Energy governance in Brazil: meeting the international agreements on climate change mitigation

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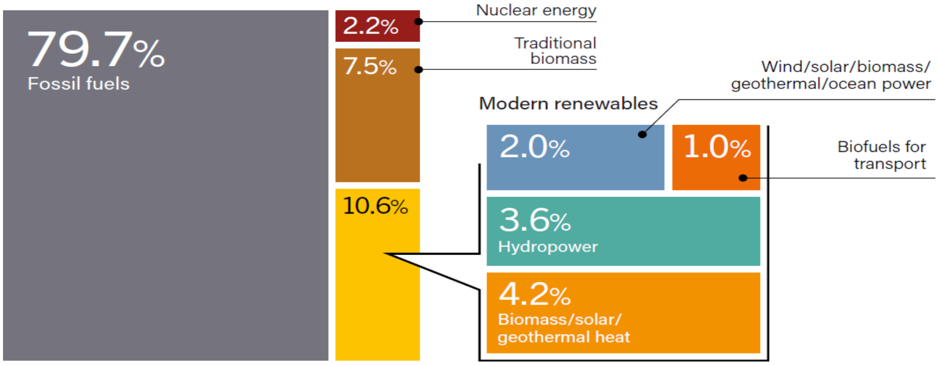
CHAPTER 4
RENEWABLES SOURCES IN BRAZIL: STEPS TOWARDS ENERGY TRANSITION

This chapter presents the developments in renewable energy in Brazil. It has three sections dedicated to investigating the country's power generation from the following sources: wind, solar and biomass. Within the last section, ethanol, and biodiesel (first and second generation), biogas, and black liquor will be addressed. Firstly, data on energy consumption source supply by sources is presented in order to clarify the extent to which energy transition is needed worldwide as well as in Brazil.

Climate change evidence is increasing, and therefore, an energy transition from fossil fuels to more intensive use of renewable energy sources is very much needed. Traditional fossil fuels –coal, petroleum, and natural gas– are non-renewable as they have formed over hundreds of millions of years, and their availability is limited. Yet, according to the REN21 report (2019), fossil fuels are the primary energy source in the world and contributed 79,7% of global final energy consumption in 2017 against 20, 3% of the energy generated from renewable sources (Figure 1). In contrast to fossil fuels, renewable energy sources are not depleted when exploited. These sources include hydro, wind, solar, biomass, geothermal, ocean thermal, wave and tidal action, as well as biogas generated of municipal and agriculture waste, and also from manure, sewage, plant material, green, and food waste.

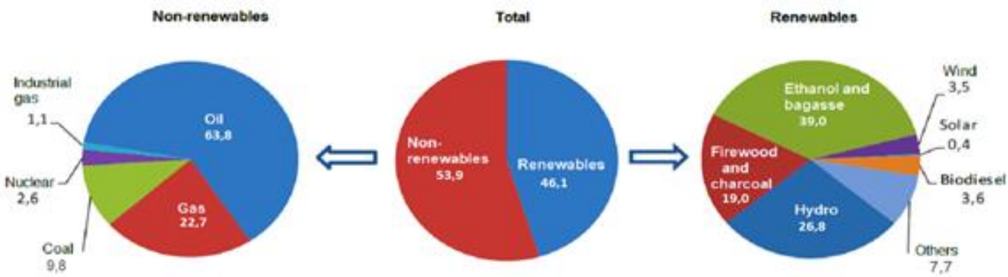
FIGURE 1. Estimated Renewable Share of Total Final Energy Consumption, 2017



Source: REN21 (2019) Based on OECD/IEA and IEA SHC.

Brazil stands out in the international scenario for having the cleanest electricity industry in the world (Abramovay, 2013; Knodt & Piefer, 2015). However, when analysing Brazilian total energy supply (Figure 2),[35] non-renewable sources are still the most used in the country, especially in the transport sector. Data from the National Agency of Petroleum, Natural Gas and Biofuels[36] (2019) show that the contribution rate of ethanol[37] to the country's transport fuel market in 2018 was 18,9% against 76,7% of fossil-based fuel and a small share of 4,4% of biodiesel.

Figure 2 **Brazilian domestic energy supply - 2019 (%)**

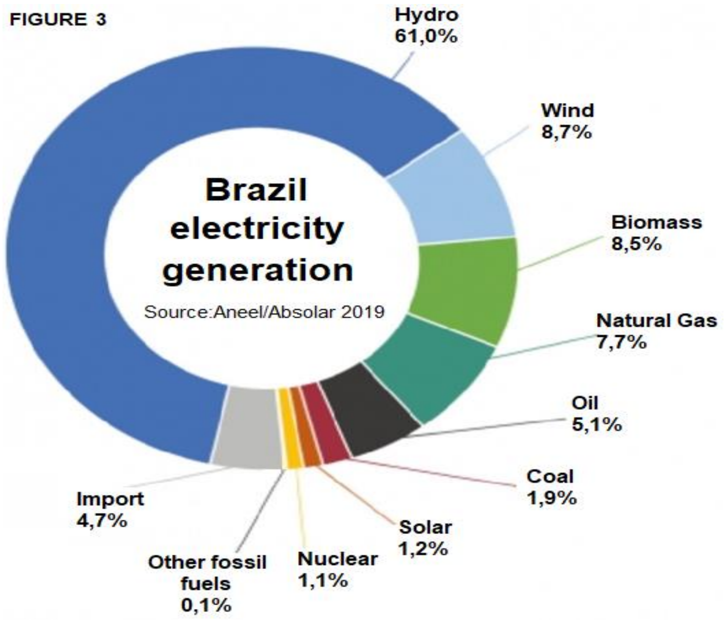


Source: Brazilian Ministry of mine and energy- 2020

[35] Own translation.
[36] ANP in Portuguese.
[37] Ethanol has already been discussed in this study.

Electricity in Brazil is generated from different renewable sources but mostly by hydroelectric plants. The history of hydro energy as the main source of energy has been previously discussed. This section will tackle the most used alternative sources after hydro which are wind, solar and biomass[38] as shown in the chart below (Figure 3).[39]

FIGURE 3



4.1 Wind power: a primarily private sector initiative

Wind energy is the transformation of the wind's motive force into useful energy, as it is the case with the use of aero generators to produce electricity, windmill to produce mechanical energy and sails to propel sailboats. As an alternative to fossil fuels, wind energy is renewable, permanently available worldwide and does not emit GHG, causing less impact on the environment. Wind power has firmly established itself as

[38] In Brazil, biomass is used to generate electricity through combustion processes and as a raw material for the manufacture of fuels such as ethanol and biodiesel, mostly used in the transport sector.
[39] Own adaptation and translation.

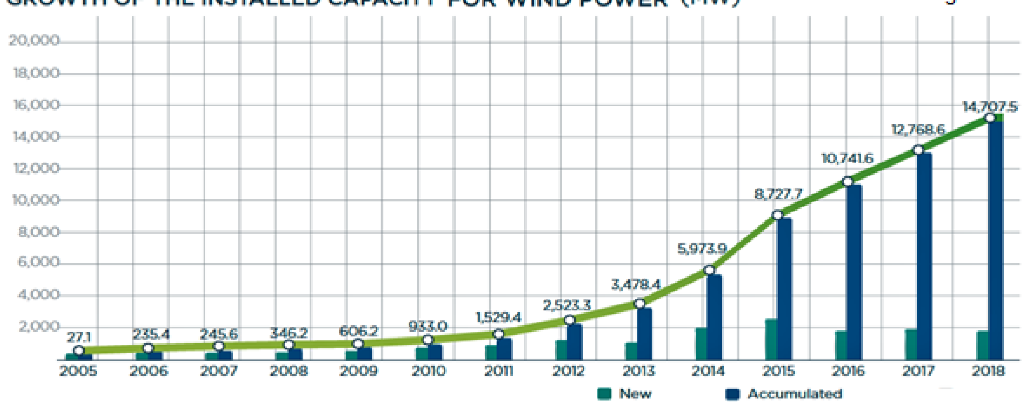
a new option for electric power generation. The extraordinary recent progress is that wind power is the lowest cost option when a new generation is added to the grid in a growing number of markets, and prices continue to fall. Commercial wind power facilities currently exist in more than ninety countries, with a total installed capacity of 591 GW at the end of 2018, providing about 8% of the global electricity supply (Ohlenforst, 2019). Wind energy has the least impact with its implementation, and most importantly, it does not emit CO_2 and can replace other CO_2 emitting sources (ABEEólica, 2019).

The first wind turbine to operate commercially in Brazil was installed in 1992 in Fernando de Noronha, an archipelago located 225 miles (360 km) from the country's northeast coast nearby the Pernambuco state. At that time, the technology was still incipient and needed to be consolidated in both domestic and international markets. Eventually, at the beginning of the 2000s, wind power was already being generated on a large-scale in different countries such as Denmark and Germany, while in Brazil, it was yet as good as non-existent (Diniz, 2018).

Between 2001 and 2002, the Brazilian electricity sector suffered a severe supply crisis that culminated in an electricity rationing plan by the then President Fernando Henrique Cardoso whose successful campaign reduced energy consumption among the population. His effort helped to prevent regular disruptions that could have affected the country's economic growth (Castro, 2014). The crisis has forced the government to execute infrastructure projects to meet the country's increasing energy demand. It also led to creating the Incentive Programme for Alternative Energy Sources PROINFA (Programa de Incentivo às Fontes Alternativas in Portuguese), an incentive programme for alternative energy generation that started in 2002. The programme aimed to foster energy generation development from alternative sources – wind, biomass, and small hydro – and is still in force.

In 2003 Luiz Inácio Lula da Silva from the Worker's Party became president. His government sustained hydropower as part of its developmentalist agenda, and simultaneously, large public support programmes were initiated to insert other alternative energy sources into the supply planning. Proinfa introduced feed-in tariffs[40] which ended in 2008. An auction-based system was introduced instead. In December 2009, the first exclusive auction for wind power contracted 13,000 MW in wind power projects (Bradshaw, 2018). From then on, wind power generation in Brazil begun to expand rapidly, as shown in the chart below.

Figure 4



Source: ANEEL/ABEEólica – Annual Wind Energy Report 2018

In 2012, ABEEólica (Brazilian Wind Energy Association) and Abragel (Brazilian clean energy generation association) joined together and launched the Renewable Energy Certification Programme in order to stimulate renewable energy generation. The project put together experts in certification, market, energy, and sustainability to specify sustainable energy ventures' concepts. Up to now, more than 1,300,000 RECs have been issued in Brazil (ABEEólica, 2019).

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40 A feed-in tariff (FIT) is a policy instrument to foster alternative energy sources' development and use. It guarantees grid access, long-term contracts (commonly between 15 to 20 years), cost-based purchase price, which means that a fraction of the resources and capital used for energy production are compensated.

According to the Brazilian Energy Research Agency (Empresa de Pesquisa Energética in Portuguese), wind power has been evaluated as considerably competitive compared to other technologies that are candidates for expansion. It costs less than thermal and hydro energy; however, wind power offers less contribution to the grid (EPE, 2018).

Abramovay argues that "the predominance of hydroelectric dams poses a risk as this source is susceptible to seasonal droughts" (2013: 7). In Brazil, rainfall does not occur year-round distributively, and with climate change, extended periods of drought are more frequent. Wind power is considered to properly complement the Brazilian hydropower-based energy supply (Bradshaw, 2018). River's lowest outflow periods is when the wind incidence is adequate for power generation. Wind speeds are higher during the dry season when reservoir levels decrease. This feature makes wind energy a suitable alternative to complement hydropower shortage when water deficit occurs (Alves, 2010; Moraes, 2015). On the other hand, the intermittency of wind power (and solar) is an issue of concern (Moraes, 2015; Bradshaw, 2018; Queiroz-Stein, 2019). The intermittent supply capacity of wind energy, which suffers from variations in wind regimes, is a critical issue. One of the main ways to solve this problem is the development of large-scale energy storage systems, which is not available within the current electrical structures (Bradshaw, 2018; Queiros-Stein, 2019).

Uncertainties in de energy policies are also a challenge for wind energy and other alternative sources. Up to 2016, Brazil registered fast economic growth. Growing energy demand required an annual increase of 4.5% in energy supply (Bradshaw, 2018). A drop in commodities' price in 2015 changed the scenario and pushed the country into a recession and consequently decreased energy consumption (Gomes, 2017). Besides, rainfall in 2016 was satisfactory to refill dams' reservoirs. These events led the government to adjust its energy contracting plans. As a result, a reserve energy auction for wind and solar to be held in December 2016, was cancelled by MME with the claim that a drop in energy demand was expected in the following year (Bradshaw, 2018). Another policy change in the sector was the unprecedented *decontracting* auction held in August 2017 by Electricity Trading Chamber (CCEE- Câmara de Comercialização de Energia Elétrica in Portuguese). The auction allowed previously contracted project to be released from their obligations against the payment of reducing fines (ABEEólica, 2018). Wind, solar and small-generation plants projects eligible to participate in the *decontracting* auction must have Reserve Energy Contracts and have not started testing. In all, twenty-five generation projects took part in the procedure from which sixteen wind farms had their contracts terminated. The energy companies pointed out distinct reasons why their projects did not take off. The most important reason was the rise of the dollar that hindered the purchase of imported equipment.

Large-scale wind generation is predominantly onshore and geographically concentrated in Brazil's Northern and Southern regions, which are, notably, the regions with the greatest potential for this source of energy (EPE, 2018). The five states with the greatest wind energy generation in 2018 were Rio Grande do Norte, Bahia, Piauí, Ceará and Rio Grande do Sul. Wind parks are connected to the national electricity grid through the National Interconnected System (SIN) and in 2018 accounted for 8.60% of total energy supply added to the system (ABEEólica, 2018; Bradshaw, 2018).

In his study, Diniz (2018) analysed 719 wind power plants and found out that 483 of them are exclusively owned by private partners, while the other 236 plants are public-private partnerships. He concluded that most wind generation projects implemented in Brazil during the last decade have been led by the private sector, stressing that the sector's regulatory and Institutional framework has been successful in stimulating private investment.

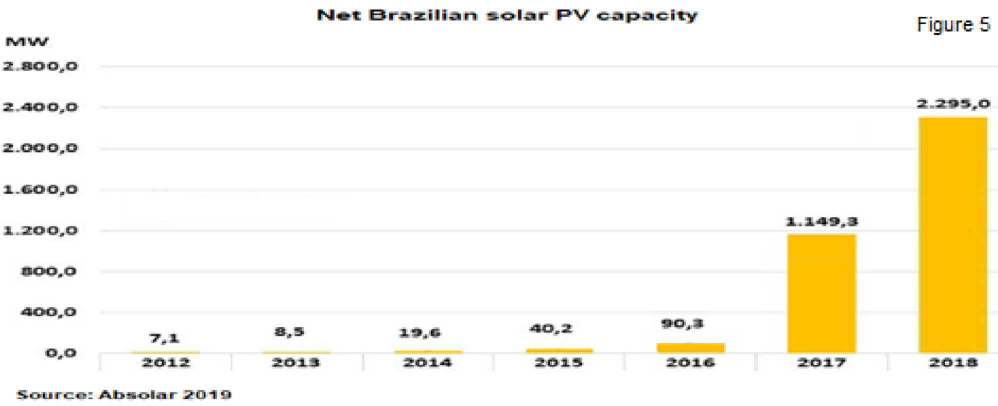
Up to 2018, BNDES invested 64.4 billion of *reais* (approximately 15.8 billion US dollars). One of the BNDES's requirements to invest in a project is that a certain amount of its funding goes to social projects. According to ABEEólica, the Brazilian wind energy association (2018), most of the time, contracted companies surpass the required percentage and develop much bigger social projects such as digital inclusion activities, oral health and nutrition, training for local workers, encourage tourism, schools, and day-care, et cetera. Opposingly, Frate, Brannstrom, Morais & Caldeira-Pires (2019) show in their study incidence of environmental justice violation in wind farms licensing processes which were granted lacking social-environmental impact evaluation and costs and risks assessment, and without relevant community consultation. Their article draws attention to unreliable municipal reports and simplified licensing processes through which wind farms projects are approved. The authors argue that wind power promoters reckon the overall support for this energy source due to its renewable features and devoid of social-environmental impact. These arguments justify wind farms promotion. Supporters argue that employment and economic activity increase whilst the environment is protected. However, critics state that employment is limited to a few people, tourism does not increase by wind farms, and the environment is negatively affected.

4.2 Solar power: sun-rich but technology poor

Solar energy is generated through technologies that convert light to electricity (Photovoltaics) and light to energy by heat (solar thermal energy[41]). In the USA in 1954, the first silicon photovoltaic cell was born, which is still one of the main elements of plates that capture solar energy. From there began the modernisation of sun energy capture. Since "Solar One" – a photovoltaic powered residence built-in 1973 by The Institute of Energy Conversion at the University of Delaware (USA) – Solar energy

[41] Solar-thermal technology uses the sun's heat to generate thermal energy, which produces steam. The steam drives a turbine that generates electricity.

for domestic use has grown considerably worldwide, considering that the global solar power installed capacity in 2018 was at least 505 GW in comparison to the 15 GW global capacity in 2008 (REN21, 2019). In Brazil, it was not until 2014 that the first centralised public solar energy purchase took place (MME, 2018b) through energy auctions supervised by The Brazilian Electricity Regulatory Agency (ANEEL- Agência Nacional de Energia Elétrica, in Portuguese). In 2017 Brazilian solar Photovoltaic (PV) capacity jumped considerably compared to previous years and continued to grow in 2018, as shown in the chart below.



Despite regular purchase from the federal government in recent years[42] (Figure 6) and a growing number of projects awarded a contract, these measures are still considered by the industry to be insufficient to encourage manufacturing in Brazil (Freire, 2017). It is important to observe that the following chart shows no data for the year 2016. It is because the only auction for reserve energy that would take place that year in December was cancelled, and both wind and solar energy were not contracted. Another event involving both energy sources was the *decontracting* auction already mentioned in the previous section. It was

[42] In 2016 solar source was let out from the first auction with the promise that it would be included in the second one, which was eventually cancelled (Absolar, 2018).

a setback also for the solar industry as it resulted in the contract termination of nine solar photovoltaic projected plants. The contracting discontinuation in 2016 and 2017 represents possible insecurity and risks for the sector in 2019 and 2020 (Sauaia, 2018).

Figure 6 **Evolution of solar PV contract auction in Brazil**

	LER* 2014	1º LER 2015	2º LER 2015	LEN** A-4 2017	LEN A-4 2018	LEN A-4 2019	LEN A-6 2019
Contracted (MW)	543,8	822,6	913,1	556,9	815,0	203,7	530,0
Cumulative contracted (MW)	553,8	1.376,4	2.289,5	2.846,4	3.661,5	3.865,2	4.395,2
Average price (US$/MWh)	88,03	84,29	78,32	44,31	33,25	17,62	20,33

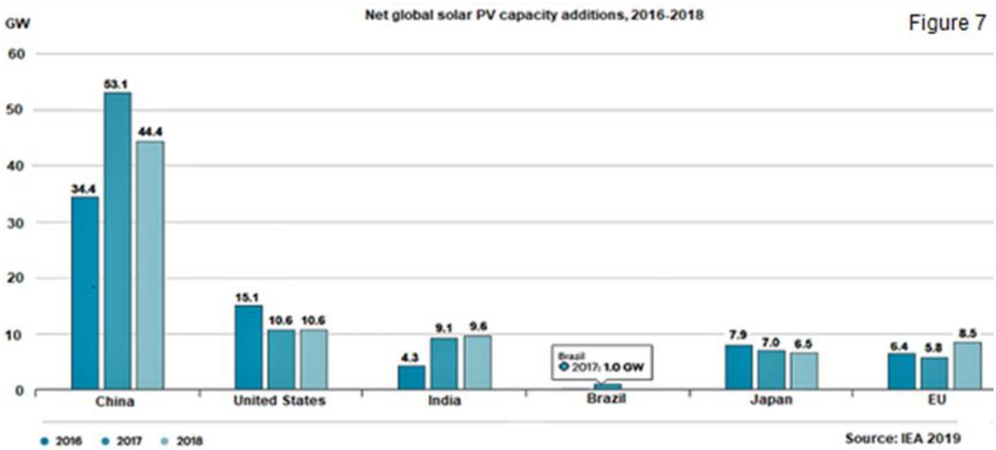
*Reserve energy auction (in Portuguese, LER-Leilão de Energia de Reserva). Contracts energy from both new and existing plants in order to increase security of electricity supply.
**New energy auction (in Portuguese, Leilão de Energia Nova). Contrats energy from plants that will still be built.

Fonte: CCEE/ABSOLAR, 2019.

The Photovoltaic industry in Brazil faces a technological, industrial, and economic gap as the country masters only the extremities of the photovoltaic manufacturing chain, which is to say, the initial stage, which is quartz ore extraction and transformation into metallurgical silicon and the last one which is the assembly of photovoltaic solar panels (Davies, Frisso & Brandão, 2018). The top four manufacturer countries in 2019 are China, Canada, South Korea, and the USA (Colville, 2019). Despite its large quartz reserve, Brazil's domestic PV technology is still dependent on importing foreign technology and components (Camilo, 2018). Like wind energy, intermittency is also a challenge for solar power as its supply variates according to the incidence of light, a problem that could be solved by energy storage systems (ABEEólica, 2018; Bradshaw, 2018).

According to experts, the country faces missed opportunities in developing solar generation due to the lack of investments and projects in the past. Today the sector is chasing advanced technologies, and the industrial process encounters competitiveness problems. The Chinese took the lead and transformed the photovoltaic generation market, with lower equipment prices and large-scale production capacity (Medeiros, 2009; Medeiros, Gagliano & Teixeira, 2012). According to Rodrigo

Sauaia, executive president of the Brazilian Associations of Photovoltaic Solar Energy, Brazil already manufactures all system components. Inverters, structures, and trackers are already quite competitive. However, one of the most important bottlenecks for the national supply chain is the unfair tax burden imposed on domestic manufacturers. The producers buy imported components and pay high taxes on these inputs, which they incorporate into their end products. This strategy makes national products up to 30% more expensive than those made abroad (Sauaia, 2018). These challenges are presented in the solar source's participation in the Brazilian energy supply, which is only 1.2% (Figure 3), and when comparing the net Brazilian solar PV capacity with the other countries as in the following chart (figure 7).



The main challenge for popularising solar power generation is its price. The reason for the high cost is the market dependence on imported photovoltaic plates and components as well as the installation of the system that must be done by specialised companies (Gobbo, Silva & Bone, 2019).

The resources for the purchase and installation of the equipment are troublesome for most middle and low-income populations. As a funding alternative for the purchase of solar power systems, is there a bill discussed in the Federal Senate that makes it possible to use the Severance Premium Reserve Fund (FGTS, Fundo de Garantia por Tempo de Serviço, in Portuguese).

Launched in 2002, the Programme of Incentives for Alternative Energy in Electricity (Proinfa) favoured wind, biomass, and small hydro with the feed-in tariff policy letting out solar energy. Photovoltaic solar energy can be generated by large power plants connected to the National Interconnected System, consisting of an extensive grid of transmission lines or by distributed generation. As solar technologies became less expensive worldwide, in 2012, the Brazilian Electricity Regulatory Agency (ANEEL) introduced net-metering regulations to facilitate distributed access,[43] micro[44] and mini[45] power generation to electricity distribution and compensation systems. The net metering regulation also applies to wind, biomass, and hydropower (ANEEL, 2012), but it was primarily formulated to foster solar power generation (Bradshaw, 2018).

Another obstacle to the expansion of photovoltaic systems is the lack of skilled professionals. There is a strong concern about the need for a workforce qualified according to international standards, a requirement that reflects on the quality of the projects undertaken. Experienced workers in photovoltaic technology are not available in all markets or geographic areas of the country, and there is a high demand for more skilled professionals in the sector (Neto, Sauaia & Koloszuk, 2019). Seeking to solve the problem, Absolar leads a proposal to create a seal or certification of quality and technical competence, in conjunction with the

[43] Distributed generation in Brazil is based on the net metering model, in which the generating consumer receives a credit to his account for the positive balance of energy generated and inserted in the grid after deducting his own consumption. The available power grid is used as backup when the locally generated power is not enough.

[44] Central geradora de energia elétrica com potência instalada menor ou igual a 75 kW.

[45] Central geradora de energia elétrica, com potência instalada superior a 75 kW e menor ou igual a 5MW.

Brazilian association of the electrical and electronic industry (Abinee),[46] Brazilian Distributed Generation Association (ABGD)[47], the German International Cooperation Agency (GIZ),[48] Brazilian national industrial apprenticeship service (Senai),[49] and of higher education institutions (Neves, 2019). However, Neto, Zago, Silva, Moreira & Lopes (2019) show that from the 278 of Brazilian universities analysed in their study, 43.8% do not offer courses in renewable energy and in their electrical engineering graduation courses. The average workload destined to the subject is only 2.02% at the institutions, including renewable energy in their graduate programmes. In addition, most of the renewable energy courses offered in electrical engineering graduation in the Brazilian university are non-compulsory, which means they are optional for their engineering students, demonstrating a lack of commitment to the field's professional qualification.

4.3 Biomass: a highly available power

Biomass is any solid, liquid, or gaseous, both vegetal and animal-based substances used to generate energy, mostly referred to as bioenergy. Examples of raw materials biomass are agricultural crops and their residues, forest waste, organic by-products (livestock and wood processing effluent), municipal solid waste, vegetable oil and animal fats waste. Biomass is used as feedstock to produce fuels, electricity, and heat. Biomass energy can be generated through the combustion of dry biomass or its gasification as well as through the capture of biogas (methane) by controlled anaerobic digestion.

Brazil has one of the world's largest agricultural commodities productions and has, therefore, a great biomass power potential both for

[46] Associação Brasileira da Industria Elétrica e Eletrônica in Portuguese.
[47] Associação Brasileira de Geração Distribuida in Portuguese.
[48] Deutsche Gesellschaft für Internationale Zusammenarbeit in German.
[49] Serviço Nacional de Aprendizagem Industrial in Portuguese.

solid biomass – used as fuel in thermoelectric plant – as well as for residual biomass from agriculture to produce second-generation (2G) ethanol and biogas. The country's high biomass availability attests to the feasibility of 2G fuel production adding value to the first generation (1G) fuel productive chain and, as a result, diversifying Brazil's energy supply. Yet, the lack of long-term public policies has been delaying expanding the use of this renewable source in the energy sector (Lopes, Martins & Miranda, 2019). Another barrier for commercial-scale production of 2G biofuels is the technological boundaries that increase production, making industrial plants economically unfeasible (Vidal, 2019). Eventually, this scenario is improving as in 2017, the then President Michel Temer sanctioned Law no. 13,576, establishing the national biofuels policy known as RenovaBio. In discussion since mid-2016, the programme proposal was launched by the Ministry of Mines and Energy (MME) on December 26, together with the Ministry of Agriculture and several representatives of the sugar-energy sector (Lorenzi & Andrade, 2019).

RenovaBio's main goals are: 1) increase the production of biofuels (with emphasis on ethanol and biodiesel); 2) guarantee a long-term market in order to ensure reliable energy supply; 3) reduce greenhouse gas emissions (GHGs) to meet targets established in Brazil's Intended Nationally Determined Contribution (iNDC) proposed at the United Nations Conference on Climate Change, COP-21 in Paris in 2015 (Câmara dos Deputados Federais, 2017).

Before RenovaBio, the government launched in February 2017 the Brazil fuel Programme introduced by MME to attract foreign investments to the oil refining sector in Brazil. Even though the MME's rapport on the Brazil fuel programme mentions biofuels several times, it only tackles crude oil and its derivatives. Issues involving bioethanol is not discussed throughout the rapport. Petrobras, a clear beneficiary of the Brazil fuel Programme, criticised the RenovaBio plans through a public consultation claiming that the guidelines of the two programmes would not be aligned and therefore would create uncertainty, which in turn, would reduce the attractiveness for investments in the fuel industry in Brazil as a whole, whether in the production of biofuels, in oil refining and in supply infrastructure (Petrobras, 2017). Lorenzi & Andrade (2019) argue that from a theoretical point of view, there is a clear conflict of interest since the RenovaBio programme – as it is currently formulated – creates a dispute between the sugar and ethanol industry and the fossil fuel sector, especially between ethanol plants and Petrobras. Furthermore, the authors also claim that these stakeholders collide in the search for sustainable solutions regarding the Brazilian environmental and energy supply issues once Petrobras advocates for preserving the current dynamics while the sugar-ethanol sector insists on the need for new incentives to the iNDC goals.

Despite the inconsistency regarding biomass power policies, development and production, this source of energy occupies first place in the Brazilian total energy supply, accounting for 61.6% of a total of 46.3 of all renewable energy production (see figure 2) and third place in the country's electricity generation grid, representing 8.5% of the country's electricity production, only behind hydro and wind energy generation which accounts for 61.0% and 8.7%, respectively (see figure 3). The participation of biomass in the Brazilian electricity grid is still below its potential, but it is believed that it will expand in the future (Marafon et al., 2016).

Biomass use listed in the chart below account mostly for electricity generation for private use, that is, not intended for the public sector, since the analyses of the energy destination data from a total of 573 plants (see chart below), shows that none of them is listed as PS or Public Service provider (SP in Portuguese). Except for 1G ethanol, biomass power is mostly used within the private industry sector.

Figure 8

Brazilian biomass power generation capacity								
Biomass		Installed capacity		*Energy destination				
		Qty	(KW)	ESP	IEP	GPR	GPR-NR482	PS
Forest	Biogas + Fuelwood	1	5.000,00	0	1	0	0	0
	BFG** + Biomaas	12	127.705,05	3	2	7	0	0
	Firewood	7	82.215,00	4	0	3	0	0
	Forestry waste	60	473.317,00	9	12	39	0	0
	Black liquor	18	2.538.634,00	10	6	2	0	0
	Charcoal	8	48.197,00	1	2	5	0	0
Subtotal		106	3.275.068,05	27	23	56	0	0
Municipal solid waste (MSW)	Biogas + MSW	21	171.588,60	0	10	11	0	0
	Charcoal + MSW	3	8.250,00	0	0	3	0	0
	MSW	1	4.278,00	0	0	1	0	0
Subtotal		25	184.116,60	0	10	15	0	0
Animal waste (AW)	AW + Biogas	14	4.481,20	0	0	14	0	0
Subtotal		14	4.481,20	0	0	14	0	0
Liquid biofuels	Ethanol	1	320,00	0	0	1	0	0
	Vegetable oil	2	4.350,40	0	0	2	0	0
Subtotal		3	4.670,40	0	0	3	0	0
Agroindustrial	Sugarcane bagasse**	407	11.669.341,20	79	211	114	0	0
	Rice Husk	13	53.333,00	1	4	8	0	0
	Biogas + AGW****	3	10.974,00	0	1	2	0	0
	Elephant grass	2	31.700,00	0	1	1	0	0
Subtotal		425	11.762.624,20	80	217	125	0	0
Total		573	15.233.684,45	107	250	213	*****	0
Destination percentage				18,8	43,8	37,4	0	0

* ESP - Electricity self-producers
IEP - Independent electricity producers
GPR - Generating plant registration
GPR-NR482 - Registered by Normative Resolution no. 482 of 2012, by Aneel.
PS - Public service providers for electricity generation. Source: IBGE 2015

** Blast Furnace Gas
*** Two plants with combine destination type: APE/PIE and APE/REG and a third one is undentified.
**** Agricultural waste
***** The plants with combined destination type and the undentified one has not been included in this sum.

Source: Aneel's generation information system (SIGA in Portuguese), 2020.

It is important to notice that the national power supply and electricity production charts published in 2019 by MME and ANEEL/Absolar, respectively, represent biomass contribution to Brazil's diversified electricity grid not only as a public good but also as fuel since many firms use it in their attempt to implement off-grid solutions. Thus, biomass power participation in the SIN does not occur through governmental public service provision; instead, enterprises are given tax, financial and credit incentives to generate biomass energy. Electricity Self-Producers (ESP) –which represent 18,6 of all plants – seek to meet their own demand with the possibility of selling their power surplus to energy distribution companies upon authorisation from ANEEL; whereas Independent Electricity Producers (IEP) have the commercialisation of energy as their main goal – upon previous authorisation – while meeting their own demand is optional (IBGE, 2016). This group accounts for 43.8% of the Brazilian biomass power generation. The GPR category is responsible for 37.6 of the production. Generating Plant Registration (GPR) is granted to small plants (with power generation capacity up to 5 MW) with no need for authorisation or concession from the regulatory agencies to operate. The other two categories (GPR-NR482 and PS) have no representatives, according to SIGA 2020. REG – RN482 are plants registered by ANEEL's Normative Resolution n. 482, of April 17, 2012, with a generation capacity of up to 1 MW which are considered mini-generators or micro-generators allowed to connect to the distribution network to inject their surpluses and, thus, be financially compensated by the distribution concessionaire. The PS category is public service providers (SP in Portuguese) for electricity generation.

4.3.1 Ethanol of first and second generation

The most common biomass-based source of energy is ethanol which is classified into two sorts, namely, first and second generation ethanol. First generation (1G) ethanol is produced from vegetable oils and sugars from edible crops such as corn and sugarcane and therefore compete with the food industry. Second generation (2G) ethanol – also known as cellulosic ethanol[50]– is produced from non-food feedstock, which is mostly by-products and waste from agriculture. First and second

[50] 2G ethanol is extracted from lignocellulosic fibres of a vegetable. In the case of sugarcane, it is obtained from straw and bagasse after extracting the juice.

generation ethanol have the same physical and chemical properties. What differs is the raw material used and the production process. Traditional ethanol (1G) is produced from sugarcane juice or molasses, corn, sugar beet, et cetera, whereas 2G ethanol is made from sugars extracted from the plant's cellulose, present in straw and sugarcane bagasse, sorghum, wood, to name a few sources.

Brazil is the second-largest producer of sugar cane 1G ethanol, behind the USA with their corn ethanol. In Brazil, first generation ethanol is produced from the juice resulting from the crushing of sugar cane which is mostly used in the transport sector. First generation ethanol production in Brazil has already been broadly discussed. This section will only tackle the country's 2G ethanol industry among other biomass-derived fuel, namely biodiesel, biogas, and black liquor.

4.3.1.1 Second generation ethanol (Bioethanol)

Also known as 2G ethanol, 2GE or bioethanol, second generation ethanol in Brazil is made from the waste resulting from ethanol and sugar production, such as straw and bagasse, which can be reused to generate electricity and more ethanol (2G). The bioconversion of lignocellulosic material into bioethanol is difficult not only because of the cost of raw material collection and storage but also due to the biomass breakdown processes, which results in a great diversity of sugars. Furthermore, the application of these physical-chemical processes requires a large amount of funding (Lima Luz, Kaminski, Kozak & Ndiaye, 2009). However, second generation ethanol has been developed systemically in Brazil since 2010, involving the government, private national and foreign firms, and research institutions (Senna & Ansanelli, 2016). Studies with several semi-perennial grass types such as elephant grass, energy cane and sorghum used as energy crops have been conducted in several countries. The results show that such plants differ in terms of production potential, physical-chemical biomass properties, environmental management demand. Laboratory and pilot-scale studies have also found the potential of elephant grass for the production of cellulosic or second generation ethanol (Marafon et al., 2016). Recent research by the Federal University of Parana and Mato Grosso states has demonstrated the potential of avocado kernels for bioethanol production (Kowalski, Schneider, Moretto, Cardoso & Gomes, 2018).

The RenovaBio programme is not the first initiative intended to foster biofuels production in Brazil. In 2011, BNDES, in collaboration with FINEP (Financiadora de Estudos e Projetos in Portuguese), launched the Innovation Support Plan for the Sugar-Energy Sectors (PAISS in Portuguese). This initiative stimulated the construction of the GranBio and Raízen plants, and the CTC (Centro de Tecnologia Canavieira in Portuguese) and Odebrecht Agro-industrial research centres which started their research and development programmes and a commercial scale 2G ethanol production. The expectation was that 2G ethanol would be introduced in the national energy matrix and revolutionise the sugar-energy sector. The prediction was that more than a dozen 2G ethanol plants would be operating by 2025. Despite the two plants built for commercial-scale production and a pilot plant of CTC, seven years after the launch of PAISS, none of the goals or expectations was met. This is due to a series of problems, especially in the pre-treatment phase,[51] which caused major plant shutdowns, in addition to an annual production below 10% of capacity since the start of operations (Lorenzi & Andrade, 2019).

4.3.2 Biodiesel of first and second generation

To produce biodiesel, different raw materials are used. First generation biodiesel is produced from natural oils (soybeans, peanuts, palm, canola, sunflower, algae), while second generation biodiesel is made from non-food-based biomass such as animal fat, industrial residues, and recycled oils (DIRUR/IPEA, 2019).

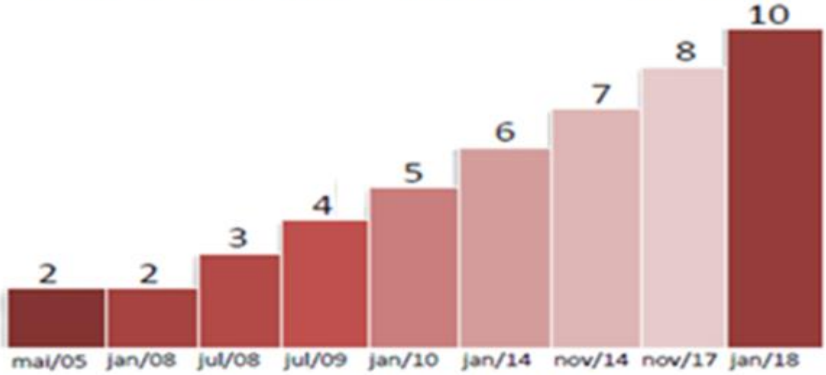
[51] Biomass (bagasse or straw) needs to be physically or chemically cleaned into their fibres to be exposed; this process is called pre-treatment.

Just as in the case of ethanol, the first generation biodiesel industry also suffers the dilemma of using food raw materials for its production. In order to solve this problem, Brazilian researchers have been working on alternative feedstock such as macauba coconut oil, castor beans and algae which have been proven to be suitable for the production of second generation biodiesel (Langer, Silva, Teixeira & Souza, 2018). In fact, initiatives to foster biodiesel manufacture and consumption in Brazil started in 2004 when the National Programme for the Production and Use of Biodiesel (PNPB in Portuguese) was launched. The programme is the roots for strengthening the biodiesel industry in Brazil (Vidal, 2018). Its main goal was to increase biodiesel production and use sustainably and contribute to social inclusion. In order to meet the objectives of the PNPB, the government created different instruments such as the Financial Support Programme for Investments in Biodiesel and tax reduction, which were adjusted according to the producer's profile, the origin of the production (by region) and the type of raw material. Priority should be given to family farming, the North and Northeast regions and castor beans as raw material.

The government implemented other measures to support the PNPB. A Social Fuel Seal was granted to biodiesel producers that prove to acquire a pre-determined percentage of raw material from family farmers for biodiesel production. Seal owners are eligible to participate in auctions to sell their products to the National Petroleum Agency (ANP in Portuguese), benefit from differentiated social contributions collection and enjoy better financing conditions from the public development bank. In addition, biodiesel was officially introduced in the Brazilian energy supply through Law 11,097 of January 13, 2005, which set the mandatory minimum percentage of 2% of biodiesel to diesel sold to the final consumer for the entire national territory. This share grew throughout the following years up to 10% in 2018, as the chart below demonstrates:

Figure 9

Evolution of the blend of biodiesel to diesel (%)



Source: Adapted from Vidal (2019); ANP (2019).

The primary feedstock used to produce biodiesel in Brazil was soybeans. Despite the governmental efforts to foster biodiesel production from different raw material, soybeans remain on top, as shown in the chart below.

Raw material used in the production of biodiesel (B100) in Brazil (m3) Figure 10

Raw matererial	2013	2014	2015	2016	2017	(%)
Soy oil	2.231.464	2.625.558	3.061.027	3.020.819	3.072.446	71,6
Cotton oil	64.359	76.792	78.840	39.628	12.426	0,3
Animal fat (1)	578.427	675.861	738.920	622.311	720.935	16,8
Other fatty materials (2)	46.756	37.255	60.086	134.297	483.544	11,3
TOTAL	2.921.006	3.415.466	3.938.873	3.817.055	4.289.351	100,0

Source: Translated from Vidal (2019); ANP (2018).

(1) Includes beef fat, chicken fat and pork fat;

(2) Includes palm oil, peanut oil, turnip oil, sunflower oil, castor oil, sesame oil, used frying oil and other fatty materials.

Furthermore, the endeavour to extend biodiesel manufacture to less developed areas and small farmers has failed. Biodiesel production concentrated in the Midwest and South of the country. According to Vidal (2019), in 2014, 85% of farmers who supplied raw materials for biodiesel production were from the south and only 7% from the country's Northeast. This was because family farming in that region was unable to produce enough castor oil to meet the demand caused by the increasing percentages for the mandatory blend of biodiesel to diesel. Sampaio & Bonacelli (2018) state that the PNPB opened the biodiesel market for soy agribusiness just like Proálcool expanded the market for sugarcane agro-industries.

4.3.3 Biogas: a non-finite energy source

Natural gas or methane is a type of fossil fuel derived from fossil remains of organic material that lies buried deep in the ground for thousands of millions of years, while biomethane or biogas is considered a green source of energy even though it is chemically identical to natural gas. The difference that makes biogas a green alternative is that it is not finite. Biogas is produced by biological processes of anaerobic digestion of organic material from agricultural and industrial residues, as well as municipal waste. Public and private sectors around the world have been investing in anaerobic digesters to increase renewable energy production.

Anaerobic digestion plants work at low temperatures allowing micro-organisms to digest the raw material in a controlled reactor in the absence of oxygen to produce biogas. In Brazil, different biomass types are used to generate biogas. According to the Brazilian Energy Research Agency (EPE, 2018), the types of biomasses most useful to produce biogas through bio digestion are liquid or pasty, such as vinasse and filter cake from the sugar-ethanol industry, residues from agro-industry and confined livestock, solid urban waste, sludge from sewage treatment and winery waste. With lower yield but still considered useful, the alternatives are bagasse and straw (from cane, soy, and corn), agricultural residues (wood, beans, peanuts, cassava, cocoa, and coconut), husks from rice and coffee. A diverse range of biomass can be used for the production of biogas. In the Brazilian scenario, biogas production is more substantial in the municipal solid waste management and sugar-ethanol industry, and therefore the focus of this section.

4.3.3.1 Biogas from Municipal Solid Waste

In landfill sites, anaerobic digestion occurs when organic waste decomposes. This naturally occurring biological process produces what is known as landfill gas which can be tapped to generate energy. Instead of going to dumps and other destinations without proper use, solid waste can be converted into energy which is fundamental to alleviate global warming and groundwater contamination. Currently, biogas production from municipal solid waste (MSW) management in Brazil accounts for an energy potential of 171.588,60 kW generated by twenty-one plants from nine different member states of the federation (SIGA, 2020). This figure is a modest fraction of the country's MSW energy potential, which is estimated to be around 7GW (Santos et al., 2019).

According to a study on landfills conducted by the Brazilian Association of Public Cleaning and Special Waste (ABRELPE) in partnership with the Brazilian Biogas Association (Abiogas), Brazil dumped more than 42 million tons of solid waste into landfills in 2018. The organisations estimate that Brazil captured 4.2 billion Nm^3 of biogas. However, only 9% of this potential was used for electricity generation (751 GWh), and another 2% produced 35 million Nm^3 of biomethane. Researchers state that if all the organic matter generated in 2018 had been destined for landfills, the country's potential could supply forty-nine million homes.

Law Nr. 12,305/10 which instituted the National Policy for Solid Waste (PRNS in Portuguese) seeks to organise how the country deals with waste, demanding transparency in waste management from public and private sectors. The policy's goal is to encourage environmental development and business management to improve production and the reuse of solid waste, including recovery and energy use (Mendonça & Bornia, 2019). Moreover, the Brazilian government's endeavour to mitigate open dumps is likely to increase the country's number of landfills. As a result, the energy potential of the source will grow. This scenario offers a great opportunity to minimise landfills' environmental impacts and their GHG emissions (Santos et al., 2019).

4.3.3.2 Biogas from sugar and ethanol industry

The Brazilian sugar-energy sector is self-sufficient in the production of electricity (Ramos & Nachiluk, 2017). Thermoelectric units in the sector are driven by the burning of sugarcane bagasse for electricity production. Currently, biogas production from the sugar-ethanol industry in Brazil represents an energy potential of 10.974,00 kW generated by three plants from three different member states of the federation (SIGA, 2020). In addition to burning bagasse, the sector has invested in biogas generated from anaerobic digestion of bagasse, vinasse, and sugarcane straw. Biogas is rich in methane, which has a calorific value that is similar to that of natural gas and therefore suitable for aero-derivative gas turbines and electricity generators. Despite this enormous potential, biogas has a modest presence in the national energy grid. However, according to the Decennial Energy Expansion Plan 2027[52] (MME/EPE, 2018) it is estimated that the cane harvest will grow at a rate of 2.8% per year until 2027, increasing the percentage of cane destined for ethanol from 55% in 2017 to 60% in 2027, an increase due to the greater demand for biofuel. As a result, there will be a growth in the amount of waste that can be used for biogas production. Considering that all vinasse and filter cake resulting from the ethanol industry will be destined for bio-digestion, biogas potential will reach 7.2 billion Nm^3 in 2027. This percentage represents the production of 3.9 billion Nm^3 of biomethane.

Biogas can be consumed directly or processed into biomethane by r*emoving* unwanted components such as CO_2 and H_2S. Biomethane has

[52] It is important to note that it is the first time that PDE 2027 explicitly supports biogas as a possible candidate for expanding the National Interconnected System – SIN (MME/EPE, 2018).

several uses, such as electrical generation, injection into natural gas networks, and biofuel for light, medium or heavy vehicles (EPE, 2018). Biomethane has the same uses as biogas, with the advantage that it can be transported for more distant use.

4.3.5 Black liquor: the fuel of the pulp and paper industry

Black liquor is a liquid waste with significant energy potential, obtained as a by-product in the paper and cellulose industry. After cooking the wood, a digestion process takes place, which turns the wood into cellulose paste. The leaching that occurs in this process results in a dark coloured liquid (black liquor) which is used as a fuel to generate energy for the pulp and paper mills.

Currently, black liquor represents an energy potential of 2.538.634,00 kW generated by 18 plants from ten different Brazilian member states of the federation (SIGA, 2020). According to the Food and Agriculture Organization of the United Nations in 2018, Brazil was the second major producer and the first major exporter of pulp for paper accounting for 11% and 24% of global rates, respectively (FAO, 2019). Unlike what happens with paper production, which grew only 0.8% per year between 2010 and 2018, the pulp industry has been growing at an accelerated rate (5.1% per year, on average, in the same period). The competitiveness of the national product ensured its good position in the global market.

Pulp production is more energy-intensive than paper production. The growth in pulp production increases the energy consumption of the pulp and paper segment and also of the industry as a whole. However, there were gains in energy efficiency due to improvements in the production process over the years. In addition, new and more efficient plants went into operation. According to the Energy Efficiency Atlas of the Brazilian Energy Research Office (EPE, 2019), in 2018, 86% of the paper and pulp industry's energy demand was driven by renewable energy, mainly black liquor and wood waste chips. The document also shows that paper production in non-integrated mills uses a less renewable energy mix – as it does not have renewable by-products from the pulp industry process – and a greater share of electricity. Consortia between pulp and paper production contributed to the increase participation of black liquor in the industry's power grid. Besides, part of the fuel oil was replaced by natural gas and wood chips.

Brazil has an international reputation for its clean energy matrix. This reputation is due to the strong contribution of hydroelectric energy to the national electricity grid. With the growing consensus that large dams are not as clean as initially thought, the country's reputation is threatened. Methane emissions from large wetlands for the construction of reservoirs and other environmental and social damage demystify large dams' environmentally friendly nature. Despite the dam tradition of the Brazilian electrical sector, the Brazilian government developed a range of policies that allowed the country's renewable energy industry into the national energy grid. The wind sector, in particular, has achieved considerable space in the Brazilian energy market. The photovoltaic energy sector was also well received in the market, although its use is greater in the private sector. In addition to these two renewable energy sources, the transportation sector has also been increasing its variety of renewable fuels with the production of second generation biofuels, biogas from solid waste and black liquor, a fuel resulting from the cellulose industry. Brazil's energy sector is formed by a variety of energy sources, which is a good premise to lead the country to an energy transition. However, it is necessary that more robust public policies are developed and implemented so that the country can fulfil its commitments made to the international community to help and contain global warming.