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# AMAZON'S HYDROELECTRIC POWER PLANTS

## Adapting the energy sector for energy security

Master Dissertation in Energy for Sustainability
in the Specialty of Energy Systems and Energy Polices

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DEPARTAMENTO DE
ENGENHARIA MECÂNICA

# AMAZON'S HYDROELECTRIC POWER PLANTS

## Adapting the energy sector for energy security

Dissertation presented to obtain the Master's degree in Energy for Sustainability in the Specialty of Indoor Energy Systems and Energy Policies

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**Coimbra, September, 2019.**

Dedicated to my family, to the Povo da Mata and the entities of light, who are always supporting and encouraging me in this journey.

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I have to say here that I believe everyone had to have an aunt Ana in life. Thank you Ana Lúcia for existing in my life and for following all my steps as a mother, I Will always want you near me!

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Luiza Brilhante is the brightest person I know. My best friend of a lifetime, thank you for digging the way into my life, and for kindly providing the photograph on the cover of this dissertation.

# Abstract

Brazil has one of the largest hydropower potentials in the world. The Amazon basin alone is considered to be the largest hydrographic basin on the planet, covering almost 90% of northern Brazil with enormous water potential, but the Amazon region also has one of the highest biodiversities in the world. In this context, despite the large contribution of renewable energy generation in Brazil, with hydroelectric power being the main contributor, the energy sector cannot be considered sustainable, since there is little energy security, and the planned increase in hydroelectric generation in the Amazon is not sufficient to meet the expected future energy demand for Brazil.

Thus, in recognition of the potential of Brazilian alternative energy, the main research question arises: Which energy sources in the Brazilian regions complement each other energetically? And which energy sources in the Brazilian regions are similar to those hydro already installed?

The main objective of this dissertation is to evaluate the diversification potential of the Brazilian energy sector that influences the energy security of the country, identifying potential scenarios of complementarity and similarity (to hydro) between alternative energy sources (solar, wind, water) in each region (North, Northeast, Southeast / Midwest, South). To this end, data from energy generation were obtained from the National Electric System Operator.

Pearson's correlation coefficient calculation was used for the assessment. Overall, the results pointed to the potential for wind energy in all regions and the solar potential in the Northeast and South regions as scenarios that should be further explored in energy sector diversification.

**Keywords:** Renewable energy; Energy diversification; Amazon, Hydropower plant.

# Resumo

O Brasil possui um dos maiores potenciais de energia hidrooelétrica do mundo. A bacia amazónica é considerada a maior bacia hidrográfica do planeta, cobrindo quase 90% do norte do Brasil, com enorme potencial hídrico, mas a região amazónica também possui uma das maiores biodiversidades do mundo. Nesse contexto, apesar da grande contribuição da geração de energia renovável no Brasil, sendo a energia hidroelétrica a principal contribuinte, o setor de energia não pode ser considerado sustentável, já que não há segurança energética, de forma que mesmo o aumento planeado de geração hidroelétrica na Amazónia não é suficiente para assegurar o consumo de energia futuro esperado para o Brasil.

Assim, em reconhecimento ao potencial das energias alternativas brasileiras, surge a principal questão de investigação: Quais fontes de energia nas diferentes regiões brasileiras se complementam energeticamente? E quais fontes de energia nas regiões brasileirasapresentam similaridade às hídricas já instaladas?

O objetivo principal desta dissertação é avaliar o potencial de diversificação do setor energético brasileiro que influencia a segurança energética do país, identificando potenciais cenários de complementaridade e similaridade (para hidroelétricas) entre fontes alternativas de energia (solar, eólica, hídrica) em cada uma das regiões (Norte, Nordeste, Sudeste / Centro-Oeste, Sul). Para tal, foram obtidos dados de geração de energia junto o Operador Nacional do Sistema Elétrico.

O cálculo do coeficiente de correlação de Pearson foi utilizado para a avaliação. No geral, os resultados apontaram para o potencial da energia eólica em todas as regiões e o potencial solar nas regiões Nordeste e Sul como cenários que devem ser mais explorados na diversificação do setor energético.

**Palavras-chave:** Energia renovável; Diversificação energética; Amazónia, Hidroelétrica.

# Summary

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# SYMBOL AND ACRONYMS

## Symbol

**ρ** – Pearson Correlation Coefficient

## Acronyms

ANEEL – National Electric Energy Agency

CRESESB - Sérgio de S. Brito Reference Center for Solar and Wind Energy

DEE – Decennial Energy Expansion Plan

EPE – Energy Research Company

GHG – GreenHouse Gases

IBGE - Brazilian Hydroelectric Potential Information System

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Analysis

ONS – National Electrical System Operator

PRODEEM - State and Municipal Energy Development Program

PROINFA – Incentive Program for Alternative Energy Sources

RES – Renewable Energy Source

SEA – Strategic Environmental Assessment

SEMA - State Secretariat and Environment

SIN – National Interconnected System

SIPOT - Brazilian Hydroelectric Potential Information System

# 1. INTRODUCTION

The Amazon region has one of the largest potentials for the generation of hydropower in the world, and hydropower plants have been installed as a source of "clean energy" to supply Brazil's energy needs. Currently, several large-scale hydropower plants are planned to be deployed in the Amazon region. However, it is clear that even with an additional 120 GW of installed hydropower capacity in the Amazon, with 80% utilization, this would still not be sufficient to meet the energy demand in Brazil in 2030 (QUEIROZ et. al., 2013).

Brazil is the 10th largest country in terms of electricity consumption (460.8 TWh in 2016) and the 9th largest in terms of electricity generation (578.9 TWh in 2016) (CIA, 2018). It would seem that Brazil does not have problems with electricity generation since the country produces more than consumes. However, Brazil is still very dependent on intermittent energy sources without any substantial complementarity (with other sources of renewable energy). Thus, there are periods of time when surplus energy is generated and periods of a deficit in generation.

The energy sector in Brazil is still not very diversified and therefore does not guarantee energy security, often resulting in supply problems (SINIMBU, 2017). What can be observed nowadays is that much of the hydropower potential installed in the Amazon region mainly serves to supply energy to the large industries from the South and Southeast of the country, resulting in the Amazon region carrying the bulk of the environmental costs, while the benefits are realized outside the region.

Thus, in order to have a more reliable energy sector in Brazil, the energy mix must be diversified. However, currently, according to the Government of Brazil (2018) and the balance sheet of the Energy Research Company (EPE), the Brazilian energy sector is predominantly based on renewable energy sources (RES), and dominated by hydropower generation, which provides 68.1% of the domestic energy supply.

Therefore, the potential of Brazil to develop and generate energy using alternative renewable sources, such as solar photovoltaic (PV), wind and biomass, should be considered. In addition, Brazil can take advantage of the complementarity between renewable energy sources, since the different regions have different profiles of renewable generation, which will prevent overloading one region, as is currently evident with the Amazon.

An important shift in Brazilian energy generation occurred in 2001 due to the energy crisis in Brazil. In order to prevent similar occurrences, the Renewable Energy Sources Incentive Program (PROINFA) was launched in 2002, to encourage the diversification of the Brazilian energy matrix. However, in 2015, there was a new crisis caused by a long drought and lack of investment in the electricity sector.

This fact underscores the importance of this work for Brazil. Brazil is still heavily dependent on hydropower plants, which is particularly risky in periods of prolonged drought where supply is augmented by thermoelectric power plants, increasing energy costs and requiring improved energy efficiency and demand-side measures, which affects the productivity of industries and economy of the country. This work seeks to evaluate how Brazil, a country recognized for its diversity, can support the generation of renewable energy in regions other than the Amazon, through complementarity between energy sources and improved energy security.

## 1.1. Motivation

This study evaluated the complementarity of alternative energy sources in order to improve energy security in the Brazilian energy sector and to inform priorities for and decision-making in investment in the renewable energy sector.

The current Brazilian Government states at Estadão (2019) that they have plans to increase the number of nuclear power plants in the country, however considering that the Angra Nuclear Power Plant 3 has been under construction since 1984 and considering the socio-environmental contradictions with the installation of hydroelectric plants in the Amazon, alternatives are recommended. Studies have shown that even with the increase of the installation of hydroelectric plants in the Amazon, this will not meet future energy demands, leaving Brazil very dependent on hydropower generation, and there is a need to diversify renewable energy sources in the country to ensure energy security.

## 1.2. Objectives

The main objective of this dissertation is to evaluate, based on the identified impacts of hydroelectric dams in the Amazon, the need for diversification of the Brazilian energy sector, taking advantage of the alternative energy potential of the country. To this end, the following specific objectives were defined:

- To assess how alternative energy sources can be complementary;
- To evaluate which regions of Brazil are fundamental for complementarity between renewable energies;
- To assess how alternative sources of energy might be similar to water;
- To evaluate which regions are fundamental in terms of similarity of generation to water;

Thus, we intend to analyze the functioning of the Brazilian energy sector in relation to hydroelectric power plants in the Amazon. The study aims to assess the need for diversification of energy generation in Brazil, notably through the use of other renewable energy sources, to identify how alternative energy sources can work in complementarity with each other, and to point out how the regions of Brazil are fundamental. in solving this problem. As well, it is intended to evaluate which regions are similar to those of water, so that in the future can replace them.

More specifically, this thesis aims to parallel Brazil's dependence on expanding the hydroelectric facility in the Amazon and the need for diversification of the Brazilian energy sector, to ensure complementarity between renewable energy generation and to emphasize the potential of other regions to beyond the Amazon to contribute to the generation of renewable energy without adding new hydroelectric plants, using other renewable resources.

In general, the research aims to provide indicators/explanations for the potentiality for and necessity of the diversification of power generation in Brazil and its benefits, aiming at a more diversified energy sector with greater energy security.

## 1.3. Structure

The main body of the thesis is divided into five main chapters. The second and third chapters refer primarily to the findings of the literature review. In the second chapter, the physical and environmental characteristics of the different Brazilian regions and their power generation potentials are outlined, highlighting the current Brazilian energy system and demonstrating the current perspectives on power generation. The second chapter includes an outline of the energy sector model proposed by the Brazilian Government is outlined and provides a general description of sustainability in power generation, the main public policies that encourage alternative sources of energy, and their actual impacts on the energy sector. The second chapter includes references to studies on the complementarity of energy in Brazil. The third chapter describes the Amazon biome and the regional nuances and dynamics of the soil, fauna, flora, climate, and hydrology. The fourth chapter sets out the method of evaluation and the data obtained in the research on energy generation and demand by region. The data covers a period of 10 years, considering the cycle from 10 to 15 years in which an energy crisis usually occurs in Brazil. This chapter presents the scenarios to be analyzed and the generation data from the National Electric System Operator that is used in the calculation of the Pearson Coefficient. The fifth chapter presents the main results and points out the best scenarios of complementarity and similarity (hydro) among the renewable energy sources in the Brazilian regions. The sixth chapter discusses the results obtained. Finally, the seventh and final chapter presents the main conclusions of the research.

# 2. SUSTAINABLE ENERGY MATRIX

The Brazilian energy policy is guided by objectives that aim to ensure equitable access to services at fair prices, maintaining rigorous commitments with the preservation of the environment, and the sustainable use of natural resources. This policy contributes simultaneously to the economic and social progress of the population and to the maintenance of one of the world's cleanest energy sectors (TOMALSQUIM, 2012).

## 2.1. Energy sector and sustainability

Recognizing the need to increase energy efficiency, the Brazilian government has proposed measures to ensure reduced dependence on oil and to meet its emission reduction goals (LIN et al., 2017). According to the Ten Year Energy Expansion Plan for 2020, developed by the Energy Research Company (EPE), the generation of energy from oil and hydropower will decrease, increasing the generation of energy from natural gas and biomass, as can be observed in Figure 1.

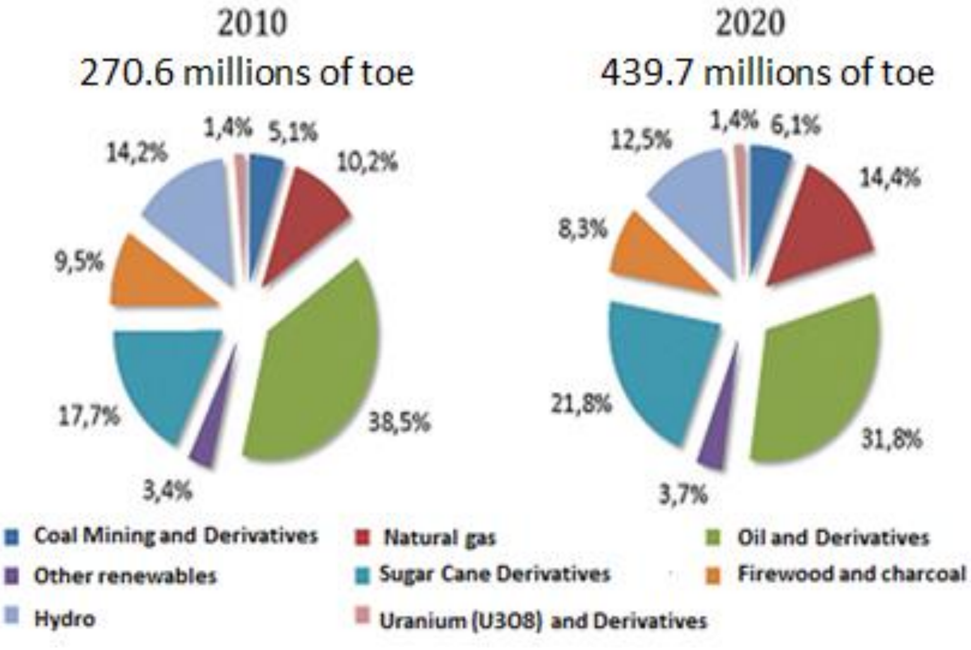

**Figure 1. Evolution of domestic energy supply.**
Source: BRASIL, 2011.

These measures point Brazil towards an increasingly sustainable energy sector, and greater diversification of energy sources, with a preference for renewable sources and low environmental impacts (TOMALSQUIM, 2012).

In addition to the traditional concern of governments in terms of energy security and economic growth, attention has also been paid to the environmental impacts of the sector, especially since the Intergovernmental Panel on Climate Change (IPCC) highlighted energy activities as the main cause of global warming and atmospheric emissions, which can significantly affect human activities and terrestrial ecosystems (HOUGHTON; JENKINS; EPHRAUMS, 1990). Thus, emission control policies in Brazil must encourage or promote an effective energy sector (a variety of energy sources that stimulate growth and at the same time guarantee environmental sustainability) (LIN et al., 2017).

Therefore, the integrated planning of energy resources is necessary. Santos et.al. (2011) points out that the integrated planning of energy resources was traditionally neglected due to institutional barriers (EPE, 2007). In practice, until recently the Federal Government only carried out expansion planning for the electricity sector, under the mandate of the Ministry of Mines and Energy - MME (SANTOS et.al., 2011).

In this context, the Integrated Energy Planning Cycle includes strategic diagnostic analyzes to identify energy potential, as well as the structure and the costs for energy development. It is recognized that Strategic Environmental Assessment (SEA) should be applied to energy expansion planning in Brazil to ensure sustainable development (SANTOS et.al., 2011).

Environmentalists and other interest groups perceive wind and natural gas as good candidates to improve the sustainability of the power generation sector. In order to diversify the energy generation sector and maintain the sustainability of the energy sector, alternatives have been identified, such as nuclear, wind, and natural gas power plants with multiple products (cogeneration and combined cycle systems) (MOREIRA, 2015).

## 2.2. Characteristics of the Brazilian regions

Covering 8,514,215 km², Brazil is the fifth largest country in the world and the largest in Latin America in terms of territorial area, extending between the latitudes 5º16'N and 33º45'S and longitudes 32º23'W and 73º59'W. The country has different regions with several climatic zones and synoptic regimes of atmospheric circulation (CRESESB, 2001).

Brazil is divided into 5 regions: North, Northeast, Midwest, Southeast, and South, as presented in Figure 2. Each region has specific characteristics in terms of soil and climate which accounts for the diversity of the country. According to IBGE (2017), the division of Brazil into regions serves academic interests, planning needs and, more recently, territory management.

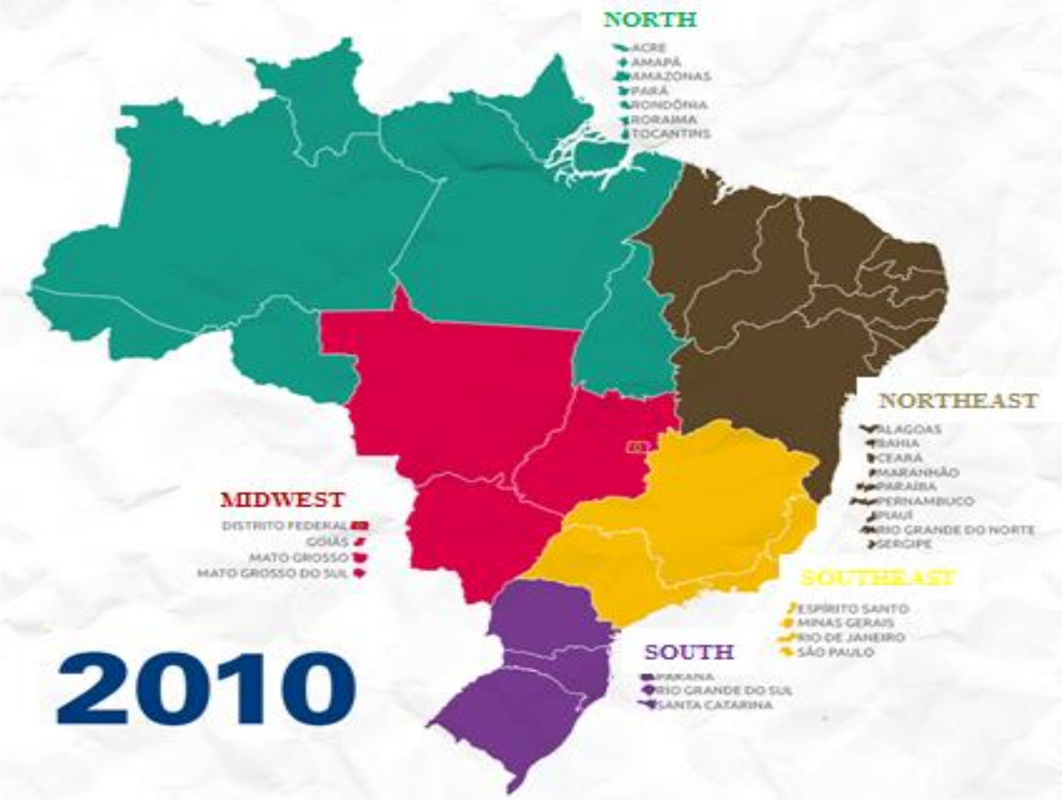

**Figure 2. Brazilian regions**
Source: Agência IBGE notícias from Revista Retratos, 2018.

The Northern region covers the greatest extent at 3,853,676,948 km², and comprises 7 states, including much of the Amazon Forest and the Amazonian biome. In spite of its extent, the region has a low population density. The climate is predominantly equatorial, and, due to the abundance of rainfall in the region, the humidity is high. The economy is based on the extractive mineral industries and agriculture. It has one of the largest water basins in the world, with enormous hydropower potential.

The Northeast region has an area of 1,544,291 square kilometers ($km^2$), consisting of nine states, with the largest number of federative units in the country, and is the second-most populous region of Brazil surpassing 56 million inhabitants. The region includes semi-arid, humid equatorial, humid, and tropical littoral climatic zones, with the largest coastal strip in Brazil. The wind potential in the Northeast is one of the largest in the whole country. Temperatures are high for most of the year and annual rainfall is very low. The local economy is boosted by tourism, due to prevailing warm weather and abundance of beaches.

The Midwest region has a territory of 1,606,403 $km^2$, and, although it is the second region in terms of territorial extent, the region is very sparsely populated, with a population density lower than the northern region. It is the only region in Brazil that has no coast, the climate is predominantly tropical with two well defined seasons: winter and summer. During the winter, the climate is very dry. The region has a diversity of biomes including the cerrado, wetland, and Amazon. The region's economy is based predominately on agricultural activities and extractive industries.

The Southeast region is the second smallest in terms of territorial extension, covering 924,620 $km^2$, and is composed of 4 states. However, the population density is the largest in the country, mainly because the region has the largest industrial, commercial, and financial centers in Brazil. The region has diverse climate zones, including the Atlantic tropical, tropical altitude, subtropical, and semi-arid zones. There is a diversity of biomes, including the Mata Atlântica, the cerrado, and the caatinga. The region has the largest hydropower capacity, however, this potential has already been realized for the most part.

The Southern region is the smallest region in the country, with an area of approximately 576,774 $km^2$, with only 3 states, but is the second-highest contributor to the Gross Domestic Product of Brazil. The economy is based on vegetable cultivation, agriculture, and livestock. The climate is predominantly subtropical, and this region experiences colder weather than the other regions of the country, with well-defined winter and summer seasons.

Thus, Brazil is very diverse in relation to climate and biomes. For this reason, and based on the extent of the country, there is enormous potential for energy generation.

Due to its latitudinal extent, the climate in Brazil varies from equatorial (wet and semi-humid) in the North to subtropical in the South region (CRESESB, 2001).

Figure 3 presents the Brazilian solar PV potential. The Northeast region, part of the Midwest, and part of the Southeast region have the greatest solar PV potential. Jannuzzi (2009) points out that Brazil has a greater solar PV potential than Germany, the leading country in installed capacity of solar PV systems.

**Figure 3. Solar Photovoltaic (PV) Power Potential.**
Source: The World Bank, 2017.

Brazil has been trying to encourage solar PV through incentive programs, the largest being PRODEEM (State and Municipal Energy Development Program) (Jannuzzi, 2009). Despite these investments, there is limited use of PV solar energy and development of the market.

Figure 4 presents the wind potential in Brazil, according to the 2001 Atlas of Wind Energy. The distribution of the winds is controlled by high-pressure systems such as the Subtropical Anticyclone of the South Atlantic and the North Atlantic and the range of low pressures related to the Equatorial Depression.

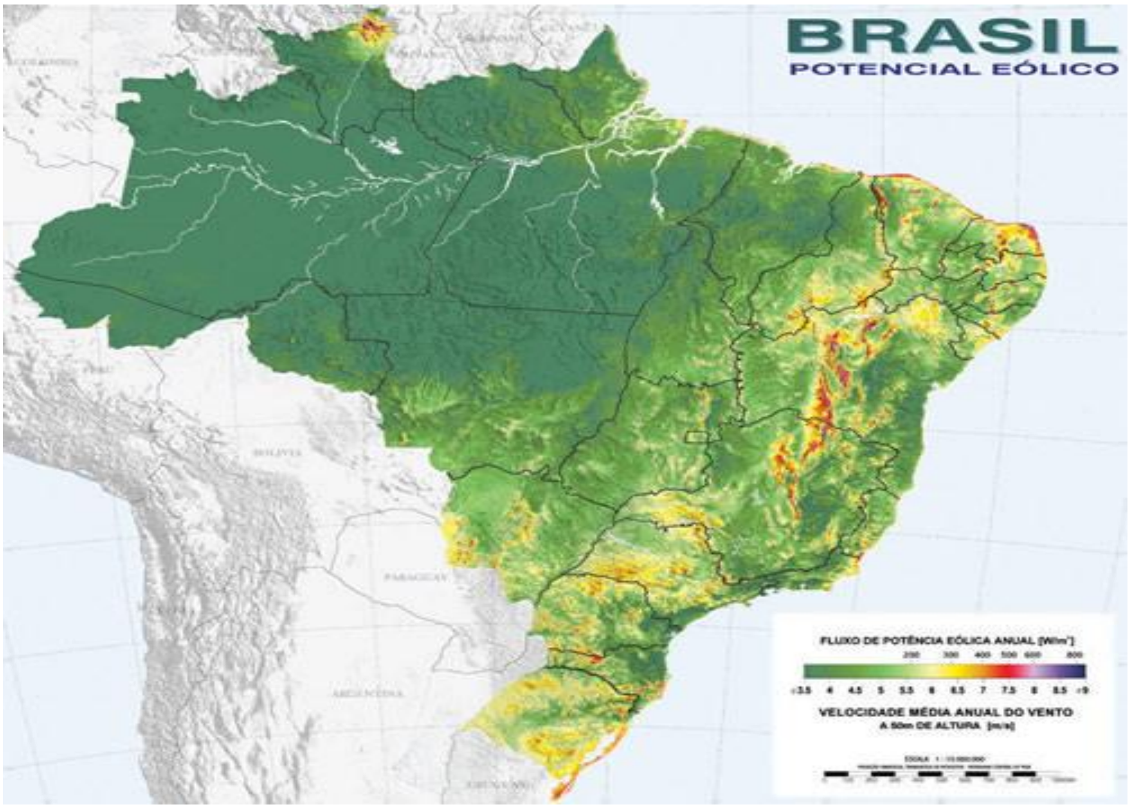

**Figure 4. Brazilian Wind Potential.**
Source: CRESESB, 2013.

According to the 2001 Atlas of Wind Energy from CRESESB (2013):

> The average position of the Equatorial Depression extends from west to east along the northern region of Brazil and on the adjacent Atlantic Ocean. It coincides with the location and orientation of the Amazon Basin, at the center of which there is a persistent range of low pressures. The Equatorial Depression is usually a zone of small pressure gradients and weak winds. North of the Equatorial Depression the winds are persistent from east to northeast. To the south, winds are persistent from east to southeast between the Equatorial Depression and the Atlantic Subtropical Anticyclone, which has an average annual position near 30ºS, 25ºW. This general profile of atmospheric circulation induces east or northeast winds over the Brazilian territory to the north of the Amazon Basin and on the northeast coast. Winds near the surface are generally weak throughout Equatorial Depression, but increase in intensity to the north and south of this range. The area between the Equatorial Depression and the latitude of 10ºS is dominated by trade winds from east to southeast. To the south of latitude 10º S, to the extreme south of Brazil, the effects are dictated by the dynamics between the high-pressure center of the Anticyclone Subtropical Atlantic, polar mass displacements and the Northeast Depression of Argentina - a center of low-pressure east of the Andes.

Figure 5 shows the Brazilian hydroelectric potential, according to the Atlas of Electric Energy of 2008. Brazil has the highest global hydroelectric potential: a total of 260,000 megawatts (MW), according to the Eletrobrás Plan (2015). Over 30% of this capacity has been converted into built or granted plants. According to the 2030 National Energy Plan, the future hydroelectric potential is approximately 126,000 MW, with more than 70% located in the Amazonas and Tocantins / Araguaia basins.

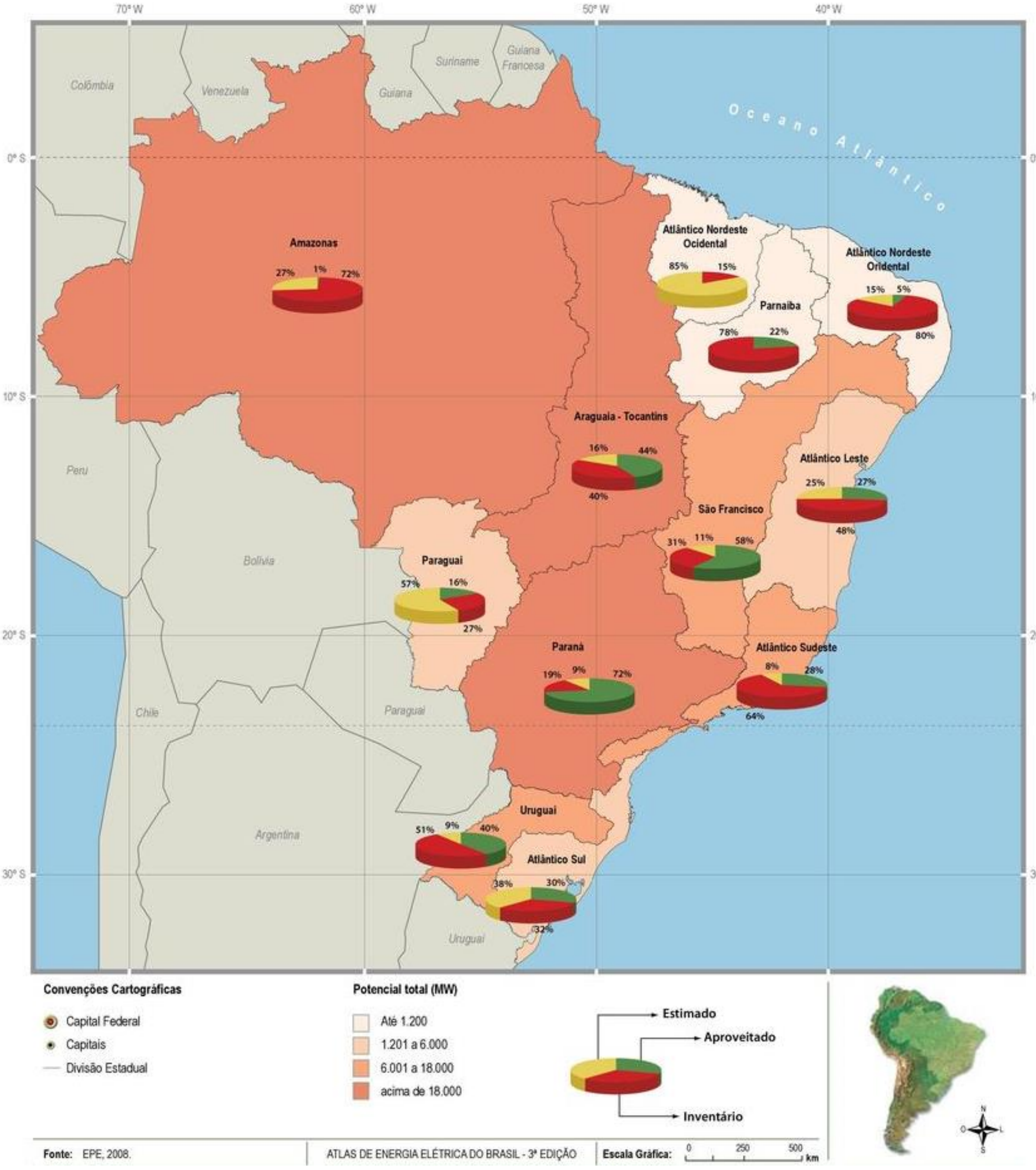

**Figure 5.Brazilian Hydroelectric Potential.**
Source: ANEEL, 2008.

## 2.3. Capacity of generation of energy in Brazil

Brazil has a total of 7,143 power plants in operation, with a total of 160.6 gigawatts (GW) of installed capacity, as shown in Table 1 (ANEEL, 2018). Additional generation capacity of 20,255 MW is expected from the 208 projects currently under construction and 398 in projects yet to be constructed.

**Table 1. Generation of energy in Brazil.**
Source: Adapted from ANEEL, 2018.

| Type | Amount | Rated Power (kW)[1] | Supervised Power (kW)[2] | %[3] |
|---|---|---|---|---|
| Hydropower (power > 30MW) | 218 | 101.892.288 | 97.075.157 | 60,37 |
| Hydropower (power between 5 and 30 MW and less than 13 km² of reservoir area) | 693 | 691.131 | 690.133 | 0,43 |
| Small Hydropower (power between 0 e 5 MW) | 427 | 5.178.959 | 5.130.531 | 3,19 |
| Waves | 1 | 50 | 50 | 0 |
| Wind | 546 | 13.450.139 | 13.427.343 | 8,35 |
| PV | 2.258 | 1.433.573 | 1.426.773 | 0,89 |
| Thermoelectric | 2.999 | 42.630.823 | 41.059.179 | 25,53 |
| Nuclear | 2 | 1.990.000 | 1.990.000 | 1,24 |
| **TOTAL** | **7.144** | **167.266.963** | **160.799.166** | **100** |

Figure 6 presents the generation of energy from July 2017 to July 2018 in Brazil, based on data obtained by the National Electric System Operator - ONS (2018). In terms of the National Interconnected System (SIN), hydropower still represents an important vector of expansion in the electrical energy supply. Most of the potential lies in the North region which presents a series of challenges, mainly in terms of environmental impacts (BRASIL, 2017). Thus, a set of strategic ecological and economic studies are needed to promote a long-term vision for hydroelectric exploitation in the Amazon (TUNDISI, 2007).

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[1] The Rated Power is equal to that considered in the Granting Act.
[2] The Supervised Power is equal to the one considered from the commercial operation of the first generating unit.
[3] The percentage values refer to Supervised Power.

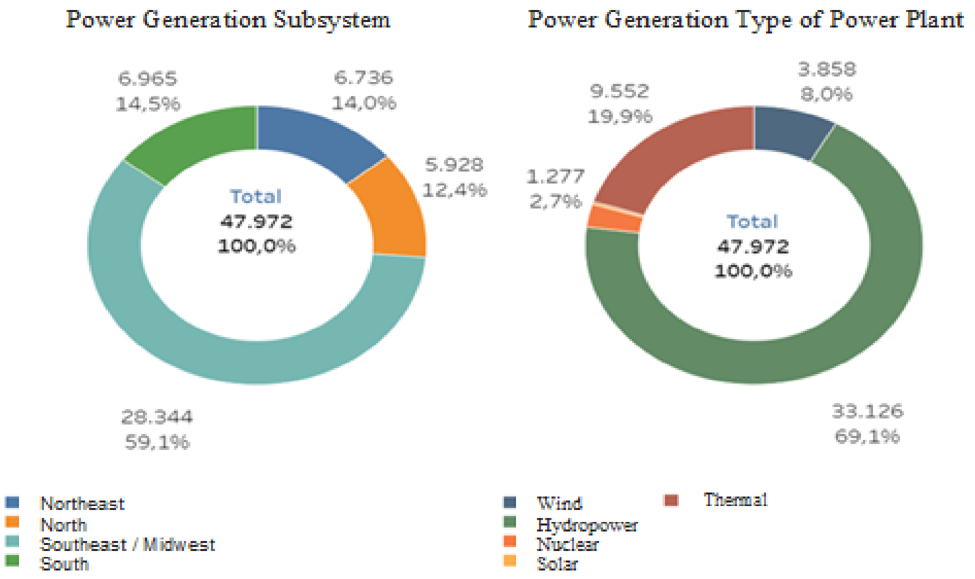


**Figure 6. Generation of energy by subsystem and by type of power plant.**
Source: ONS, 2018.

Energy generation in the Southeast and Midwest regions is currently larger, as the Amazon river basin, which makes up 20% of the total global freshwater, with an abundance of rivers, was not considered a potential source of energy until the late seventies. This was due to the flat topography of the rivers, where waterfalls are rare, and the difference in height between their springs and sea level is only a few hundred meters. In addition, there are challenges with the transmission of this energy through the forest and with connection to the SIN (MATOS, 2011).

In general, the Brazilian electric sector is characterized by large hydropower plants with multi-year reservoirs for water regulation. As the potential water resources near the centers of consumption have been exhausted, Brazil has been experiencing an expansion of its electricity grid limits. Many hydropower plants are located far from the main centers of consumption, resulting in higher costs of transport and distribution (SILVA² et.al., 2016).

Compared to the South and Southeastern regions, energy generation in the Amazonian basin presents problems relating to spatial and temporal scales (TUNDISI, 2007). Renewable energy sources are intermittent and cannot replace traditional sources in isolation (TRANIM, 2016).

Figure 7 presents the electricity flows in Brazil and the main sources and consumers of generated energy, and the contribution of hydropower plants is undeniable. However, when the expansion of hydropower negatively affects biodiversity, it is necessary to look for alternative ways to meet energy needs and achieve energy security.

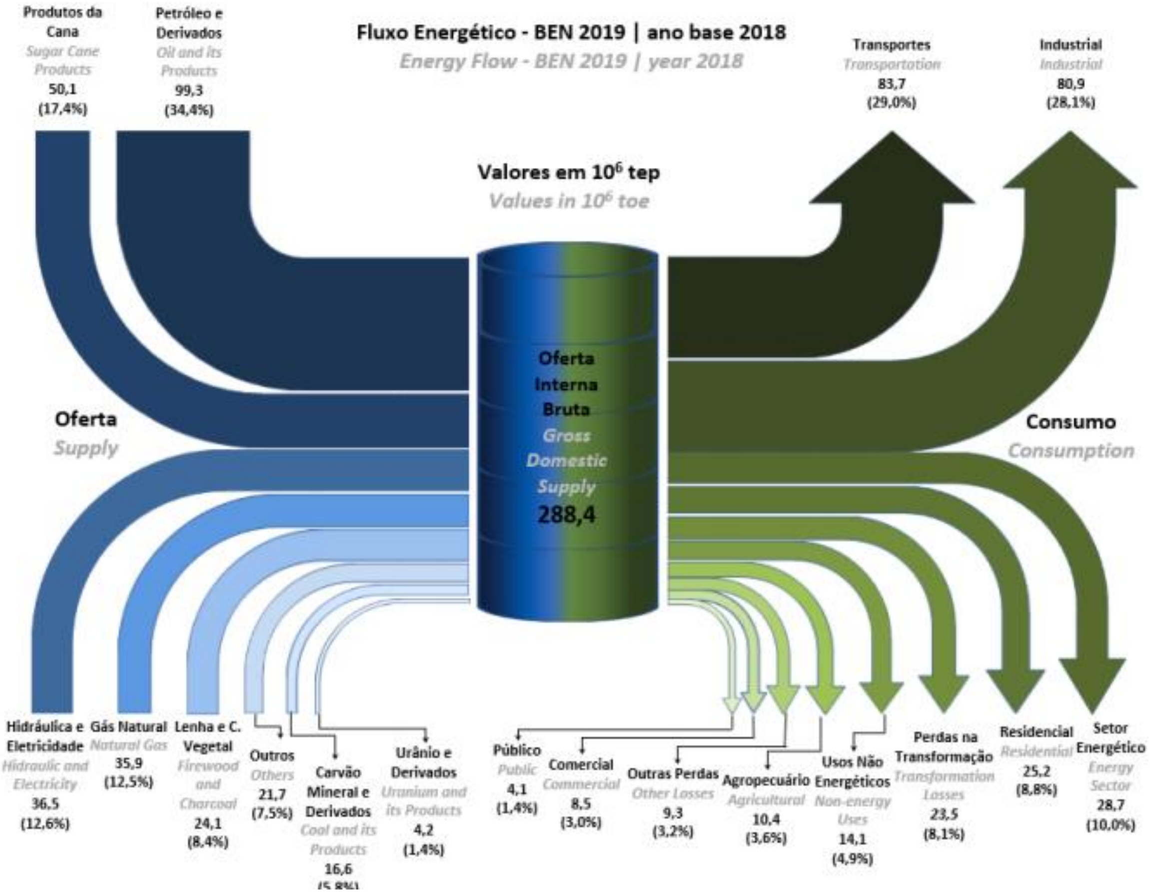


**Figure 7. Electricity Flux, year 2019.**
Source: EPE, 2019.

In order to reduce the reliance on hydroelectric power from the Amazon Basin, Brazil must look beyond the expansion of wind power generation. One option would be to replace some of the most polluting fossil fuel power plants with new renewable or nuclear power plants. Another option would be to increase storage capacity by building low-impact storage tanks or to evaluate the use of batteries and introduce mechanisms to reduce thermal generation requirements during peak load periods. Finally, demand-side interventions, such as better energy efficiency or load control, can support emissions mitigation efforts (FARIA, 2017).

## 2.4. Public policies for sustainable energy sector

The Incentive Program for Alternative Sources of Energy (PROINFA), established in 2002, was a great landmark and is the main public policy in Brazil that aims at diversifying the country's energy matrix through alternative sources of energy. Despite this policy, there is little evidence of actual planning for a truly sustainable sector in Brazil, according to ESTADÃO (2019). The current Minister of Mines and Energy, Bento Albuquerque, stated in a note that he intends to resume the plan to build between four to eight new nuclear power plants in the country. Currently, the country has only two nuclear plants that account for 1.1% of the national power generation.

Therefore, Brazil is not aligned with the global trend of seeking solutions to generate energy with lower environmental impact. As an example, the European Commission has set the mandatory target of 32% energy obtained from renewable sources in 2030 in the European Union.

The current planning model of the Brazilian electric sector was established in 2004 and allows for the offer and the realization of auctions. The main objective of the auctions is to ensure that the supply is expanded to meet the demand growth with the lowest possible generation cost, and guaranteeing the tariff modality, one of the pillars of the regulatory framework of the Brazilian electric sector (SILVA et.al., 2014).

Historically, Brazil sought to rely on national energy resources whenever possible, due to the costs associated with importing oil and its derivatives. However, as world trade grows and Brazil increases its relative share, it is necessary to consider whether this policy will be valid in the future (GOLDEMBERG & MOREIRA, 2005).

Concern about the dependence on fossil fuels has led to greater diversification of energy sources, with a preference for renewable sources with lower environmental impact (TOLMASQUIM, 2012). It should be noted that the diversification of energy sources is justifiable in terms of the availability of energy sources since the country has the potential to expand non-renewable energy sources, such as oil, natural gas, coal, among others. However, it also has strong potential for renewable energy sources, such as wind, solar, biomass, hydrogen, and ocean energy (SILVA et.al., 2014).

A large number of variables involved in energy planning requires complex energy policies. The importance of these policies is increasing since the energy sector depends on private investments. Therefore, the role of government is increasingly limited to the management of expansion, and government must define policies in the interest of society, not driven by private sector interests (GOLDEMBERG & MOREIRA, 2005).

In a geopolitical approach, it is important that a country does not rely on one or only a few sources of energy. Political disruptions in other countries can lead to serious setbacks for the energy sector, which is not uncommon (SILVA et.al., 2014).

Therefore, international aspects, related to the import and export of energy, also require the establishment of planning policies. For example, data on the advantages of producing or importing energy in the country are not usually included in energy planning and decision-making (GOLDEMBERG & MOREIRA, 2005). Brazil's energy sector is currently faced with two large problems according to Alcoforado (2012):

> The first is related to the need to reduce the consumption of oil products to reduce $CO_2$ emissions and contribute to the fight against global warming. The second concerns the country's electricity supply, which may involve the construction of several large hydropower plants in the Amazon with their environmental impacts on the Amazon forest and the indigenous communities there. However, the first is still disputed by the current government that does not believe in global warming and has plans to build more nuclear power plants in Brazil, the second is not taken into account considering the numerous hydroelectric projects for the Amazon region.

So it is necessary to diversify the Brazilian energy sector, for the sake of the environment and to improve energy security. Thus, in order for the renewable energy market to be leveraged, a greater diversity of resources is necessary for the development of more accessible technologies and the establishment of a favorable and safe regulatory framework for investors. Although Brazil has entities that are responsible for the planning and expansion of the energy axis, there is a need for adaptation to the new economic and socio-environmental parameters in order to fully utilize the energy generation capacity (MYSZCZUK & SOUZA, 2018).

The recent blackouts in Brazil can be attributed to four factors (ALCOFORADO, 2012):

I. Lack of adequate coordination of the protection system that was not able to isolate the problem in the affected area, leading to blackouts in the three regions of the country;

II. Lack of dual protection systems in critical areas that can be triggered in the occurrence of failures in the electrical system;

III. Lack of an adequate maintenance service that minimizes the occurrence of failures in the electrical system, and

IV. Lack of emergency energy supply systems in critical areas that can be triggered during blackouts.

Planning in the Brazilian energy sector must consider the deterioration of the quality of the service by the private companies involved in the sector which can be addressed through improvement in the regulation of the sector.

Scenario planning is fundamental for both the formulation of policies and the development of business strategies, especially those related to investments. There are several challenges in building scenarios, especially in long-term planning. One of the main difficulties is to predict the impact of energy technologies that currently may not be feasible on a large scale or are not yet available (DRANKA & FERREIRA, 2018).

In Brazil, hydroelectricity is still the most widely used source for the generation of electric energy. However, the energy sector and related infrastructure must be adapted based on the shift to renewable sources and ambitious targets (MYSZCZUK & SOUZA, 2018). Brazil has enormous potential for generating renewable energy and to achieve a more sustainable energy sector, however, there are several controversies in terms of the regulation of the electricity sector, as reported by Alcoforado (2012):

- Although Brazil has a hydroelectric potential of 83 GW outside the North that could be used without affecting the Amazon rainforest, the Brazilian government continues to plan and implement large hydroelectric projects in the Amazon region.
- The 2030 National Energy Plan does not utilize the significant potential for solar energy in Brazil, and PV panels should be widely disseminated in isolated communities in rural areas where the cost of electricity supplied by the grid is higher.
- The 2030 National Bioenergy Plan has not considered the great biomass potential in Brazil, which is estimated to be around 10 terawatt-hours (TWh) / year (10,000 gigawatt-hours [GWh] / year). Only 4.75 GW, which corresponds to 2.1% of the biomass potential, will be installed by 2030.

## 2.5. Complementarity between Brazilian alternative energy sources

The complementarity between the energy sources is essential to ensure the matching between generation and demand. There has been limited research in this regard, subject has been the object of research. Nowadays, different approaches can observe on the subject, however there is still research to contribute to the bibliographical in Brazil, mainly due to the fact that in recent years, the Amazon region has been the target for installation of large hydropower projects.

Matos et.al. (2011) states that due to the characteristics of the region it is not advisable to allow for "the implementation of industry enterprises, and especially the development of communities living in the forest, which relegates the population to a situation of low social and economic development, giving rise to a predatory natural resources, risking the environment where they are inserted”. The study concluded that “although the rivers of the Amazon Forest have great potential for the installation of hydroelectric plants; this is the main option for the Brazilian government for energy generation as the country has major engineering expertise in this technology and due to the immediate generation of thousands of direct and indirect jobs related to construction of these plants; this solution, which is apparently exempt of $CO_2$ emissions is environmentally hazardous to local biodiversity”.

Soito and Freitas (2011) warn about the environmental impacts of and contribution to global climate change related to the expansion of hydroelectric plants in the Amazon. The authors noted that energy losses occur mainly because the hydroelectric power plants are located outside the centers of consumption. In addition, in this region, there are more rigorous socio-environmental restrictions.

Silva et. al. (2015) analyzed wind and hydropower complementarity in Brazil's national energy planning, and highlight the challenges. Silva et. al. (2015) strongly object to the 2030 National Energy Plan and stated that it "should have taken into account the factors of popular participation in the construction of the plan, index of human development of the population, and the insertion of the environmental variable, not as a correction of small importance, but as essential working hypotheses" and warn of the "wind potential in Brazil, especially in the Northeast, which shows potential for more aggressive growth in wind capacity for the next few years”.

Moreira et.al. (2015) propose increased investments in wind power plants and natural gas with combined-cycle and cogeneration systems to improve the sustainability of electricity generation in Brazil.

Ricardo et.al. (2015) studied the complementarity of wind and solar PV sources in the state of Paraná. According to the authors, "the potential of these sources to produce electric energy is based on the climatic and geographical characteristics of the State. Through the analysis of scenarios, the result of this research shows that the generation of electric energy by PV or wind power source is an excellent technical option, able to complement the current demand for electric power in the state of Paraná and still contribute to the electrical sector of other Brazilian states".

Cantão (2015) presented a quantitative and comprehensive analysis of the hydroelectric complementarity in Brazil. This analysis included mathematical models associated with the complementarity of energy sources. This study is quite complex as it used the PHOENIX model that, according to Mauricio Pereira Cantão (2015), "differentiates in terms of individualized plants and is non-linear, multi-objective, stochastic, and able to verify the electrical constraints". In Cantão et.al. (2017) a similar evaluation of hydroelectric complementarity is presented through correlation maps, and this analysis is considered useful for operation and expansion strategies.

Silva[1] et.al. (2016) assessed the complementarity of Brazilian hydropower and offshore energy, confirming that there is strong seasonal complementarity between the wind regimes of the Northeast and North regions. This study used monthly precipitation data and compared this to the wind speed (verified by satellites), concluding that "during dry periods, thermal power is usually required to back up the system”.

Mendes et.al. (2017) uses a methodological approach "with information from various scenarios of climate change and compares those with standard hydrological records and hydroelectric generation information". This study indicates that the hydrographic basins of the Amazon region are located in a region sensitive to the effects of climate change, and concluded that "climate change is a significant uncertainty in the projections of financial revenues obtained from hydroelectric generation in the Amazon, possibly posing considerable risks and endangering an expansion energy system based on hydroelectric resources of the region”.

According to Faria et. al. (2017), "the Brazilian government has plans to build 26 large hydroelectric plants in the Amazon basin between 2013 and 2028”. Based on this expansion plan, the study created “alternative scenarios where wind and natural gas power plants replace the large hydropower plants. The scenarios were compared using various performance indicators: greenhouse gas emissions, land use, capital and operating costs, wind reduction, and energy storage in hydroelectric reservoirs”, concluding that "all capacity scenarios result in annual increases in GHG emissions from power generation in 2028 compared to 2014”.

Hunt et.al. (2018) analyze the water cycles of Brazil, motivated by the last Brazilian energy crises that resulted from a prolonged drought, based on the natural river flow data from the main Brazilian dams from 1931 to 2017. It was concluded that "hydroelectric generation in Brazil has a cyclical pattern of 10 to 15 years" and "periodic droughts in this cyclical pattern generally coincide with energy crises due to generation reduction”. The authors suggest the diversification of energy generation and the "increase in the share of renewable sources and an increase in potential energy storage of the country”.

Luz et.al. (2018) present a multi-objective model for the expansion of the energy sector with a high share of RES, promoting the use of non-hydro RES. The main findings of this study indicated that the high use of wind does not assist with the supply of peak demand since the period of lower generation coincides with the period of higher demand. With the objective to meet the government's goals and the peak demand, solar PV was found to be the most suitable non-hydro renewable source to ensure the expansion, since its daily generation curve coincides with the peak load period.

# 3. ENERGY AND AMAZON

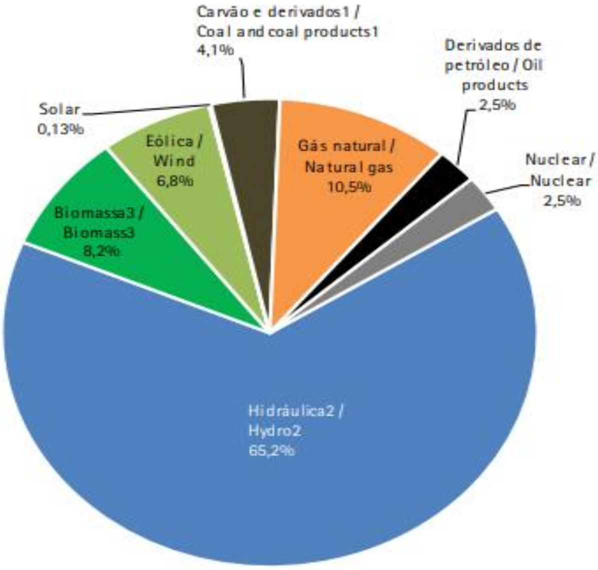
The largest hydropower plants in Brazil are installed in the Amazon, and there are plans for the installation of five additional power plants in the region, such as Cachoeira do Caí; Cachoeira dos Patos, Jamanxim, Jatobá, and São Luiz do Tapajós. However, Brazil cannot continue to depend on hydropower plants, because, despite the large potential that is still available, this option does not guarantee energy security. Therefore, changes to the energy sector are required to ensure security in the generation of energy.

## 3.1. Hydraulic Energy and the Amazon

Brazil has a vast potential in terms of harnessing renewable energy in all 27 states, especially in terms of electricity generation (HUNT et. al., 2018). The country can be considered an energy and environmental power since the country has a rich diversity of alternative energy sources (TOMALSQUIM, 2012). Renewable sources represent 80.4% of Brazil's domestic electricity supply, which includes domestic production plus imports, which are essentially of renewable origin (EPE, 2018).

Brazil is a large country that relies on a largely renewable energy sector with a major focus on hydropower, which has historically allowed for low carbon electricity production. However, the increase in demand and climate change impacts related to these renewable resources represent important challenges for long-term power planning (DRANKA et. al., 2018).

Figure 8 shows that Brazil has a predominantly renewable electric sector, mainly based on hydropower that accounts for 65.2% of the domestic supply (EPE, 2018). This is translated into a significant dependence of the country's electricity on water availability (CADERNO SETORIAL DOS RECURSOS HÍDRICOS, 2006).



[4][5][6]

**Figure 8. Internal Supply of Electricity by Source.**
Source: EPE, 2018.

However, considering the significance of the environmental aspects of the Amazon region, characterized by important Conservation Units and Indigenous Lands, it is possible that a large part of the estimated hydropower potential in the Amazon region (41%) is not environmentally sustainable (CADERNO SETORIAL DOS RECURSOS HÍDRICOS, 2006).

Table 2 presents the potential of each sub-basin of the Amazon Region and restrictions. Such restrictions occur due to environmental factors, or location within indigenous demarcated territories, national parks, quilombo areas, sustainable development reserves, environmental protection areas, national forests, biological reserves, etc. Based on data from SIPOT (Eletrobrás, 2006) and ANEEL (2006), the hydroelectric potential to be harnessed in the Amazon basin is about 106,000 MW. The potential in the basin is estimated at 77,058 MW, distributed in 13 sub-basins, and is concentrated in four sub-basins (Tapajós, Xingu, Madeira, and Trombetas) which account for almost 90% of this potential (BRASIL, 2007). However, including the Tocantins/ Araguaia basin, the 15 sub-basins have an estimated potential of 88,355 MW.

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[4] Includes coke oven gas,

[5] Includes electricity imports,

[6] Includes firewood, sugarcane bagasse, black-liquor and other primary sources.

**Table 2. Socio-environmental constraints on the hydroelectric potential by sub-basin.**
Source: Adapted from HERNADEZ, 2012.

| Sub-basin | Available Potential (MW) | Potential with restrictions (MW) | Potential with restrictions (%) |
|---|---|---|---|
| Tapajós | 24,626 | 17,841 | 72.40 |
| Xingu | 22,795 | 17,114 | 75 |
| Madeira | 14,700 | 1,556 | 10.50 |
| Trombetas | 6,236 | 4,745 | 76 |
| Tocantins | 8,202 | 7,109 | 87 |
| Negro | 4,184 | 4,184 | 100 |
| Araguaia | 3,095 | 3,095 | 100 |
| Jari | 1,691 | 1,373 | 81.10 |
| Branco | 1,079 | 660 | 61.10 |
| Paru | 938 | 118 | 61.10 |
| Oiapoque | 250 | 250 | 100 |
| Purus | 213 | 213 | 100 |
| Maecuru | 161 | 161 | 100 |
| Nhamundá | 110 | 110 | 100 |
| Uatumã | 75 | 0 | 0 |
| **TOTAL** | **88,355** | **58,529** | **66,20** |

In the Amazon basin, more than 44% of the potential will have direct impacts on indigenous lands, since more than 25% of Amazonia is reserved. National parks are the second most impacted feature (BRASIL¹, 2017).

Tolmasquim states that the North is the country's great hydroelectric frontier, but it is also the region with the greatest biodiversity (of fauna and flora) with large indigenous communities, so the great challenge is to assess whether the hydroelectric potential can be used without risk to the ecological heritage (ESTADÃO, 2014).

Therefore, large technical interventions must include the life cycle analysis (LCA) of hydroelectric power plants, including the methane emissions associated with reservoirs in areas of tropical forest (HERNANDEZ, 2012).

Currently, hundreds of hydropower dams have already been built in the Amazon basin and numerous proposals for new dams are being considered. The cumulative negative environmental effects of existing dams and proposed dams, if built, could trigger huge hydrophysical and biotic disturbances that will affect alluvial plains in the Amazon Basin, the estuary, and the sediment plume (LATRUBESSE, 2017).

To quantify the current impacts and potential future impacts of dams in the Amazon basin, Latrubesse (2017) introduced an "Environmental Dams Vulnerability Index". Latrubesse concluded that the scale of the predictable environmental degradation indicates the need for collective action among states to avoid cumulative and far-reaching impacts and also suggested institutional innovations to evaluate and avoid the probable impoverishment of the Amazonian rivers (LATRUBESSE, 2017).

In summary, the hydropower dams in the Amazon can represent a wrong choice in relation to the region's environmental heritage. Brazil requires an appropriate energy plan to address the challenges posed by climate change and development (GREENPEACE, 2016).

José Goldemberg argues that the diversification of the energy sector can be ensured by increasing the share of wind and biomass, in particular by taking advantage of the large potential of sugarcane bagasse in the production of electricity (ESTADÃO, 2014). Greenpeace (2016) proposed scenarios (Table 3) for the optimal combinations that would be feasible and could guarantee the equivalent energy as that generated by the São Luiz do Tapajós hydropower project.

**Table 3. Scenarios of renewable sources to replace the proposed São Luiz do Tapajós Hydroelectric Plant.**
Source: Adapted from GREENPEACE, 2016.

| Combination of power plants | Physical Warranty (average MW) |
|---|---|
| PV + wind | 4,425 |
| PV + wind + biomass | 4,093 |
| Wind + biomass | 4,185 |

## 3.2. Amazonian Biome

The Brazilian Amazon is threatened by the uncontrolled exploitation of its natural resources. More than 750,000 $km^2$ of forests have already been destroyed by activities, such as agricultural production, mining, illegal logging, and large infrastructure projects, especially hydropower plants, putting the region's biodiversity at risk, forcing the displacement of indigenous communities, and aggravating global climate change (GREENPEACE, 2016).

The Amazon is the only large continuous expanse of tropical rainforest in the world (ROCHA et.al., 2012). With an area of approximately 7 million $km^2$, which corresponds to 56% of the Earth's tropical forests, the Amazon plays an important role in energy, humidity, and mass exchange between the continental surface and the atmosphere, providing services key to maintaining the regional and global climate, such as: storage and absorption of excess carbon from the atmosphere, the transport of trace gases, aerosols and water vapor to remote regions, and precipitation recycling (ROCHA et.al., 2015).

The Amazonian biome occupies 40% of the national territory in Brazil and the Amazon region is formed by the states of Pará, Amazonas, Amapá, Acre, Rondônia and Roraima and some parts of Maranhão, Tocantins and Mato Grosso. The Amazon region is a complex mosaic of different types of vegetation, including closed rain forest, forested forest, savannas, forest and bamboo, marshes, mountain and submontane forest, and liana forest (MURCIA-PIRES, 1984; NELSON & OLIVEIRA, 2001).

The Amazon region is recognized as having the largest animal and plant biodiversity in the world and it has several hydrographic basins that form the largest global reservoir of freshwater. The Amazon biome is composed of the Amazon basin and the Tocantins Araguaia basin. According to SEMA (2012), the Amazon basin region (represented by no. 1 in Figure 9) comprises the Amazon river, the hydrographical basins of the rivers in the Ilha do Marajó, and the hydrographic basin of the rivers located in the state of Amapá that flow into the North Atlantic. The hydrographic region of Tocantins / Araguaia (represented by no. 2 in Figure 9) includes the hydrographic basin of the Tocantins river until its mouth in the Atlantic Ocean.

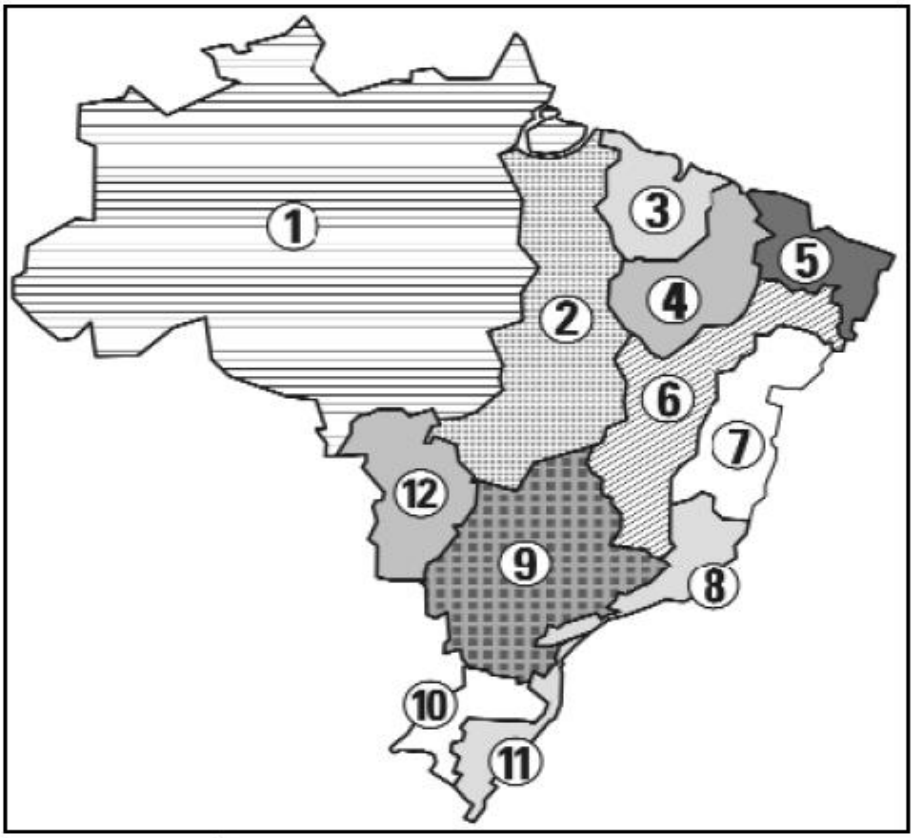

**Figure 9. National hydrographic regions.**
Source: SEMAS, 2012.

The Amazonian rivers have a well-developed alluvial plain, with the formation of terraces composed of quaternary sediments. The climate is predominantly tropical humid, with an average precipitation of 2,000 mm/year, which increases to the northeast, reaching, in some parts of the subandine zone to more than 4,000 mm/year. (LATRUBESSE et.al., 2005).

Currently, according to Rocha et.al. (2012) changes to the Amazonian humidity balance of are due to changes in land use and global climate which are in turn due to the increase in GHG emissions. Together with deforestation, this has contributed to an increase in the surface temperature in the Amazon basin at 3.4 °C, on average. This is pf great concern as it could cause instability to the Amazonian ecosystems (ROCHA, 2012).In general, although the Amazon region covers a large area, Vinícius Machado Rocha et.al. (2012) concluded that the region is not very adaptable to the magnitude of the changes in land use and the global climate.

## 3.3. Use of water resources in the Amazon

The historical use of water resources in Brazil can be divided into three phases, the fragmentary phase, the sectorial phase, and the holistic phase (BENJAMIM, 1999):

- The fragmentary phase occurred from the discovery of Brazil until 1930 in which there was no concern or interest with the environment, with some exceptions, and water protection was not included. Legislation to ensure the preservation of natural resources was only intended to ensure the preservation of resources that had economic value, such as Brazil wood.
- In the sectorial phase, regulations on the right to use water resources were introduced but were limited to the private use of and with limited economic value.
- Finally, in the holistic phase, the importance of sustainable management of this water resources was recognized, with the implementation of laws and incentives to improve the management of water resources.

It is evident that the Amazon has been degraded since the discovery of Brazil, mainly through the extraction of natural resources with economic value. More recently, at the time of the military dictatorship and its vision of 'Integrating not to deliver' and 'Land without man for man without land', programs were implemented that encouraged occupation of the Amazon, without assessment of the environmental impact of the migration on the Amazon or consideration of impact mitigation.

Most of the main hydropower resources of the Southeast, South, and North regions have already been developed. Additional resources are still available in the Amazon region, but several social and environmental groups advocate against their development (MOREIRA, 2015). In general, the ecological impacts of the construction of hydropower plants in the Amazon are mainly due to the effect of the removal of flooded terrestrial vegetation, the impact on the floodplains, the deterioration of water quality, and the loss of terrestrial and aquatic ecosystem service, including biodiversity (TUNDISI et al., 2006).

The potential impact on indigenous peoples is also significant as the greatest concentration of these communities in the Amazon is located within the area with the highest potential for hydropower development (FEARNSIDE, 2015). The Belo Monte (Pará) is expected to be the third-largest hydropower plant in the world and forms part of the Federal Government's Growth Acceleration Program, initially planned by the military government in the middle of the forest in the Xingu river basin. This area is home to more than 20 indigenous communities, and although they are directly affected by the project, they did not participate in the process (SILVEIRA, 2017).

The scale of planned hydropower development for the Amazon is tremendous. The "Plan 2010" listed 79 potential dams in the Amazon, as presented in Figure 3 (FEARNSIDE, 2015). These dams would flood 10 million hectares, or approximately 2% of the Legal Amazon region and approximately 3% of the Brazilian portion of the Amazon rainforest (FEARNSIDE, 2015).

**Figure 10. Hydroelectric plants planned for the Amazon.**
Source: FEARNSIDE, 2015.

According to the 2020 Ten Year Energy Expansion Plan (BRAZIL, 2011), the energy generation of planned hydropower plants in the northern region of Brazil is 8,035 MW, as shown in Table 4.

**Table 4. New hydro projects to be feasible from 2019 to 2020.**
Source: Adapted from BRASIL, 2011.

| Entry into Operation | | Project of Hydropower plant | River | Power (MW) |
|---|---|---|---|---|
| Year | Month | | | |
| 2019 | out | Cachoeira dos Patos | Jamanxim | 528 |
| | nov | Marabá | Tocantins | 2.160 |
| 2020 | out | Jatobá | Tapajós | 2.336 |
| | out | Jamanxim | Jamanxim | 881 |
| | out | Cachoeira do Caí | Jamanxim | 802 |
| | nov | Serra Quebrada | Tocantins | 1.328 |
| Total | | | | 8035 |

The São Luiz do Tapajós hydropower plant was supposed to start operation in 2017 (but was delayed to 2019). This plant will have a capacity of 6,133 MW according to the 2020 Energy Expansion Plan (BRAZIL, 2011). In addition to the São Luiz do Tapajós hydropower plant, there are a further four dams planned for the Tapajós Hydroelectric Complex, as presented in Figure 11, on the Tapajós River, in Pará, and on one of the largest tributaries of the Amazon River, the river Jamanxim (GREENPEACE, 2016).

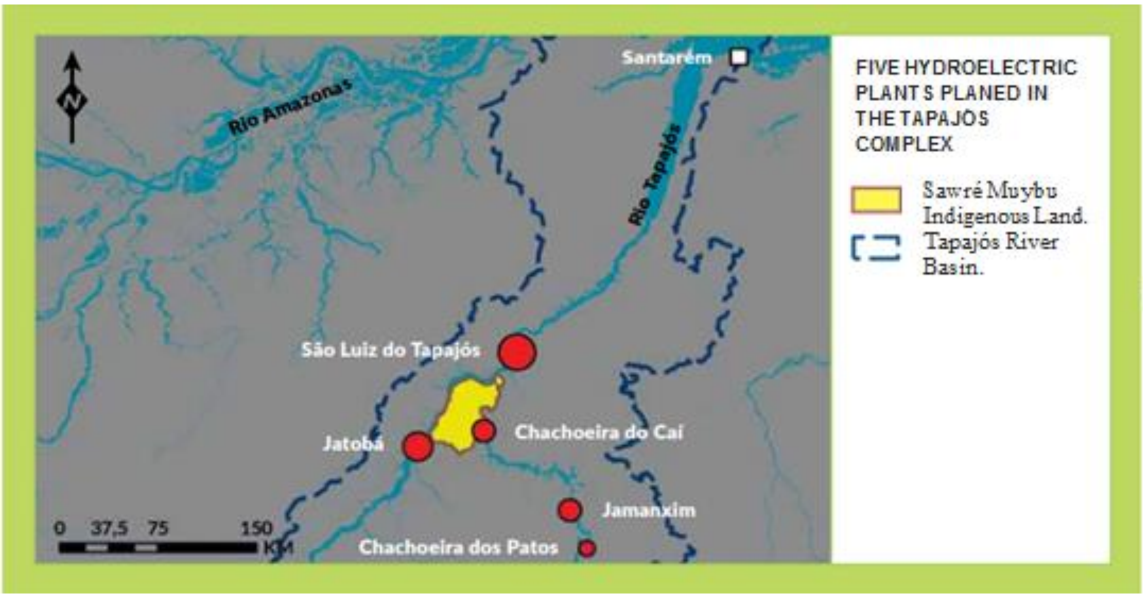

**Figure 11. Hydropower plants planned for the Tapajos complex.**
Source: GREENPEACE, 2016.

# 4. EVALUATION AND DATA

## 4.1. Evaluation

The research was subdivided methodologically into three parts:

1. Data collection;
2. Definition of the scenarios;
3. Data analysis.

The first part consisted of the collection of data made available by the Brazilian Government through the National Electric System Operator (ONS). Monthly data was obtained on the generation of renewable energy (solar, wind, and hydro) from each region of the country. The second stage consisted of the definition of the various scenarios relating to several generation mix options distributed between the sources and the regions.

These scenarios were selected because they complement each other or provide an alternative to strictly hydropower, as can be seen in Table 5. The aim of this study is to observe the complementarity between alternative energy sources in Brazil, focusing on scenarios in which energy sector diversification could occur with a focus on alternative, under-utilized energy sources in Brazil, reducing dependence on hydropower, and preventing further impacts on the Amazonian basin.

Among the scenarios, present in the Table 5, it is not possible to analyze the solar PV energy of the north region and the biomass of all the regions because there is currently no generation integrated with the SIN; and also the wind energy which was integrated with the SIN in 2017, and it is not possible to verify complementarity over only two years. The scenarios are analyzed graphically, and the energy generation data will be normalized between 0 and 1, to obtain a graph showing the complementarity between the months over a year. Such normalization is implemented for each year, so the impact of any variation in installed capacity is low.

**Table 5. Scenarios**

| Scenarios | Source and Region | |
|---|---|---|
| Scenario 01 | Hydro - North | Wind - Northeast |
| Scenario 02 | Hydro - North | Wind - Southeast/ Midwest |
| Scenario 03 | Hydro - North | Wind – South |
| Scenario 04 | Hydro - North | Solar Northeast |
| Scenario 05 | Hydro - North | Solar - Southeast/ Midwest |
| Scenario 06 | Hydro - North | Solar South |
| Scenario 07 | Hydro - Northeast | Wind - Southeast/ Midwest |
| Scenario 08 | Hydro - Northeast | Wind South |
| Scenario 09 | Hydro - Northeast | Solar - Southeast/ Midwest |
| Scenario 10 | Hydro - Northeast | Solar South |
| Scenario 11 | Wind - Northeast | Solar - Southeast/ Midwest |
| Scenario 12 | Wind – Northeast | Solar South |
| Scenario 13 | Hydro - Southeast/ Midwest | Wind - Northeast |
| Scenario 14 | Hydro - Southeast/ Midwest | Wind – South |
| Scenario 15 | Hydro - Southeast/ Midwest | Solar Northeast |
| Scenario 16 | Hydro - Southeast/ Midwest | Solar – South |
| Scenario 17 | Wind - Southeast/ Midwest | Solar Northeast |
| Scenario 18 | Wind - Southeast/ Midwest | Solar – South |
| Scenario 19 | Hydro – South | Wind Northeast |
| Scenario 20 | Hydro – South | Wind - Southeast/ Midwest |
| Scenario 21 | Hydro - South | Solar Northeast |
| Scenario 22 | Hydro - South | Solar - Southeast/ Midwest |
| Scenario 23 | Wind - South | Solar Northeast |
| Scenario 24 | Wind - South | Solar - Southeast/ Midwest |

The third and last stage was the analysis of the data obtained from the different scenarios, with the objective of evaluating the generation of energy across the regions of Brazil. Pearson's Correlation Coefficient (Equation 01) was used for this analysis, and the results show correlation ranging from -1 to 1. Negative results have a correlation of contrariety, so complementarity is associated with negative values. The correlation of similarity occurs when the values are greater than 0, indicating no complementarity. It was not necessary to standardize the Pearson coefficient, as the variance between the data is important.

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} . \sqrt{\sum_{i}^{n}(y_i - \bar{y})^2}} = \frac{cov\ (x,y)}{\sqrt{var\ (x).var(y)}} \quad \text{(Equation 01)}$$

The correlations can be observed in Table 6. The complementarity interactions between the sources of energy generation assume negative values, as the availability of the sources of alternative energy is inversely proportional. In contrast, if the result assumes a positive value, a similarity relation is obtained.

**Table 6. Pearson Correlation.**
Source: PERON, 2017.

| **$\rho$Value (positive and negative)** | **Correlation** |
|---|---|
| 0 - 0.19 | Very weak |
| 0.20 – 0.39 | Low |
| 0.40 – 0.69 | Moderate |
| 0.70 – 0.89 | Strong |
| 0.90 – 1.00 | Very Strong |

## 4.2. Data

Since the implementation of PROINFA, a program aimed at encouraging the diversification of alternative energy sources, wind energy production in Brazil has increased from 0.022075 GWh in 2003 to 48,443 GWh in 2018. Solar energy was explored following the 2015 Brazilian energy crisis. Only 21 GWh of solar energy was integrated into the Unified Energy System in 2015. Over the 10 year period, Brazilian hydro energy had the highest generation rate, as can be seen in Table 7, where the northern region alone contributed 447,555 GWh.

**Table 7. Brazil alternative energy generation.**
Source: Created by the author with data from ONS, 2018.

| Year | Solar power generation (GWh) | Wind power generation (GWh) | Hydroelectric power generation (GWh) |
|---|---|---|---|
| 2009 | 0 | 710 | 414,546 |
| 2010 | 0 | 1,448 | 422,481 |
| 2011 | 0 | 1,905 | 449,139 |
| 2012 | 0 | 3,174 | 439,142 |
| 2013 | 0 | 4,189 | 412,556 |
| 2014 | 0 | 9,917 | 391,469 |
| 2015 | 21 | 21,905 | 390,272 |
| 2016 | 31 | 33,455 | 416,767 |
| 2017 | 652 | 42,336 | 401,148 |
| 2018 | 2,917 | 48,443 | 417,906 |
| **TOTAL** | **3,621** | **167,482** | **4,155,426** |

In the assessment of the contribution of alternative energy sources (solar, wind, and water) in Brazil over a period of 10 years, hydropower is the major contributor. However, there is evidence for complementarity between the energy sources over the 10 year period, despite the variability in data and limited generation prior to the last 4 years.

Currently, the hydro energy source generates much more energy than solar or wind in Brazil. Using Pearson's Coefficient of Correlation, it was possible to verify the temporal variability in energy generation over a year. In this way, the generation data that were obtained from the ONS is presented in Table 8. Additionally, similar tables were compiled for all the scenarios identified in Table 5.

**Table 8. Scenario 01**

| | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- North | Wind (GW.h) – Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) – Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast | Hydro (GW.h)- North | Wind (GW.h) - Northeast |
| Jan | 3705 | 11 | 3964 | 57 | 3735 | 51 | 4667 | 188 | 3709 | 210 | 5406 | 363 | 3903 | 1405 | 2226 | 958 | 4016 | 2516 | 5281 | 2858 |
| Feb | 3986 | 8 | 4361 | 92 | 4241 | 47 | 4797 | 139 | 4852 | 232 | 5214 | 312 | 4104 | 1032 | 4284 | 1612 | 5625 | 1922 | 6015 | 1719 |
| Mar | 5056 | 6 | 5400 | 81 | 4659 | 31 | 5603 | 120 | 5877 | 217 | 5664 | 305 | 5278 | 879 | 4683 | 1722 | 7188 | 1579 | 7086 | 1865 |
| Apr | 4361 | 3 | 5034 | 51 | 4987 | 25 | 5631 | 129 | 5767 | 138 | 5649 | 270 | 5931 | 768 | 5219 | 1992 | 6254 | 2071 | 7638 | 2318 |
| May | 4664 | 3 | 4489 | 59 | 5335 | 40 | 4603 | 157 | 5874 | 171 | 5780 | 300 | 6200 | 1296 | 3703 | 2054 | 6215 | 2276 | 7534 | 3197 |
| Jun | 4658 | 7 | 2964 | 75 | 3699 | 62 | 3035 | 144 | 3120 | 174 | 3196 | 537 | 4146 | 1354 | 2502 | 2357 | 4358 | 2896 | 5029 | 3832 |
| Jul | 3362 | 7 | 2679 | 70 | 2384 | 81 | 3180 | 199 | 2807 | 217 | 2574 | 729 | 2737 | 1652 | 2195 | 2907 | 2757 | 3547 | 3110 | 4413 |
| Aug | 2723 | 27 | 2358 | 124 | 2817 | 147 | 2841 | 243 | 2666 | 309 | 3225 | 982 | 2837 | 2141 | 1937 | 3033 | 2216 | 3748 | 3090 | 4688 |
| Sep | 2078 | 50 | 1910 | 145 | 2853 | 174 | 2311 | 248 | 2886 | 344 | 3298 | 915 | 3518 | 1904 | 1721 | 3106 | 3038 | 4451 | 2736 | 4814 |
| Oct | 1758 | 64 | 1509 | 115 | 2255 | 196 | 1875 | 237 | 2621 | 373 | 2146 | 1156 | 2257 | 2049 | 2005 | 3080 | 2083 | 4216 | 2928 | 4127 |
| Nov | 1847 | 72 | 1596 | 128 | 1885 | 212 | 1823 | 211 | 2042 | 355 | 2134 | 952 | 1636 | 1648 | 2487 | 2951 | 1892 | 3347 | 2954 | 4449 |
| Dec | 3104 | 64 | 1803 | 91 | 3842 | 206 | 3074 | 258 | 2712 | 323 | 2697 | 1030 | 1530 | 1865 | 3453 | 2659 | 3390 | 3061 | 7207 | 3228 |

# 5. RESULTS

Due to the fact that Brazil has a vast hydropower potential, other alternative sources of energy (wind and solar) are not prioritized. This study shows that solar and wind power, despite having the potential for complementarity, only started to be explored in some states after the Brazilian water crises in 2001 and 2015.

In this way, this research aimed to verify the complementarity between alternative energy sources that are included in the SIN in Brazil, using Pearson's Correlation Coefficient, by comparing the generation data obtained from the ONS over each of the 10 years. Complementarity is possible due to the distinct climate zones across Brazil, allowing some regions to complement each other in the generation of energy. This complementarity was assessed from the scenarios reported in Chapter 4 (Evaluation).

However, it should be pointed out that this research does not seek to relegate hydropower but to verify the contribution of possible alternative and complementary energy sources. These alternative energy sources are considered necessary to improve Brazilian energy security.

In the scenarios analyzed, several types of correlations were identified, as shown in Table 9, among them the complementarity scenarios between two sources, which are the scenarios sought in this research, since what is wanted is to find out which sources complement each other temporarily to ensure security energy to the country. The results that show a correlation of moderate, strong or very strong complementarity are presented in this Chapter. The remaining results are presented in Appendix 1.

**Table 9. Scenario results**

| Scenarios | | $\rho$average | Correlation | |
|---|---|---|---|---|
| Scenario 01 | Hydro – North<br>Wind – Northeast | -0.78 | Strong | complementarity |
| Scenario 02 | Hydro – North<br>Wind – Southeast/Midwest | -0.44 | Moderate | complementarity |
| Scenario 03 | Hydro – North<br>Wind – South | -0.65 | Moderate | complementarity |
| Scenario 04 | Hydro – North<br>Solar –Northeast | -0.51 | Moderate | complementarity |
| Scenario 05 | Hydro – North<br>Solar - Southeast/ Midwest | -0.18 | Very weak | complementarity |
| Scenario 06 | Hydro – North<br>Solar South | 0.07 | Very weak | similarity |
| Scenario 07 | Hydro – Northeast<br>Wind - Southeast/ Midwest | 0.02 | Very weak | similarity |
| Scenario 08 | Hydro – Northeast<br>Wind – South | -0.65 | Moderate | complementarity |
| Scenario 09 | Hydro – Northeast<br>Solar - Southeast/ Midwest | -0.18 | Very weak | complementarity |
| Scenario 10 | Hydro – Northeast<br>Solar – South | 0.31 | Low | similarity |
| Scenario 11 | Wind – Northeast<br>Solar - Southeast/ Midwest | 0.19 | Very weak | similarity |
| Scenario 12 | Wind – Northeast<br>Solar South | -0.21 | Low | complementarity |
| Scenario 13 | Hydro - Southeast/ Midwest<br>Wind - Northeast | -0.08 | Very weak | complementarity |
| Scenario 14 | Hydro - Southeast/ Midwest<br>Wind – South | -0.19 | Very weak | complementarity |
| Scenario 15 | Hydro - Southeast/ Midwest<br>Solar Northeast | -0.16 | Very weak | complementarity |
| Scenario 16 | Hydro - Southeast/ Midwest<br>Solar – South | 0.48 | Moderate | similarity |
| Scenario 17 | Wind - Southeast/ Midwest<br>Solar Northeast | 0.45 | Moderate | similarity |
| Scenario 18 | Wind - Southeast/ Midwest<br>Solar – South | 0.42 | Moderate | similarity |
| Scenario 19 | Hydro – South<br>Wind Northeast | -0.22 | Low | complementarity |
| Scenario 20 | Hydro – South<br>Wind - Southeast/ Midwest | 0.50 | Moderate | similarity |
| Scenario 21 | Hydro – South<br>Solar Northeast | -0.14 | Very weak | complementarity |
| Scenario 22 | Hydro – South<br>Solar - Southeast/ Midwest | 0.21 | Low | similarity |
| Scenario 23 | Wind – South<br>Solar Northeast | 0.67 | Moderate | similarity |
| Scenario 24 | Wind – South<br>Solar - Southeast/ Midwest | 0.30 | Low | similarity |

## 5.1. Scenario 01: Hydro – North Region and Wind – Northeast Region

Scenario 01, shown in Figure 12, shows complementarity across most months of the year between these two sources over the 10 years study period.

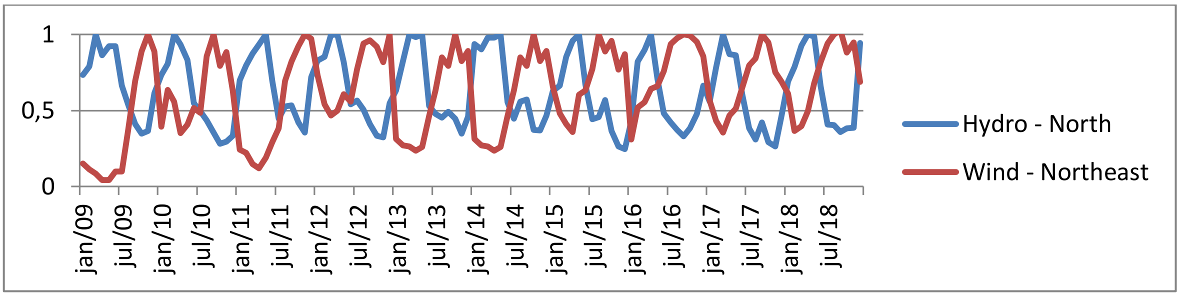

**Figure 12. Scenario 01 energy generation correlation.**

Using the Pearson Correlation Coefficient, the results for each of the 10 years are presented in Table 10.

**Table 10. Pearson Correlation Coefficient for Scenario 01.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | -0.86 | -0.72 | -0.74 | -0.80 | -0.73 | -0.91 | -0.78 | -0.54 | -0.89 | -0.83 |

According to Table 11, it can be observed that the years 2009, 2010, 2011, 2012, 2013, 2015, 2017, and 2018 show strong complementarity among sources. The year 2016 indicates a moderate complementarity, and the year 2014 presents a very strong complementarity. It is understood, that, in general, Scenario 01 presents a correlation of strong complementarity ($\rho_{average}$= -0.78).

**Table 11. Scenario 01 complementarity.**

| Year | Pearson Scenario 01 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2016 | -0.54 | 0.40 – 0.69 | Moderate |
| 2009 | -0.86 | 0.70 – 0.89 | Strong |
| 2010 | -0.72 | | |
| 2011 | -0.74 | | |
| 2012 | -0.80 | | |
| 2013 | -0.73 | | |
| 2015 | -0.78 | | |
| 2017 | -0.89 | | |
| 2018 | -0.83 | | |
| 2014 | -0.91 | 0.90 – 1.00 | Very Strong |

## 5.2. Scenario 02: Hydro – North Region and Wind – Southeast/Midwest Region

Figure 13 indicates complementarity over the 4-year period in Scenario 02, since wind generation in the Southeast and Midwest began only in 2015, due to the energy crisis.

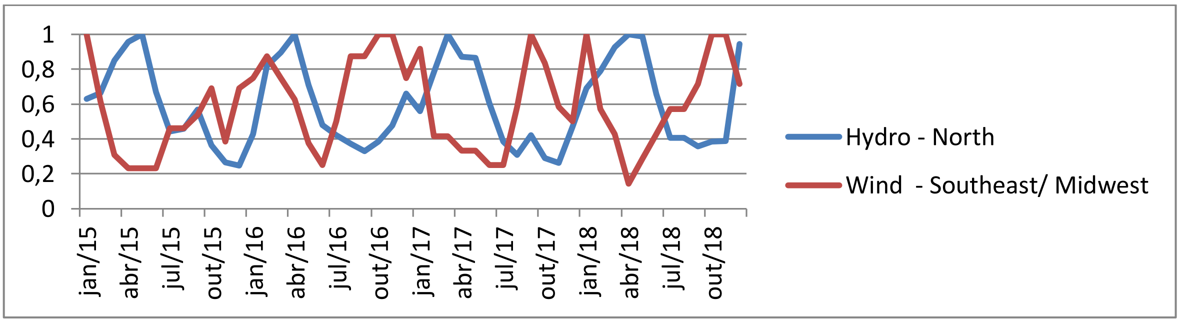

**Figure 13. Scenario 02 energy generation correlation.**

Using the Pearson Correlation Coefficient the results for each of the 4 years are presented in Table 12 :

**Table 12. Pearson Correlation Coefficient for Scenario 02.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | - | - | - | - | - | - | -0.48 | -0.19 | -0.46 | -0.62 |

In Table 13, only the results from 2015 are presented, as there was no generation of wind power generation in the Southeast / Midwest region in the previous years. However, from 2015 onwards, the results show a correlation of contrariness. In 2016, the correlation is very weak and in the years 2015, 2017, and 2018 this correlation is moderate. In general, this scenario presents a moderate complementarity correlation ($\rho_{average}$= -0.44).

**Table 13. Scenario 02 complementarity.**

| Year | Pearson Scenario 02 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2016 | -0.19 | 0.0 - 0.19 | Very weak |
| 2015 | -0.48 | 0.40 – 0.69 | Moderate |
| 2017 | -0.46 | | |
| 2018 | -0.62 | | |

## 5.3. Scenario 03: Hydro – North Region and Wind – South Region

Figure 14 shows the Scenario 03 that compares the extremes of Brazil, the Northern region and Southern region, over a period of 10 years.

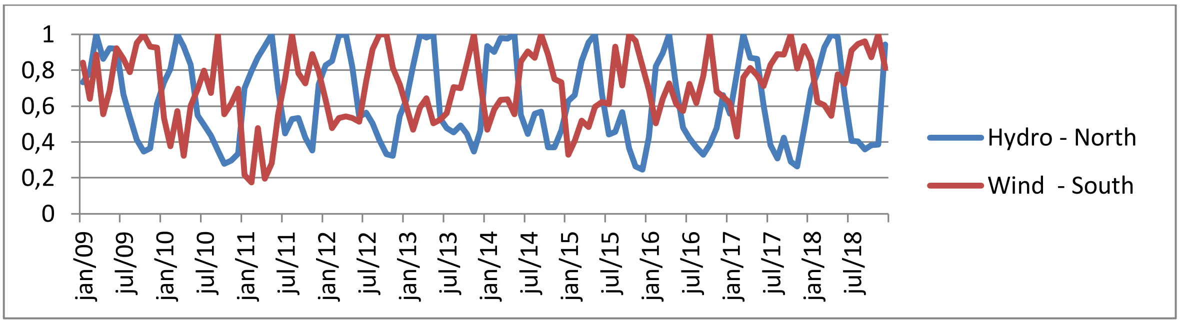

**Figure 14. Scenario 03 energy generation correlation.**

Using the Pearson Correlation Coefficient, the results for each of the 10 years are presented in Table 14 :

**Table 14. Pearson Correlation Coefficient for Scenario 03.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | -0.54 | -0.60 | -0.78 | -0.80 | -0.61 | -0.79 | -0.69 | -0.38 | -0.51 | -0.81 |

Table 15 shows that the years 2011, 2012, 2014, and 2018 presented a strong correlation, however, the years 2010, 2013, 2015, and 2018 presented a moderate correlation and the year 2016 presented a low correlation. In general, the correlation of complementarity is moderate ($\rho_{average}$= -0.65) over the 10 years period. However, in general, the sources complement each other.

**Table 15. Scenario 03 complementarity.**

| Year | Pearson Scenario 03 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2016 | -0.38 | 0.20 – 0.39 | Low |
| 2009 | -0.54 | 0.40 – 0.69 | Moderate |
| 2010 | -0.60 | | |
| 2013 | -0.61 | | |
| 2015 | -0.69 | | |
| 2017 | -0.51 | | |
| 2011 | -0.78 | 0.70 – 0.89 | Strong |
| 2012 | -0.80 | | |
| 2014 | -0.79 | | |
| 2018 | -0.81 | | |

## 5.4. Scenario 04: Hydro – North Region and Solar – Northeast Region

In this scenario, it was only possible to analyze data from 2015 onwards, when solar energy was integrated into the SIN, as shown in Figure 15. The Northeastern region is the largest solar generator, an alternative source that is still widely overlooked in the Brazilian energy sector. The solar potential of the Northeast region is due to the proximity to the Equator, resulting in little variation in energy production throughout the year.

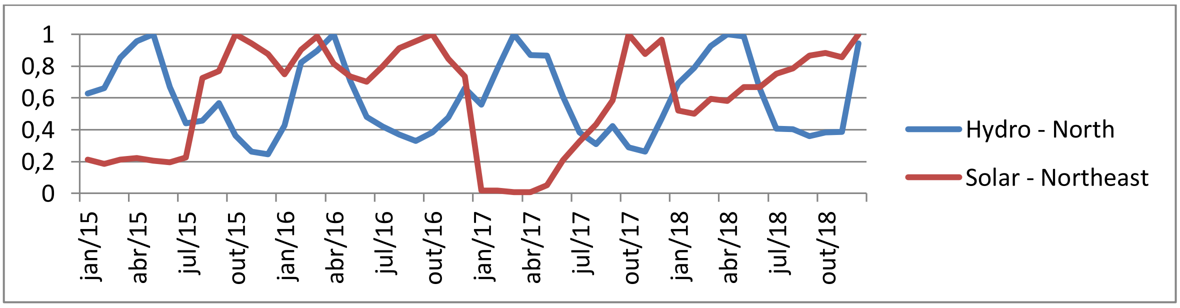

**Figure 15. Scenario 04 energy generation correlation.**

Using the Pearson Correlation Coefficient the results for each of the 4 years are presented in Table 16 :

**Table 16. Pearson Correlation Coefficient for Scenario 04.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | - | - | - | - | - | - | -0.77 | -0.05 | -0.78 | -0.44 |

The great variability in the solar generation in the southern region is reflected in Table 17 and its varying correlations. The years 2015 and 2017 presented a strong correlation, the year 2018 presented a moderate correlation, and the year 2016 showed a very weak correlation. Observing this historical series, the sources indicate a correlation of contrariness, affirming the complementarity, even if moderate ($\rho_{average}$= -0.51).

**Table 17. Scenario 04 complementarity.**

| Year | Pearson Scenario 04 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2016 | -0.05 | 0.0 - 0.19 | Very weak |
| 2018 | -0.44 | 0.40 – 0.69 | Moderate |
| 2015<br>2017 | -0.77<br>-0.78 | 0.70 – 0.89 | Strong |

## 5.5. Scenario 08: Hydro – Northeast and Wind – South

In this scenario, it was possible to carry out the analysis over the entire 10 year period. Figure 16 shows the temporal complementarity between the water and wind sources of the Northeast and South regions of Brazil.

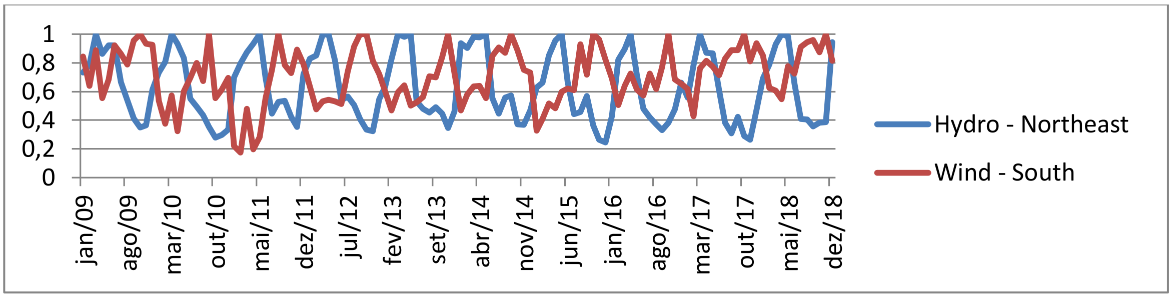

**Figure 16. Scenario 08 energy generation correlation.**

Using the Pearson Correlation Coefficient the results for each of the 10 years are presented in Table 18:

**Table 18. Pearson Correlation Coefficient for Scenario 08.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | -0.54 | -0.60 | -0.78 | -0.80 | -0.61 | -0.79 | -0.69 | -0.38 | -0.51 | -0.81 |

From Table 19, in the years 2009, 2010, 2013, 2015, and 2017, the correlation is of moderate complementarity, in 2016, there is a correlation of low complementarity, and in the years 2011, 2012, and 2014, there is a correlation of strong complementarity. Overall, Scenario 08 presents a moderate complementarity correlation ($\rho_{average}$= - 0.65). This is a scenario that may allow for diversification in the generation of wind energy in the South.

**Table 19. Scenario 08 complementarity.**

| Year | Pearson Scenario 08 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2009 | -0.54 | 0.40 – 0.69 | Moderate |
| 2010 | -0.60 | | |
| 2013 | -0.61 | | |
| 2015 | -0.69 | | |
| 2017 | -0.51 | | |
| 2016 | -0.38 | 0.20 – 0.39 | Low |
| 2011 | -0.78 | 0.70 – 0.89 | Strong |
| 2012 | -0.80 | | |
| 2014 | -0.79 | | |
| 2018 | -0.81 | | |

## 5.6. Scenario 16: Hydro – Southeast/ Midwest and Solar – South

This scenario was analyzed over 4 years. It should be noted that the generation near zero does not mean that there was no generation, but that when compared monthly with that of the calculated year, the value was less than the maximum value of the same period.

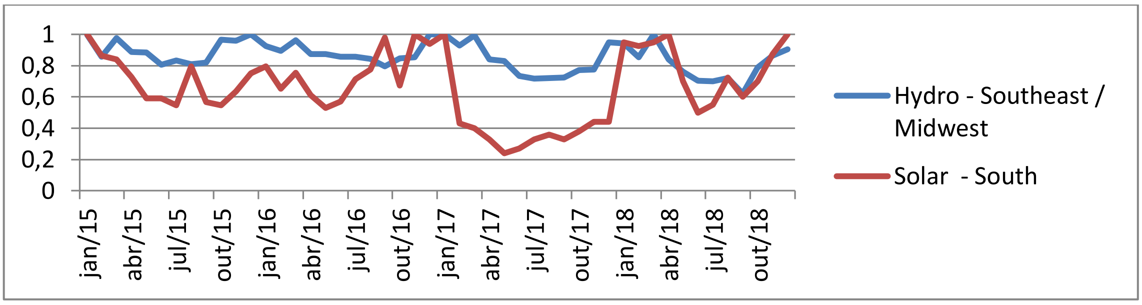

**Figure 17. Scenario 16 energy generation correlation.**

Using the Pearson Correlation Coefficient the results for each of the 4 years are presented in Table 20:

**Table 20. Pearson Correlation Coefficient for Scenario 16.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | - | - | - | - | - | - | 0.39 | 0.07 | 0.59 | 0.86 |

Table 21 shows that this scenario presents a similarity correlation for all the analyzed years; the correlations were weak in 2015, very weak in 2016, moderate in 2017, and strong in 2018. Thus, this scenario presents no complementarity but a moderate similarity correlation ($\rho_{average}$= 0.48).

**Table 21. Scenario 16 complementarity.**

| Year | Pearson Scenario 16 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2015 | 0.39 | 0.20 – 0.39 | Low |
| 2016 | 0.07 | 0 - 0.19 | Very weak |
| 2017 | 0.59 | 0.40 – 0.69 | Moderate |
| 2018 | 0.86 | 0.70 – 0.89 | Strong |

## 5.7. Scenario 20: Hydro – South and Wind – Southeast / Midwest

In Scenario 20, due to the integration of wind power into the SIN in the Southeast / Midwest region from 2015, the analysis was carried out for only 4 years.

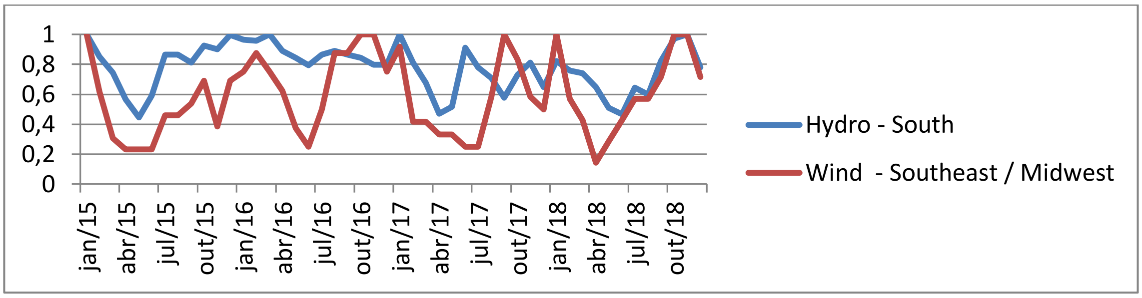

**Figure 18. Scenario 20 energy generation correlation.**

Using the Pearson Correlation Coefficient the results for each of the 4 years are presented in Table 22:

**Table 22. Pearson Correlation Coefficient for Scenario 20.**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| **PEARSON** | - | - | - | - | - | - | 0.83 | 0.21 | 0.14 | 0.81 |

As in Table 23, there is no correlation of complementarity for Scenario 20. In 2015 and 2018, the correlation of similarity was strong, 2016 presented a correlation of low similarity, and in 2017 the correlation of similarity was very weak. In general, the scenario presented a correlation of moderate similarity ($\rho_{average}$= 0.50).

**Table 23. Scenario 20 complementarity.**

| Year | Pearson Scenario 20 | $\rho$Value (positive and negative) | Correlation |
|---|---|---|---|
| 2005<br>2018 | 0.83<br>0.81 | 0.70 – 0.89 | Strong |
| 2016 | 0.21 | 0.20 – 0.39 | Low |
| 2017 | 0.14 | 0 - 0.19 | Very weak |

# 6. DISCUSSION OF THE RESULTS

This research verified the temporal complementarity and similarity (with hydro), through Pearson's correlation, between the alternative sources of energy in Brazil. The complementarity and similarity are related to availability in each time period, which is relevant for balance and energy security in the electric energy sector. Complementarity and similarity can only be guaranteed if the sources present at least a moderate correlation. Table 24 indicates the accepted values for temporal complementarity or similarity.

**Table 24. Correlations that ensures complementarity and similarity**

| $\rho$Value (negative or positive) | Correlation |
|---|---|
| 0.40 – 0.69 | Moderate |
| 0.70 – 0.89 | Strong |
| 0.90 – 1.00 | Very Strong |

Negative ρValues indicate moderate and strong complementarity correlations. Thus, Scenarios 01, 02, 03, 04, and 08 presented acceptable temporal complementarity, as shown in Table 25.

**Table 25. Scenarios that demonstrate complementarity**

| Scenarios | | $\rho$average | Correlation |
|---|---|---|---|
| Scenario 01 | Hydro – North<br>Wind – Northeast | -0.78 | Strong |
| Scenario 02 | Hydro – North<br>Wind – Southeast/Midwest | -0.44 | Moderate |
| Scenario 03 | Hydro – North<br>Wind – South | -0.65 | Moderate |
| Scenario 04 | Hydro – North<br>Solar –Northeast | -0.51 | Moderate |
| Scenario 08 | Hydro – Northeast<br>Wind – South | -0.65 | Moderate |

The results allow for optimization of the use of reservoirs in periods of drought. Wind generation should be increased in the Northeast, Southeast / Midwest, and South regions, with the highest potential for complementarity, with wind being an under-utilized source that has not yet reached half of its generation potential. Zaparolli (2019) states that the potential for wind power generation in Brazil is estimated at about 500 GW, according to the Brazilian Association of Wind Energy (ABEEólica), which is sufficient to meet three times the current energy demand of Brazil three times greater than energy generation of the current national park.

Solar energy offers the potential for complementarity, specifically in the Northeast region. In spite of the high potential for capturing solar energy in Brazil, the Northeast region has greater energy availability because it is close to the Equator. While the North is also close to the Equator, its climatic characteristics reduce the available radiation. According to Bezerra (2018), the Northeastern region has the greatest potential for solar energy in relation to the other regions, as the northeast region has the highest level of irradiance in the inclined plane (annual average of 5,52 $kWh/m^2$.day) and lower interannual variability during the year.

From the obtained results, correlations of moderate similarity (the ρValue should be positive) were also found. Scenarios 16 and 20 presented acceptable temporal similarity with hydro sources as observed in Table 26.

**Table 26. Scenarios that demonstrate similarity**

| Scenarios | | $\rho$average | Correlation |
|---|---|---|---|
| Scenario 16 | Hydro - Southeast/ Midwest<br>Solar – South | 0.48 | Moderate |
| Scenario 20 | Hydro – South<br>Wind - Southeast/ Midwest | 0.50 | Moderate |

Complementarity results demonstrate which sources can work together, supporting one another, temporarily. In contrast, high similarity results between the sources indicate the possibility of replacing one energy source with another. In this way, the scenarios indicated in Table 26 were identified. Note that wind sources have not yet reached half of their generation potential, as well as solar. Therefore, Scenarios 16 and 20 are the most interesting because the water sources in the Southeast and South have already been fully utilized, and the solar source in the Southern region for Scenario 16 and the wind source in the Southeast / Midwest region for Scenario 20 are presented as alternative sources.

There is significant wind potential in Brazil in the Northeast, Southeast, and South regions and there is still much to be explored, as emphasized by Zaparolli (2019), when he states that the potential is more than three times higher than the current one national park generating electric power.

The Southern region presents a good capacity for solar energy generation although it is the most distant from the Equator. According to ANEEL (2002), most of Brazil is located relatively close to the Equator, however, the majority of the Brazilian population and the socio-economic activities of the country are concentrated in regions farther from the Equator. The challenge of limited solar generation in the South region can be addressed by adjusting the position of the collector or solar panel according to local latitude and the period of the year in which more energy is required to maximize the use of solar radiation, according to ANEEL (2002).

Finally, the results show that although there are generally correlations with the water sources, it is important to highlight the importance of complementary and similar sources for sector diversification, improved energy security, and to avoid another energy crisis. Wind sources (in the Northeast, Southeast / Midwest, and South) and solar (in the Northeast) should be recognized as complementary sources for hydropower to optimize the use of reservoirs during periods of drought, and are also capable of replacing hydropower as they have similar temporal variations.

# 7. CONCLUSIONS AND FUTURE WORK

## 7.1. Conclusions

Brazil is a very diverse country due to its immense size and each region has its own natural and cultural characteristics; it can be said that there are several countries within one. However, the country needs more consistent energy planning that takes advantage of this natural diversity, in order to guarantee energy security. In this research, the strong reliance on hydropower in Brazil is evident, and, despite being considered a renewable resource, hydropower does not guarantee energy security and has resulted in negative environmental impacts in the Amazon region.

Thus, there is a need for diversification of the Brazilian energy sector, raising the question as to which sources could be used in this diversification and in which regions installation would be feasible. There is a need to analyze the potential of using different energy sources between the regions to generate energy in a complementary way, as well as to identify regions which could replace existing hydropower sources with alternative energy sources.

Through the methodology applied in this dissertation, the generation of energy from the alternative sources available in each Brazilian region was analyzed, with the exception of the biomass because it is not integrated with the SIN, and solar and wind sources in the North because it was only integrated into the SIN in 2015. The Pearson coefficient was used to identify complementary regions and sources and regions with high similarity to hydro. Only results that had the least moderate correlation would be accepted.

Scenarios 01, 02, 03, 04, and 08 are identified as complementary scenarios: Hydro - North and Wind - Northeast (ρaverage = -0.78); Hydro - North and Wind - Southeast / Midwest (ρaverage = -0.44); Hydro - North and Wind - South (ρaverage = -0.65); Hydro - North and Solar - Northeast (ρaverage = -0.51); Hydro - Northeast and Solar - South (ρaverage = -0.65). The results pointed to several possible sources and regions that could complement the installed hydroelectric sources, as a way of diversifying generation and taking advantage of the potential of these under-utilized sources. The use of alternative sources to ensure complementarity with hydropower could enable optimization of the reservoirs and their use during periods of drought.

Scenarios presenting a high similarity with hydropower (Scenarios 16 and 20) were also identified. In this case, only water sources were accepted, which demonstrate the possibility of future use of such resources to reducing reliance on hydropower: Water - Southeast / Midwest and Solar - South (ρaverage = 0.48); Hydro - South and Wind - Southeast / Midwest (ρaverage = 0.50). It should be emphasized that the solar and wind sources in the regions in Scenarios 16 and 20, are presented as alternative sources that generate energy in a similar way to water, and can thus replace them for a future increase of generation capacity.

In this research, it was also possible to visualize the complementarity and similarity correlations between the sources graphically, based on variations in energy generation. Thus, the calculation model was used to evaluate the hypotheses, which allowed an analysis of the energy mix scenarios, and the selection of the best options for sector diversification.

The results of this research have shown that the potential for diversification is very high, as, there are several energy source options in the country. Thus, it is possible to diversify the energy sector and guarantee energy security in Brazil, reducing reliance on hydropower, and ensuring a more sustainable sector.

In general, the results pointed to the potential of wind energy across all regions and the solar potential in the Northeast region and South region as scenarios which should be explored in sector diversification. Thus, this work contributed to studies of the expansion of the Brazilian energy sector, at the macro scale, by SIN, identifying the main sources of alternative energy and their respective distributions in the regions. The research did not disregard the contribution of the hydroelectric plants and their generation potential but indicated alternatives to it. The characterization of thermoelectric plants was not included in the scope of this work. However, with the diversification of the energy sector, thermoelectric plants that previously compensated for the generation of energy during the water crises may, with diversification, become redundant.

In this research, some limitations were identified. Due to lack of data, biomass cannot be analyzed, as well as the wind and solar sources of the Northern region. However, this did not affect the final objective, due to the availability of a high number of scenarios.

## 7.2. Future work

It is recommended for future studies that a demand-service analysis based on the scenarios identified in this research, to verify whether it will be necessary to use thermoelectric plants or whether the country can rely on the alternative sources in the indicated scenarios.

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# APPENDIX 1 – TABLES OF ENERGY GENERATION

Energy generation data collected from the National Electric System Operator.

**Table 27. Scenario 02**

| SCENARIO 02 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest | Hydro (GW.h)- North | Wind (GW.h) - Southeast/ Midwest |
| jan | 3705 | 0 | 3964 | 0 | 3735 | 0 | 4667 | 0 | 3709 | 0 | 5406 | 0 | 3903 | 13 | 2226 | 6 | 4016 | 11 | 5281 | 7 |
| feb | 3986 | 0 | 4361 | 0 | 4241 | 0 | 4797 | 0 | 4852 | 0 | 5214 | 0 | 4104 | 8 | 4284 | 7 | 5625 | 5 | 6015 | 4 |
| mar | 5056 | 0 | 5400 | 0 | 4659 | 0 | 5603 | 0 | 5877 | 0 | 5664 | 0 | 5278 | 4 | 4683 | 6 | 7188 | 5 | 7086 | 3 |
| apr | 4361 | 0 | 5034 | 0 | 4987 | 0 | 5631 | 0 | 5767 | 0 | 5649 | 0 | 5931 | 3 | 5219 | 5 | 6254 | 4 | 7638 | 1 |
| may | 4664 | 0 | 4489 | 0 | 5335 | 0 | 4603 | 0 | 5874 | 0 | 5780 | 0 | 6200 | 3 | 3703 | 3 | 6215 | 4 | 7534 | 2 |
| jun | 4658 | 0 | 2964 | 0 | 3699 | 0 | 3035 | 0 | 3120 | 0 | 3196 | 0 | 4146 | 3 | 2502 | 2 | 4358 | 3 | 5029 | 3 |
| jul | 3362 | 0 | 2679 | 0 | 2384 | 0 | 3180 | 0 | 2807 | 0 | 2574 | 0 | 2737 | 6 | 2195 | 4 | 2757 | 3 | 3110 | 4 |
| aug | 2723 | 0 | 2358 | 0 | 2817 | 0 | 2841 | 0 | 2666 | 0 | 3225 | 0 | 2837 | 6 | 1937 | 7 | 2216 | 7 | 3090 | 4 |
| sept | 2078 | 0 | 1910 | 0 | 2853 | 0 | 2311 | 0 | 2886 | 0 | 3298 | 0 | 3518 | 7 | 1721 | 7 | 3038 | 12 | 2736 | 5 |
| oct | 1758 | 0 | 1509 | 0 | 2255 | 0 | 1875 | 0 | 2621 | 0 | 2146 | 0 | 2257 | 9 | 2005 | 8 | 2083 | 10 | 2928 | 7 |
| nov | 1847 | 0 | 1596 | 0 | 1885 | 0 | 1823 | 0 | 2042 | 0 | 2134 | 0 | 1636 | 5 | 2487 | 8 | 1892 | 7 | 2954 | 7 |
| dec | 3104 | 0 | 1803 | 0 | 3842 | 0 | 3074 | 0 | 2712 | 0 | 2697 | 0 | 1530 | 9 | 3453 | 6 | 3390 | 6 | 7207 | 5 |

**Table 28. Scenario 03**

| SCENARIO 03 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South | Hydro (GW.h)- North | Wind (GW.h) - South |
| janu | 3705 | 33 | 3964 | 26 | 3735 | 20 | 4667 | 68 | 3709 | 86 | 5406 | 105 | 3903 | 157 | 2226 | 418 | 4016 | 391 | 5281 | 518 |
| feb | 3986 | 25 | 4361 | 18 | 4241 | 16 | 4797 | 51 | 4852 | 67 | 5214 | 130 | 4104 | 195 | 4284 | 305 | 5625 | 272 | 6015 | 380 |
| mar | 5056 | 34 | 5400 | 28 | 4659 | 44 | 5603 | 57 | 5877 | 85 | 5664 | 142 | 5278 | 248 | 4683 | 387 | 7188 | 482 | 7086 | 369 |
| april | 4361 | 21 | 5034 | 16 | 4987 | 18 | 5631 | 58 | 5767 | 92 | 5649 | 143 | 5931 | 232 | 5219 | 439 | 6254 | 516 | 7638 | 332 |
| ma | 4664 | 27 | 4489 | 29 | 5335 | 26 | 4603 | 57 | 5874 | 72 | 5780 | 124 | 6200 | 286 | 3703 | 372 | 6215 | 490 | 7534 | 473 |
| jun | 4658 | 36 | 2964 | 34 | 3699 | 51 | 3035 | 55 | 3120 | 75 | 3196 | 190 | 4146 | 298 | 2502 | 347 | 4358 | 452 | 5029 | 441 |
| jul | 3362 | 34 | 2679 | 39 | 2384 | 69 | 3180 | 79 | 2807 | 80 | 2574 | 203 | 2737 | 292 | 2195 | 438 | 2757 | 526 | 3110 | 555 |
| aug | 2723 | 31 | 2358 | 33 | 2817 | 92 | 2841 | 98 | 2666 | 101 | 3225 | 195 | 2837 | 446 | 1937 | 373 | 2216 | 564 | 3090 | 576 |
| sept | 2078 | 37 | 1910 | 49 | 2853 | 72 | 2311 | 107 | 2886 | 100 | 3298 | 224 | 3518 | 343 | 1721 | 465 | 3038 | 563 | 2736 | 585 |
| octo | 1758 | 39 | 1509 | 27 | 2255 | 67 | 1875 | 107 | 2621 | 120 | 2146 | 199 | 2257 | 479 | 2005 | 605 | 2083 | 634 | 2928 | 532 |
| nove | 1847 | 36 | 1596 | 30 | 1885 | 82 | 1823 | 87 | 2042 | 143 | 2134 | 168 | 1636 | 462 | 2487 | 413 | 1892 | 514 | 2954 | 609 |
| dece | 3104 | 36 | 1803 | 34 | 3842 | 73 | 3074 | 77 | 2712 | 104 | 2697 | 164 | 1530 | 394 | 3453 | 395 | 3390 | 593 | 7207 | 496 |

**Table 29. Scenario 04**

| SCENARIO 04 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) – Northeast | Hydro (GW.h)- North | Solar (GW.h) - Northeast | Hydro (GW.h)- North | Solar (GW.h) – Northeast |
| Jan | 3705 | 0 | 3964 | 0 | 3735 | 0 | 4667 | 0 | 3709 | 0 | 5406 | 0 | 3903 | 0,51 | 2226 | 1,7 | 4016 | 2 | 5281 | 120 |
| Feb | 3986 | 0 | 4361 | 0 | 4241 | 0 | 4797 | 0 | 4852 | 0 | 5214 | 0 | 4104 | 0,44 | 4284 | 2,05 | 5625 | 2 | 6015 | 115 |
| Mar | 5056 | 0 | 5400 | 0 | 4659 | 0 | 5603 | 0 | 5877 | 0 | 5664 | 0 | 5278 | 0,51 | 4683 | 2,24 | 7188 | 1 | 7086 | 137 |
| Apr | 4361 | 0 | 5034 | 0 | 4987 | 0 | 5631 | 0 | 5767 | 0 | 5649 | 0 | 5931 | 0,53 | 5219 | 1,85 | 6254 | 1 | 7638 | 134 |
| May | 4664 | 0 | 4489 | 0 | 5335 | 0 | 4603 | 0 | 5874 | 0 | 5780 | 0 | 6200 | 0,49 | 3703 | 1,67 | 6215 | 6 | 7534 | 154 |
| Jun | 4658 | 0 | 2964 | 0 | 3699 | 0 | 3035 | 0 | 3120 | 0 | 3196 | 0 | 4146 | 0,47 | 2502 | 1,59 | 4358 | 25 | 5029 | 154 |
| Jul | 3362 | 0 | 2679 | 0 | 2384 | 0 | 3180 | 0 | 2807 | 0 | 2574 | 0 | 2737 | 0,54 | 2195 | 1,81 | 2757 | 39 | 3110 | 173 |
| Aug | 2723 | 0 | 2358 | 0 | 2817 | 0 | 2841 | 0 | 2666 | 0 | 3225 | 0 | 2837 | 1,73 | 1937 | 2,07 | 2216 | 52 | 3090 | 181 |
| Sept | 2078 | 0 | 1910 | 0 | 2853 | 0 | 2311 | 0 | 2886 | 0 | 3298 | 0 | 3518 | 1,84 | 1721 | 2,17 | 3038 | 70 | 2736 | 199 |
| Oct | 1758 | 0 | 1509 | 0 | 2255 | 0 | 1875 | 0 | 2621 | 0 | 2146 | 0 | 2257 | 2,39 | 2005 | 2,27 | 2083 | 120 | 2928 | 203 |
| Nov | 1847 | 0 | 1596 | 0 | 1885 | 0 | 1823 | 0 | 2042 | 0 | 2134 | 0 | 1636 | 2,25 | 2487 | 1,92 | 1892 | 105 | 2954 | 197 |
| Dece | 3104 | 0 | 1803 | 0 | 3842 | 0 | 3074 | 0 | 2712 | 0 | 2697 | 0 | 1530 | 2,09 | 3453 | 1,67 | 3390 | 116 | 7207 | 230 |

Table 30. Scenario 05

| SCENARIO 05 | | jan | febr | mar | apr | may | jun | jul | aug | sept | oct | nov | dece |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- North | 3705 | 3986 | 5056 | 4361 | 4664 | 4658 | 3362 | 2723 | 2078 | 1758 | 1847 | 3104 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | Hydro (GW.h)- North | 3964 | 4361 | 5400 | 5034 | 4489 | 2964 | 2679 | 2358 | 1910 | 1509 | 1596 | 1803 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | Hydro (GW.h)- North | 3735 | 4241 | 4659 | 4987 | 5335 | 3699 | 2384 | 2817 | 2853 | 2255 | 1885 | 3842 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | Hydro (GW.h)- North | 4667 | 4797 | 5603 | 5631 | 4603 | 3035 | 3180 | 2841 | 2311 | 1875 | 1823 | 3074 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | Hydro (GW.h)- North | 3709 | 4852 | 5877 | 5767 | 5874 | 3120 | 2807 | 2666 | 2886 | 2621 | 2042 | 2712 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | Hydro (GW.h)- North | 5406 | 5214 | 5664 | 5649 | 5780 | 3196 | 2574 | 3225 | 3298 | 2146 | 2134 | 2697 |
| | Solar (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | Hydro (GW.h)- North | 3903 | 4104 | 5278 | 5931 | 6200 | 4146 | 2737 | 2837 | 3518 | 2257 | 1636 | 1530 |
| | Solar (GW.h) - Southeast/ Midwest | 0,4 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 |
| 2016 | Hydro (GW.h)- North | 2226 | 4284 | 4683 | 5219 | 3703 | 2502 | 2195 | 1937 | 1721 | 2005 | 2487 | 3453 |
| | Solar (GW.h) - Southeast/ Midwest | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 |
| 2017 | Hydro (GW.h)- North | 4016 | 5625 | 7188 | 6254 | 6215 | 4358 | 2757 | 2216 | 3038 | 2083 | 1892 | 3390 |
| | Solar (GW.h) - Southeast/ Midwest | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,3 | 6 | 31 | 28 | 39 |
| 2018 | Hydro (GW.h)- North | 5281 | 6015 | 7086 | 7638 | 7534 | 5029 | 3110 | 3090 | 2736 | 2928 | 2954 | 7207 |
| | Solar (GW.h) - Southeast/ Midwest | 56 | 43 | 61 | 64 | 76 | 76 | 90 | 87 | 96 | 87 | 76 | 105 |

**Table 31. Scenario 06**

| SCENARIO 06 | | jan | feb | mar | apr | may | jun | jul | aug | sept | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- North | 3705 | 3986 | 5056 | 4361 | 4664 | 4658 | 3362 | 2723 | 2078 | 1758 | 1847 | 3104 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | Hydro (GW.h)- North | 3964 | 4361 | 5400 | 5034 | 4489 | 2964 | 2679 | 2358 | 1910 | 1509 | 1596 | 1803 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | Hydro (GW.h)- North | 3735 | 4241 | 4659 | 4987 | 5335 | 3699 | 2384 | 2817 | 2853 | 2255 | 1885 | 3842 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | Hydro (GW.h)- North | 4667 | 4797 | 5603 | 5631 | 4603 | 3035 | 3180 | 2841 | 2311 | 1875 | 1823 | 3074 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | Hydro (GW.h)- North | 3709 | 4852 | 5877 | 5767 | 5874 | 3120 | 2807 | 2666 | 2886 | 2621 | 2042 | 2712 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | Hydro (GW.h)- North | 5406 | 5214 | 5664 | 5649 | 5780 | 3196 | 2574 | 3225 | 3298 | 2146 | 2134 | 2697 |
| | Solar (GW.h) – South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | Hydro (GW.h)- North | 3903 | 4104 | 5278 | 5931 | 6200 | 4146 | 2737 | 2837 | 3518 | 2257 | 1636 | 1530 |
| | Solar (GW.h) - South | 0,44 | 0,38 | 0,37 | 0,32 | 0,26 | 0,26 | 0,24 | 0,35 | 0,25 | 0,24 | 0,28 | 0,33 |
| 2016 | Hydro (GW.h)- North | 2226 | 4284 | 4683 | 5219 | 3703 | 2502 | 2195 | 1937 | 1721 | 2005 | 2487 | 3453 |
| | Solar (GW.h) - South | 0,39 | 0,32 | 0,37 | 0,3 | 0,26 | 0,28 | 0,35 | 0,38 | 0,48 | 0,33 | 0,49 | 0,46 |
| 2017 | Hydro (GW.h)- North | 4016 | 5625 | 7188 | 6254 | 6215 | 4358 | 2757 | 2216 | 3038 | 2083 | 1892 | 3390 |
| | Solar (GW.h) - South | 1 | 0,43 | 0,4 | 0,33 | 0,24 | 0,27 | 0,33 | 0,36 | 0,33 | 0,38 | 0,44 | 0,44 |
| 2018 | Hydro (GW.h)- North | 5281 | 6015 | 7086 | 7638 | 7534 | 5029 | 3110 | 3090 | 2736 | 2928 | 2954 | 7207 |
| | Solar (GW.h) - South | 0,38 | 0,37 | 0,38 | 0,4 | 0,28 | 0,2 | 0,22 | 0,29 | 0,24 | 0,28 | 0,35 | 0,4 |

**Table 32. Scenario 07**

| SCENARIO 07 | | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- Northeast | 3347 | 3529 | 4053 | 3972 | 5080 | 4475 | 4716 | 4354 | 4135 | 4767 | 4925 | 4523 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | Hydro (GW.h)- Northeast | 4256 | 4030 | 4257 | 3505 | 3506 | 3091 | 3482 | 3365 | 3622 | 4256 | 3781 | 4505 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | Hydro (GW.h)- Northeast | 4246 | 3932 | 4279 | 4036 | 3456 | 3654 | 3965 | 4264 | 4494 | 5046 | 4460 | 4696 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | Hydro (GW.h)- Northeast | 5199 | 4521 | 5165 | 4686 | 4511 | 4309 | 3676 | 4057 | 3968 | 3800 | 3291 | 4585 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | Hydro (GW.h)- Northeast | 3831 | 2664 | 2876 | 2833 | 2595 | 2497 | 2991 | 2713 | 2692 | 2888 | 2636 | 2768 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | Hydro (GW.h)- Northeast | 2754 | 2322 | 2606 | 2504 | 2506 | 2464 | 2461 | 2439 | 2376 | 2498 | 2430 | 2624 |
| | Wind (GW.h) - Southeast/ Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | Hydro (GW.h)- Northeast | 2510 | 2229 | 2547 | 2343 | 2540 | 2033 | 2085 | 2142 | 2048 | 2078 | 1936 | 1959 |
| | Wind (GW.h) - Southeast/ Midwest | 13 | 8 | 4 | 3 | 3 | 3 | 6 | 6 | 7 | 9 | 5 | 9 |
| 2016 | Hydro (GW.h)- Northeast | 2172 | 1918 | 1959 | 1751 | 1853 | 1748 | 1815 | 1820 | 1778 | 1864 | 1803 | 1775 |
| | Wind (GW.h) - Southeast/ Midwest | 6 | 7 | 6 | 5 | 3 | 2 | 4 | 7 | 7 | 8 | 8 | 6 |
| 2017 | Hydro (GW.h)- Northeast | 1724 | 1551 | 1684 | 1559 | 1503 | 1189 | 1240 | 1237 | 1144 | 1151 | 1154 | 1312 |
| | Wind (GW.h) - Southeast/ Midwest | 11 | 5 | 5 | 4 | 4 | 3 | 3 | 7 | 12 | 10 | 7 | 6 |
| 2018 | Hydro (GW.h)- Northeast | 1216 | 1264 | 1497 | 1310 | 1382 | 1342 | 1353 | 1333 | 1274 | 1455 | 1445 | 1681 |
| | Wind (GW.h) - Southeast/ Midwest | 7 | 4 | 3 | 1 | 2 | 3 | 4 | 4 | 5 | 7 | 7 | 5 |

**Table 33. Scenario 08**

| dec | nov | oct | sep | aug | jul | jun | may | apr | mar | feb | jan | SCENARIO 08 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3104 | 1847 | 1758 | 2078 | 2723 | 3362 | 4658 | 4664 | 4361 | 5056 | 3986 | 3705 | Hydro (GW.h)- Northeast | 2009 |
| 36 | 36 | 39 | 37 | 31 | 34 | 36 | 27 | 21 | 34 | 25 | 33 | Wind (GW.h) - South | |
| 1803 | 1596 | 1509 | 1910 | 2358 | 2679 | 2964 | 4489 | 5034 | 5400 | 4361 | 3964 | Hydro (GW.h)- Northeast | 2010 |
| 34 | 30 | 27 | 49 | 33 | 39 | 34 | 29 | 16 | 28 | 18 | 26 | Wind (GW.h) - South | |
| 3842 | 1885 | 2255 | 2853 | 2817 | 2384 | 3699 | 5335 | 4987 | 4659 | 4241 | 3735 | Hydro (GW.h)- Northeast | 2011 |
| 73 | 82 | 67 | 72 | 92 | 69 | 51 | 26 | 18 | 44 | 16 | 20 | Wind (GW.h) - South | |
| 3074 | 1823 | 1875 | 2311 | 2841 | 3180 | 3035 | 4603 | 5631 | 5603 | 4797 | 4667 | Hydro (GW.h)- Northeast | 2012 |
| 77 | 87 | 107 | 107 | 98 | 79 | 55 | 57 | 58 | 57 | 51 | 68 | Wind (GW.h) - South | |
| 2712 | 2042 | 2621 | 2886 | 2666 | 2807 | 3120 | 5874 | 5767 | 5877 | 4852 | 3709 | Hydro (GW.h)- Northeast | 2013 |
| 104 | 143 | 120 | 100 | 101 | 80 | 75 | 72 | 92 | 85 | 67 | 86 | Wind (GW.h) - South | |
| 2697 | 2134 | 2146 | 3298 | 3225 | 2574 | 3196 | 5780 | 5649 | 5664 | 5214 | 5406 | Hydro (GW.h)- Northeast | 2014 |
| 164 | 168 | 199 | 224 | 195 | 203 | 190 | 124 | 143 | 142 | 130 | 105 | Wind (GW.h) - South | |
| 1530 | 1636 | 2257 | 3518 | 2837 | 2737 | 4146 | 6200 | 5931 | 5278 | 4104 | 3903 | Hydro (GW.h)- Northeast | 2015 |
| 394 | 462 | 479 | 343 | 446 | 292 | 298 | 286 | 232 | 248 | 195 | 157 | Wind (GW.h) - South | |
| 3453 | 2487 | 2005 | 1721 | 1937 | 2195 | 2502 | 3703 | 5219 | 4683 | 4284 | 2226 | Hydro (GW.h)- Northeast | 2016 |
| 395 | 413 | 605 | 465 | 373 | 438 | 347 | 372 | 439 | 387 | 305 | 418 | Wind (GW.h) - South | |
| 3390 | 1892 | 2083 | 3038 | 2216 | 2757 | 4358 | 6215 | 6254 | 7188 | 5625 | 4016 | Hydro (GW.h)- Northeast | 2017 |
| 593 | 514 | 634 | 563 | 564 | 526 | 452 | 490 | 516 | 482 | 272 | 391 | Wind (GW.h) - South | |
| 7207 | 2954 | 2928 | 2736 | 3090 | 3110 | 5029 | 7534 | 7638 | 7086 | 6015 | 5281 | Hydro (GW.h)- Northeast | 2018 |
| 496 | 609 | 532 | 585 | 576 | 555 | 441 | 473 | 332 | 369 | 380 | 518 | Wind (GW.h) - South | |

**Table 34. Scenario 09**

| SCENARIO 09 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Hydro (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest |
| jan | 3705 | 0 | 3964 | 0 | 3735 | 0 | 4667 | 0 | 3709 | 0 | 5406 | 0 | 3903 | 0,4 | 2226 | 0,3 | 4016 | 0,3 | 5281 | 56 |
| feb | 3986 | 0 | 4361 | 0 | 4241 | 0 | 4797 | 0 | 4852 | 0 | 5214 | 0 | 4104 | 0,3 | 4284 | 0,3 | 5625 | 0,3 | 6015 | 43 |
| mar | 5056 | 0 | 5400 | 0 | 4659 | 0 | 5603 | 0 | 5877 | 0 | 5664 | 0 | 5278 | 0,3 | 4683 | 0,3 | 7188 | 0,3 | 7086 | 61 |
| apr | 4361 | 0 | 5034 | 0 | 4987 | 0 | 5631 | 0 | 5767 | 0 | 5649 | 0 | 5931 | 0,3 | 5219 | 0,3 | 6254 | 0,3 | 7638 | 64 |
| may | 4664 | 0 | 4489 | 0 | 5335 | 0 | 4603 | 0 | 5874 | 0 | 5780 | 0 | 6200 | 0,2 | 3703 | 0,2 | 6215 | 0,2 | 7534 | 76 |
| jun | 4658 | 0 | 2964 | 0 | 3699 | 0 | 3035 | 0 | 3120 | 0 | 3196 | 0 | 4146 | 0,2 | 2502 | 0,2 | 4358 | 0,2 | 5029 | 76 |
| jul | 3362 | 0 | 2679 | 0 | 2384 | 0 | 3180 | 0 | 2807 | 0 | 2574 | 0 | 2737 | 0,2 | 2195 | 0,2 | 2757 | 0,2 | 3110 | 90 |
| aug | 2723 | 0 | 2358 | 0 | 2817 | 0 | 2841 | 0 | 2666 | 0 | 3225 | 0 | 2837 | 0,2 | 1937 | 0,2 | 2216 | 0,3 | 3090 | 87 |
| sep | 2078 | 0 | 1910 | 0 | 2853 | 0 | 2311 | 0 | 2886 | 0 | 3298 | 0 | 3518 | 0,3 | 1721 | 0,3 | 3038 | 6 | 2736 | 96 |
| oct | 1758 | 0 | 1509 | 0 | 2255 | 0 | 1875 | 0 | 2621 | 0 | 2146 | 0 | 2257 | 0,3 | 2005 | 0,3 | 2083 | 31 | 2928 | 87 |
| nov | 1847 | 0 | 1596 | 0 | 1885 | 0 | 1823 | 0 | 2042 | 0 | 2134 | 0 | 1636 | 0,3 | 2487 | 0,3 | 1892 | 28 | 2954 | 76 |
| dec | 3104 | 0 | 1803 | 0 | 3842 | 0 | 3074 | 0 | 2712 | 0 | 2697 | 0 | 1530 | 0,3 | 3453 | 0,3 | 3390 | 39 | 7207 | 105 |

**Table 35. Scenario 10**

| SCENARIO 10 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South | Hydro (GW.h)- Northeast | Solar (GW.h) - South |
| jan | 3347 | 0 | 4256 | 0 | 4246 | 0 | 5199 | 0 | 3831 | 0 | 2754 | 0 | 2510 | 0,44 | 2172 | 0,39 | 1724 | 1 | 1216 | 0,38 |
| feb | 3529 | 0 | 4030 | 0 | 3932 | 0 | 4521 | 0 | 2664 | 0 | 2322 | 0 | 2229 | 0,38 | 1918 | 0,32 | 1551 | 0,43 | 1264 | 0,37 |
| mar | 4053 | 0 | 4257 | 0 | 4279 | 0 | 5165 | 0 | 2876 | 0 | 2606 | 0 | 2547 | 0,37 | 1959 | 0,37 | 1684 | 0,4 | 1497 | 0,38 |
| apr | 3972 | 0 | 3505 | 0 | 4036 | 0 | 4686 | 0 | 2833 | 0 | 2504 | 0 | 2343 | 0,32 | 1751 | 0,3 | 1559 | 0,33 | 1310 | 0,4 |
| may | 5080 | 0 | 3506 | 0 | 3456 | 0 | 4511 | 0 | 2595 | 0 | 2506 | 0 | 2540 | 0,26 | 1853 | 0,26 | 1503 | 0,24 | 1382 | 0,28 |
| jun | 4475 | 0 | 3091 | 0 | 3654 | 0 | 4309 | 0 | 2497 | 0 | 2464 | 0 | 2033 | 0,26 | 1748 | 0,28 | 1189 | 0,27 | 1342 | 0,2 |
| jul | 4716 | 0 | 3482 | 0 | 3965 | 0 | 3676 | 0 | 2991 | 0 | 2461 | 0 | 2085 | 0,24 | 1815 | 0,35 | 1240 | 0,33 | 1353 | 0,22 |
| aug | 4354 | 0 | 3365 | 0 | 4264 | 0 | 4057 | 0 | 2713 | 0 | 2439 | 0 | 2142 | 0,35 | 1820 | 0,38 | 1237 | 0,36 | 1333 | 0,29 |
| sep | 4135 | 0 | 3622 | 0 | 4494 | 0 | 3968 | 0 | 2692 | 0 | 2376 | 0 | 2048 | 0,25 | 1778 | 0,48 | 1144 | 0,33 | 1274 | 0,24 |
| oct | 4767 | 0 | 4256 | 0 | 5046 | 0 | 3800 | 0 | 2888 | 0 | 2498 | 0 | 2078 | 0,24 | 1864 | 0,33 | 1151 | 0,38 | 1455 | 0,28 |
| nov | 4925 | 0 | 3781 | 0 | 4460 | 0 | 3291 | 0 | 2636 | 0 | 2430 | 0 | 1936 | 0,28 | 1803 | 0,49 | 1154 | 0,44 | 1445 | 0,35 |
| dec | 4523 | 0 | 4505 | 0 | 4696 | 0 | 4585 | 0 | 2768 | 0 | 2624 | 0 | 1959 | 0,33 | 1775 | 0,46 | 1312 | 0,44 | 1681 | 0,4 |

**Table 36.Scenario 11**

| SCENARIO 11 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest | Wind (GW.h)- Northeast | Solar (GW.h) - Southeast/ Midwest |
| jan | 11 | 0 | 57 | 0 | 51 | 0 | 188 | 0 | 210 | 0 | 363 | 0 | 1405 | 0,4 | 958 | 0,3 | 2516 | 0,3 | 2858 | 56 |
| feb | 8 | 0 | 92 | 0 | 47 | 0 | 139 | 0 | 232 | 0 | 312 | 0 | 1032 | 0,3 | 1612 | 0,3 | 1922 | 0,3 | 1719 | 43 |
| mar | 6 | 0 | 81 | 0 | 31 | 0 | 120 | 0 | 217 | 0 | 305 | 0 | 879 | 0,3 | 1722 | 0,3 | 1579 | 0,3 | 1865 | 61 |
| apr | 3 | 0 | 51 | 0 | 25 | 0 | 129 | 0 | 138 | 0 | 270 | 0 | 768 | 0,3 | 1992 | 0,3 | 2071 | 0,3 | 2318 | 64 |
| may | 3 | 0 | 59 | 0 | 40 | 0 | 157 | 0 | 171 | 0 | 300 | 0 | 1296 | 0,2 | 2054 | 0,2 | 2276 | 0,2 | 3197 | 76 |
| jun | 7 | 0 | 75 | 0 | 62 | 0 | 144 | 0 | 174 | 0 | 537 | 0 | 1354 | 0,2 | 2357 | 0,2 | 2896 | 0,2 | 3832 | 76 |
| jul | 7 | 0 | 70 | 0 | 81 | 0 | 199 | 0 | 217 | 0 | 729 | 0 | 1652 | 0,2 | 2907 | 0,2 | 3547 | 0,2 | 4413 | 90 |
| aug | 27 | 0 | 124 | 0 | 147 | 0 | 243 | 0 | 309 | 0 | 982 | 0 | 2141 | 0,2 | 3033 | 0,2 | 3748 | 0,3 | 4688 | 87 |
| sep | 50 | 0 | 145 | 0 | 174 | 0 | 248 | 0 | 344 | 0 | 915 | 0 | 1904 | 0,3 | 3106 | 0,3 | 4451 | 6 | 4814 | 96 |
| oct | 64 | 0 | 115 | 0 | 196 | 0 | 237 | 0 | 373 | 0 | 1156 | 0 | 2049 | 0,3 | 3080 | 0,3 | 4216 | 31 | 4127 | 87 |
| nov | 72 | 0 | 128 | 0 | 212 | 0 | 211 | 0 | 355 | 0 | 952 | 0 | 1648 | 0,3 | 2951 | 0,3 | 3347 | 28 | 4449 | 76 |
| dec | 64 | 0 | 91 | 0 | 206 | 0 | 258 | 0 | 323 | 0 | 1030 | 0 | 1865 | 0,3 | 2659 | 0,3 | 3061 | 39 | 3228 | 105 |

**Table 37. Scenario 12**

| SCENARIO 12 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South | Wind (GW.h)- Northeast | Solar (GW.h) - South |
| jan | 11 | 0 | 57 | 0 | 51 | 0 | 188 | 0 | 210 | 0 | 363 | 0 | 1405 | 0,44 | 958 | 0,39 | 2516 | 1 | 2858 | 0,38 |
| feb | 8 | 0 | 92 | 0 | 47 | 0 | 139 | 0 | 232 | 0 | 312 | 0 | 1032 | 0,38 | 1612 | 0,32 | 1922 | 0,43 | 1719 | 0,37 |
| mar | 6 | 0 | 81 | 0 | 31 | 0 | 120 | 0 | 217 | 0 | 305 | 0 | 879 | 0,37 | 1722 | 0,37 | 1579 | 0,4 | 1865 | 0,38 |
| apr | 3 | 0 | 51 | 0 | 25 | 0 | 129 | 0 | 138 | 0 | 270 | 0 | 768 | 0,32 | 1992 | 0,3 | 2071 | 0,33 | 2318 | 0,4 |
| may | 3 | 0 | 59 | 0 | 40 | 0 | 157 | 0 | 171 | 0 | 300 | 0 | 1296 | 0,26 | 2054 | 0,26 | 2276 | 0,24 | 3197 | 0,28 |
| jun | 7 | 0 | 75 | 0 | 62 | 0 | 144 | 0 | 174 | 0 | 537 | 0 | 1354 | 0,26 | 2357 | 0,28 | 2896 | 0,27 | 3832 | 0,2 |
| jul | 7 | 0 | 70 | 0 | 81 | 0 | 199 | 0 | 217 | 0 | 729 | 0 | 1652 | 0,24 | 2907 | 0,35 | 3547 | 0,33 | 4413 | 0,22 |
| aug | 27 | 0 | 124 | 0 | 147 | 0 | 243 | 0 | 309 | 0 | 982 | 0 | 2141 | 0,35 | 3033 | 0,38 | 3748 | 0,36 | 4688 | 0,29 |
| sep | 50 | 0 | 145 | 0 | 174 | 0 | 248 | 0 | 344 | 0 | 915 | 0 | 1904 | 0,25 | 3106 | 0,48 | 4451 | 0,33 | 4814 | 0,24 |
| oct | 64 | 0 | 115 | 0 | 196 | 0 | 237 | 0 | 373 | 0 | 1156 | 0 | 2049 | 0,24 | 3080 | 0,33 | 4216 | 0,38 | 4127 | 0,28 |
| nov | 72 | 0 | 128 | 0 | 212 | 0 | 211 | 0 | 355 | 0 | 952 | 0 | 1648 | 0,28 | 2951 | 0,49 | 3347 | 0,44 | 4449 | 0,35 |
| dec | 64 | 0 | 91 | 0 | 206 | 0 | 258 | 0 | 323 | 0 | 1030 | 0 | 1865 | 0,33 | 2659 | 0,46 | 3061 | 0,44 | 3228 | 0,4 |

**Table 38. Scenario 13**

| SCENARIO 13 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast | Hydro (GW.h)- Southeast / | Wind (GW.h) - Northeast |
| Jan | 21325 | 11 | 23156 | 57 | 24137 | 51 | 25823 | 188 | 21677 | 210 | 23751 | 363 | 20805 | 1405 | 23203 | 958 | 26400 | 2516 | 26209 | 2858 |
| Feb | 21364 | 8 | 20737 | 92 | 20781 | 47 | 24611 | 139 | 20716 | 232 | 21512 | 312 | 17907 | 1032 | 22405 | 1612 | 24500 | 1922 | 23742 | 1719 |
| Mar | 24149 | 6 | 23021 | 81 | 22791 | 31 | 26689 | 120 | 21802 | 217 | 20765 | 305 | 20373 | 879 | 24103 | 1722 | 26228 | 1579 | 27824 | 1865 |
| Apr | 23266 | 3 | 21446 | 51 | 22055 | 25 | 24286 | 129 | 20269 | 138 | 19136 | 270 | 18518 | 768 | 21928 | 1992 | 22195 | 2071 | 23396 | 2318 |
| May | 21749 | 3 | 21002 | 59 | 21850 | 40 | 25251 | 157 | 20353 | 171 | 17283 | 300 | 18439 | 1296 | 21893 | 2054 | 21883 | 2276 | 21185 | 3197 |
| Jun | 20919 | 7 | 20098 | 75 | 21857 | 62 | 23265 | 144 | 20470 | 174 | 16095 | 537 | 16851 | 1354 | 21460 | 2357 | 19371 | 2896 | 19604 | 3832 |
| Jul | 22052 | 7 | 21943 | 70 | 22161 | 81 | 24262 | 199 | 21455 | 217 | 17096 | 729 | 17410 | 1652 | 21498 | 2907 | 18889 | 3547 | 19483 | 4413 |
| Aug | 20903 | 27 | 21173 | 124 | 22572 | 147 | 23961 | 243 | 21052 | 309 | 17306 | 982 | 16927 | 2141 | 21157 | 3033 | 18982 | 3748 | 20048 | 4688 |
| Sep | 20875 | 50 | 21226 | 145 | 21654 | 174 | 22557 | 248 | 20423 | 344 | 17261 | 915 | 17140 | 1904 | 19953 | 3106 | 19078 | 4451 | 17273 | 4814 |
| Oct | 21676 | 64 | 22137 | 115 | 22290 | 196 | 23951 | 237 | 21783 | 373 | 19144 | 1156 | 20183 | 2049 | 21217 | 3080 | 20332 | 4216 | 21950 | 4127 |
| Nov | 22694 | 72 | 23143 | 128 | 22883 | 212 | 22819 | 211 | 22113 | 355 | 18188 | 952 | 20001 | 1648 | 21380 | 2951 | 20506 | 3347 | 24005 | 4449 |
| Dec | 22610 | 64 | 23789 | 91 | 24890 | 206 | 23770 | 258 | 24223 | 323 | 19893 | 1030 | 20882 | 1865 | 25072 | 2659 | 25093 | 3061 | 25128 | 3228 |

**Table 39. Scenario 14**

| SCENARIO 14 | | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- Southeast / Midwest | 21325 | 21364 | 24149 | 23266 | 21749 | 20919 | 22052 | 20903 | 20875 | 21676 | 22694 | 22610 |
| | Wind (GW.h) - South | 33 | 25 | 34 | 21 | 27 | 36 | 34 | 31 | 37 | 39 | 36 | 36 |
| 2010 | Hydro (GW.h)- Southeast / Midwest | 23156 | 20737 | 23021 | 21446 | 21002 | 20098 | 21943 | 21173 | 21226 | 22137 | 23143 | 23789 |
| | Wind (GW.h) - South | 26 | 18 | 28 | 16 | 29 | 34 | 39 | 33 | 49 | 27 | 30 | 34 |
| 2011 | Hydro (GW.h)- Southeast / Midwest | 24137 | 20781 | 22791 | 22055 | 21850 | 21857 | 22161 | 22572 | 21654 | 22290 | 22883 | 24890 |
| | Wind (GW.h) - South | 20 | 16 | 44 | 18 | 26 | 51 | 69 | 92 | 72 | 67 | 82 | 73 |
| 2012 | Hydro (GW.h)- Southeast / Midwest | 25823 | 24611 | 26689 | 24286 | 25251 | 23265 | 24262 | 23961 | 22557 | 23951 | 22819 | 23770 |
| | Wind (GW.h) - South | 68 | 51 | 57 | 58 | 57 | 55 | 79 | 98 | 107 | 107 | 87 | 77 |
| 2013 | Hydro (GW.h)- Southeast / Midwest | 21677 | 20716 | 21802 | 20269 | 20353 | 20470 | 21455 | 21052 | 20423 | 21783 | 22113 | 24223 |
| | Wind (GW.h) - South | 86 | 67 | 85 | 92 | 72 | 75 | 80 | 101 | 100 | 120 | 143 | 104 |
| 2014 | Hydro (GW.h)- Southeast / Midwest | 23751 | 21512 | 20765 | 19136 | 17283 | 16095 | 17096 | 17306 | 17261 | 19144 | 18188 | 19893 |
| | Wind (GW.h) - South | 105 | 130 | 142 | 143 | 124 | 190 | 203 | 195 | 224 | 199 | 168 | 164 |
| 2015 | Hydro (GW.h)- Southeast / Midwest | 20805 | 17907 | 20373 | 18518 | 18439 | 16851 | 17410 | 16927 | 17140 | 20183 | 20001 | 20882 |
| | Wind (GW.h) - South | 157 | 195 | 248 | 232 | 286 | 298 | 292 | 446 | 343 | 479 | 462 | 394 |
| 2016 | Hydro (GW.h)- Southeast / Midwest | 23203 | 22405 | 24103 | 21928 | 21893 | 21460 | 21498 | 21157 | 19953 | 21217 | 21380 | 25072 |
| | Wind (GW.h) - South | 418 | 305 | 387 | 439 | 372 | 347 | 438 | 373 | 465 | 605 | 413 | 395 |
| 2017 | Hydro (GW.h)- Southeast / Midwest | 26400 | 24500 | 26228 | 22195 | 21883 | 19371 | 18889 | 18982 | 19078 | 20332 | 20506 | 25093 |
| | Wind (GW.h) - South | 391 | 272 | 482 | 516 | 490 | 452 | 526 | 564 | 563 | 634 | 514 | 593 |
| 2018 | Hydro (GW.h)- Southeast / Midwest | 26209 | 23742 | 27824 | 23396 | 21185 | 19604 | 19483 | 20048 | 17273 | 21950 | 24005 | 25128 |
| | Wind (GW.h) - South | 518 | 380 | 369 | 332 | 473 | 441 | 555 | 576 | 585 | 532 | 609 | 496 |

Table 40. Scenario 15

| dec | nov | oct | sep | aug | jul | jun | may | apr | mar | feb | jan | SCENARIO 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22610 | 22694 | 21676 | 20875 | 20903 | 22052 | 20919 | 21749 | 23266 | 24149 | 21364 | 21325 | Hydro (GW.h)- Southeast / Midwest | 2009 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 23789 | 23143 | 22137 | 21226 | 21173 | 21943 | 20098 | 21002 | 21446 | 23021 | 20737 | 23156 | Hydro (GW.h)- Southeast / Midwest | 2010 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 24890 | 22883 | 22290 | 21654 | 22572 | 22161 | 21857 | 21850 | 22055 | 22791 | 20781 | 24137 | Hydro (GW.h)- Southeast / Midwest | 2011 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 23770 | 22819 | 23951 | 22557 | 23961 | 24262 | 23265 | 25251 | 24286 | 26689 | 24611 | 25823 | Hydro (GW.h)- Southeast / Midwest | 2012 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 24223 | 22113 | 21783 | 20423 | 21052 | 21455 | 20470 | 20353 | 20269 | 21802 | 20716 | 21677 | Hydro (GW.h)- Southeast / Midwest | 2013 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 19893 | 18188 | 19144 | 17261 | 17306 | 17096 | 16095 | 17283 | 19136 | 20765 | 21512 | 23751 | Hydro (GW.h)- Southeast / Midwest | 2014 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Solar (GW.h) - Northeast | |
| 20882 | 20001 | 20183 | 17140 | 16927 | 17410 | 16851 | 18439 | 18518 | 20373 | 17907 | 20805 | Hydro (GW.h)- Southeast / Midwest | 2015 |
| 2,09 | 2,25 | 2,39 | 1,84 | 1,73 | 0,54 | 0,47 | 0,49 | 0,53 | 0,51 | 0,44 | 0,51 | Solar (GW.h) - Northeast | |
| 25072 | 21380 | 21217 | 19953 | 21157 | 21498 | 21460 | 21893 | 21928 | 24103 | 22405 | 23203 | Hydro (GW.h)- Southeast / Midwest | 2016 |
| 1,67 | 1,92 | 2,27 | 2,17 | 2,07 | 1,81 | 1,59 | 1,67 | 1,85 | 2,24 | 2,05 | 1,7 | Solar (GW.h) - Northeast | |
| 25093 | 20506 | 20332 | 19078 | 18982 | 18889 | 19371 | 21883 | 22195 | 26228 | 24500 | 26400 | Hydro (GW.h)- Southeast / Midwest | 2017 |
| 116 | 105 | 120 | 70 | 52 | 39 | 25 | 6 | 1 | 1 | 2 | 2 | Solar (GW.h) - Northeast | |
| 25128 | 24005 | 21950 | 17273 | 20048 | 19483 | 19604 | 21185 | 23396 | 27824 | 23742 | 26209 | Hydro (GW.h)- Southeast / Midwest | 2018 |
| 230 | 197 | 203 | 199 | 181 | 173 | 154 | 154 | 134 | 137 | 115 | 120 | Solar (GW.h) - Northeast | |

**Table 41. Scenario 16**

| SCENARIO 16 | | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- Southeast / Midwest | 21325 | 21364 | 24149 | 23266 | 21749 | 20919 | 22052 | 20903 | 20875 | 21676 | 22694 | 22610 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | Hydro (GW.h)- Southeast / Midwest | 23156 | 20737 | 23021 | 21446 | 21002 | 20098 | 21943 | 21173 | 21226 | 22137 | 23143 | 23789 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | Hydro (GW.h)- Southeast / Midwest | 24137 | 20781 | 22791 | 22055 | 21850 | 21857 | 22161 | 22572 | 21654 | 22290 | 22883 | 24890 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | Hydro (GW.h)- Southeast / Midwest | 25823 | 24611 | 26689 | 24286 | 25251 | 23265 | 24262 | 23961 | 22557 | 23951 | 22819 | 23770 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | Hydro (GW.h)- Southeast / Midwest | 21677 | 20716 | 21802 | 20269 | 20353 | 20470 | 21455 | 21052 | 20423 | 21783 | 22113 | 24223 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | Hydro (GW.h)- Southeast / Midwest | 23751 | 21512 | 20765 | 19136 | 17283 | 16095 | 17096 | 17306 | 17261 | 19144 | 18188 | 19893 |
| | Solar (GW.h) - South | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | Hydro (GW.h)- Southeast / Midwest | 20805 | 17907 | 20373 | 18518 | 18439 | 16851 | 17410 | 16927 | 17140 | 20183 | 20001 | 20882 |
| | Solar (GW.h) - South | 0,44 | 0,38 | 0,37 | 0,32 | 0,26 | 0,26 | 0,24 | 0,35 | 0,25 | 0,24 | 0,28 | 0,33 |
| 2016 | Hydro (GW.h)- Southeast / Midwest | 23203 | 22405 | 24103 | 21928 | 21893 | 21460 | 21498 | 21157 | 19953 | 21217 | 21380 | 25072 |
| | Solar (GW.h) - South | 0,39 | 0,32 | 0,37 | 0,3 | 0,26 | 0,28 | 0,35 | 0,38 | 0,48 | 0,33 | 0,49 | 0,46 |
| 2017 | Hydro (GW.h)- Southeast / Midwest | 26400 | 24500 | 26228 | 22195 | 21883 | 19371 | 18889 | 18982 | 19078 | 20332 | 20506 | 25093 |
| | Solar (GW.h) - South | 1 | 0,43 | 0,4 | 0,33 | 0,24 | 0,27 | 0,33 | 0,36 | 0,33 | 0,38 | 0,44 | 0,44 |
| 2018 | Hydro (GW.h)- Southeast / Midwest | 26209 | 23742 | 27824 | 23396 | 21185 | 19604 | 19483 | 20048 | 17273 | 21950 | 24005 | 25128 |
| | Solar (GW.h) - South | 0,38 | 0,37 | 0,38 | 0,4 | 0,28 | 0,2 | 0,22 | 0,29 | 0,24 | 0,28 | 0,35 | 0,4 |

**Table 42. Scenario 17**

| SCENARIO 17 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - Northeast |
| jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0,51 | 6 | 1,7 | 11 | 2 | 7 | 120 |
| feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0,44 | 7 | 2,05 | 5 | 2 | 4 | 115 |
| mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0,51 | 6 | 2,24 | 5 | 1 | 3 | 137 |
| apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,53 | 5 | 1,85 | 4 | 1 | 1 | 134 |
| may | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,49 | 3 | 1,67 | 4 | 6 | 2 | 154 |
| jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,47 | 2 | 1,59 | 3 | 25 | 3 | 154 |
| jul | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0,54 | 4 | 1,81 | 3 | 39 | 4 | 173 |
| aug | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 1,73 | 7 | 2,07 | 7 | 52 | 4 | 181 |
| sep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1,84 | 7 | 2,17 | 12 | 70 | 5 | 199 |
| oct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 2,39 | 8 | 2,27 | 10 | 120 | 7 | 203 |
| nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 2,25 | 8 | 1,92 | 7 | 105 | 7 | 197 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 2,09 | 6 | 1,67 | 6 | 116 | 5 | 230 |

## Table 43. Scenario 18

| SCENARIO 18 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) – South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South | Wind (GW.h)- Southeast / Midwest | Solar (GW.h) - South |
| jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0,44 | 6 | 0,39 | 11 | 1 | 7 | 0,38 |
| feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0,38 | 7 | 0,32 | 5 | 0,43 | 4 | 0,37 |
| mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0,37 | 6 | 0,37 | 5 | 0,4 | 3 | 0,38 |
| apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,32 | 5 | 0,3 | 4 | 0,33 | 1 | 0,4 |
| may | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,26 | 3 | 0,26 | 4 | 0,24 | 2 | 0,28 |
| jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0,26 | 2 | 0,28 | 3 | 0,27 | 3 | 0,2 |
| jul | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0,24 | 4 | 0,35 | 3 | 0,33 | 4 | 0,22 |
| aug | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0,35 | 7 | 0,38 | 7 | 0,36 | 4 | 0,29 |
| sep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0,25 | 7 | 0,48 | 12 | 0,33 | 5 | 0,24 |
| oct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0,24 | 8 | 0,33 | 10 | 0,38 | 7 | 0,28 |
| nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0,28 | 8 | 0,49 | 7 | 0,44 | 7 | 0,35 |
| dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0,33 | 6 | 0,46 | 6 | 0,44 | 5 | 0,4 |

**Table 44. Scenario 19**

| SCENARIO 19 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast | Hydro (GW.h)- South | Wind (GW.h) - Northeast |
| jan | 5056 | 11 | 6203 | 57 | 6625 | 51 | 3727 | 188 | 4988 | 210 | 7415 | 363 | 9859 | 1405 | 8525 | 958 | 8355 | 2516 | 6662 | 2858 |
| feb | 3447 | 8 | 6209 | 92 | 7671 | 47 | 5182 | 139 | 4572 | 232 | 5916 | 312 | 8396 | 1032 | 8445 | 1612 | 6774 | 1922 | 6134 | 1719 |
| mar | 3467 | 6 | 6573 | 81 | 7464 | 31 | 4972 | 120 | 5648 | 217 | 6471 | 305 | 7347 | 879 | 8828 | 1722 | 5649 | 1579 | 6003 | 1865 |
| apr | 2123 | 3 | 6003 | 51 | 6643 | 25 | 2141 | 129 | 5474 | 138 | 6036 | 270 | 5597 | 768 | 7845 | 1992 | 3937 | 2071 | 5233 | 2318 |
| may | 1386 | 3 | 6709 | 59 | 6513 | 40 | 1824 | 157 | 4379 | 171 | 6339 | 300 | 4408 | 1296 | 7433 | 2054 | 4331 | 2276 | 4130 | 3197 |
| jun | 1379 | 7 | 6929 | 75 | 5799 | 62 | 4620 | 144 | 5370 | 174 | 8188 | 537 | 5824 | 1354 | 6999 | 2357 | 7611 | 2896 | 3780 | 3832 |
| jul | 3981 | 7 | 7217 | 70 | 8189 | 81 | 5684 | 199 | 7005 | 217 | 8811 | 729 | 8542 | 1652 | 7642 | 2907 | 6526 | 3547 | 5211 | 4413 |
| aug | 7545 | 27 | 6987 | 124 | 8837 | 147 | 6515 | 243 | 8424 | 309 | 7105 | 982 | 8537 | 2141 | 7864 | 3033 | 5921 | 3748 | 4850 | 4688 |
| sep | 7732 | 50 | 5661 | 145 | 8142 | 174 | 5498 | 248 | 8232 | 344 | 7889 | 915 | 7992 | 1904 | 7645 | 3106 | 4809 | 4451 | 6656 | 4814 |
| oct | 7982 | 64 | 6106 | 115 | 8014 | 196 | 5544 | 237 | 8786 | 373 | 8430 | 1156 | 9124 | 2049 | 7445 | 3080 | 6101 | 4216 | 7847 | 4127 |
| nov | 7151 | 72 | 5020 | 128 | 7213 | 212 | 3705 | 211 | 7708 | 355 | 8181 | 952 | 8862 | 1648 | 7039 | 2951 | 6778 | 3347 | 8088 | 4449 |
| dec | 6537 | 64 | 6274 | 91 | 4886 | 206 | 3278 | 258 | 6770 | 323 | 6293 | 1030 | 9818 | 1865 | 7025 | 2659 | 5421 | 3061 | 6318 | 3228 |

**Table 45. Scenario 20**

| SCENARIO 20 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest | Hydro (GW.h)- South | Wind (GW.h) - Southeast / Midwest |
| jan | 5056 | 0 | 6203 | 0 | 6625 | 0 | 3727 | 0 | 4988 | 0 | 7415 | 0 | 9859 | 13 | 8525 | 6 | 8355 | 11 | 6662 | 7 |
| feb | 3447 | 0 | 6209 | 0 | 7671 | 0 | 5182 | 0 | 4572 | 0 | 5916 | 0 | 8396 | 8 | 8445 | 7 | 6774 | 5 | 6134 | 4 |
| mar | 3467 | 0 | 6573 | 0 | 7464 | 0 | 4972 | 0 | 5648 | 0 | 6471 | 0 | 7347 | 4 | 8828 | 6 | 5649 | 5 | 6003 | 3 |
| apr | 2123 | 0 | 6003 | 0 | 6643 | 0 | 2141 | 0 | 5474 | 0 | 6036 | 0 | 5597 | 3 | 7845 | 5 | 3937 | 4 | 5233 | 1 |
| may | 1386 | 0 | 6709 | 0 | 6513 | 0 | 1824 | 0 | 4379 | 0 | 6339 | 0 | 4408 | 3 | 7433 | 3 | 4331 | 4 | 4130 | 2 |
| jun | 1379 | 0 | 6929 | 0 | 5799 | 0 | 4620 | 0 | 5370 | 0 | 8188 | 0 | 5824 | 3 | 6999 | 2 | 7611 | 3 | 3780 | 3 |
| jul | 3981 | 0 | 7217 | 0 | 8189 | 0 | 5684 | 0 | 7005 | 0 | 8811 | 0 | 8542 | 6 | 7642 | 4 | 6526 | 3 | 5211 | 4 |
| aug | 7545 | 0 | 6987 | 0 | 8837 | 0 | 6515 | 0 | 8424 | 0 | 7105 | 0 | 8537 | 6 | 7864 | 7 | 5921 | 7 | 4850 | 4 |
| sep | 7732 | 0 | 5661 | 0 | 8142 | 0 | 5498 | 0 | 8232 | 0 | 7889 | 0 | 7992 | 7 | 7645 | 7 | 4809 | 12 | 6656 | 5 |
| oct | 7982 | 0 | 6106 | 0 | 8014 | 0 | 5544 | 0 | 8786 | 0 | 8430 | 0 | 9124 | 9 | 7445 | 8 | 6101 | 10 | 7847 | 7 |
| nov | 7151 | 0 | 5020 | 0 | 7213 | 0 | 3705 | 0 | 7708 | 0 | 8181 | 0 | 8862 | 5 | 7039 | 8 | 6778 | 7 | 8088 | 7 |
| dec | 6537 | 0 | 6274 | 0 | 4886 | 0 | 3278 | 0 | 6770 | 0 | 6293 | 0 | 9818 | 9 | 7025 | 6 | 5421 | 6 | 6318 | 5 |

**Table 46. Scenario 21**

| SCENARIO 21 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) – Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) - Northeast | Hydro (GW.h)- South | Solar (GW.h) – Northeast |
| jan | 5056 | 0 | 6203 | 0 | 6625 | 0 | 3727 | 0 | 4988 | 0 | 7415 | 0 | 9859 | 0,51 | 8525 | 1,7 | 8355 | 2 | 6662 | 120 |
| feb | 3447 | 0 | 6209 | 0 | 7671 | 0 | 5182 | 0 | 4572 | 0 | 5916 | 0 | 8396 | 0,44 | 8445 | 2,05 | 6774 | 2 | 6134 | 115 |
| mar | 3467 | 0 | 6573 | 0 | 7464 | 0 | 4972 | 0 | 5648 | 0 | 6471 | 0 | 7347 | 0,51 | 8828 | 2,24 | 5649 | 1 | 6003 | 137 |
| apr | 2123 | 0 | 6003 | 0 | 6643 | 0 | 2141 | 0 | 5474 | 0 | 6036 | 0 | 5597 | 0,53 | 7845 | 1,85 | 3937 | 1 | 5233 | 134 |
| may | 1386 | 0 | 6709 | 0 | 6513 | 0 | 1824 | 0 | 4379 | 0 | 6339 | 0 | 4408 | 0,49 | 7433 | 1,67 | 4331 | 6 | 4130 | 154 |
| jun | 1379 | 0 | 6929 | 0 | 5799 | 0 | 4620 | 0 | 5370 | 0 | 8188 | 0 | 5824 | 0,47 | 6999 | 1,59 | 7611 | 25 | 3780 | 154 |
| jul | 3981 | 0 | 7217 | 0 | 8189 | 0 | 5684 | 0 | 7005 | 0 | 8811 | 0 | 8542 | 0,54 | 7642 | 1,81 | 6526 | 39 | 5211 | 173 |
| aug | 7545 | 0 | 6987 | 0 | 8837 | 0 | 6515 | 0 | 8424 | 0 | 7105 | 0 | 8537 | 1,73 | 7864 | 2,07 | 5921 | 52 | 4850 | 181 |
| sep | 7732 | 0 | 5661 | 0 | 8142 | 0 | 5498 | 0 | 8232 | 0 | 7889 | 0 | 7992 | 1,84 | 7645 | 2,17 | 4809 | 70 | 6656 | 199 |
| oct | 7982 | 0 | 6106 | 0 | 8014 | 0 | 5544 | 0 | 8786 | 0 | 8430 | 0 | 9124 | 2,39 | 7445 | 2,27 | 6101 | 120 | 7847 | 203 |
| nov | 7151 | 0 | 5020 | 0 | 7213 | 0 | 3705 | 0 | 7708 | 0 | 8181 | 0 | 8862 | 2,25 | 7039 | 1,92 | 6778 | 105 | 8088 | 197 |
| dec | 6537 | 0 | 6274 | 0 | 4886 | 0 | 3278 | 0 | 6770 | 0 | 6293 | 0 | 9818 | 2,09 | 7025 | 1,67 | 5421 | 116 | 6318 | 230 |

**Table 47. Scenario 22**

| SCENARIO 22 | | jan | feb | mar | apr | may | jun | jul | aug | sep | oct | nov | dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | Hydro (GW.h)- South | 5056 | 3447 | 3467 | 2123 | 1386 | 1379 | 3981 | 7545 | 7732 | 7982 | 7151 | 6537 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | Hydro (GW.h)- South | 6203 | 6209 | 6573 | 6003 | 6709 | 6929 | 7217 | 6987 | 5661 | 6106 | 5020 | 6274 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | Hydro (GW.h)- South | 6625 | 7671 | 7464 | 6643 | 6513 | 5799 | 8189 | 8837 | 8142 | 8014 | 7213 | 4886 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | Hydro (GW.h)- South | 3727 | 5182 | 4972 | 2141 | 1824 | 4620 | 5684 | 6515 | 5498 | 5544 | 3705 | 3278 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2013 | Hydro (GW.h)- South | 4988 | 4572 | 5648 | 5474 | 4379 | 5370 | 7005 | 8424 | 8232 | 8786 | 7708 | 6770 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | Hydro (GW.h)- South | 7415 | 5916 | 6471 | 6036 | 6339 | 8188 | 8811 | 7105 | 7889 | 8430 | 8181 | 6293 |
| | Solar (GW.h) - Southeast / Midwest | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | Hydro (GW.h)- South | 9859 | 8396 | 7347 | 5597 | 4408 | 5824 | 8542 | 8537 | 7992 | 9124 | 8862 | 9818 |
| | Solar (GW.h) - Southeast / Midwest | 0,4 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 |
| 2016 | Hydro (GW.h)- South | 8525 | 8445 | 8828 | 7845 | 7433 | 6999 | 7642 | 7864 | 7645 | 7445 | 7039 | 7025 |
| | Solar (GW.h) - Southeast / Midwest | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,2 | 0,3 | 0,3 | 0,3 | 0,3 |
| 2017 | Hydro (GW.h)- South | 8355 | 6774 | 5649 | 3937 | 4331 | 7611 | 6526 | 5921 | 4809 | 6101 | 6778 | 5421 |
| | Solar (GW.h) - Southeast / Midwest | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 | 0,2 | 0,3 | 6 | 31 | 28 | 39 |
| 2018 | Hydro (GW.h)- South | 6662 | 6134 | 6003 | 5233 | 4130 | 3780 | 5211 | 4850 | 6656 | 7847 | 8088 | 6318 |
| | Solar (GW.h) - Southeast / Midwest | 56 | 43 | 61 | 64 | 76 | 76 | 90 | 87 | 96 | 87 | 76 | 105 |

**Table 48. Scenario 23**

| SCENARIO 23 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast | Wind (GW.h)- South | Solar (GW.h) - Northeast |
| jan | 33 | 0 | 26 | 0 | 20 | 0 | 68 | 0 | 86 | 0 | 105 | 0 | 157 | 0,51 | 418 | 1,7 | 391 | 2 | 518 | 120 |
| feb | 25 | 0 | 18 | 0 | 16 | 0 | 51 | 0 | 67 | 0 | 130 | 0 | 195 | 0,44 | 305 | 2,05 | 272 | 2 | 380 | 115 |
| mar | 34 | 0 | 28 | 0 | 44 | 0 | 57 | 0 | 85 | 0 | 142 | 0 | 248 | 0,51 | 387 | 2,24 | 482 | 1 | 369 | 137 |
| Apr | 21 | 0 | 16 | 0 | 18 | 0 | 58 | 0 | 92 | 0 | 143 | 0 | 232 | 0,53 | 439 | 1,85 | 516 | 1 | 332 | 134 |
| May | 27 | 0 | 29 | 0 | 26 | 0 | 57 | 0 | 72 | 0 | 124 | 0 | 286 | 0,49 | 372 | 1,67 | 490 | 6 | 473 | 154 |
| Jun | 36 | 0 | 34 | 0 | 51 | 0 | 55 | 0 | 75 | 0 | 190 | 0 | 298 | 0,47 | 347 | 1,59 | 452 | 25 | 441 | 154 |
| Jul | 34 | 0 | 39 | 0 | 69 | 0 | 79 | 0 | 80 | 0 | 203 | 0 | 292 | 0,54 | 438 | 1,81 | 526 | 39 | 555 | 173 |
| Aug | 31 | 0 | 33 | 0 | 92 | 0 | 98 | 0 | 101 | 0 | 195 | 0 | 446 | 1,73 | 373 | 2,07 | 564 | 52 | 576 | 181 |
| Sep | 37 | 0 | 49 | 0 | 72 | 0 | 107 | 0 | 100 | 0 | 224 | 0 | 343 | 1,84 | 465 | 2,17 | 563 | 70 | 585 | 199 |
| Oct | 39 | 0 | 27 | 0 | 67 | 0 | 107 | 0 | 120 | 0 | 199 | 0 | 479 | 2,39 | 605 | 2,27 | 634 | 120 | 532 | 203 |
| Nov | 36 | 0 | 30 | 0 | 82 | 0 | 87 | 0 | 143 | 0 | 168 | 0 | 462 | 2,25 | 413 | 1,92 | 514 | 105 | 609 | 197 |
| Dec | 36 | 0 | 34 | 0 | 73 | 0 | 77 | 0 | 104 | 0 | 164 | 0 | 394 | 2,09 | 395 | 1,67 | 593 | 116 | 496 | 230 |

**Table 49. Scenario 24**

| SCENARIO 24 | 2009 | | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest | Wind (GW.h)- South | Solar (GW.h) - Southeast / Midwest |
| jan | 33 | 0 | 26 | 0 | 20 | 0 | 68 | 0 | 86 | 0 | 105 | 0 | 157 | 0,4 | 418 | 0,3 | 391 | 0,3 | 518 | 56 |
| Feb | 25 | 0 | 18 | 0 | 16 | 0 | 51 | 0 | 67 | 0 | 130 | 0 | 195 | 0,3 | 305 | 0,3 | 272 | 0,3 | 380 | 43 |
| Mar | 34 | 0 | 28 | 0 | 44 | 0 | 57 | 0 | 85 | 0 | 142 | 0 | 248 | 0,3 | 387 | 0,3 | 482 | 0,3 | 369 | 61 |
| Apr | 21 | 0 | 16 | 0 | 18 | 0 | 58 | 0 | 92 | 0 | 143 | 0 | 232 | 0,3 | 439 | 0,3 | 516 | 0,3 | 332 | 64 |
| May | 27 | 0 | 29 | 0 | 26 | 0 | 57 | 0 | 72 | 0 | 124 | 0 | 286 | 0,2 | 372 | 0,2 | 490 | 0,2 | 473 | 76 |
| Jun | 36 | 0 | 34 | 0 | 51 | 0 | 55 | 0 | 75 | 0 | 190 | 0 | 298 | 0,2 | 347 | 0,2 | 452 | 0,2 | 441 | 76 |
| Jul | 34 | 0 | 39 | 0 | 69 | 0 | 79 | 0 | 80 | 0 | 203 | 0 | 292 | 0,2 | 438 | 0,2 | 526 | 0,2 | 555 | 90 |
| Aug | 31 | 0 | 33 | 0 | 92 | 0 | 98 | 0 | 101 | 0 | 195 | 0 | 446 | 0,2 | 373 | 0,2 | 564 | 0,3 | 576 | 87 |
| Sep | 37 | 0 | 49 | 0 | 72 | 0 | 107 | 0 | 100 | 0 | 224 | 0 | 343 | 0,3 | 465 | 0,3 | 563 | 6 | 585 | 96 |
| Oct | 39 | 0 | 27 | 0 | 67 | 0 | 107 | 0 | 120 | 0 | 199 | 0 | 479 | 0,3 | 605 | 0,3 | 634 | 31 | 532 | 87 |
| Nov | 36 | 0 | 30 | 0 | 82 | 0 | 87 | 0 | 143 | 0 | 168 | 0 | 462 | 0,3 | 413 | 0,3 | 514 | 28 | 609 | 76 |
| Dec | 36 | 0 | 34 | 0 | 73 | 0 | 77 | 0 | 104 | 0 | 164 | 0 | 394 | 0,3 | 395 | 0,3 | 593 | 39 | 496 | 105 |

# APPENDIX 2 – PEARSON CORRELATION COEFFICIENT FOR THE SCENARIOS

Pearson's calculation for the 24 scenarios.

**Table 50. Pearson Correlation Coefficient for all the Scenarios**

| Scenarios | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | ρaverage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | -0.86 | -0.72 | -0.74 | -0.80 | -0.73 | -0.91 | -0.78 | -0.54 | 0.89 | -0.83 | -0.78 |
| 02 | - | - | - | - | - | - | -0.48 | -0.19 | -0.46 | -0.62 | -0.44 |
| 03 | -0.54 | -0.60 | -0.78 | -0.80 | -0.61 | -0.79 | -0.69 | -0.38 | -0.51 | -0.81 | -0.65 |
| 04 | - | - | - | - | - | - | -0.77 | -0.05 | -0.78 | -0.44 | -0.51 |
| 05 | - | - | - | - | - | - | -0.09 | 0.28 | -0.53 | -0.39 | -0.18 |
| 06 | - | - | - | - | - | - | 0.17 | -0.38 | -0.09 | 0.58 | 0.07 |
| 07 | - | - | - | - | - | - | -0.05 | 0.19 | -0.14 | 0.09 | 0.02 |
| 08 | -0.54 | -0.60 | -0.78 | -0.80 | -0.61 | -0.79 | -0.69 | -0.38 | -0.51 | -0.81 | -0.65 |
| 09 | - | - | - | - | - | - | -0.09 | 0.28 | -0.53 | -0.39 | -0.18 |
| 10 | - | - | - | - | - | - | 0.51 | -0.02 | 0.49 | 0.26 | 0.31 |
| 11 | - | - | - | - | - | - | -0.17 | -0.23 | 0.41 | 0.75 | 0.19 |
| 12 | - | - | - | - | - | - | -0.36 | 0.37 | -0.15 | -0.69 | -0.21 |
| 13 | -0.03 | -0.03 | -0.34 | 0.56 | -0.49 | 0.35 | 0.07 | 0.52 | -0.72 | -0.72 | -0.08 |
| 14 | -0.13 | -0.01 | 0.24 | -0.55 | 0.45 | -0.71 | 0.03 | -0.3 | -0.46 | -0.44 | 0.19 |
| 15 | - | - | - | - | - | - | 0.26 | -0.26 | -0.34 | -0.32 | -0.16 |
| 16 | - | - | - | - | - | - | 0.39 | 0.07 | 0.59 | 0.86 | 0.48 |
| 17 | - | - | - | - | - | - | 0.27 | 0,71 | 0.40 | 0.41 | 0.45 |
| 18 | - | - | - | - | - | - | 0.47 | 0.63 | 0.52 | 0.04 | 0.42 |
| 19 | -0.84 | 0.45 | -0.09 | -0.35 | -0.84 | -0.55 | 0.54 | -0.67 | 0.03 | 0.12 | -0.22 |
| 20 | - | - | - | - | - | - | 0.83 | 0.21 | 0.14 | 0.81 | 0.50 |
| 21 | - | - | - | - | - | - | -0.53 | -0.41 | 0.02 | 0.35 | -0.14 |
| 22 | - | - | - | - | - | - | 0.52 | 0.30 | -0.03 | 0.04 | 0.21 |
| 23 | - | - | - | - | - | - | 0.89 | 0.42 | 0.71 | 0.66 | 0.67 |
| 24 | - | - | - | - | - | - | -0.28 | 0.30 | 0.55 | 0.62 | 0.30 |

# APPENDIX 3- GRAPHICS FOR THE SCENARIOS

Graphs normalized from the maximum generation of energy of each year.

**Figure 19. Scenario 05 energy generation correlation**

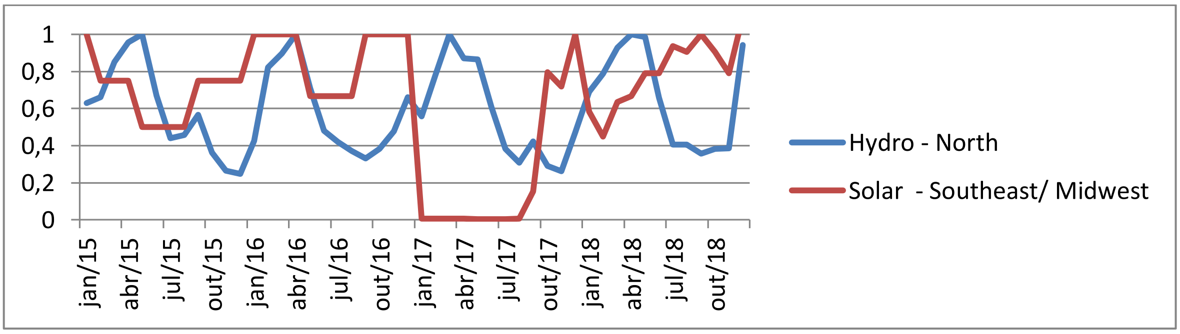

**Figure 20. Scenario 06 energy generation correlation**

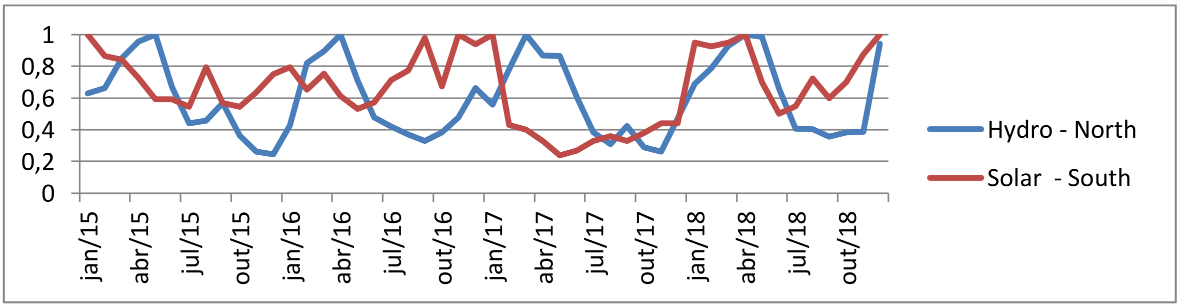

**Figure 21. Scenario 07 energy generation correlation**

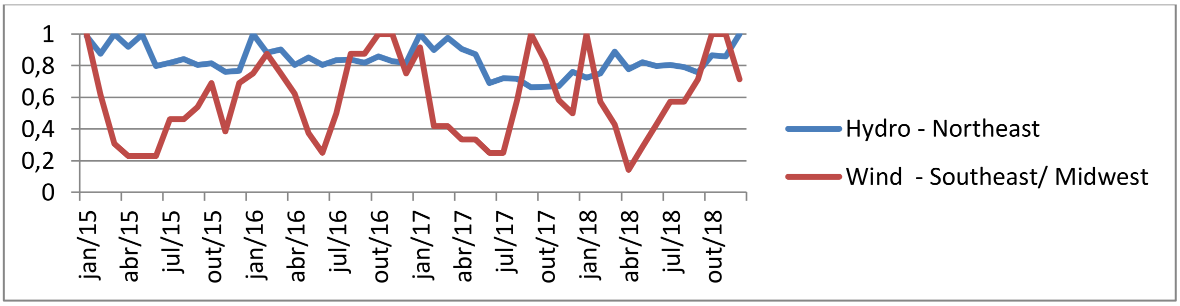

Figure 22. Scenario 09 energy generation correlation

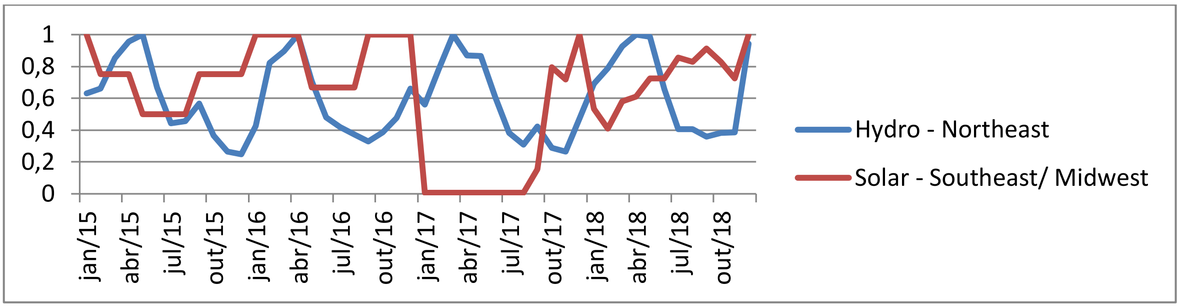

Figure 23. Scenario 10 energy generation correlation

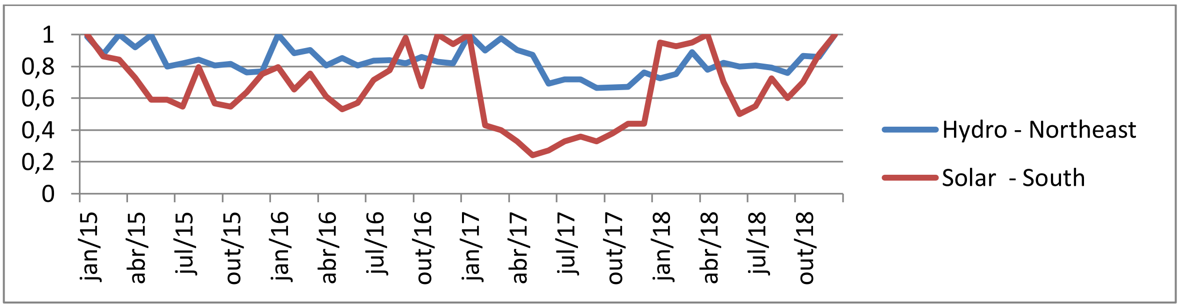

Figure 24. Scenario 11 energy generation correlation

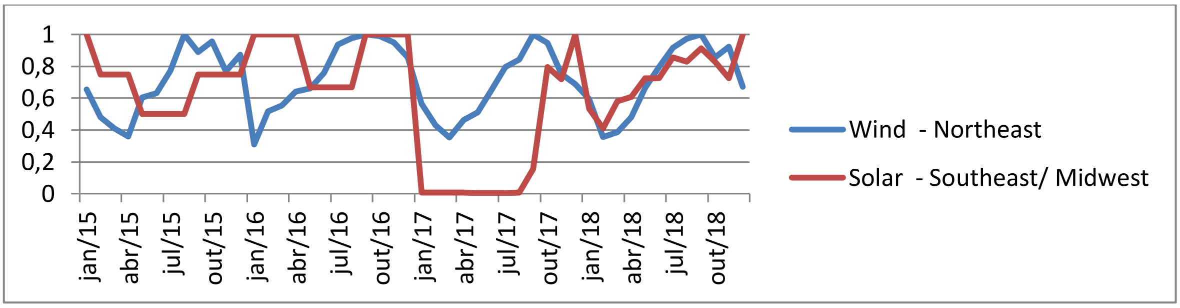

Figure 25. Scenario 12 energy generation correlation

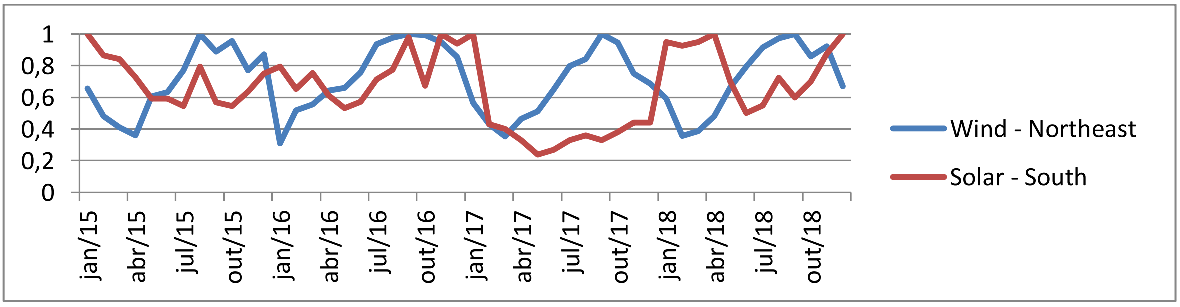

Figure 26. Scenario 13 energy generation correlation

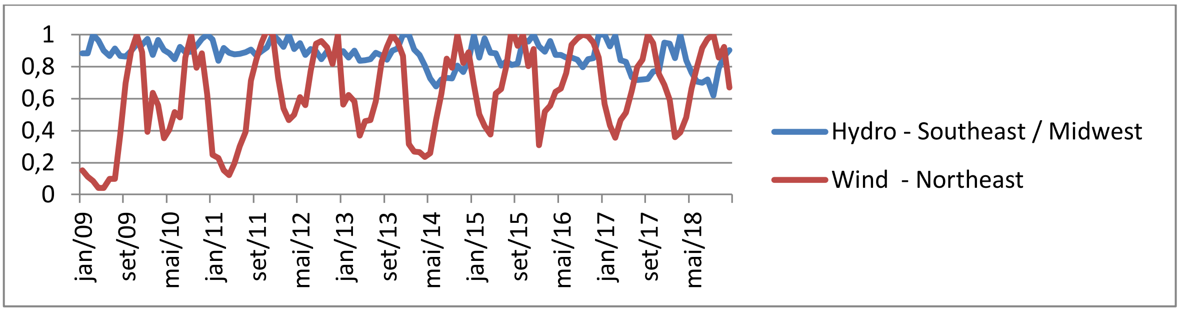

Figure 27. Scenario 14 energy generation correlation

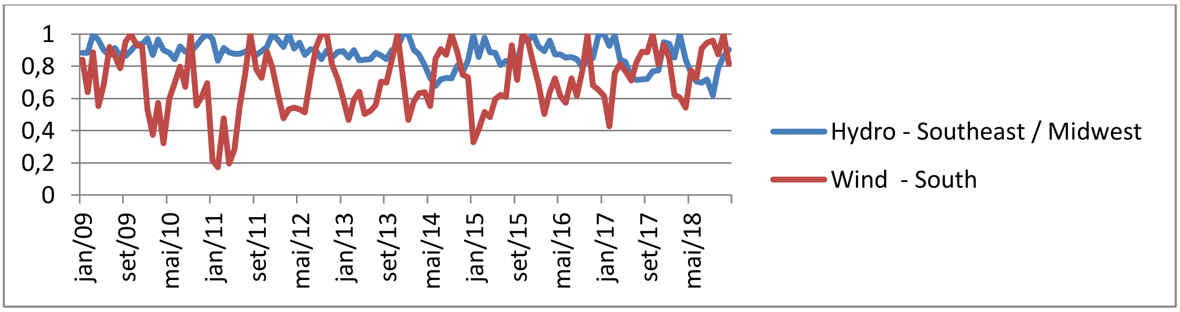

Figure 28. Scenario 15 energy generation correlation

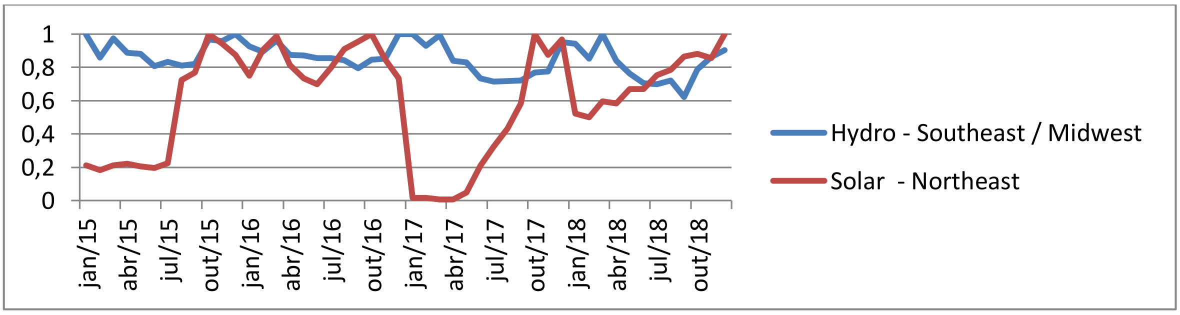

Figure 29. Scenario 17 energy generation correlation

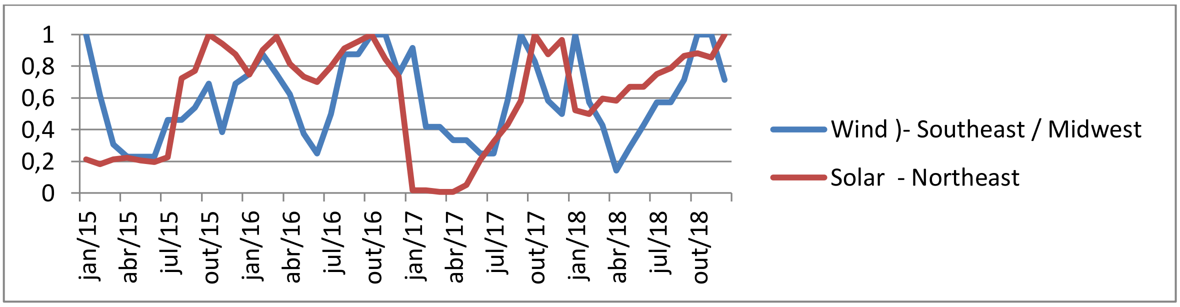

Figure 30. Scenario 18 energy generation correlation

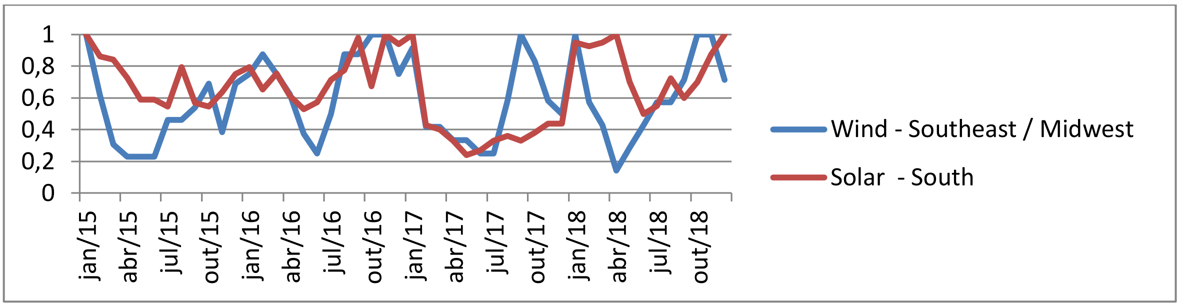

Figure 31. Scenario 19 energy generation correlation

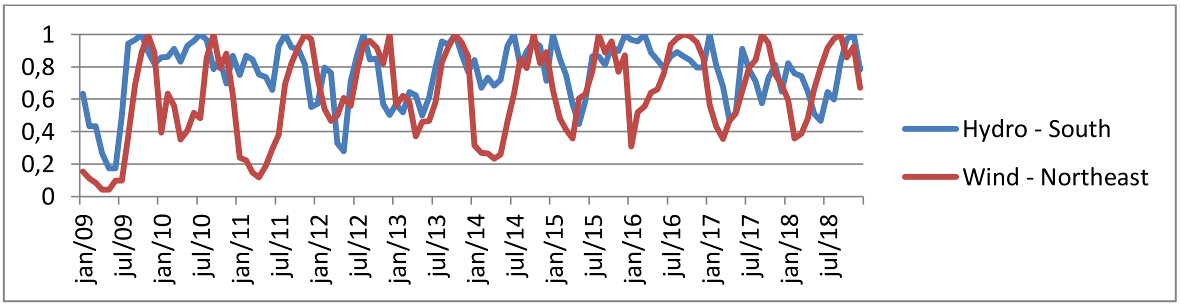

Figure 32. Scenario 21 energy generation correlation

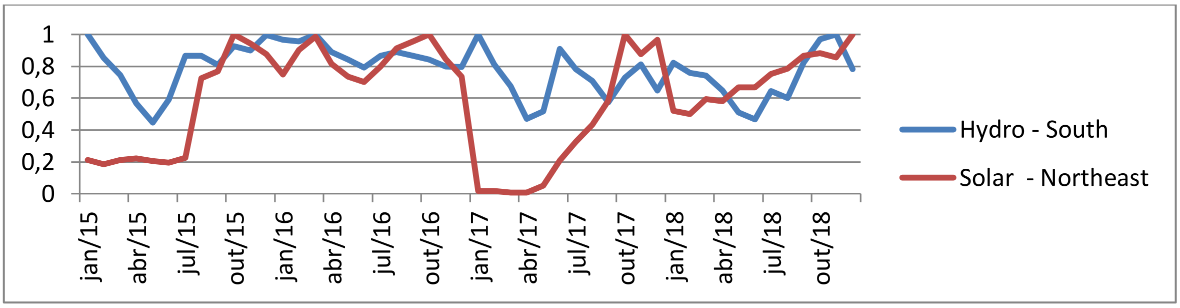

Figure 33. Scenario 22 energy generation correlation

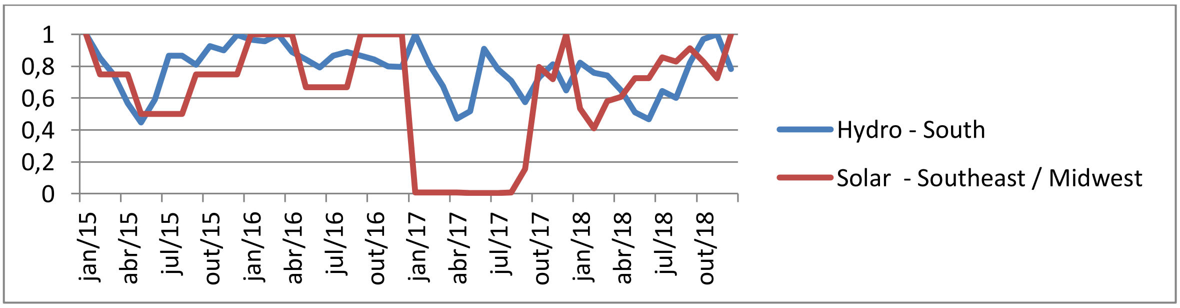

Figure 34. Scenario 23 energy generation correlation

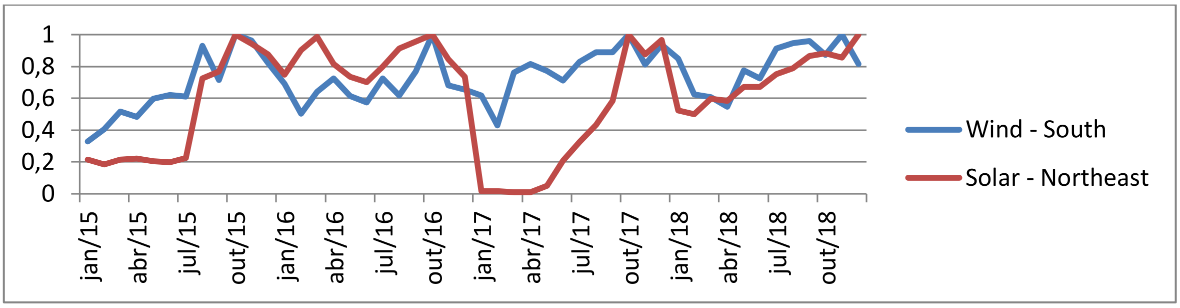

Figure 35. Scenario 24 energy generation correlation