MINISTÉRIO DE MINAS E ENERGIA
SECRETARIA DE PLANEJAMENTO E DESENVOLVIMENTO ENERGÉTICO

2029

PDE 2029
(Ten-Year Energy Expansion Plan)
Executive Summary

ApexBrasil | MINISTÉRIO DAS RELAÇÕES EXTERIORES | epe Empresa de Pesquisa Energética | MINISTÉRIO DE MINAS E ENERGIA | PÁTRIA AMADA BRASIL GOVERNO FEDERAL

INTRODUCTION

The Ten-Year Energy Expansion Plan (henceforth, PDE as in the Portuguese acronym) is an annual informative document elaborated by the EPE under the guidelines and support of the staff of the Secretariat of Energy Planning and Development (SPE) and the Secretariat of Petroleum, Natural Gas and Biofuel (SPG), both at Ministry of Mines and Energy (MME).

The PDE's main goal is to indicate, and not exactly to determine, the prospects – from the government's point of view – for the expansion of the energy sector on the period of ten years, within an integrated vision for the different energy sources. Such vision enables drawing important elements for the planning of the energy sector, with benefits in terms of increased reliability, lower production costs and reduced environmental impacts.

Prepared between March 2019 and September 2019, PDE 2029 presents the following novelties compared to the last cycle:

- discussion on the impacts of the New Gas Market;
- evolution of the total installed generation capacity, taking into account self-production and distributed generation, in addition to centralized generation, auto-production;
- first analysis of operational flexibility requirements, with a focus on greater participation of non-controllable sources;
- participation of the demand response as an alternative to meet the growing requirement for power capacity;
- consolidation of the Distributed Energy Resources concept encompassing gains in energy efficiency, micro and mini distributed generation, electric energy auto-production and solar thermal energy;
- the analysis of alternatives for compensation of generation credits (within the scope of the revision of REN 482) and for the case of application of binomial tariff;
- economic viability analyses for three different business models with batteries (storage behind the meter).

In particular for the expansion of centralized electric energy generation, PDE 2029 provides a reference path for which three sensitivity (what-if) analyses are carried out: the first considering alternative demand paths, the second considering expansion with greater supply of low-cost national natural gas, and the third considering different power supply criteria. Such alternatives are important means of communicating, on the one hand, the uncertainty of the choices made in planning studies, as well as assessing the most relevant facts that indicate future developments.

By showing how the planning considers the development of the Brazilian energy system under different conditions of its evolution, PDE provides important indicators to guide the initiatives and decisions of agents in order to properly coordinate the country's economic growth projections and the necessary expansion of supply, so as to ensure that society is supplied energy with appropriate costs, on technically and environmentally sustainable bases.

This Executive Summary brings a short version of the main analyses made in PDE 2029 regarding the assumptions, prospects on energy demand, evolution of energy efficiency and distributed generation, expansion of centralized electric energy generation, expansion of electric energy transmission, prospects on oil and natural gas production, evolution of petroleum products supply, expansion of natural gas and biofuels supply, and social and environmental analysis.

The full version of the document with more details on the issues, in addition to supplementary material such as data charts, figures, methodological notes, among other material for consultation, are available on the PDE 2029 page at the EPE website in Portuguese.

Finally, we would like to thank Apex-Brasil (The Brazilian Trade and Investment Promotion Agency) for the financial support of this PDE 2029 Executive Summary English version.

ECONOMIC ASSUMPTIONS

Brazil's per capita GDP is expected to grow 2.2% per year until 2029, reflecting an average growth of 2.9% per year for GDP and of 0.6% per year for the Brazilian population.

Over the period, a more sustained growth is possible due to the adopted assumption that reforms, even if partial, will be conducted, aiming to improve the business environment, enabling higher level of investments (around 21.5% of GDP in the second five-year span of the period) and increased productivity of the economy.

There is considerable uncertainty on the projection of GDP growth, especially regarding its potential growth. Although a cyclical recovery in the short term is possible due to the high level of idleness in the economy, a higher sustained growth would depend on addressing complex structural problems. In this case of greater economic expansion (3.5% per year on average), the accumulated GDP growth could reach 46% in the ten-year period, 10 pp higher than in the reference trajectory (Table 1).

Table 1. GDP growth trajectories

Trajectory	Average GDP Growth Rate (% p.a.)		
	2019-2024	2024-2029	2019-2029
Reference	2.8	3.0	2.9
Alternative	3.7	3.5	3.5

In terms of sectors, economic recovery is expected to boost the sectors that are more associated with domestic demand (services, processing industry, and construction) from 2020, while the primary exporting sectors (agriculture and extraction industry) will have good performance throughout the period.

ENERGY DEMAND

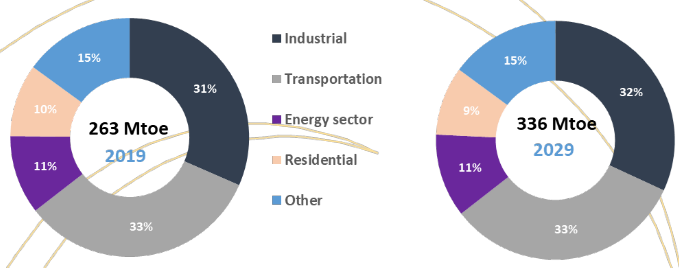
The final energy consumption grows at the average rate of 2.5% per year between 2019 and 2029 (Table 2). Per capita consumption grows 18% in the period, reaching about 1.5 toe/inhab by the end of 2029. Energy intensity is reduced in the period, thanks not only to energy efficiency, but also due to a change in the participation of sectors in energy consumption.

Table 2. Final energy consumption indicators

Indicator	Year		
	2019	2024	2029
Final Energy Consumption (million toe)	263	295	336
Final Energy Consumption per capita (toe/inhab./year)	1.25	1.35	1.50
Energy Intensity of the Economy (tep/thous. R$)	0.064	0.062	0.061

In the analysis by sector (Figure 1), the industry and the Transportation sector still represent almost 2/3 of the final energy consumption over the entire period. The energy sector (energy production) gains importance in the final consumption, influenced mainly by the increased production of the pre-salt layer and of the sugar-ethanol sector.

Figure 1 - Final energy consumption evolution by sector



In the total energy demand of the transportation sector, the highlight is the growing share of hydrous ethanol and biodiesel. The national fleet of light-duty vehicles (LDV) will remain essentially flex fuel, with a small share of hybrid and electric vehicles at the end of the horizon (about 3%).

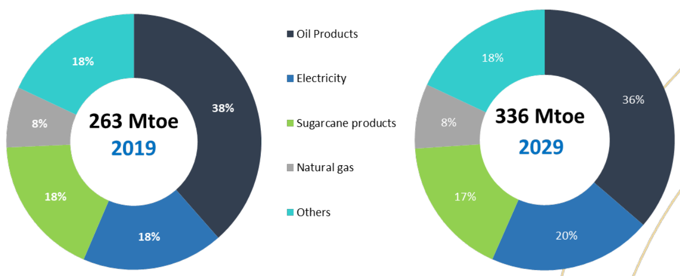
As for industrial consumption, the segments of paper and pulp, and food and beverages are highlighted, which gain importance in the 10-year period, to the detriment of the segments of chemistry and pig iron and steel. Greater participation in the industry is achieved by sources with lower impact regarding greenhouse gas emissions, with electricity, sugarcane derivatives and the black liquor obtained in the pulp production process.

In the residential sector, air conditioning will be the main responsible for electric energy consumption in households. Lights will be the devices with the highest reduction in participation in total consumption, resulting from increased penetration of LED technology. Also noteworthy is the increased demand for LPG due to the replacement of the use of traditional biomass in rural areas and increased demand for natural gas due to the expansion of the distribution network in urban areas.

In the analysis by source (Figure 2), the trend of increasing electrification of the country is maintained. Sugarcane derivatives and biodiesel also gain importance over the period. Petroleum derivatives remain as the main source of final energy, although a portion of its potential market is reduced by ethanol and biodiesel, especially in the transportation sector.

The relative importance of biodiesel, ethanol, and black liquor is expected to grow, the latter being widely used for electricity auto-production

Figure 2 Final energy consumption evolution by source



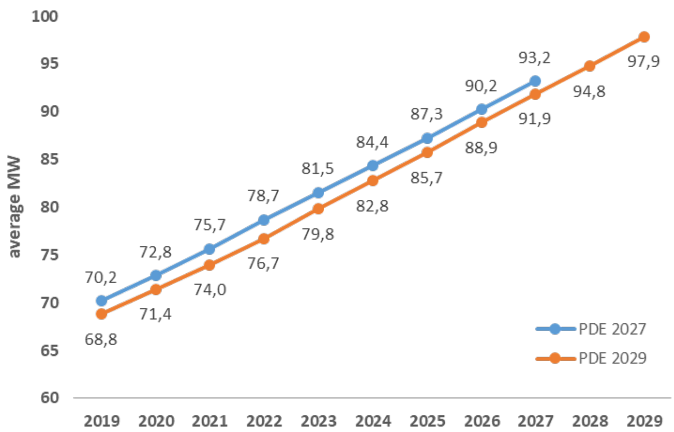
As for natural gas consumption, its prospects are associated with the developments of the *Novo Mercado de Gás* (New Gas Market) Program and the prospects of additional supply of natural gas from the pre-salt layer and from the Sergipe-Alagoas Basin. Both can contribute to the competitive supply of natural gas, increasing the attractiveness of investments in intensive industries in this source. These impacts are detailed in the *Novo Mercado de Gás* section.

Total electricity consumption is expected to grow about 11% more than the Brazilian economy in the 10-year period, influenced both by traditional auto-production and grid consumption.

Industrial grid consumption grows below the average, with improvement in the second five-year span. The number of residential consumers reaches a total of 86 million in 2029, for an average residential consumption in the range of 200 kWh/month, exceeding the historical maximum observed.

The load estimate for PDE 2029 is quite similar to the PDE 2027 forecast (Figure 3). In 2029, compared with the PDE 2027 forecast, the PDE 2029 projection is situated 1.4 average GW below in the reference trajectory and about 5.5 average GW above in the faster growth trajectory.

Figure 3. Load Evolution



ENERGY EFFICIENCY AND DISTRIBUTED ENERGY RESOURCES

The distributed energy resources (DER) considered in PDE 2029 comprise: energy efficiency, micro and mini distributed generation (DG), energy auto-production (non-injected) and solar thermal energy. Although demand response may be included in the DER concept, it was not addressed in more depth.

It is estimated that the energy contribution from the DER as source of service may account for 17% of electricity consumption by 2029, with auto-production and energy efficiency being the alternatives with the greatest contribution in this period. When considering the total energy consumption, it is estimated that the distributed energy resources can meet about 9% of this energy demand by 2029, again highlighting the energy efficiency and auto-consumption portions.

Tabela 3. Efficiency and DER

Indicator		Year		
		2019	2024	2029
Total Energy (thous. toe)	Energy Efficiency	1,655 (1%)	9,032 (3%)	21,127 (6%)
	Non-injected auto-production	5,166 (2%)	6,088 (2%)	7,281 (2%)
	Micro and Mini DG	168 (<0.5%)	689 (<0.5%)	1,704 (0.5%)
	Solar Thermal Energy	11 (<0.5%)	65 (<0.5%)	117 (<0.5%)
Electric Energy (GWh)	Energy Efficiency	2,149 (<0.5%)	16,409 (2%)	39,859 (5%)
	Non-injected auto-production	60,069 (10%)	70,790 (10%)	84,667 (10%)
	Micro and Mini DG	1,948 (<0.5%)	8,013 (1%)	19,812 (2%)
	Solar Thermal Energy	128 (<0.5%)	751 (<0.5%)	1,363 (<0.5%)
Fuels (thous. toe)	Energy Efficiency	1,470	7,620	17,699

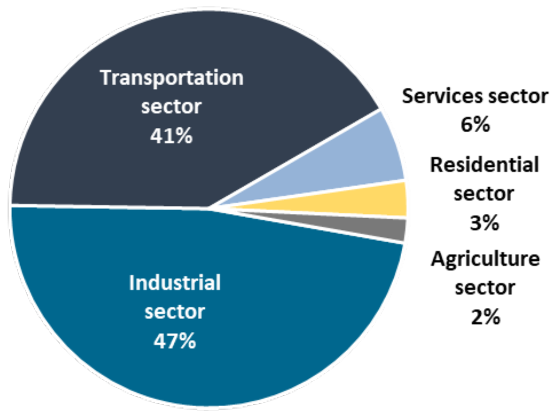
Notes: (1) Total energy = electricity consumption + fuel consumption, excluding fuel consumption in the residential sector.
(2) Solar thermal energy considered only for the residential sector;
(3) The level of total losses considered was 18%.

ENERGY EFFICIENCY

In 2029, energy efficiency will reach 21 million toe, which represents 8% of Brazil's final energy consumption in 2018. Among the final consumption sectors, the largest contribution should be observed in industry and transportation (Figure 4).

The conserved electric energy (40 TWh) corresponds to the generation of a hydroelectric power plant with installed capacity of about 9.5 GW, equivalent to the sum of the Brazilian part of the Itaipu HPP and of the Xingó HPP.

Figure 4. Contribution from each sector to the total conservation of energy



The conserved fuel volume (338,000 barrels per day) will correspond to 10% of the oil produced in the country in 2018.

In the industry, the conserved energy will represent 6% of the final energy demand forecast for 2029. Electricity conservation will represent 4.2%, or 15 TWh, equivalent to the current consumption of the mining and pelletizing industry in 2018.

In the transportation sector, due to technological improvements and intensity of use, energy efficiency reaches gains of around 7% in 2029.

In the construction sector, it is estimated that electricity conservation can reach 8 TWh in 2029, corresponding to 3.7% of total electricity consumption in households in the same year. It is also estimated that the water heating electricity consumption avoided due to SHS can reach 1.4 TWh in 2029, or about 55% of the avoided consumption when considering all other sources.

In commercial and public buildings, the energy conservation projection was estimated at 6%, a reduction of 1.2 million toe that year. Electric energy conservation, on the other hand, was estimated at 7% of the projected consumption in 2029, reducing the final consumption by approximately 15 TWh that year.

Finally, it is estimated that the agriculture sector's energy demand will drop by around 4% or 475 thous. toe in 2029, and the major potential for economy is concentrated in the diesel equivalent (diesel oil and biomethane) with 67% and electricity with 32%.

MICRO AND MINI DISTRIBUTED GENERATION (GD)

In Brazil, there are especially two regulatory revision processes with impacts on micro and mini DG that are being promoted by ANEEL. One of them is the revision of REN 482, which deals especially with the energy compensation mechanism. The other concerns the low voltage tariff model, which affects all consumers served by this voltage, but also impacts micro and mini generators. Adequate charge for use of the micro and mini generator network involves the definition of a binomial tariff with demand measurement for these consumers, an important economic signal for micro and mini generators.

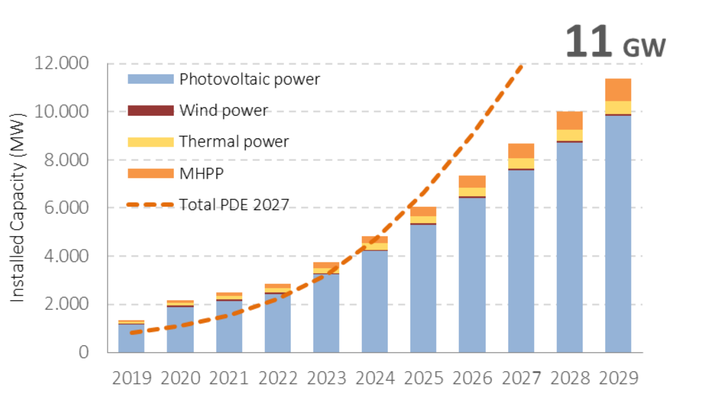
The following regulatory assumptions were considered in PDE 2029:

- New compensation mechanism for micro and mini DG with effect from 2021:
    - For local systems, it was considered that the FIO A, FIO B and TUSD Encargos tariff portions would not be liable to compensation.
    - For remote systems, the same treatment as that of local systems was used with the additional removal of the TUSD Perdas portion.
- Binomial tariff for new micro and mini generators from 2022. The FIO A and FIO B portions were considered as components that would no longer be charged volumetrically, and therefore would not be liable to compensation with micro and mini DG.

In case the model of full compensation and monomial tariffs is maintained, there will be a greater introduction of micro and mini DG. However, in case the alternative of lower introduction is adopted (with binomial and partial compensation), the country may have problems with centralized energy supply.

For 2029, 11.4 GW of micro and mini DG is projected (Figure 5), which will require almost R$ 50 billion in investments over the period. In terms of energy, the installed capacity should contribute

Figura 5. Evolution of the Installed Capacity of Micro and Mini DG

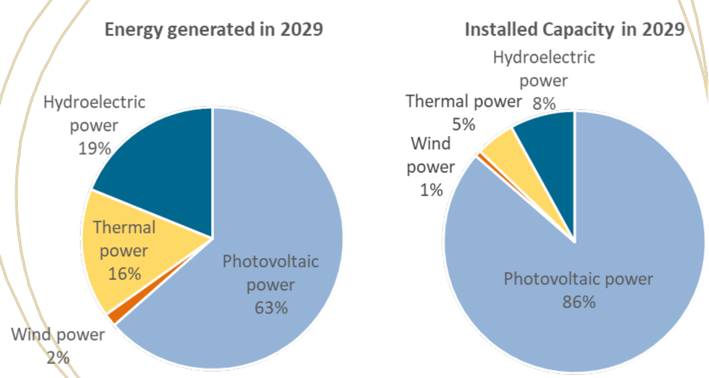


with the generation of 2,300 average MW, enough to meet 2.3% of the total national load at the end of the period.

Among the micro and mini DG technologies, the one based on photovoltaic solar energy stands out. However, mainly through the remote auto-consumption and shared generation model, there is great potential for wind, thermoelectric and hydroelectric generation.

The growth in the first years presented in PDE 2029 reflects the greater speed of action that the market has been carrying out recently, mainly due to the “rush” before the possible changes provided in the regulation. In the years after the revision of REN 482 and the application of the binomial tariff there is reduced growth in the market, but the expectation is that there will be a recovery in the second half of the ten-year period.

Figura 6. Energy and Installed Capacity by Source



Centralized Electricity Generation

The indicative prospects for expanding the supply of electric energy through centralized generation by 2029 are presented.

As novelties in this edition we can highlight: analysis of the operational flexibility requirements considering the reference expansion, the effects of eventual modernization (or repowering) of the Brazilian hydroelectric park, and inclusion in the list of candidate technologies of *offshore* wind generation from 2027.

GUIDELINES AND ASSUMPTIONS

With respect to the input parameters for the computational models, the following are highlighted :

- CVaR parameters defined in alpha = 50% and lambda = 40%;
- Growth in electricity consumption in Paraguay served by the Itaipu HPP of 5.4% per year after 2023;
- Deficit cost equal to R$ 4,944.89/MWh;
- Real discount rate of 8% per year;
- The dates of entry into operation of the projects contracted in auction were considered according to monitoring of the Power System Monitoring Department (DMSE);
- The dates of entry into commercial operation of projects considered “without forecast” were January 2026 for Angra 3 NPP and July 2023 for São Roque HPP.
- VUC variation of TPPs is associated with the future fuel price trajectory, in constant currency, considering the projections of the reference scenario published, by EIA, in the *Annual Energy Outlook*.

The following assumptions were also considered:

- The limits of interchange between the regions were defined considering the evolution of the National Interconnected System (SIN) forecast for the ten-year period, in accordance with the reliability criteria used in the electrical studies of transmission expansion.
- In case of modernization of the existing thermoelectric park, the following were considered:
  - the possibility of some of them extending their useful life through a *retrofit* process in which, in the following month after their removal, these plants become candidates for expansion with an investment cost defined by a CAPEX of 40% of a new TPP, with VUC revision;
  - the thermal power plants that are part of the PPT or without CCEAR or with CCEARs ended in the simulation period were removed from the system, respectively at the end of the PPT or at the end of their contract (whichever is longer) or after 25 years of operation or on the dates of termination of the respective contracts;
  - for plants that, since the beginning of the simulation period, do not add available power to the system, the possibility of *retrofit* and, consequently, return of the plant after its removal was not considered;

Finally, the following energy policy guidelines were incorporated into the construction of the reference expansion:

- Indication of uniform annual expansion of wind power supply between the Northeast and South regions from 2023, limited to 3,000 MW, 80% being allocated to the Northeast and 20% to the South region;
- Indication of uniform annual expansion of centralized photovoltaic solar power supply between 1,000 and 2,000 MW from 2023;
- Indication of maximum annual expansion for SHPP of 300 MW from 2023;
- Indication of uniform annual expansion of the supply of sugarcane bagasse biomass (null variable unit cost – VUC) from 2023 of a minimum of 150 MW;
- Indication of annual expansion of forest biomass thermal power plants between 50 and 100 MW from 2024, in line with the proportional growth of the supply of raw material based on forest management plans;
- Indication of uniform annual expansion of biogas supply limited to the maximum of 30

MW from 2023, considering the use of waste from the sugar and ethanol sector;

- Limit of 1,000 MW per year, from 2024, for storage technologies ;
- Limit of 1,000 MW per year, from 2026, for thermal power plants powered by Domestic Natural Gas, with 50% inflexibility;
- Availability from 2023 of thermal power plants powered by imported natural gas, with different levels of efficiency and inflexibility;
- Limit of 500 MW per year, from 2026, for thermal power plants powered by Domestic Coal, with 50% inflexibility ;

CONTRACTED EXPANSION

The expansion contracted in auctions until 2019 and with beginning of operation between 2020 and 2029 is presented in Table 4.

Table 4. Expansion contracted until 2019

Sources	Annual increase (MW)									
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Biomass + BiogAs	231	147	50	115	0	0	0	0	0	0
Wind power	353	107	264	1,521	1,212	0	0	0	0	0
Hydroelectric power	611	36	0	204	0	0	0	0	0	0
SHPP+MHPP	225	177	111	10	38	0	0	0	0	0
Photovoltaic power	298	557	585	0	0	0	0	0	0	0
Thermal power	1,802	1,305	0	2,238	363	0	1,405	0	0	0

REMOVAL OF THERMOELECTRIC CAPACITY FROM THE SIN

In the PDE 2029 period, the thermoelectric power supply existing at the end of the contract and/or the need for modernization due to the long period in operation amounts to approximately 15,500 MW of installed capacity.

Important aspects in this removal of capacity are the end of the Energy Development Account (CDE) in 2027, which allows the operation of domestic coal-fired thermal power plants with a low Variable Unit Cost (VUC), and the end of the PPT over the ten-year period, as shown in Table 5.

REFERENCE EXPANSION

The energy load projections for all regions of the SIN, already including electrical losses in the transmission grid and the reduction of distributed generation, consider four levels (light, medium and heavy, in addition to the fourth level, lasting 10 hours/month, which was established to represent the system's maximum demand).

Table 5. Removal of Installed Capacity of TPP

Motivating Fact	Annual removal (MW)								
	2021	2022	2023	2024	2025	2026	2027	2028	2029
Termination of CCEAR (NG TPP)	0	554	0	736	1,475	1,133	500	178	0
Termination of CCEAR (DO/FO TPP)	0	0	191	983	1,484	207	381	201	0
End of CDE Subsidies (Coal TPP)	0	0	0	0	0	0	0	1,227	0
End of PPT subsidies (NG TPP)	249	313	120	1,687	572	0	0	0	0
End of Useful Life	0	0	0	1,278	640	869	534	0	0
Total	**249**	**867**	**311**	**4,684**	**4,171**	**2,209**	**1,415**	**1,606**	**0**

The average annual growth of the SIN load (without reduction in DG), over the ten-year period, is of 2,900 average MW, representing an average rate of 3.6% per year. The maximum demand shows the same growth rate of the energy load, thus maintaining the load factor over the period.

In order to meet this expected growth in the reference trajectory, it is concluded, in general, that the wind, solar (taking into account the expansion by DG) and natural gas supply represent the main drivers of the growth in electric energy supply over the next ten years at the Marginal Expansion Cost (CME) of generation of the centralized system equal to R$ 247/MWh and estimated investments around R$ 239 billion in the period from 2023 to 2029 to supply the load in the regulated and free environments.

The indicative expansion in the reference trajectory is shown in Table 6.

Table 6. Cumulative Indicative Expansion

Sources	2023	2024	2025	2026	2027	2028	2029
	MW						
Thermal – Retrofit	1,116	3,153	4,977	6,110	6,610	6,788	6,788
Biomass + Biogas	180	460	740	1,020	1,300	1,580	1,860
Wind power	3,000	6,000	9,000	12,000	15,000	18,000	21,000
Hydroelectric power	0	0	0	385	803	1,298	1,819
SHPP	300	600	900	1,200	1,500	1,800	2,100
Photovoltaic power	1,000	2,000	3,000	4,000	5,000	6,000	7,000
Thermal power	0	3,872	6,164	9,709	12,830	15,854	20,997

Despite the reduction in the participation of hydro power plants, the system maintains the predominance of renewable and non-GHG-emitting sources. In the case of reference, the participation of these sources is still significant. However, even with the decrease in relative participation, the HPP shows an indicative expansion in the period of PDE 2029, according to the list in Table 7.

Table 7. Indicative Hydroelectric Expansion

Name	Total Installed Power (MW)	Year of Entry into Operation
Telêmaco Borba	118	2026
Tabajara	400	2027
Apertados	139	2027
Ercilândia	87	2027
Bem Querer	650	2028
Castanheira	140	2028
Comissário	140	2029

In the case of SHPP and MHPP, all the potential available to the model was used, totaling an additional indicative supply of 2,100 MW by 2029, distributed between the Southeast/Midwest and South regions.

Regarding biomass, considering the supply from sugarcane bagasse, biogas (both with null VUC) and forest residues, the total expansion in the 10-year period was of 1,860 MW, allocated to the SE/MW subsystem.

The wind source maintains its trend of resource with greater participation in the matrix expansion to meet the monthly energy demand, with 21,000 MW of additional installed capacity, in addition to the amount already contracted that is in the implementation process. This evolution leads its participation to approximately 17% of the installed capacity of the SIN in 2029.

The photovoltaic solar technology, which shows 7,000 MW of additional indicative centralized supply, reflects the prospect of evolution of its relative competitiveness in the period of PDE 2029.

On the side of the expectation of average monthly operation, the predominance of renewable sources in the generation of electric energy is notorious, complemented with thermoelectric generation mainly in the months of the dry period. Despite still being the predominant source, the hydroelectric source has its participation in energy to serve the load reduced from 71% in 2020 to 61% in 2029. This reduction is compensated by the increase in the participation of other renewable sources, which grow from 19% in 2020 to 29% of the load in 2029. Despite the increase in thermoelectric share in installed capacity, in terms of expected generation value, its contribution remains practically stable over the period, at 10% of the market.

In this configuration, thermoelectric plants play the key role of providing operational security when the system requests it. In order to compensate the removal of approximately 15,500 MW from the system, the MDI opts for the total expansion of 27,800 MW of thermoelectric plants of various technologies, of which 6,800 MW represent the extension of useful life of the plants that are candidates for retrofit that proved to be economically attractive, maintained their current efficiency. It is also possible that the system also has part of the 8,700 MW that did not become competitive at the considered modernization hypotheses. It is important to highlight that, in addition to providing operational security, this expansion brings as an additional benefit the modernization of the installed park, with gains in operating efficiency. Moreover, in order to meet the load growth and complement the supply to all system requirements, there is a need to increase the total thermoelectric supply of the SIN by additional 12,300 MW. This increase in supply leads the thermoelectric participation in the installed capacity to grow from 14% in 2019 to 18% in 2029.

When considering all possible events, thermoelectric generation presents great uncertainty, as a result of the dispersion between future operating conditions, which values the flexible characteristic of the indicative plants. Among the various uncertainties that influence this amount, perhaps the main one is related to the inflows in hydroelectric plants and, consequently, to the levels of storage in the reservoirs of the HPPs.

With different amounts and probabilities, the thermoelectric dispatch can occur in any month of the year, closing the supply-demand balance and allowing greater use of natural resources. In addition to the variation between months, the modulation of thermoelectric production on an intramonth-scale makes clear the important role of these indicative thermoelectric plants of guaranteeing the supply of instantaneous power, adding capacity to the system. The need for a specific supply for this purpose appears already from 2024 and will require a specific contracting model in order to become viable efficiently.

In general, the future transmission system is sufficiently robust to not limit energy exchanges between the subsystems of the SIN. However, in energy and power analysis, further research is needed. This is the case, for example, in the Northeast region: while the analyses for power supply indicate the predominance of import in the region, due to the low contribution of wind sources to this service, for energy purposes (in average monthly terms) the situation is reversed. Especially in the months of the period of greatest wind production, the flow of energy supply already reaches the limits of interchange, as a result the eventual increase in local thermoelectric supply with high dispatch factor may require expansion of the interconnections to enable the flow to other regions.

Finally, security restrictions not captured in the current PDE methodology may lead to the need for an indication of location expansion different from the analysis made.

FLEXIBILITY ANALYSIS

Despite being an initial approach on the subject, it is possible to trace the need for approximately 7,500 MWh/h in 2029 in the SIN to meet the load variation requirements considering 95% of possible occurrences. It is important to highlight that this requirement, considering the presence of uncontrollable sources, is inferior to the requirement considering only the variations of the load curve considered. While for protection as to 99% of possible time variations, the system requirement increases to 13,000 MWh/h, both for gross and net load. In addition, a more detailed analysis of the exchange limits is necessary to determine the existence or not of margins for flexibility.

In terms of flexibility requirements, the Northeast subsystem is the most impacted. Considering risk levels of 95% and 99%, for example, it is observed that the peak-hour requirement increases every month when we introduce uncontrollable sources. We also observed that, due solely to demand, the highest requirements occur between December and March and, with the introduction of uncontrollable sources, the most critical situations migrate to the dry period, between June and September (although March still has a high requirement). These are months with great production of wind energy, which may explain the large peaks observed during this period.

SENSITIVITY (WHAT-IF) ANALYSIS

In addition to the following 3 alternatives, a case regarding the increased availability of natural gas was also considered, which will be addressed in the Novo Mercado de Gás section.

1. ALTERNATIVE DEMAND TRAJECTORIES

Two alternative demand expansions are analyzed: higher demand trajectory and lower demand trajectory.

In general, the expansion in all cases maintains the same mix of generation sources, with minor changes due to the demand profile to be met. The most significant change occurs for photovoltaic expansion. In the higher trajectory it presents a greater participation, while in the lower trajectory the maintenance of the same floor leads to a relative increase.

1.1 *HIGHER -DEMAND TRAJECTORY*

In the higher trajectory, the average growth rate of the energy load is 4.1% per year, against 3.6% per year of the reference trajectory. This results in an energy load of approximately 5,300 average MW more in 2029, with an average increase over the 10 -year period of around 2,900 average MW.

To meet the greater market growth, the following assumptions considered in the reference trajectory have been changed:

- Upper limit for wind expansion of 3,500 MW/year from 2027;
- Upper limit for total coal expansion of 1,500 MW by 2029;
- Upper limit for total expansion of thermal power plants powered by Domestic Natural Gas of 4,000 MW by 2029;
- Reduction in the investment cost of the photovoltaic solar option by 30%, resulting in approximately R$ 2,400/kW.

The resulting expansion for the case of higher demand leads to an increase in the installed capacity of the SIN of approximately 16,000 MW at the end of the ten-year period in relation to the reference trajectory.

In the breakdown by sources and generation technology, there is an increase in wind expansion, remaining at the upper limit until 2029. The upper limits, in this situation, are also reached for coal and domestic natural gas thermal plants, which have 50% inflexibility and a lower VUC than flexible LNG. This result shows that, with a higher consumption of electric energy, the competitiveness of the inflexible option increases even if the costs (fixed and variable) of the reference case are maintained. In other words, the higher load reduces the prospect of system overflow, increasing the attractiveness of base technologies.

The expansion of photovoltaic plants reaches the end of the period with an increase of about 6,900 MW. There is also an increase of about 4,000 MW in expansion of flexible LNG thermal plants (open cycle and combined cycle). Finally, the total amount of hydroelectric plants was unchanged until the end of the period, only with reschedule for earlier beginning of the expansion of the Ercilândia and Castanheira HPPs.

This expansion requires an increase in the estimated investment of about R$ 48 billion, in the period from 2021 to 2029, in relation to the reference case. Thus, investment at portion indicative of generation totals R$ 287 billion to meet the higher market.

In the reference case and in the higher demand case, also considering the photovoltaic portion of the distributed generation, the expansion occurs, predominantly, in a balanced way between wind, photovoltaic solar, and natural gas sources. These three sources are, in this PDE, the main drivers of the expansion of electric energy supply over the ten -year period.

1.2 *LOWER-DEMAND TRAJECTORY*

On the other hand, the lower demand projection shows an average annual load growth rate of 2.9% per year. This results in an energy load of approximately 6,600 average MW less than the reference in 2029, with an average decrease over the ten-year period of around 3,600 average MW.

As for the analysis of the lower demand trajectory, the assumptions of the reference case were maintained.

There is a decrease in hydroelectric expansion of 280 MW and about 7,500 MW of wind expansion. This decrease occurred between 2023 and 2025, and, from 2026, the expansion in this case maintains the same level of annual increase as in the reference case. In addition, there was no expansion of thermal plants powered by coal and domestic natural gas. Again, the relation between demand and the attractiveness of inflexible technologies is clear. The lower growth in load reduces the attractiveness of these resources, for the assumptions considered, and to increase their competitiveness in a trajectory of lower growth it is necessary that the level of variable operating costs is lower than those used in this PDE.

There is also the decrease of 6,500 MW in expansion of flexible LNG thermoelectric plants (open cycle and combined cycle). An important point to note is that, even in this case, the thermoelectric expansion begins in 2024, now with approximately 800 MW instead of the 3,800 MW of the reference case. This highlights the importance that actions to promote the contracting of sources that can meet the power capacity requirements are taken in the short term.

This expansion has investments below the reference case of approximately R$ 66 billion in the period from 2021 to 2029, totaling an investment of R$ 172 billion to serve the lower market.

2. NEW POWER SUPPLY CRITERIA

The proposal for new supply criteria aims to replace the current criteria for equality between CMO and CME and 5% energy deficit risk limit.

The reference case considered an indicative thermoelectric expansion that contains a significant portion for power supply. As this portion adds little energy to the system, and in order to isolate only the effect of the power capacity supply, for this *what if* the same operation policy of the reservoirs of the reference case was used.

There has been proposal of cases with lower thermoelectric supply in order to degrade the power supply and cases with higher supply aiming at the opposite effect.

The PDE 2029 reference case was adjusted so the $_{5\%}$ CVaR was less than 5% of the maximum instantaneous demand in all months of the period. This criterion, although unofficial, signals that the average interruption for the 5% worst scenarios is equivalent to the operational reserve requirement related to the demand. For the PDE Reference Case, the most critical situation presented 4.1% of the maximum instantaneous demand as the highest $CVaR_{5\%}$.

The smaller the thermoelectric supply, the greater the CVaR of unsupplied power; in the extreme situation, where the entire thermoelectric supply for specific power supply is removed, the $_{5\%}$ CVaR of the worst month exceeds 11.5% of the maximum demand.

On the other hand, as additional supply is included, the system will have a more comfortable service, with lower probability and impacts from the load cut.

It is noted that, without the indicative expansion, the monthly deficit risks are already high from 2024, reaching 55% in 2028. On the other hand, the highest power deficit risk considering the Reference Expansion was 12.6%. The months that presented the highest monthly deficit risks are those between September and February, comprising the months of greatest demand and also of low hydraulic availability. Therefore, the increments in the power expansion of the reference trajectory promoted a significant reduction in the monthly deficit risks, mainly in these months.

Operational changes can also be adopted in order to use the additional supply as a resource to bring forward the thermoelectric dispatch, in order to keep the reservoirs higher in the dry period, increasing the security of the power supply.

Although the average annual risk of the PDE reference case is less than 5%, there is a wide variation over the months. This variation is reduced in the case with greater expansion. The case with the increase of 5,800 MW in the expansion makes the highest monthly risk reduced from 12.6% to 5.7%.

The smaller the acceptable interruption, the greater the additional power supply should be.

This means that for more comfortable situations of power service, increases in supply affect the quality of service very little when compared to situations at the other extreme, when a reduction in supply of the same value has greater impact on the quality of service. Thus, it is important that in situations of favorable quality of service, the expansion of supply aimed at power service is made at the lowest possible fixed cost in situations of favorable quality of service

3. ALTERNATIVES FOR POWER SUPPLY

Two options can contribute if the market conditions necessary for power supply are created: the modernization (and repowering) of hydroelectric plants and the response on the demand side.

As a result, this case expanded the entire available supply of the two candidate technologies (2,000 MW of HPP modernization and 2,000 MW of response to demand), with a decrease in the same amount of thermoelectric plants, which provided this same service, leading to reductions in total investment cost and system operation. It is worth mentioning that a significant portion of this reduction in the need for complementary power (2,750 MW) occurs between 2026 and 2027, when this supply was made available to the model. The reduction in total investment cost in relation to the reference alternative was of approximately R$ 4.8 billion, by 2029.

Regarding the role of each technology in the system, the HPP modernization increases the power modulation capacity whenever the hydraulic resource is available, considering the power limit by fall height of the reservoirs. As this technology does not have a variable operating cost, the expected dispatch when serving instances of greater requirement is high. This option allocates the entire thermoelectric park used to serve the peak that had not been dispatched for energy reasons.

While the response to demand, since it can have a variable cost, which can be high, tends to operate only when the system has already used the cheaper technologies. Thus, it has a dispatch factor consistent with that of thermoelectric plants of equivalent VUC. Response to demand also operates to increase system security at more critical times; however, since its fixed cost is lower than that of a new plant, the allocation of resources can be more efficient with its use. It should be noted, however, that unlike thermal power plants, in extreme energy situations, where the dispatch must be sustained for a long period, response to demand has a limited contribution. In this case, a reduction in consumption over long periods can have negative impacts.

In summary, the development of these resources for the SIN is of fundamental importance because they bring efficiency in the allocation of investments and in the operation of the system.

Although they replace other technologies for the provision of some services, such as the supply of power capacity, they should be seen as another resource to compose the optimal mix of supply.

Finally, it is important to highlight that, in order for these technologies to advance, it is necessary to implement regulatory changes, such as the actions discussed within the scope of the Modernization WG.

PHYSICAL GUARANTEE BALANCE

The commercial balance of physical guarantee signals a need to contract a new supply to meet the total energy market of between 13,000 and 25,000 average MW of contracts backed by new projects over the ten-year period.

This interval is only an estimate of the energy to be contracted to supply the needs of the system and may differ from the actual needs signaled by market agents, since the demand of the auctions for new energy, which supply the regulated market, comes from information from distributors that use economic projections and contracting strategies that may be different from those adopted in PDE 2029. Similar reasoning applies to contracting to supply the expansion of the free market.

Electric Power Transmission

In terms of diagnosing the expansion of the transmission system, the delay in works and the failure to install tendered facilities negatively impacted the evolution of the systems planned for the SIN, notably of those installations responsible for the outflow of generated energy (Belo Monte HPP and renewable plants in the Northeast), strengthening regional interconnections. For each project, a specific analysis was carried out and in the vast majority the mitigating solutions recommended in the EPE studies have already been tendered. However, the following reinforcements are pending to be granted: Poções III 230 kV TL – Itapebi C1, SE 230/69 kV Pirajá, Camaçari IV 230 kV TL – Pirajá C1 and C2, Camaçari IV 500 kV TL – Sapeaçu C1, recommended for meeting the load in the state of Bahia and the sectioning of the Angelim II 500 kV TL – Recife II C2 at SE Suape II, for the outflow of generation in this substation.

Due to the indicative nature of the generation expansion and the current contractual deadlines for the implementation of transmission facilities, EPE has been successfully conducting prospective studies that aim to bring forward the transmission system to integrate the potential of alternative renewable sources estimated on the base of the registrations of energy auctions. Nevertheless, it is important to note that the expansions proposed in the prospective studies are not restricted to the utilization of solar power and wind power projects and can be utilized to market the energy from any types of sources.

The EPE has carried out so far 10 studies with influence on the connection of renewables, namely: (i) one study aiming to enable the marketing of the wind power potential of the southern region of the country; (ii) seven studies aiming to provide the system with capacity to market the various generation potentials of the Northeast and North regions; and (iii) two prospective studies focused on marketing the photovoltaic generation potential of the North and Northwest regions of Minas Gerais, as well as of the northwest region of the state of São Paulo and northeast of the state of Goiás.

Regarding the potential for renewable generation in the Northeast region, the significant participation, in addition to the prospects, of wind and solar sources in this region (higher than that considered in the assumptions of the transmission study that resulted in the expansion of the Northeast-Southeast/Midwest interconnection) point to the need for further studies focusing on interconnections and possible expansions, in addition to those already planned for implementation by 2023.

One of the next challenges to be faced by the transmission planning consists in the aging of the Brazilian transmission system, a fact that tends to become more critical in the coming years. Ensuring the replacement of the electrical system infrastructure at end of useful life is essential so the transmission grid can operate with the reliability and quality levels required by society.

Available in PDE 2029, the works plan and expansion estimates for the last years of the ten-year period generate expectation for total investment of R$ 103 billion, of which R$ 73 billion in transmission lines and R$ 30 billion in substations, including border facilities.

Considering only the new installations of transmission lines and substations to be granted, the estimated total value is about R$ 39 billion (of which R$ 15 billion in indicative works), of which about R$ 23 billion in transmission lines and approximately R$ 16 billion in substations, including border facilities.

Table 8. Expansion of Transmission Lines

Voltage	±800 kV	750 kV	±600 kV	500 kV	440 kV	345 kV	230 kV	TOTAL
	km							
Existing in 2019	4,168	2,683	12,816	51,791	6,758	10,319	59,097	147,632
2020–2029 evolution	2.920	0	0	28,146	228	1,526	16,179	48,998
2020–2024 evolution	0	0	0	20,735	122	1,294	9,644	31,795
2025–2029 evolution	2.920	0	0	7,411	106	232	6,534	17,203
2029 estimate	11.966	2,683	12,816	80,973	7,028	11,853	76,098	203,417

Table 9. Expansion of Substations

Voltage	750kV	500kV	440kV	345kV	230kV	TOTAL
	MVA					
Existing in 2019	24,897	174,156	30,082	52,445	103,626	385,206
2020–2029 evolution	0	85,052	5,773	16,102	54,334	161,262
2020–2024 evolution	0	56,886	2,750	9,269	30,628	99,533
2025–2029 evolution	0	28,166	3,023	6,833	23,706	61,728
2029 estimate	24,897	266,468	35,855	69,247	160,886	557,354

Figure 7. Total investment in transmission lines by voltage

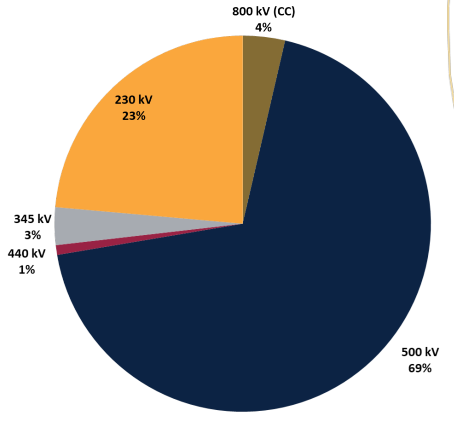
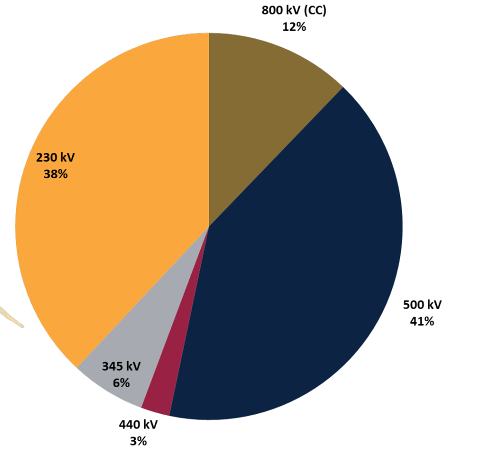


Figure 8. Total investment in substations by

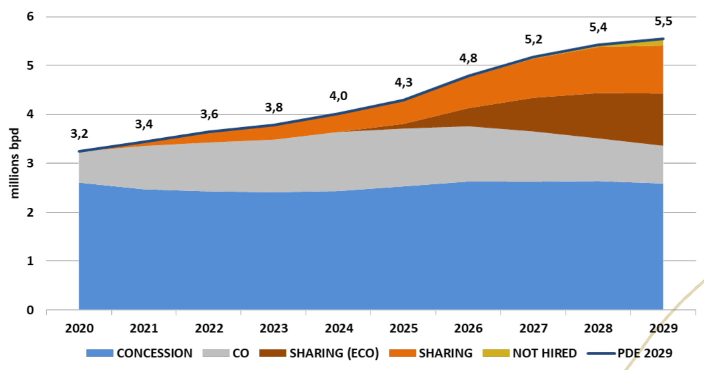


Production of Oil and Natural Gas

Oil production (with prevalence of the type classified as median) is expected to reach 5.5 million barrels per day (bbl/ day) in 2029, approximately double the value recorded in 2018.

Production sustained only on resources in the reserve category should reach the largest volumes in 2027, keeping the level around 4 million bbl/day to the end of the period. Onerous Concession areas are responsible for about 44% of the production of resources in the reserve category in 2029. The production estimated for the end of the 10-year period without contribution from Onerous Concession areas for resources in the reserve category would reach only 2.4 million bbl/day (Figure 9).

Figure 9 Production of domestic oil by type of contract



Production from contingent resources is mainly supported by pre-salt accumulations in the Santos and Campos Basins and by ultra-deep discoveries in the Sergipe-Alagoas and Espírito Santo-Mucuri Basins, for which production is estimated at 92% of the total contingent resources at the end of the period.

The largest contributions to total production remain being those from the production units located in ultra-deep waters, which account for about 82% of domestic production, and from the production units in deep waters with about 11%. Onshore production does not exceed 3% of the total.

Considering the incorporation of surplus volumes of areas that can be unitized within the Onerous Concession to the respective reserves, the entire Onerous Concession will account for about 35% of the total oil production in 2029. The production sharing contract, on the other hand, participates with 18% and the Concession Contracts prevail contributing with 47% of the domestic production at the end of the ten-year period.

Currently, the pre-salt contribution represents about 59% of Brazil's total oil production and 56% of the natural gas production. At the end of the ten -year period, the pre-salt will account for a significant portion (about 77%) of the domestic oil production, with a strong participation of the Santos Basin. The post-salt will contribute with approximately 14%, mainly from the Campos Basin production fields, and the extra-pre-salt with participation of about 9%.

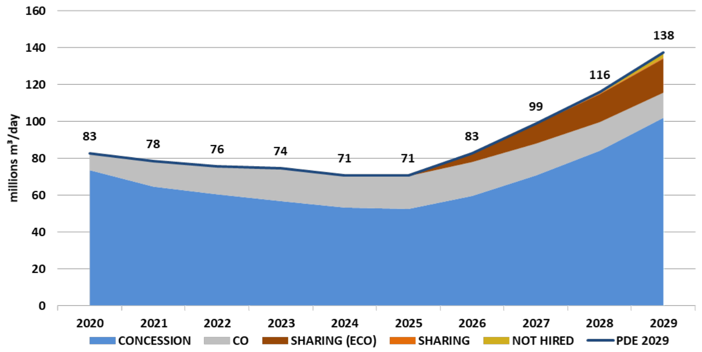
Regarding the production modules in Onerous Concession fields, Búzios stands out with the entry of three modules included in the Operator's planning until 2022, which projects cumulatively a production of about 950,000 barrels per day in 2029. Another highlight is the Mero field, under a Production Sharing contract, which can reach another 630,000 barrels per day at the end of the ten-year period. These three units account for 29% of the oil production forecast for the end of the period.

Gross natural gas production is expected to reach more than 250 million m^3/day in 2029, sustained by the evolution of resources in the reserve category that, despite reaching a production peak close to 155 million m^3/day in 2028, is compensated by the contribution of the production of contingent and undiscovered resources. The greatest contributions are associated with the Santos, Campos, Solimões and Parnaíba basins.

In the gross natural gas production forecasts of this PDE, all Onerous Concession areas, in 2029, including the surplus, accounts for about 30% of the total and the Concession Contracts prevail contributing massively with about 57% of the domestic gross natural gas production at the end of the 10-year period.

As shown in Figure 10, the forecast for net natural gas production shows a slight decrease in the first 5 years due to the natural decline of fields in production in the Post-salt and Extra Pre-salt.

Figure 10. Net Production of Natural Gas



Its behavior does not follow gross production, in this period, due to the high rates of reinjection of the pre-salt gas, mainly to increase oil recovery. Thus, despite significant volumes, monetization of this gas depends on a number of investments and definitions as to consumer market considering the high costs for utilization of this energy input. From 2025, net production is expected to increase through the entry of new projects, with emphasis on the Sergipe-Alagoas and Solimões Basins and the start of production of the Onerous Concession Surplus.

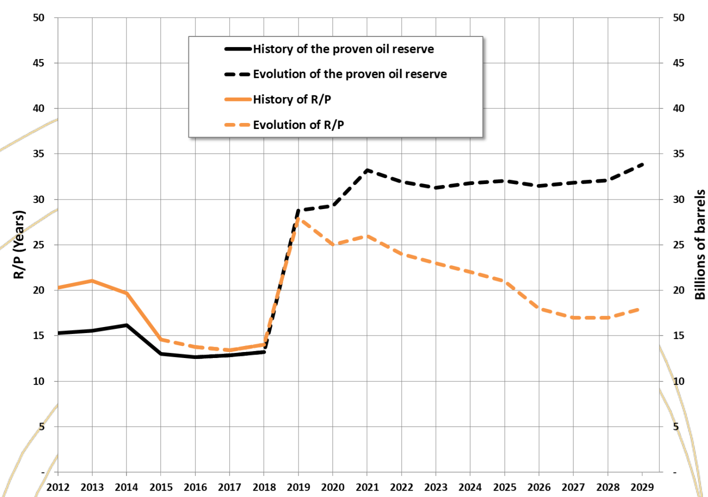
The production of natural gas from contingent resources is mainly supported by the pre-salt accumulations in the Santos and Campos Basin, by the discoveries in ultra-deep waters in the Sergipe-Alagoas Basin and by onshore production in the Parnaíba and Solimões basins, with expected production at the end of the period of this Plan. Together, these accumulations contribute with 80% of the total contingent resources in 2027. From 2022, production of undiscovered resources is expected to start in contracted areas and in the following year, in areas still without contract with the Union. The production estimated for the total undiscovered resources is about 8% of the domestic production in 2029.

The largest proportion of gas to be produced in the 10-year period is of associated gas, and the contributions from the Campos and Santos basins, together, account for about 84% of the total forecast for 2029, with very significant production from the pre-salt accumulations. In the case of non -associated natural gas, there is predominant influence of the productive units in the Barreirinhas, Campos, Parnaíba, Recôncavo, Santos and Solimões basins.

The proven oil reserves may reach about 34 billion barrels in 2029, considering all the estimated volumes mentioned above. The R/P ratio may reach relatively high levels for oil: between 17 and 23 years (Figure 11) – and for natural gas: between 16 and 29 years.

Investments for E&P activities in Brazil are estimated to remain between US$ 424 billion and US$ 472 billion in the 10-year period. This is an assessment of aggregate investments of the entire E&P sector in the country, which may be redone in case of deepening of economic prospects.

Figure 11. Oil: R/P ratio



To support such production forecasts of this plan, the estimate for entry into operation of new Stationary Production Units (SPU) is 42 units from 2019 to 2029.

Supply of Petroleum Products

Despite the volatility due to short-term factors pushing oil prices to inverse directions, prices (Table 10) should continue their trajectory of increase over the medium term until stabilizing in values close to breakeven prices of more expensive projects in fields today considered marginal.

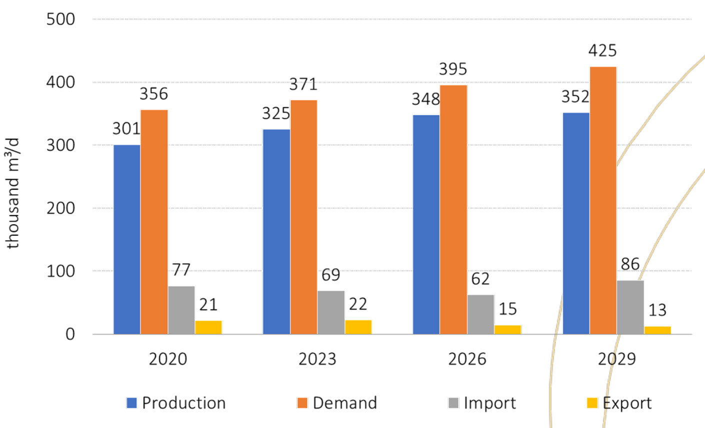
Table 10. Brent Oil Price

December 2018 US$/barrel									
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
70	70	71	73	75	77	78	80	81	82

The scenario considered, in which the evolution of global demand is greatly affected by public policies, technologies and consumer preferences, should lead to a relative appreciation of cleaner fuels with lower sulfur content.

According to the scenario adopted, the country is expected to continue as a net importer of the main products (Figure 12), over the period under study, especially imports of naphtha, aviation kerosene (jet fuel), and diesel oil.

Figure 12. Balance of the Main Petroleum Products



LPG imports have a trend of decrease over the 10-year period, mainly due to the increase in the production of Natural Gas Processing Plants (NGPP).

The results for gasoline indicate that Brazil will act as an importer of this product, with the import volume growing at the end of the period and exceeding the historical maximum.

Fuel oil production, which remains with surpluses throughout the analysis period, sufficiently meets the mandatory demand and the optional bunker market for foreign ships.

In the scenario of international prices defined in this study, the S10 diesel oil is more valued than the aviation kerosene (jet fuel), which economically favors domestic production of S10.

If there is need to produce more aviation kerosene, refining facilities may increase the production of this product, up to a certain limit, to the detriment of diesel oil.

The supply of S10 diesel oil could be significantly expanded through the construction of new hydrotreating units in refining facilities, especially in refineries previously producing diesel oil with high sulfur content. Additional hydrotreating capacity would enable greater availability of processing in distillation units of some refineries and, consequently, increased production of products.

The necessity of importing considerable volumes of products (especially A diesel oil) and the significant cabotage of A gasoline and A diesel oil requires attention in relation to the country's logistics infrastructure.

With maximum use of the capacities of some pipelines and terminals, it will be necessary to improve the operational efficiency of logistic processes to prevent possible regional lacks of supply.

Investments in logistics infrastructure of products are important in order to ensure the supply of fuel throughout the country.

Proposing initiatives and measures is essential for developing the new structure of the national market of fuels, with emphasis on fostering the entry of new players into the sector and free competition, in an objective and clear regulatory environment, as indicated in the Brazil Fuel initiative. Ways to foster new investments in the expansion of refining facilities, seeking the security of the national supply, should be developed, considering that the country will consolidate its condition of oil exporter over the period of this study.

Natural Gas Supply

The developments of the Novo Mercado de Gás (NMG) Program, especially with the entry of new agents and with the increase of investments in the sector, may change the dynamics of the regional market of natural gas, as well as the access of the domestic market to the LNG market.

The price of natural gas from LNG in Brazil, at first, will be affected by the price of the international market and not by the expansion of LNG supply in the country. This is because the import capacity has not been used in its full capacity, but rather providing operational flexibility and modulating LNG imports by the need to meet the national demand for thermoelectric power.

In a "business as usual" trajectory, the net production of natural gas grows from 83 million m^3/day in 2020 to 138 million m^3/day in 2029. While the projected domestic potential supply of the integrated grid will grow from about 54 million m^3/day in 2020 to approximately 86 million m^3/day in 2029.

There is an increase in the domestic production of associated gas, in which the pre-salt corresponds to the level of 47% of the domestic supply in 2029, and also an increase in the domestic production of non-associated gas from the Sergipe-Alagoas Basin.

As for the volume imported from Bolivia, it was considered the maintenance of the maximum import volume of 30 million m^3/day until the end of 2021 and the reduction to 20 million m^3/day from 2022. In this trajectory, the potential import of LNG corresponds to the installed capacity of the existing terminals, 47 million m^3/day, from 2020 to 2029.

For a trajectory of high gas demand for thermoelectric generation, LNG is the preferred option due to the need to complement domestic or imported volumes (via pipelines) to enable meeting such demands. In the cases of low thermoelectric demand, it is observed that domestic gas or gas imported via pipelines may be sufficient.

Expansion to meet the peak demand of the electric power system can be achieved using different technologies, one of which being open-cycle natural gas-fired thermal power plants. In the case of such demand being fully met by this technology, there would be an increase of 67 million m^3/day in natural gas demand between 2024 and 2029.

To meet this indicative demand, one of the proposed solutions would be the gradual installation of three to four new LNG terminals (indicative) until the end of the period, with capacity of 21 million m^3/day each. There would be, in this case, the challenge of developing a business model that adopted a situation of flexibility of the supply of natural gas. It should be noted that these terminals may be those in the stage of planning by several agents, depending on the conditions that may be established in the planning period and the business models that will be defined.

The evolution of the market considering the impacts of the Novo Mercado de Gás is presented in the following section .

NATURAL GAS, ELECTRICITY AND INDUSTRY INTEGRATION

The Novo Mercado de Gás (NMG) Program, launched in July 2019, aims to create a competitive natural gas market, in order to attract investments, expand infrastructure, recover the competitiveness of the domestic industry and, above all, improve the utilization of gas of the pre-salt layer, of the SE/AL basin and of other discoveries for the sector.

Among the actions taken to further open up the natural gas (NG) market, the Cease and Desist Agreement (TCC) signed between Petrobras and CADE was essential, although its impacts have not yet been fully perceived by this planning cycle.

Another important milestone was the conclusion of the Gasbol public call process, the first carried out in the entry and exit model. Although its result was impacted by Bolivia's political context, ANP, TBG and Petrobras entered a Commitment Agreement that could enable the entry of new agents over 2020.

DEMAND

1.1 NON-THERMOELECTRIC DEMAND

Assuming a competitive supply of NG (price of delivery to the final consumer of up to 7 USD/MMBtu, excluding taxes), the segments that showed viability for the entry of new plants were: Methanol, Ethene and Propene, Nitrogen Fertilizers, Pelletizing, Iron-sponge, Glass, White Ceramics and Mining. The demand growth due to NMG in these sectors is approximately twice the demand growth in the trajectory that does not consider the effects of the NMG program between 2019 and 2029 (Figure 13). Thus, the non-thermoelectric demand for NG can grow by approximately 45% in ten years.

1.2 THERMOELECTRIC DEMAND

Considering a reduction in domestic NG prices in the period and the availability of natural gas supply for thermoelectric plants in the period, the natural gas availability curve associated with the NMG program was established, shown in Figure 14.

In this sense, besides the curve above, the following assumptions were considered in addition to those described for the Reference Case:

Figure 13. Evolution of the non-thermoelectric demand

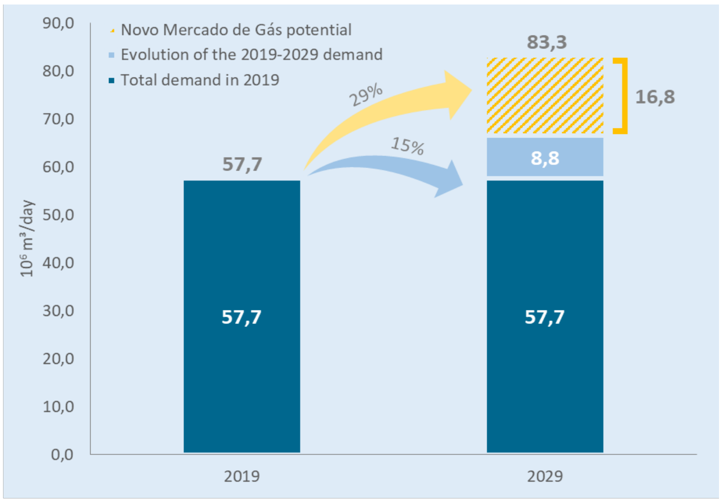
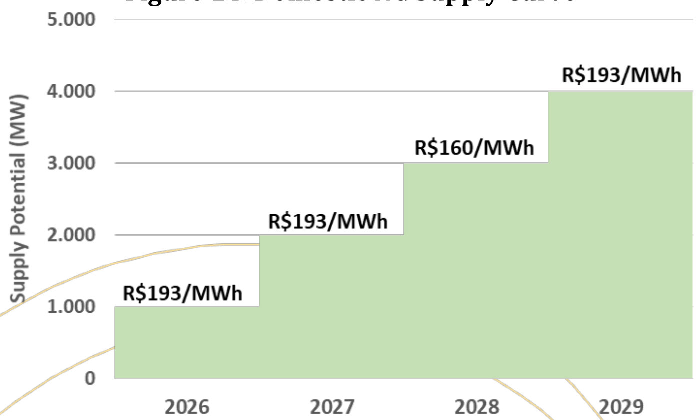


Figure 14. Domestic NG Supply Curve



- Uniform expansion in two *steps* (amount optimized by the IDM) for Domestic NG: between 2027 and 2030; and between 2031 and 2033, in line with the availability of gas supply;
- Maximum limit of 1,000 MW/year, from 2026;
- TPP with domestic gas with inflexibility of 50% of the installed capacity, constant in all months of the year.

The indicative expansion over the ten-year period of domestic natural gas thermoelectric generation is of 2,600 MW. Compared with the reference case, there is an addition of 1,600 MW, an expansion limited mainly by the domestic gas production curve.

This new configuration adds more energy to the system due to the lower VUC value, and also to a higher probability of dispatch of these projects in relation to those with operating costs referenced to LNG. There is also a factor close to 80% for those using domestic natural gas. As a result, inflexible thermoelectric plants may be of interest to the system, depending on the relation between the price of natural gas, generation efficiency and the level of inflexibility compared with the “premium flexibility.”

In addition, the further expansion of TPPs with greater inflexibility, using the most competitive fuel, practically replaces an equivalent amount of flexible thermoelectric plants.

Finally, by preserving reservoir levels, these TPPs also help to increase the availability of power in HPPs.

1.2.1 SENSITIVITY ANALYSES

Sensitivities were additionally prepared for the thermoelectric demand for natural gas in order to capture the relation between VUC, the price of natural gas and the inflexibility of the thermoelectric plants in a context of higher competitiveness of the domestic natural gas.

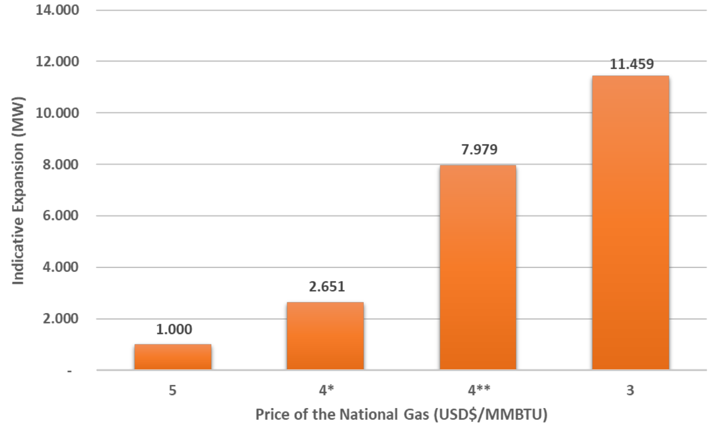
In general, the greater expansion of inflexible TPPs occurs to replace the indicative supply of the other technologies, since, by adding energy and power capacity to the system, their greater introduction tends to reduce the need for expansion to meet these two requirements in a combined manner.

However, the amount of thermoelectric supply with inflexibility depends on the level of the fuel price in the optimal expansion of the Brazilian electrical system. In other words, the compulsory generation of technologies powered by fossil fuels must present a price that compensates for their inclusion in the matrix, since the country has a vast potential of natural resources that present variable production costs close to zero.

Figure 15 below shows some cases analyzed. For example, removing the limitation of 1,000 MW per year in the expansion of thermoelectric plants (in the prospect of sufficient availability of natural gas at US$ 4/MMBtu in the PDE 2029 period to meet the additional expansion and maintaining the 50% inflexibility level), the electrical system admits an expansion of up to about 8,000 MW in the ten-year period, in case the other assumptions of the reference scenario are maintained.

Finally, it is important to note that, in situations where the price of natural gas is equivalent in any region of the country, mathematical models point to the economic benefit of these inflexible

Figure 15. Domestic NG Supply Curve



Notes: (1) (*) Considering an additional expansion limit of 2,000 MW of NG TPP at the price of US$ 4/MMBtu .
(2) (**) Considering unlimited supply of NG, at the price of US$ 4/MMBtu .
(3) Another sensitivity assesses the effect with domestic natural gas made available at US$ 3/MMBtu for thermoelectric plants, despite the unlikely occurrence of this price level in large scale in Brazil. This sensitivity implies a VUC of R$ 127/MWh, when considered operating inflexibility of the TPPs of 80%. In this case, the expansion is of up to 11,500 MW of thermoelectric plants with a high degree of inflexibility .

thermoelectric plants being located close to the load centers, reducing the need to expand the transmission system, resulting in reduced costs and electrical losses, in addition to increased electrical security in the SIN. However, strategic energy policy decisions aimed at stimulating development in other regions of Brazil may lead to a distribution of this potential supply associated with the expansion of exchanges between regions for the marketing of surplus generation. One of the possibilities to be evaluated is the development potential of the secondary market in the Northeast region.

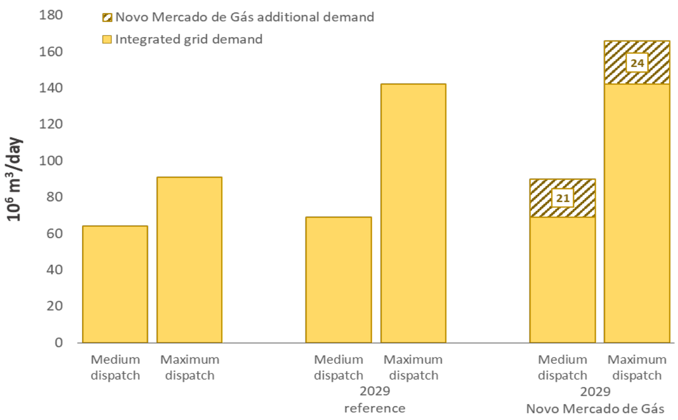
All of these issues are under discussion in the working group created by the Monitoring Committee for the opening of the natural gas market, according to guidelines

1.3 TOTAL DEMAND

The non-thermoelectric demand in the integrated grid would reach 79 million m^3/day in 2029, considering the effects of the NMG. Including the non-thermoelectric demand outside the grid (isolated systems), the total would reach 83.3 million m^3/day. The thermoelectric demand, on the other hand, should see an additional growth of 7 million m^3/day by 2029, considering the full dispatch of the new plants. The additional growth in demand considering the average dispatch is of 4.2 million m^3/day.

Thus, the potential demand for natural gas in addition to the reference trajectory due to the Novo Mercado de Gás (Figure 16) can reach 21 million m^3/day (considering the thermoelectric demand with average dispatch), and may reach 24 million m³ with the maximum dispatch in 2029.

Figure 16. Domestic NG Supply Curve



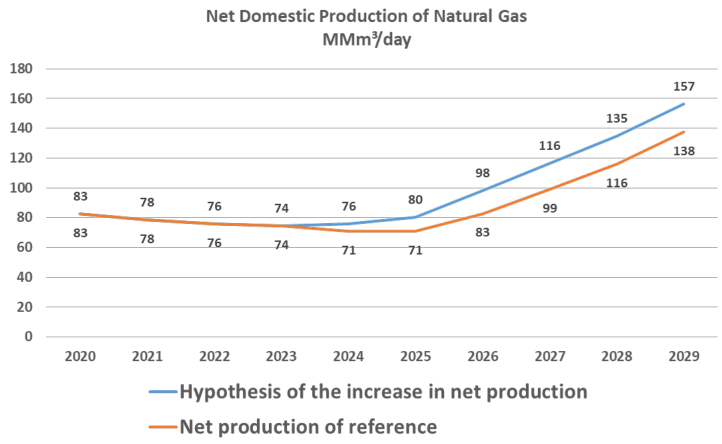
SUPPLY

On the domestic supply side, it was considered that some oil and natural gas producing fields could decide to send a larger portion of their gross production of natural gas to the coast. The viability of this strategy for several E&P entrepreneurs would be improved with the natural gas flow and processing infrastructures being shared, and with completion of the construction of the new pre-salt routes (Routes 4, 5 and 6), which would encourage the connection of several projects to the flow and processing infrastructure, as well as the reduction of unit costs by optimizing the use of this infrastructure.

In the case of imported supply, it was considered that up to 6 new LNG terminals could be connected to the integrated transport pipeline network, of which three are planned (Barra dos Coqueiros/SE, Porto do Açu/RJ and Barcarena/PA) and three are indicatives in the reference scenario, in addition to two additional hypothetical terminals among the several options announced and in process of environmental licensing in Brazil, totaling 8 regasification terminals. This interconnection would allow the surplus natural gas not being used by TPPs to be sent to the integrated grid, with these volumes being marketed in their area of influence through short-term contracts, with great liquidity and competitive prices.

The total effect on the net domestic production of Natural Gas is shown in Figure 17.

Figure 17. Net Domestic Production of Natural Gas

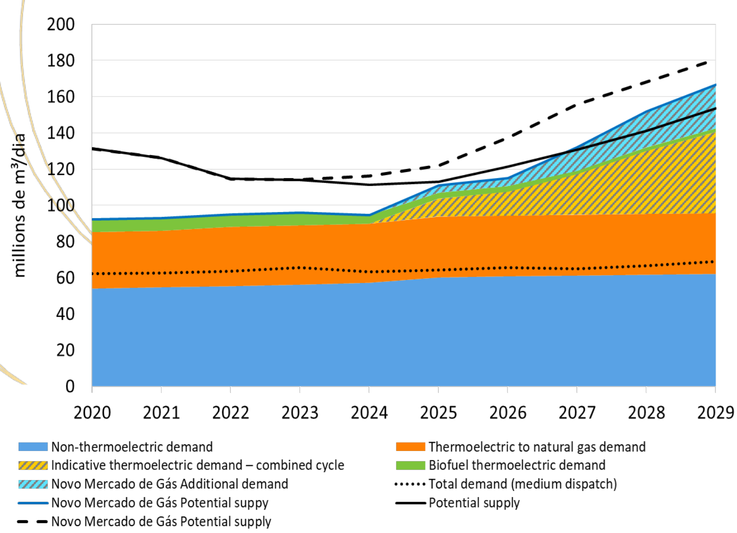


It is also important to note that the gross production of natural gas expected in this PDE cycle has considerable volumes from the pre-salt layer, which include higher own consumption for the operation of compressors and production units, greater injection for recovery of pressure of the reservoirs, in addition to CO_2 injection after separation. These factors make the difference between Gross Production and Net Production greater than in previous cycles.

NATURAL GAS BALANCE IN THE INTEGRATED GRID

With the evolution of the total demand for natural gas and of the supply as a result of the developments of the Novo Mercado de Gás program, the natural gas balance in the integrated grid is shown in Figure 18.

Figure 18. Natural gas balance in the Integrated Grid with additional volumes considered in the Novo Mercado de Gás



LOGISTICS

Natural gas may be supplied via imports or domestic production, with an emphasis on the pre-salt layer. Imported or domestic gas considers two alternatives for transportation, the first through gas pipelines and the second via LNG terminals.

The gas produced in the pre-salt may be moved initially by the flow routes in operation or by the projected routes. Subsequently, it will be transported via gas pipeline, in a traditional way, through the existing network or through the expansion of new gas pipelines.

Another option will be the installation of liquefaction terminals for transportation, using the vast Brazilian coast, using cabotage ships with access to the main ports in the country.

In the case of LNG, the cabotage alternative may represent a more economical solution, depending on the characteristics of the market, the prices charged and the terms of the contracts. In the evaluations to be made by the entrepreneurs, the issues of costs and implementation deadlines should prevail, the definition of which will take into account the technical, economic and environmental analyses of the pipeline versus cabotage modes.

Table 11. Expected and indicative investments in the PDE 2029 period

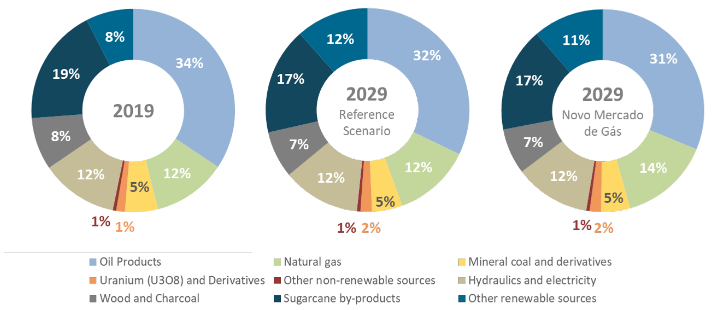
Classification	Expected	Indicatives	
		Business as Usual	Novo Mercado de Gás
Outflow pipelines	6.10	3.13	13.65
Transport pipelines	0.13	-	17.06
LNG Regasification Terminals	1.20	1.20	0.80
NGPP	2.69	3.50	11.30
Total	10.12	7.83	42.81

INVESTMENTS

Indicative investments associated with the *Novo Mercado de Gás* reach R£ 87 billion. Adding investments of R$ 18 billion in a "business as usual" trajectory, total investments in the natural gas sector are expected to reach around R$ 60 billion in the period.

Investments related to the expansion of the natural gas supply are estimated at about R$ 60 billion, of which about R$ 10 billion in planned projects and R$ 50 billion in indicative projects. Among the indicative projects, it is considered the case in which the indicative open-cycle thermal demand forecast in the 10-year period is supplied by 3 to 4 exclusive new LNG terminals, in addition to new indicative ventures by the opening of the market with the *Novo Mercado de Gás* Program.

Figure 19. Domestic Energy Supply



DOMESTIC ENERGY SUPPLY

Compared with the reference scenario, the participation of natural gas in the domestic energy supply (OIE) increases from 12% to 14%, in 2029, considering the average thermoelectric demand (Figure 19).

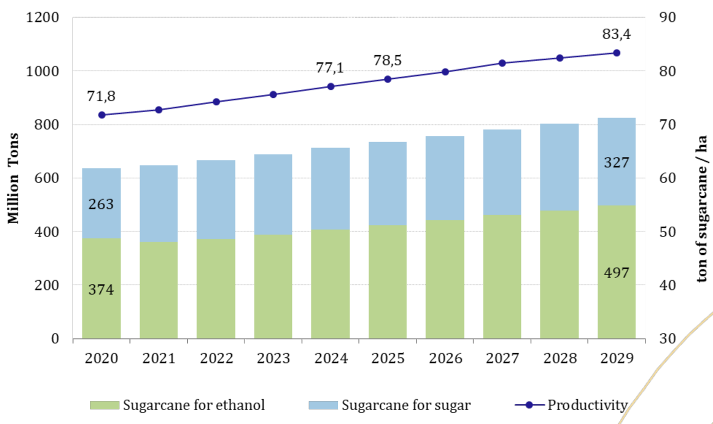
In addition, there may be indirect benefits from the NMG related to the production of natural gas liquids in NGPP. The processing of additional volumes of natural gas can generate additional supplies of ethane, propane, butane and C5+, depending on the fractionation decisions made.

BIOFUELS SUPPLY

The establishment of the National Biofuels Policy (RenovaBio) corroborates the positive developments and the strengthening of the biofuels sector, allowing its relevant expected participation in the Brazilian energy matrix in the next ten-year period.

With investments in renovation of the sugarcane crops, adequate cultural practices and adjustment between the mechanization of harvesting and planting of sugarcane, it is estimated a recovery of production indicators of this culture – agricultural productivity and industrial yield in kg of Total Recoverable Sugars (TRS) per ton of cane (ATR/tc).

Figure 20. Productivity, harvested sugar cane and destination

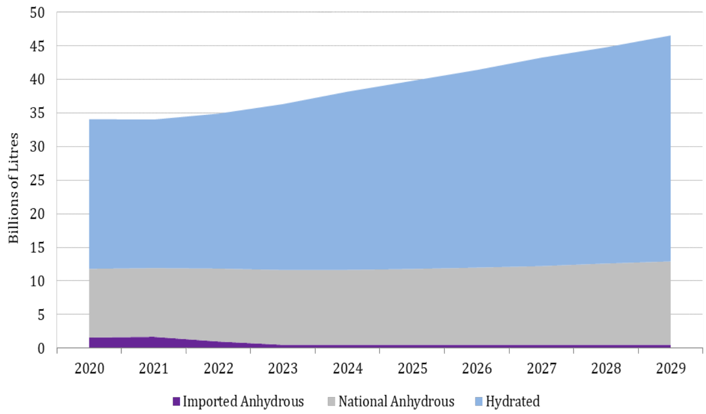


In addition, reduced production costs and increased competitiveness of ethanol in relation to gasoline are expected. Such facts, associated with the need to increase the milling capacity, will foster investments in greenfield units and in the expansion of some existing units.

It is also considered the introduction of energy cane in small percentages, and that 2G ethanol production will be significant only at the end of the period. Corn ethanol production is estimated to reach approximately 4 billion liters in 2029.

The total ethanol supply reaches 47 billion liters in 2029, with 34 billion liters referring to hydrated ethanol. (Figure 21)

Figure 21. Total ethanol supply



It is expected an expansion of the bioelectricity generation period, incorporating straws and tips and, in some cases, different sugar cane biomasses. It is estimated that 6,700 average MW will be available for marketing in 2029.

For biodiesel, soybean oil is expected to remain as the main raw material in the 10-year period. In strategic terms, developing alternative crops in relation to soybeans is important for the PNPB. Among vegetable oils, palm oil presents the largest production volume in the international market, as well as more competitive prices.

Biogas from the bio-digestion of vinasse and filter cake will have a higher participation in the energy matrix. Its production potential is estimated at 7.1 billion Nm^3 in 2029, and can be used to generate electricity, replace diesel oil and mixed with fossil natural gas, in pipeline grids .

Aviation biokerosene (BioQAV) is expected to reach a market share of 1% (103,000 m^3) of the total aviation fuel demand in 2029, with specific airlines adopting certified technological paths.

SOCIOENVIRONMENTAL ANALYSIS

In order to contribute to the supply models and to define the expansion planned in PDE 2029, in the socio-environmental analysis, the following were carried out: 1) procedural analysis of the hydroelectric plants (of the 47 HPPs analyzed, only 9 would have a possible operation date in the 10-year period) and 2) socio-environmental complexity analysis of the oil and natural gas production units, which resulted in: 72 PUs of the set of 783 analyzed with concession contracts classified as of high socio-environmental complexity; and reduction in the ten-year period of 14% to 17% in the forecast volume of oil and natural gas for the Union's Production Units.

In this Plan, 10 socioenvironmental themes were indicated that seek to summarize the most significant interferences of the set of planned projects: Fauna, Territorial organization, Landscape, Indigenous peoples and lands, Quilombola communities, Air quality, Water resources, Waste, Conservation units and Native vegetation. With the purpose of directing efforts to issues that increase the uncertainty associated with the expected planning, two themes were selected as priorities for the environmental management of the energy sector: "Indigenous peoples and lands" and "Conservation units ".

The theme "Indigenous peoples and lands" was considered a priority due to the multiple associated challenges that involve the sensitivity of the peoples due to their cultural diversity, the fact that about 60% of the Brazilian hydroelectric potential is superimposed on indigenous lands, in addition to the lack of definitions about legal and normative devices in relation to the peoples affected by enterprises.

The theme "Conservation units" was considered a priority due to the difficulties in reconciling the purposes of a CU with the expansion of energy supply.

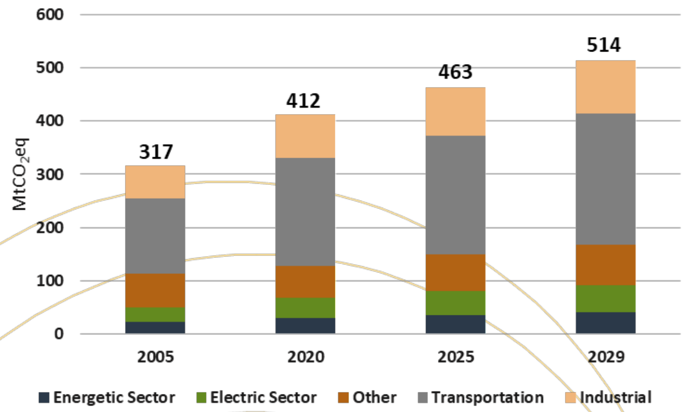
GREENHOUSE GASES (GHG)

In its NDC, Brazil proposed a 37% reduction in its emissions by 2025, based on the 2005 emissions. There is no formal distribution of goals between the different sectors, so the country may achieve the goals by different alternative paths.

GHG emissions per unit of energy consumed in Brazil are small compared with other countries. However, energy consumption per capita is expected to increase considerably by 2030 and, thus, the sector's emissions will be increasing.

The main sectors responsible for greenhouse gas emissions in energy production and consumption (Figure 22) are the transportation and industry sectors, which, over the period, will remain responsible for most emissions of the energy sector, amounting to 67% in 2029.

Figure 22. Evolution of the sector participation in GHG emissions by energy production and use



In the electricity sector, generation from non-GHG-emitting sources will represent 94% of the total electric energy generation in 2029. Therefore, additional efforts to mitigate greenhouse gas emissions should focus on sectors that present opportunities with better cost-to-benefit ratio.

The energy supply and consumption expansion scenario over the ten-year period meets and surpasses the target for 2020 – indicated in Decree 9,578/18, which regulates the PNMC – and the trajectory stipulated in Brazil's NDC for the energy sector. Thus, it can be stated that the PDE scenario is aligned with the PNMC and with the international commitments assumed by Brazil in the Paris Agreement.

MAIN FORECASTS

At the end of the 10-year period, the resident population is estimated to reach 224 million inhabitants, with average growth of 0.6% per year. The per capita GDP will reach R$ 24,000 in constant values of 2017, with growth of 2.3% per year.

Correspondingly, the final energy consumption grows at an average rate of 2.6% per year, reaching 318 million at the end of 2029.

It is estimated that the domestic energy supply reaches about 380 million toe, an average annual growth of 2.6%. The domestic electricity supply grows at an average rate of 3.8% per year, reaching an estimated supply of 951 TWh at the end of 2029. In per capita terms, the domestic electricity supply increases from about 3,077 kWh to 4,200 kWh in 2029.

Table 12. Indicators: Final de Energy Consumption

Itemization		2019	2024	2029	Average anual variation		
					2019 a 2024	2024 a 2029	2019 a 2029
Resident Population	(10^6 inhab)	211	218	224	0.7%	0.5%	0.6%
GDP	(10^9 reais of 2017)	4,143	4,765	5,526	2.8%	3.0%	2.9%
	per capita (10^3 R$/inhab.)	19.6	21.8	24.6	2.1%	2.5%	2.3%
Domestic energy supply	(10^6 tep)	295	332	380	2.4%	2.8%	2.6%
	by GDP (tep/10^3 R$)	0.071	0.070	0.069	-0.5%	-0.2%	-0.4%
	per capita (toe/inhab.)	1.40	1.52	1.70	1.6%	2.2%	1.9%
Domestic eletricity supply	(TWh)	649	794	942	4.1%	3.5%	3.8%
	by GDP (kWh/10^3 R$)	157	167	171	1.2%	0.5%	0.8%
	per capita (kWh/inhab.)	3,077	3,637	4,200	3.4%	2.9%	3.2%
Final energy consumption	(10^6 tep)	247	278	318	2.4%	2.7%	2.6%
	per capita (toe/inhab.)	0.060	0.058	0.058	-0.4%	-0.3%	-0.3%
	by GDP (toe/10^3 R$)	1.17	1.27	1.42	1.7%	2.2%	1.9%

Regarding the domestic energy supply, renewable energies show average growth of 2.9% per year, with emphasis on the average growth of 7% per year in the supply from the other renewable sources (wind, solar, biodiesel and black liquor). Thus, the percentage of renewable energy sources in the Brazilian energy matrix is estimated at 48% in 2029 (Table 13).

On the other hand, it is noted the reduction in the participation of oil and its products in the total domestic energy supply, from 34% in 2019 to 32% in 2029. Despite the increased production of crude oil, prospects for the replacement of gasoline with ethanol and of fuel oil and LPG with natural gas are the main determinants for the decrease expected in the period.

Table 13. Domestic Energy Supply Evolution in the 10-year Period

	2019		2024		2029		2019-2029
	thous. tep	%	thous. tep	%	thous. tep	%	Average Variation (% p.a.)
Non-Renewable Energy	**157,293**	**53**	**171,778**	**52**	**196,652**	**52**	**2.3**
Oil and Oil Products	101,439	34	110,256	33	122,323	32	1.9
Natural Gas	34,709	12	38,679	12	46,842	12	3.0
Coal and Derivatives	15,454	5	17,022	5	18,404	5	1.8
Uranium (U3O8) and Derivatives	4,071	1	3,974	1	6,959	2	5.5
Other Non-Renewable Sources	1,620	1	1,847	1	2,124	1	2.7
Renewable Energy	**138,150**	**47**	**160,051**	**48**	**183,844**	**48**	**2.9**
Hydraulic Energy and Electricity	36,180	12	44,572	13	46,896	12	2.6
Firewood and Charcoal	24,591	8	26,251	8	28,311	7	1.4
Sugar Cane Derivatives	55,019	19	56,384	17	64,719	17	1.6
Other Renewable Sources	22,360	8	32,844	10	43,919	12	7.0
Total	**29,444**	**100**	**331,829**	**100**	**380,496**	**100**	**2.6**

It is observed that the country has progressed in convergence to the fulfilment of the goals undertaken, with emphasis on the expectation of overcoming them regarding the composition of the energy matrix, in particular as to the participation of renewable sources (excluding hydro), for which a participation of 35% is projected, with participation of bioenergy estimated at 19% (Table 14).

Table 14. Monitoring of NDC measures x PDE 2026 Projections

INDICATORS		**NDC**	**PDE 2029**
		Reference year 2025	
Energy Efficiency	Electricity	8%	7%
Electric energy	Participation of wind, solar and biomass energy, including DG and auto-production	22%	25%
	Participation of hydroelectricity in centralized generation	71%	71%
Energy matrix	Participation of renewable sources, except hydro	32%	35%
	Participation of bioenergy	18%	19%
	Total participation of renewable sources	45%	48%

Thus, contrary to what occurs in most countries, in Brazil the electricity sector contributes little to the total greenhouse gas emissions.

Considering that the country fulfills the absolute commitment of its NDC, of 1.3 $GtCO_2e$ in 2025, the emissions from the SIN forecast in this PDE would represent about 3% of this total.

Therefore, additional efforts to mitigate greenhouse gas emissions should not focus on the electric power sector, but on sectors that present opportunities with better cost-to-benefit ratio.

Emissions resulting from the production and consumption of energy will grow 63% between 2005 and 2029. This increase is lower than that expected for the gross domestic supply in the same period (72%). Thus, the indicator for the intensity of GHG emissions in the use of energy in 2029 will be lower than that observed in 2005. The indicator for the intensity of emissions of the economy should also close the 10-year period below that observed for 2005.

Table 15. Carbon intensity in the Brazilian economy due to the production and use of energy

Item	Unit	2005	2020	2025	2029
GHG emissions in energy production and use	$10^6 tCO_2e$	317	412	463	514
GDP	Billion R$ [2010]	3,122	4,254	4,910	5,526
Gross Domestic Supply	10^6 toe	218	298	338	376
Carbon intensity in energy use	$kgCO_2e$/toe	1,452	1,384	1,371	1,364
Carbon intensity in the economy	$kgCO_2e$/R$ [2010]	101.3	96.9	94.3	92.9

The estimated generation including auto-production (representing almost 11% of the total generation in the period) is presented in Table 16. The participation of wind generation reaches more than 16% at the end of the period, while auto -production using solar generation almost doubles the generation expected in the period under analysis.

Table 16. Total Electricity Generation

Centralized Generation	2019		2024		2029	
	TWh	%	TWh	%	TWh	%
Hydroelectric power	418	64	514	65	538	57
Natural Gas	36	6	33	4	42	4
Coal	6	1	7	1	6	1
Nuclear	15	2	15	2	26	3
Biomass	38	6	33	4	40	4
Wind power	65	10	95	12	155	16
Solar (centralized)	5	1	10	1	21	2
Others	4	1	8	1	10	1
Subtotal (meets Load)	**587**	**90**	**715**	**90**	**838**	**89**
Auto-production & Distributed Generation	**2019**		**2024**		**2029**	
	TWh	**%**	**TWh**	**%**	**TWh**	**%**
Biomass (biogas, sugar cane bagasse, black liquor and firewood)	31	5	38	5	47	5
Solar power	1	0	5	1	13	1
Hydroelectric power	0,1	0	0,2	0	0,3	0
Wind power	3	0	4	0	7	1
Non-renewable sources	27	4	31	4	38	4
Subtotal (auto-prod. & DG)	62	10	79	10	104	11
Total	**649**	**100**	**794**	**100**	**942**	**100**

In terms of installed capacity, the expected evolution is shown in Table 17 below.

Table 17. Evolution of the Installed Capacity

SOURCE	2019	2024	2029
		MW	
RENEWABLE SOURCES	**146,712**	**167,469**	**200,198**
HYDRO[(a)]	101,926	102,783	104,701
CENTRALIZED	101,288	102,139	103,958
AUTO-PRODUCTION	638	644	743
SHPP and MHPP	6,458	7,852	9,956
CENTRALIZED	6,385	7,545	9,045
DG	73	307	911
WIND	15,045	24,532	39,561
CENTRALIZED	15,017	24,475	39,475
DG	28	57	86
BIOMASS[(b)] and BIOGAS	19,928	22,471	25,535
CENTRALIZED	13,412	14,415	15,815
AUTO-PRODUCTION and DG	6,516	8,056	9,720
SOLAR	3,354	9,831	20,444
CENTRALIZED	2,182	5,622	10,622
DG	1,172	4,209	9,822
NONRENEWABLE SOURCES	**28,801**	**36,440**	**50,785**
CENTRALIZED	22,672	29,293	42,059
URANIUM	1,990	1,990	3,395
NATURAL GAS[(d)]	12,921	21,234	36,190
COAL	3,017	3,017	2,083
FUEL OIL[(e)]	3,697	2,510	25
DIESEL OIL[(e)]	1,047	542	366
AUTO-PRODUCTION	6,129	7,147	8,726
BRAZIL TOTAL	**175,513**	**203,909**	**250,983**
ITAIPU 50Hz [(c)]	**7,000**	**7,000**	**7,000**
TOTAL AVAILABLE	**182,513**	**210,909**	**257,983**

Notes: (a) The values in the table indicate the installed power in December of each year, considering the motorization of the HPPs.
(b) Includes biomass-fired plants with VUC>0 and VUC=0 (sugarcane bagasse). For sugarcane bagasse-fired plants, the projects are accounted for with the total installed power
(c) In natural gas, the amount of process gas is also included
(d) Thermoelectric plants powered by diesel and fuel oil are removed from the Reference Expansion Plan on the dates their contracts end.
(e) Portion of the Itaipu HPP belonging to Paraguay, whose surplus energy is exported to the Brazilian market.

Over the last decades, the difference between total energy demand and primary energy production has been maintaining a downward trajectory. If such trend continues over the next 10 years, Brazil will have surplus energy in its energy matrix, reaching more than 140 million toe in 2029, which is equivalent to approximately 25% of the country's total energy production (Table 18).

Table 18. Evolution of the Primary Energy Supply

Itemization	2019	2024	2029	2019-2024	2024-2029	2019-2029
		thous. toe			Variation (% p.a.)	
Total Energy Demand (A)	310,212	349,585	411,188	2.4	3.3	2.9
Final Consumption	262,636	294,678	336,130	2.3	2.7	2.5
Losses	47,576	54,906	75,058	2.9	6.5	4.7
Primary Energy Production (B)	354,168	421,452	551,525	3.5	5.5	4.5
Surplus Energy (B) - (A)	43,956	71,867	140,336	10.3	14.3	12.3

Table 19 shows the evolution of the energy supply in the oil chain, where there is an important increase in the production of crude oil, with an annual average of 5.4%. Therefore, there is a detachment in relation to the energy demand for petroleum products, which shows 2.3% average annual growth. With that, at the end of the 10-year period, surplus energy amounts to approximately 156 million toe in the Brazilian petroleum chain, which is responsible for the significant excess of surplus energy of the Brazilian energy matrix in the period of the plan.

Table 19. Evolution of the Supply of Oil and Petroleum Products

Itemization	2019	2024	2029	2019-2024	2024-2029	2019-2029
	thous toe			Variation (% p.a.)		
Demand for Petroleum Products (A)	112,258	125,484	140,255	2.3	2.3	2.3
Final Consumption	106,751	118,884	132,869	2.2	2.2	2.2
Processing	5,507	6,600	7,386	3.7	2.3	3.0
Oil Production (B)	174,437	216,321	296,848	4.4	6.5	5.5
Crude Oil	168,950	207,467	286,568	4.2	6.7	5.4
Natural Gas Liquids	1,005	1,139	1,450	2.5	4.9	3.7
Biodiesel	4,483	7,715	8,830	11.5	2.7	7.0
Surplus Energy (B) - (A)	62,179	90,837	156,593	7.9	11.5	9.7

Table 20 presents the projected natural gas balance, with emphasis on the decrease, in the first five years, in the processing in NGPP, due to the decreased need for thermoelectric dispatch. In the second five-year span, the supply from NGPP resumes expansion and comes close to 70 million m^3/day, in 2029, due to the increase in general consumption.

As for the final consumption, it can be highlighted the growth acceleration in the second half of the ten-year period, with emphasis on the residential and non-energy (raw material) sectors. The final consumption of natural gas is estimated to increase, on average, 1.5% per year over the next ten years, reaching 63 million m^3/day in 2029.

Table 20. Dry Natural Gas Balance

Itemization	2019	2024	2029	2019-2024	2024-2029	2019-2029
	mil m^3/dia			Variação (% a.a.)		
Total Expected Supply	77.574	78.694	87.607	0,3	2,2	1,2
NGPP	52.789	51.772	70.548	-0,4	6,4	2,9
Import	24.785	26.923	17.059	1,7	-8,7	-3,7
Total Expected Consumption	77.574	78.694	87.607	0,3	2,2	1,2
Processing into electricity (1)	22.721	19.859	23.990	-2,7	3,9	0,5
Final consumption	54.853	58.835	63.618	1,4	1,6	1,5
Non-energy consumption	5.394	5.441	7.381	0,2	6,3	3,2
Energy consumption	49.459	53.395	56.237	1,5	1,0	1,3
Energy sector (2)	13.042	13.664	13.623	0,9	-0,1	0,4
Residential	1.289	1.642	2.043	5,0	4,5	4,7
Transportation	6.153	6.533	6.913	1,2	1,1	1,2
Industry	28.129	30.503	32.345	1,6	1,2	1,4
Others (3)	845	1.054	1.313	4,5	4,5	4,5

Notas: (1) Inclues auto-productio.
(2) Does not include consumption in E&P.
(3) Includes the: commercial, public and agricultural sectors.

Table 21 shows the quantitative values for domestic energy production over the PDE 2029 period, with emphasis on the production of natural gas and oil.

The next tables (Tables 22 to 24) indicate the physical expansion of the system in the 10-year period, while Table 25 presents the estimate of the associated amount of investments. Table 26 shows the list of hydroelectric projects made available to PDE 2029 to execute the expansion of centralized generation, while Table 27 shows the summary of the studies conducted in the Environmental Analysis. Finally, Table 28 presents the projection for the domestic energy matrix in 2029.

Table 21. Domestic Energy Production

Source	Unit	2019	2024	2029	2019-2024		2024-2029		2019-2029	
					Increment	%	Increment	%	Increment	%
Oil	thous. barrels/day	3,267	4,012	5,542	745	23%	1,530	38%	2,275	70%
Natural Gas	million m^3/day	114.6	131.9	198.9	17.3	15%	67.0	51%	84.3	74%
Diesel Oil	million m^3	43.8	52.2	54.9	8.5	19%	2.7	5%	11.1	25%
Fuel Oil	million m^3	11.5	12.2	11.0	0.7	6%	-1.1	-9%	-0.5	-4%
Gasoline	million m^3	23.9	25.1	25.4	1.2	5%	0.3	1%	1.6	7%
LPG	million m^3	10.5	13.3	15.1	2.8	27%	1.8	13%	4.6	44%
Kerosene	million m^3	6.4	6.7	7.2	0.3	5%	0.5	7%	0.8	12%
Ethanol	million m^3	35.1	37.7	46.1	2.6	7%	8.4	22%	11.0	31%
Electricity	TWh	649	794	942	145	22%	148	19%	293	45%

Table 22. Installed Capacity for Electricity Generation in the National Interconnected System

Source	2019	2024	2029	2019-2024		2024-2029		2019-2029	
		GW		Increment	%	Increment	%	Increment	%
Installed Capacity	176	204	251	28	16%	47	23%	61	44%
Hydroelectric power	108	110	114	3	2%	3	3%	6	6%
Thermal power	34	42	55	8	22%	13	31%	20	60%
Wind power	15	25	40	9	63%	15	61%	25	163%
Centralized Solar	2	6	11	3	158%	5	89%	8	387%
Nuclear	2	2	3	0	0%	1	71%	1	71%
Auto-production and DG	15	20	29	5	36%	10	48%	15	101%

Table 23. Electric Energy Transmission

ITEM	Unit	2019	2024	2029	2019-2024		2024-2029		2019-2029	
					Increment	%	Increment	%	Increment	%
Transmission Lines	km	147,632	186,214	203,417	38,582	26%	17,203	9%	55,785	38%
Substations	MVA	385,206	495,625	557,353	110,419	29%	61,728	12%	172,147	45%

Table 24. Natural Gas Transport

ITEM	Unit	2019	2024	2029	2019-2024		2024-2029		2019-2029	
					Increment	%	Increment	%	Increment	%
Gas pipelines	km	9,409	9,503	9,503	94	1%	0	0%	94	1%

Table 25. Summary of Estimates of Investments

TYPE	Billion R$ 2020–2029 period	%
Electric Energy Supply	456	19.6%
Centralized Generation	303	13.0%
Distributed Generation (microgeneration and mini generation)	50	2.1%
Transmission	104	4.4%
Oil and Natural Gas	1.805	77.4%
Exploration and Production of Oil and Natural Gas	1.736	74.4%
Supply of Petroleum Products	37	1.6%
Supply of Natural Gas	33	1.4%
Supply of Liquid Biofuels	71	3.0%
Ethanol - Production units and pipeline and port infrastructure	69	2.9%
Biodiesel – Production plants	2	0.1%
TOTAL	**2,332**	**100%**

Table 26. List of Hydroelectric Projects Made Available to PDE 2029

Earliest Date for Entry into Operation	HPP	Power (MW)	Basin	River	FU
2025	Apertados	139	Piquiri	Piquiri	PR
2025	Davinópolis	74	Piquiri	Piquiri	PR
2025	Ercilândia	87	Piquiri	Piquiri	PR
2025	Telêmaco Borba	118	Tibagi	Tibagi	PR
2026	Castanheira	140	Juruena	Arinos	MT
2026	Comissário	140	Piquiri	Piquiri	PR
2027	Tabajara	400	Ji-Paraná	Ji-Paraná	RO
2028	Bem Querer	650	Branco	Branco	RR
2028	Formoso	342	São Francisco	São Francisco	MG
After 2029	Buriti Queimado	142	Tocantins	Almas	GO
After 2029	Foz do Piquiri	93	Piquiri	Piquiri	PR
After 2029	Foz do Xaxim	63	Uruguai	Chapecó	SC
After 2029	Itaguaçu	92	Paranaíba	Claro	GO
After 2029	Itapiranga	724	Uruguai	Uruguai	SC/RS
After 2029	Jatobá	1.650	Tapajós	Tapajós	PA
After 2029	Maranhão	125	Tocantins	Maranhão	GO
After 2029	Mirador	80	Tocantins	Tocantizinho	GO
After 2029	Paranã	90	Tocantins	Paranã	TO
After 2029	Porteiras	86	Tocantins	Maranhão	GO
After 2029	Porto Galeano	81	Sucuriú	Sucuriú	MS
After 2029	Santo Antônio	84	Uruguai	Uruguai	SC/RS
After 2029	Saudade	61	Uruguai	Chapecó	SC
-	**Total**	**5,461**	-	-	-

Table 27. Summary of the Expansion Planned in PDE 2029

SOURCE OR ACTIVITY	PDE 2029 EXPANSION
HPP	- 1,914 MW (10 HPPs), in the North, Midwest and South regions of Brazil - Contracted: 240 MW (3 HPPs) and Indicative: 1,674 MW (7 HPPs). - Amazon Hydrographic Region (HR): 3 HPPs and 62% power, Paraná HR: 6 HPPs and 30% power and Uruguay HR: 1 HPP and 7% power .
SHPP	- 2,664 MW - Contracted: 564 MW (49 SHPPs) mainly in the South, Southeast and Midwest regions - Indicative: 2,100 MW in the S and SE/MW subsystems
Fossil termal power plants (NG, coal) and nuclear power plants	- 28,112 MW - Contracted: 7,114 MW - 6 NG HPPs (5,423 MW), 2 diesel HPPs (286 MW) and 1 nuclear power plant (1,405 MW) - Indicative: 20,997 MW (70% in the SE/MW, 25% in the S, and 5% in the NE subsystem)
Biomass thermal power plant	- 3,141 MW - Contracted: 584 MW, 68% of which is sugarcane bagasse. Forest waste plants, wood chips, elephant grass and biogas are also included - Indicative: - 1,860 MW 57% sugarcane bagasse; 32% wood chips and 11% biogas
Wind power	- 24,438 MW - Contracted: 3,438 MW (130 parks) in the Northeast - Indicative: 21,000 MW in the NE and S subsystems
Solar power	- 8,442 MW - Contracted: 1,442 MW (52 projects), 77% of which in the Northeast and 23% in the Southeast - Indicative: 7,000 MW in the NE and SE/MW subsystems
Transmission	- 48,998 km (33% of the system), in all regions of Brazil - 31,795 km (65%) are expected to start operating by 2024 - Socioenvironmental analysis of 412 TLs, 34,975 km extension - North (6,748 km), Northeast (9,824 km), Midwest (1,937 km), Southeast (7,551 km) and South (8,915 km)
Exploration and productio of oil and NG	- 276 PUs (production units in contracted areas) for exploration and production of oil and natural gas will start their production of conventional resources over the ten-year period, in addition to 23 UPUs (PUs in non-contracted areas that belong to the Union – Federal Government) - Onshore PUs in the North and Northeast regions. - Offshore PUs are concentrated in the Southeast, occurring also in the Northeast and South
Refineries, NGPPs and LNG Terminals	- 1 refinery (installation of the 2nd train) in the Northeast (PE) - 3 regasification terminals in the Northeast (SE), Southeast (RJ) and North (PA) - 2 NGPPs in the Southeast (RJ) and Northeast (BA)
Gas pipelines	- 1 transport gas pipeline in the Southeast (RJ)
Ethanol	- 34 billion liters (2020) to 47 billion liters (2029) - In the Midwest, 1 sugar cane unit (1.4 Mtc); 9 corn units and 4 flex units (2.6 billion liters) - Indicative: 13 sugar cane units (45 Mtc) and expansion of existing units (16 Mtc); 2G ethanol (760 million liters)
Biodiesel	- 6.9 billion liters (2020) to 11.4 billion liters (2029) - 8 units under construction (1.5 billion liters) and 9 expansions (0.8 billion liters) in all regions - Indicative: 2.4 billion liters
Auto-production and Distributed generation	- Auto-production: 5,456 MW (Thermoelectric power: 5,331 MW and Hydroelectric power: 125 MW) - Distributed generation: 10,016 MW (Photovoltaic power: 8,650 MW, MHPP: 838 MW, Thermoelectric power: 471 MW and Wind power: 57 MW)

Table 28. Energy Matrix Projection for 2029

CONSOLIDATED - 2029 (10^3tep)	PRIMARY ENERGY SOURCES										SECONDARY ENERGY SOURCES																
	OIL	NATURAL GAS	STEAM COAL	METALLURGICAL COAL	URANIUM U_3O_8	HYDRAULIC ENERGY	FIREWOOD	SUGAR CANE PRODUCTS	OTHER PRIMARY SOURCES	TOTAL PRIMARY ENRGY	DIESEL OIL	FUEL OIL	GASOLINE	LPG	NAPHTHA	KEROSENE	GAS COKE	MINERAL COAL COKE	URANIUM CONTAINED IN UO_2	ELECTRICITY	CHARCOAL	ANHYDROUS AND HYDRATED ETHANOL	OTHER SECONDARY FROM OIL	NON-ENERGY PETROLEUM PRODUCTS	TAR	TOTAL SECONDARY ENERGY	TOTAL
PRODUCTION	286,568	72,055	949	0	6,959	45,565	28,311	65,514	45,603	515,706	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	551,525
IMPORT	5,198	5,479	6,120	10,141	0	0	0	0	475	37,657	12.147	0	3,908	1,115	3,992	2,241	0	1,194	0	1,330	0	267	1,935	849	0	28,978	56,391
STOCK VARIATIONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL SUPPLY	291,766	77,534	7,069	10,141	6,959	45,565	28,311	65,514	46,078	553,362	12.147	0	3,908	1,115	3,992	2,241	0	1,194	0	1,330	0	267	1,935	849	0	28,978	607,916
EXPORT	-183,149	0	0	0	0	0	0	0	-35	-165,749	-1.319	-7,248	0	0	0	-3,450	0	0	0	0	0	-1,062	-464	0	0	-13,543	-196,728
NON-UTILIZED	0	-2,567	0	0	0	0	0	0	0	-2,384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2,567
REINJECTION	0	-28,126	0	0	0	0	0	0	0	-28,126	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-28,126
GROSS DOMESTIC SUPPLY	108,617	46,842	7,069	10,141	6,959	45,565	28,311	65,514	46,042	365,061	10.828	-7,248	3,908	1,115	3,992	-1,209	0	1,194	0	1,330	0	-795	1,471	849	0	15,435	380,496
TOTAL PROCESSING	-108,617	-20,279	-2,301	-10,141	-6,959	-45,565	-10,314	-30,306	-34,747	-269,230	53.298	10,190	20,293	9,217	2,744	5,885	1,703	8,294	0	79,707	4,722	23,788	10,867	6,669	303	237,678	-31,552
OIL REFINERIES	-108,617	0	0	0	0	0	0	0	-1,450	-110,067	46.559	10,536	19,591	4,742	5,857	5,885	0	0	0	0	0	0	10,002	6,113	0	109,284	-783
NATURAL GAS PLANTS	0	-8,125	0	0	0	0	0	0	988	-7,137	0	0	0	4,359	0	0	0	0	0	0	0	0	0	556	0	4,915	-2,222
GASIFICATION PLANTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COKE PLANTS	0	0	0	-10,141	0	0	0	0	0	-10,141	0	0	0	0	0	0	2,171	8,294	0	0	0	0	-1,089	0	309	9,685	-456
NUCLEAR FUEL CYCLE	0	0	0	0	-6,959	0	0	0	0	-6,959	0	0	0	0	0	0	0	0	6,855	0	0	0	0	0	0	6,855	-104
UTILITY POWER PLANTS	0	-6,761	-2,071	0	0	-44,970	-1,164	-5,634	-15,371	-75,971	-1.871	0	0	0	0	0	0	0	-6,855	70,722	0	0	0	0	0	61,996	-13,975
AUTOPRODUCING POWER PLANTS	0	-4,931	-230	0	0	-595	-291	-3,211	-7,580	-16,838	-417	-346	0	0	0	0	-468	0	0	8,985	0	0	-549	0	-6	7,198	-9,640
CHARCOAL KILNS	0	0	0	0	0	0	-8,859	0	0	-8,859	0	0	0	0	0	0	0	0	0	0	4,722	0	0	0	0	4,722	-4,137
DISTILLERIES	0	0	0	0	0	0	0	-21,461	0	-21,461	0	0	0	0	0	0	0	0	0	0	0	21,313	0	0	0	21,313	-148
OTHER PROCESSING	0	-462	0	0	0	0	0	0	-11,335	-11,797	9.028	0	703	116	-3,113	0	0	0	0	0	0	2,475	2,503	0	0	11,711	-86
LOSSES INDISTRIBUTION AND STORAGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-12,814	0	0	0	0	0	-12,814	-12,814
FINAL CONSUMPTION	0	26,563	4,768	0	0	0	17,997	35,208	11,295	95,831	64.126	2,941	24,201	10,332	6,736	4,676	1,703	9,487	0	68,223	4,722	22,992	12,338	7,518	303	240,299	336,130
FINAL NON-ENERGY NON-CONSUMPTION	0	2,371	0	0	0	0	0	0	0	2,371	0	0	0	0	6,736	2	0	0	0	0	0	603	276	7,518	189	15,324	17,694
FINAL ENERGY CONSUMPTION	0	24,192	4,768	0	0	0	17,997	35,208	11,295	93,460	64.126	2,941	24,201	10,332	0	4,674	1,703	9,487	0	68,223	4,722	22,390	12,061	0	114	224,976	318,436
ENERGY SECTOR	0	10,504	0	0	0	0	0	16,020	0	26,525	1.531	197	0	0	0	0	175	0	0	5,983	0	0	3,466	0	0	11,352	37,877
RESIDENTIAL	0	656	0	0	0	0	4,795	0	0	5,451	0	0	0	7,999	0	0	0	0	0	17,805	288	0	0	0	0	26,092	31,543
COMMERCIAL	0	422	0	0	0	0	92	0	0	514	25	33	0	485	0	0	0	0	0	11,681	87	0	0	0	0	12,311	12,825
PUBLIC	0	0	0	0	0	0	0	0	0	0	2	15	0	319	0	0	0	0	0	5,383	0	0	0	0	0	5,719	5,719
AGRICULTURAL	0	0	0	0	0	0	3,040	0	0	3,040	5.799	15	0	25	0	0	0	0	0	3,437	10	8	0	0	0	92,94	12,334
TRANSPORT	0	2,220	0	0	0	0	0	0	47	2,267	55.186	1,230	24,201	0	0	4,673	0	0	0	277	0	22,382	0	0	0	107,950	110,217
INDUSTRIAL	0	10,389	4,768	0	0	0	10,070	19,188	11,249	55,664	1.582	1,452	0	1,506	0	1	1,528	9,487	0	23,657	4,336	0	8,595	0	114	52,258	107,922