for generating electricity, the nuclear source involves several controversies regarding contamination, as verified in the case of Caetité in Bahia, which in 2008, in an investigation carried out by Greenpeace, was found contamination of wells located at 20 km from the city. According to the EcoDebate site, twenty-two water supply points were examined by technicians from the Government of Bahia and it was found that eight of them indicated levels of radiation seven times higher than that allowed by the World Health Organization, a fact that negatively affected the trade in the region for fear of marketing of contaminated products.

3.8. Waves

CE is the BR's state which owns the best conditions for allocating a wave power plant, due to the constant activity of trade winds, which causes high and frequent waves, essential for the plant appropriate operation (Oliveira, 2016). CE's first wave power plant was established in Pecém Harbour in 2012, for the harbour electricity supply. The plant was financed by Tractebel Energia S.A., by means of the Technological Research and Development Program of the National Agency of Electric Energy (ANEEL), supported by CE's government. The project main innovation is the use of a high-pressure system to rotate the turbine, a concept developed and patented by Coppe (Estefen, 2006). Each module, or mechanical arm, has a rated power of 50 kW and suggests the use of 10 modules to reach 0.5 MW. One of the objectives of this project is to reduce electricity production costs, similarly what succeeded with wind energy. The total investment cost was elaborated aiming to indicate the installation per device option or a multiplicity plant option, with the costs being listed both per installed MW and investment for the plant implementation. Table 2 shows the investment cost of the mentioned project.

Table 2 - Total cost for electricity generation from waves, Pecém Harbour project, CE

Installation cost	US$ 2,820,000.00 / MWh
Investment cost	US$ 93.51 / MWh
Generation cost	US$ 103.51 / MWh
Operation and maintenance costs	US$ 10.00 / MWh

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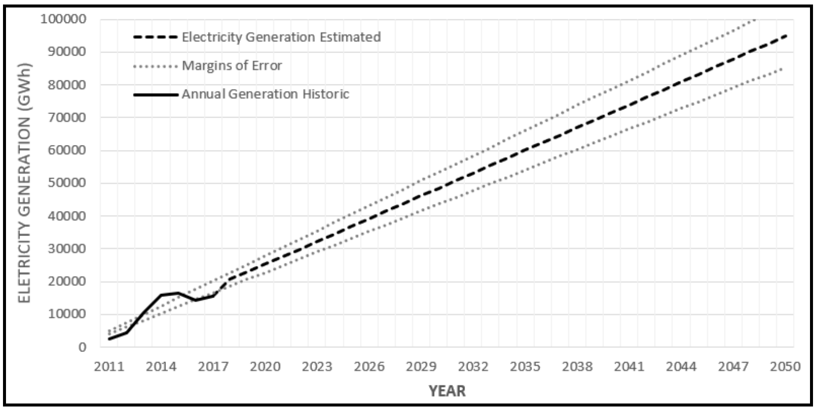
4 PROPOSAL OF CEARÁ'S ENERGETIC SCENARIOS FOR 2050

CE's estimated electricity generation in 2017 was 15,547 GWh. Of these, approximately 10,168 GWh comes from TEP (NG: 2,542 GWh, fuel oil: 102 GWh, diesel: 102 GWh and coal: 7,422 GWh), 5,364 GWh from wind farms and 16 GWh for the sum of hydroelectric and PV (BEN 2018).

CE's generation estimate for 2050 was based on electricity generation data for the years 2011 to 2017. Based on these values, an extrapolation was made, through linear regression, to estimate generation data from 2017 to 2050. Graph 5 contains a darker central line, which represents the estimated total generation, and lighter lines, above and below that central line, which represent 10% margins of error, up and down. Thus, the total CE's electricity generation for 2050 was estimated at

94,775 GWh, a value used as a reference for the creation of three different scenarios for 2050: conservative, transition and 100% renewable.

Graph 5 – CE's total electricity generation forecasting for 2050



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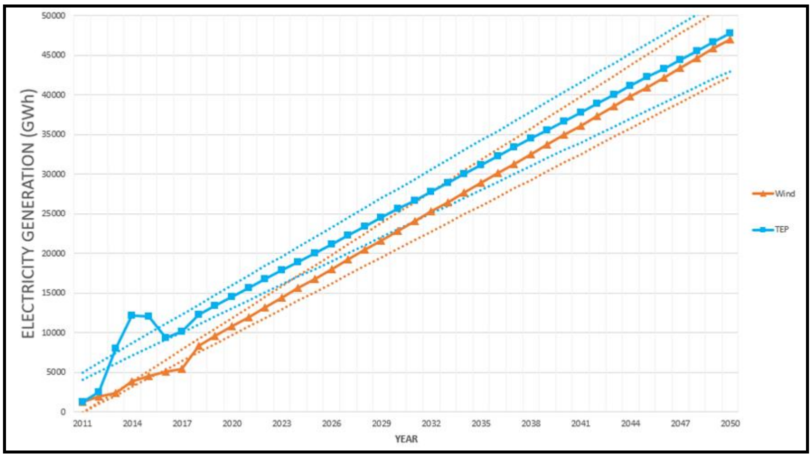
4.1. Conservative scenario

For the development of the conservative scenario, it was considered that the growth of CE's electric matrix will happen at a linear pace until 2050 and that the sources used for electricity generation will maintain a proportion of 50% from TEP and 50% from wind farms. Thus, CE's future matrix will have little difference in relation to the current one, according to Graph 6, which presents the participation of each source.

Graph 6 – CE's electricity generation forecasting for 2050 by source, conservative scenario



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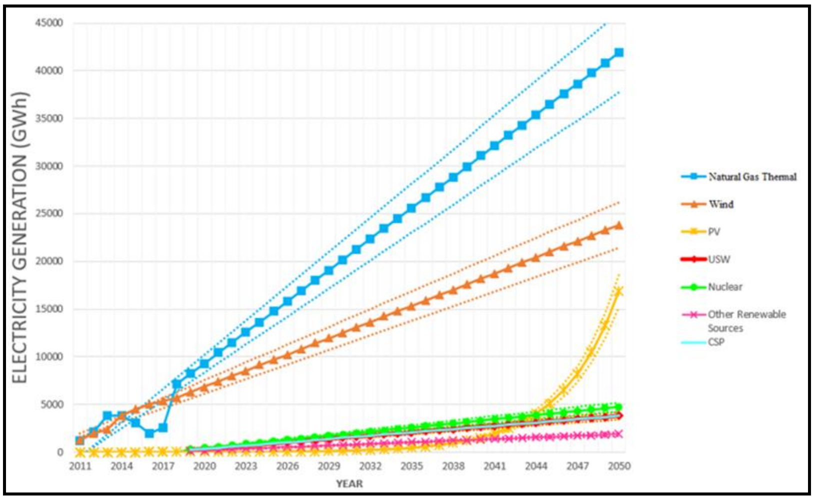
Considering the conservative scenario for 2050 (50% of the electricity production from thermal source and 50% from wind), electricity generation in 2050 is 47,014 GWh from wind and 47,759 GWh from thermal source. Graph 6 shows no only the forecasting of the increase in generation, but also presents limits of 10% above and below these values (dotted lines), which correspond to a safety margin for generation forecasts. The share of fuel sources for CE's TEP in 2017 follows with the same percentages for the progression in 2050.

4.2. Transition scenario

For the development of the transition scenario, it was considered that the growth of CE's electric matrix will occur at a mix of linear and exponential paces until 2050; nevertheless, the sources of electricity generation will change significantly, and the main change will be no use of coal-fired TEP. In the transition scenario, it was considered that 50% of the electricity generation comes from no renewable sources, with the other 50% coming from renewable sources. Of the forms of renewable generation used in 2017, it was decided to maintain only wind and PV; among TEP, only NG. Among the new forms of CE's generation for 2050, thermonuclear, CSP, USW and wave energy were considered. The evolution of these forms of generation is shown in Graph 7. Of the total generation, 42,649 GWh corresponds to NG thermal plants; 4,739 GWh to thermonuclear; 1,896 GWh to waves; 3,791 GWh to USW; 3,791 GWh to CSP; 16,888 GWh to PV and 23,694 GWh to wind power (45% comes from NG thermal plants, 5% from nuclear, 25% from wind, 15% from PV, 4% from CSP, 4% from USW and 2% from other renewable sources).

Graph 7 – CE’s electricity generation forecasting for 2050 by source, transition scenario



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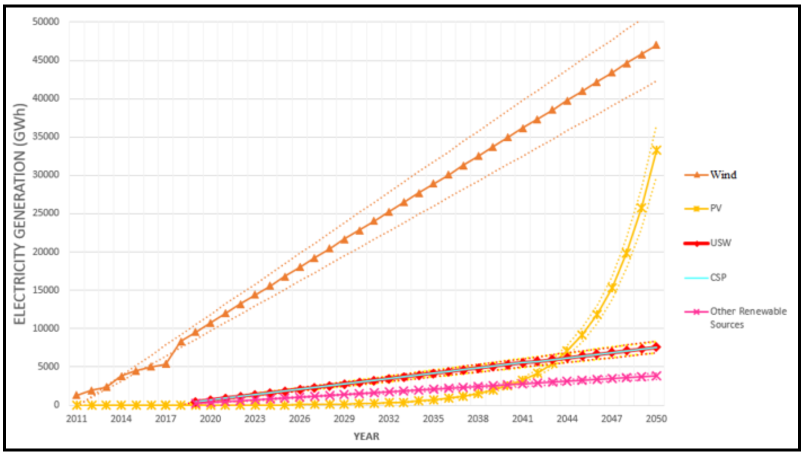
4.3. 100% renewable scenario

For the 100% renewable scenario, no participation of fossil or nuclear fuels was considered. Due to the large current participation of the wind source in CE, it is estimated that in 2050 a percentage of 50% (47,388 GWh) of the electricity production will come from wind farms; for PV, a 30% (28,432 GWh) generation share is considered, as well as 8% (7,582 GWh) of CSP and 8% (7,582 GWh) of USW; the remainder, 4% (3,791GWh), refers to other renewable sources, such as wave energy and hydrogen.

Solar and wind sources were selected as the main sources of CE´s electricity generation in this scenario due to the current growth rate of participation and due to the state's characteristic climatic conditions. Regarding the participation of USW, CSP, waves and hydrogen, the E[R] scenario of Greenpeace was taken as reference. A highlight in Graph 8 is the differentiated form of growth of the PV generation. The exponential growth is due to the favorable climatic characteristics of the state, increased conversion efficiency and lower costs for the components of PV systems.

Graph 8 – CE's electricity generation forecasting for 2050 by source, 100% renewable scenario



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5 CONCLUSIONS

There is a wide variety of electricity generation technologies currently in CE. For future scenarios, in addition to the existing ones (TEP, PV and wind), there is the possibility of implementing technologies that use USW, nuclear, waves and CSP, in addition to the insertion of hydrogen. In the present study, three scenarios are considered: the conservative scenario maintains the current participation of each generation technology in the state: 50% of the generation comes from fossil fuels and 50% from renewable sources; in terms of electricity, this means 47,014 GWh from wind farms and 47,759 GWh from thermal source.

For CE's transition scenario, the percentage of 50% renewable and 50% non-renewable is maintained. However, 42,649 GWh come from NG, 23,694 GWh from wind farms, 16,888 GWh from solar, 4,739 GWh from thermonuclear, 3,791 GWh from USW, 3,791 GWh from CSP and 1,896 GWh from waves.

For the CE's 100% renewable scenario, it is considered that there is no participation of fossil or nuclear fuels. In this case, it is estimated that in 2050, 50% of the electricity generation, equivalent to 47,388 GWh, comes from wind farms; 30%, equivalent to 28,432 GWh, comes from PV; 8%, which represents 7,582 GWh, comes from CSP and 8%, representing 7,582 GWh, from USW; 4%, corresponding to 3,791 GWh, comes from other renewable sources, such as waves and hydrogen.

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