PDE 2027

The Ten-Year Energy Expansion Plan 2027

Executive Summary

Empresa de Pesquisa Energética

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 BioFuels (SPG), both at Ministry of Mines and Energy (MME).

The PDE main objective is to indicate (and not exactly to determine) the perspectives of the expansion of the energy industry in the horizon up to 2027, from the government's point of view.

Based on an integrated view of the various energy sources, and taking into account the uncertainties associated with a prospective exercise, the PDE is elaborated using the best available information, bringing benefits such as increased reliability, lower production costs, and sustainable development.

By showing how our studies envision the development of the Brazilian energy system under different conditions of its evolution, the PDE provides important signals to guide the actions and decisions of the agents. As a result, it enables the necessary expansion of energy supply at the least possible cost, on a technically and environmentally sustainable basis.

This Executive Summary presents a condensed version of the main analyses conducted in the PDE 2027, regarding the evolution of: the energy demand, the energy efficiency and the distributed generation, the centralized power generation, the power transmission, the production of oil and natural gas, the supply of oil products, the supply of natural gas and biofuels and the social and environmental analysis.

Prepared between February and September, 2018, the full version of the document (with additional material such as data, graphs, figures, methodological notes, among others) is available on the EPE's website: (http://www.epe.gov.br)

We would like to thank APEX Brasil (https://portal.apexbrasil.com.br/) for providing a first translation of this Executive Summary of the PDE 2027. The final version was revised by Emilio H. Matsumura and Pedro A.M. David.

Economic Assumptions

Brazil's per capita GDP is expected to grow 2.2% per year on average from 2018 to 2027, reflecting a growth rate of 2.8% per year for GDP and 0.6% per year for the Brazilian population.

Over the period, a more sustained growth is possible taking into account that economic reforms, even if partial, will be conducted, aiming at improving the business environment and increasing the investment (which is expected to grow to a level of 21.5% of GDP in the last 5-year horizon), thus improving the overall productivity of the economy in the horizon.

There is considerable uncertainty in the forecast of GDP growth, in particular, on its potential growth. Although a cyclical recovery in the short term is possible due to the effects of the reduction in the short-term interest rates (SELIC) and the high level of idleness in the economy, a higher sustained growth would depend on addressing complex structural problems. In this case, the cumulative GDP growth could reach 39% in the 10-year period, 7 p.p. higher than in the reference trajectory (Table 1).

Table 1. GDP economic growth trajectories

Trajectory	Average GDP Growth Rate (% p.y.)		
	2017-2022	2022-2027	2017-2027
Reference	2.7	3.0	2.8
Alternative	3.2	3.5	3.3

In terms of sectors, economic recovery is expected to boost the sectors that are more associated with domestic demand (services, manufacturing industry, and construction) from 2019, while the primary exporting sectors (agriculture and extraction industry) should have a good performance throughout the period.

Energy Consumption

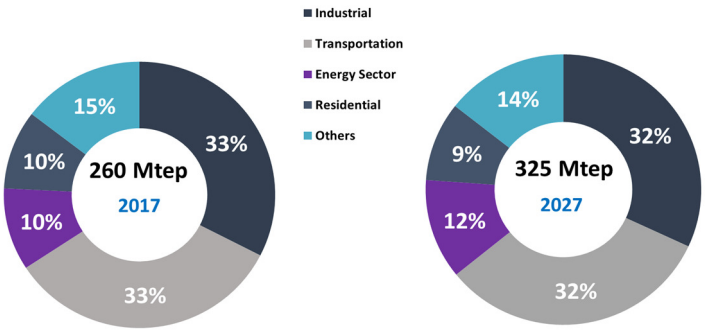
The final energy consumption is expected to grow at an average rate of 2.3% per year up to 2027 (Table 2). The per capita final energy consumption rises 18% in the period, reaching about 1.5 toe per capita by the end of 2027. Energy intensity is reduced in the period, due to energy efficiency and a change in energy consumption towards less energy-intensive sectors.

Table 2. Final energy consumption indicators

Indicator	Year		
	2017	2022	2027
Final Energy Consumption (million toe)	260	286	325
Final consumption of energy per capita (toe/inhab./year)	1,25	1,33	1,47
Energy Intensity of Economics (tep/thousand R$)	0,040	0,038	0,037

In the analysis by sector (Figure 1), the industry and the transportation sector represent almost 2/3 of the final energy consumption throughout the period. The energy sector (energy production) increases its share on final consumption, influenced mainly by the larger production in the pre-salt layer and sugar cane ethanol.

Figure 1 - Final energy consumption evolution by sector



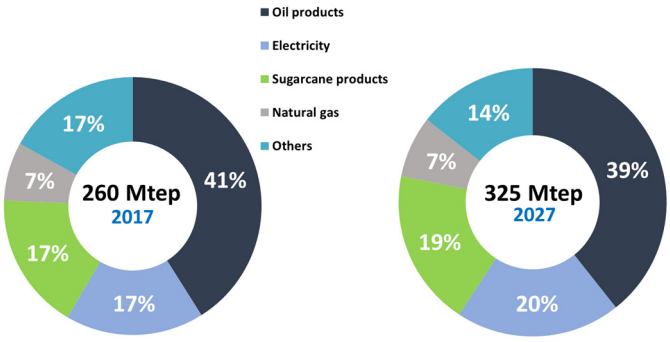
In the total energy demand of the transportation sector, the highlight is the growing share of hydrous ethanol and biodiesel. The national fleet of light-duty vehicles (LDV) will remain essentially flex fuel, with a small share of hybrid and electric vehicles at the end of the horizon (less than 2%).

As for the industrial consumption, the segment of paper and pulp, and the one comprising pig iron and steel are expected to become relatively more important in the 10-year period, to the detriment of the chemicals and food and beverage segments. Electricity and black liquor obtained in the pulp production process (widely used for self-production of electricity) are expected to increase their share in the industry energy consumption.

As for the residential sector, the air conditioning will be the main responsible for electricity consumption in households. The share of traditional light bulbs will show the highest reduction in total consumption, as it is replaced by LED technology.

In the analysis by source (Figure 2), the country's trend of increasing electrification is maintained. Natural gas, sugar cane derivatives and biodiesel also gain importance over the period. Crude oil products remain as the main final source of energy, although part of its potential market is reduced by ethanol and biodiesel, especially in the transportation sector.

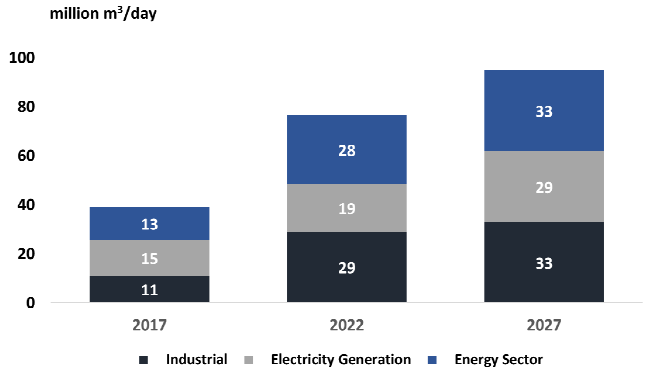
Figure 2 Final energy consumption evolution by source



As for natural gas consumption (Figure 3), its reduction is associated with the larger electricity generation expected for the last 5 years of the horizon, in relation to the values observed in 2018. This is related to the expected improved hydrological conditions observed recently and the start of full operation of large hydropower projects built in recent years.

The disinvestment program of Petrobras represents a great opportunity for new agents to enter the industry. If the barriers to the natural gas market are properly addressed, there is a promising prospect for natural gas in the energy mix.

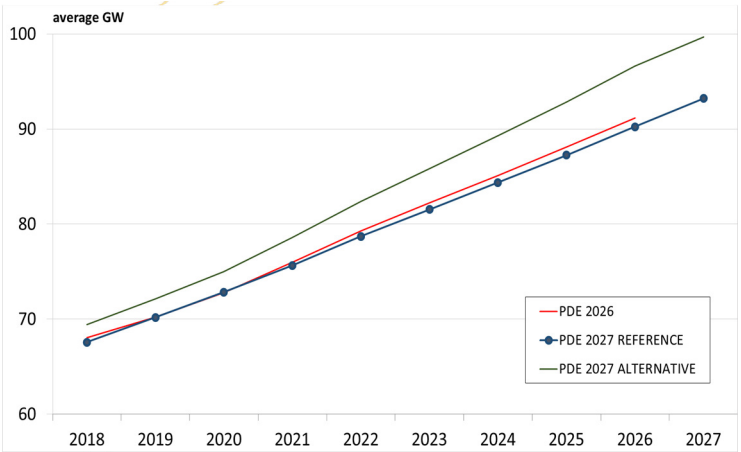
Figure 3 Final natural gas consumption evolution



Total electricity consumption is expected to grow about 28% above the average of Brazilian economy in the 10-year period. Industrial consumption from the grid grows below the average, with an improvement in the second five-year span. The number of residential consumers reaches the total of 84 million in 2027, for an average residential consumption in the range of 200 kWh/month.

The load estimate for the PDE 2027 is quite similar to that of the PDE 2026 forecast (Figure 4), being 1,000 averageMW below the reference line in 2026 (5,500 averageMW above the PDE 2028 in the faster-growth trajectory).

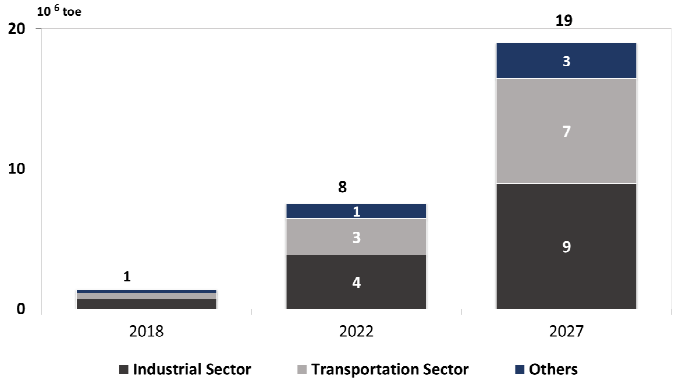
Figure 4: Load Evolution



Energy Efficiency

In 2027, energy efficiency will reach 19 million toe, which represents 8% of Brazil's final energy consumption in 2017 (Figure 5).

Figure 5. Total conserved energy



The saved electricity consumption (41 TWh) will correspond to the generation of a hydropower plant (HPP) with installed capacity of about 10 GW, equivalent to the sum of the Brazilian part of Itaipu HPP and Xingó HPP.

The saved fuel volume (318,000 barrels per day) will correspond to 11% of the oil produced in the country in 2017.

In the industry, the saved energy will represent 6% of the final energy demand forecast in 2027. Saved electricity will represent 5.6%, equivalent to the current consumption of the pig iron and steel industry.

In the transportation sector, due to technological improvements of LDV engines and prioritization of public transportation sector in exclusive lanes, among other factors, energy efficiency reaches gains around 6% in 2027.

In the residential sector, the saved electricity is estimated at 4% of total consumption. Increased income, above what is expected, would lead to larger sales of new, more efficient equipment and higher energy saving rates, *ceteris paribus*.

Distributed Generation (DG)

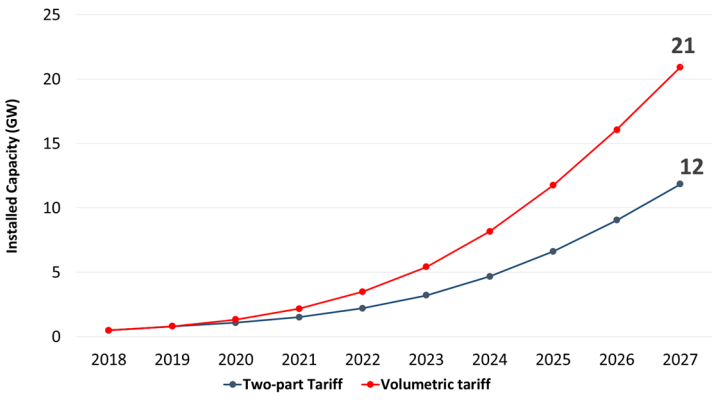
If the current regulatory conditions are maintained (full compensation system and 100% volumetric tariffs), the installed capacity of 21 GW from microgenerators and minigenerators can be reached in 2027.

As the current tariff imbalances are not sustainable in the long-run, the reference expansion (Figure 6) considers the application of binomial tariff from 2020 onwards for new microgenerators and minigenerators. It is estimated that there will be 1.35 million adopters in 2027, amounting to 12 GW installed and which will require R$ 60 billion in investments. The generators should contribute with 2,400 average MW at the end of the 10-year period, meeting 2.4% of the total national load.

Among the generation technologies, the photovoltaic technology is the most representative, with 82% of the installed capacity and 55% of the generated energy.

Other sources, such as biomass, and wind energy and CGHs (mini HPPs) should gain space mainly through models of remote self-consumption and shared generation, as they may have lower costs than the photovoltaic technology.

Figure 6. Distributed Generation Evolution



Centralized Electricity Generation

The power generation expansion planning is done with the aid of the Investment Decision Model (IDM), which minimizes the expansion (investment plus operation) cost, subject to meet the maximum power demand and the average power consumption, in addition to traditional capacity criteria.

The IDM represents the system operation by a number of production scenarios, yielded from the Hydrothermal Power System Operation Model, which considers the hydrological uncertainty. The choice of scenarios is done iteratively, until the Expansion Marginal Cost, calculated by the IDM model, "equals" the Operation Marginal Cost, calculated by the Hydrothermal System Operation Model.

Besides the economic (least cost) criterion, the expansion plan is also adjusted to not exceed the energy and power deficit risk levels, set by National Council for Energy Policy (CNPE).

The main innovation of the IDM version used in the PDE 2027 is the representation of the load by the traditional load duration curve, discretized into four average load levels plus one peak demand. The peak demand constraint allows the IDM to value the power generation flexibility and energy storage capacity features, which are very important for the operation of the system with higher penetration of wind and solar generation.

GUIDELINES AND ASSUMPTIONS

Main assumptions:

- The system operation objective function considers a convex combination of expected operation cost value and the average value of the 50% higher costs;
- Power supply from the Itaipu HPP to Paraguay System is the one defined on Monthly Energy Operation Program (PMO) values from May 2018 to 2022, growing at 5% per year after 2023;
- The energy deficit cost equals R$ 4,596/MWh;
- The real discount rate is 8% per year;
- The initial operation dates of newly added generation follows the updated schedule acknowledged by the Power System Monitoring Department (DMSE) of the MME.
- The following assumptions were considered for the stalled ("no starting date forecast") projects:
  - Angra 3 NPP: commercial operation in January 2026;
  - São Roque HPP: commercial operation in July 2023;
  - ABENGOA projects: the flow capacity of the power trunks limits considers the result of the 2017 public tender, coming into commercial operation in March 2023;

Energy Policy Guidelines

It was considered a constant annual expansion of:

- Wind power up to 2,000 MW, divided between Northeast (80%) and South (20%) regions, from 2023 on;
- Centralized solar photovoltaic (PV) power, between 1,000MW to 2,000 MW, from 2023 on;
- Cane bagasse biomass, between 450 MW and 500 MW, with null variable cost from 2023 on;
- Forest biomass thermal power plants, between 50MW to 100 MW, from 2024 on, following forest management plans;
- Biogas fueled thermal power, up to 30 MW, from 2023 on;

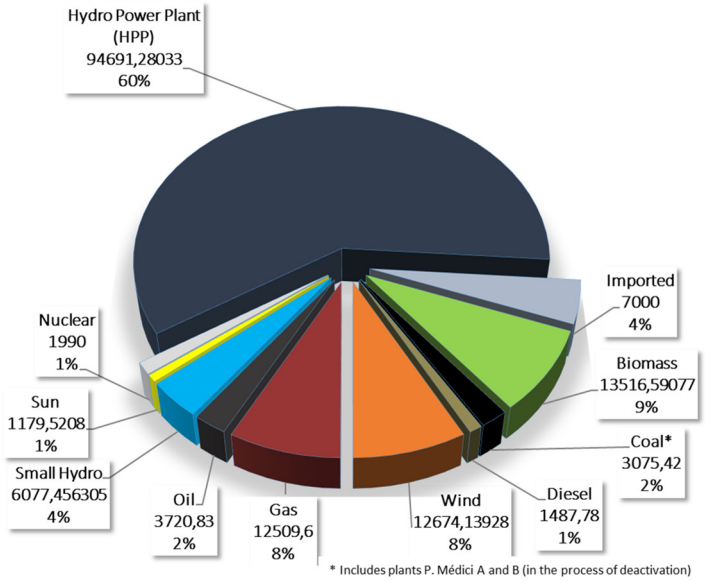
The following additional guidelines were also included:

- Maximum expansion for Small Hydro Power (SMP) Plants: up to 350 MW in 2023 and 2024; up to 450 MW between 2025 and 2027, and up to 600 MW afterwards;
- Indication of Tabajara HPP in 2025 and Castanheira in 2027, due to the advanced stage of the studies for their respective development.

INITIAL CONFIGURATION

In May 2018, the National Interconnected System (SIN) had an installed capacity of about 158 GW (Figure 7).

Figure 7. Installed capacity in May 2018



The expansion already committed in PPAs until 2018 and starting operation between 2018 and 2028 is presented in Table 3.

Table 3. Expansion contracted until 2018

Sources	Annual increment (MW)									
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Biomass + Biogas	81	0	55	129	82	177	0	0	0	0
Wind power	950	1,327	118	102	179	1,322	0	0	0	0
HPP	1,933	1,563	3,667	0	62	142	0	0	0	0
PCH+CGH	168	115	193	162	37	67	0	0	0	0
PV power	588	428	62	574	807	0	0	0	0	0
Thermal power	28	746	1,802	1,305	0	2,139	0	0	1,405	0

REFERENCE EXPANSION

The Energy Supply Expansion Marginal Cost (CME), calculated by the IDM, is R$ 234/MWh. The indicative expansion, showed in Table 4, would require an investment of about R$ 156 billion, from 2022 to 2027 for the supply of load in the regulated and free environments.

Table 4. Indicative Cumulative Expansion

Sources	2022	2023	2024	2025	2026	2027
	MW					
OC TPP + Storage Technology	204	1,305	3,997	7,762	7,762	13,142
Biomass + Biogas	0	480	1,010	1,540	2,070	2,600
Wind Power	0	2,000	4,000	6,000	8,000	10,000
HPP	0	0	118	674	1,034	1,351
PCH + CGH	0	350	700	1,150	1,600	2,050
PV power	0	1,000	2,000	3,000	4,000	5,000
Thermal power	0	0	3,454	3,972	3,972	5,124

The HPPs considered for the indicative capacity expansion are shown in Table 5.

Table 5. Indicative HPP Expansion

Name	Total Installed Capacity (MW)	Estimated minimum date for start operation
Telêmaco Borba	118	2024
Apertados	139	2025
Itaocara I	150	2025
Tabajara	400	2025
Ercilândia	87	2026
Comissário	140	2026
Bem Querer	650	2027
Castanheira	140	2027

The methodology for the Small Hydropower Plants (SHP) as candidates for expansion was improved in the PDE 2027. This approach enabled identifying the South, Southeast and Midwest subsystems as holders of 92% of the available Brazilian potential for SHP. A total of 136 projects were considered.

Considering the supply of sugar cane bagasse, biogas (both with null variable cost) and forest residues, the total expansion of biomass is expected to be 2,600 MW for the 10-year period, in the SE+MidW subsystem.

The share of wind energy source will increase to 12% of the total installed capacity in 2027. Together with the solar PV technology, which has 5,000 MW of additional indicative expansion, they will keep the renewable profile of the Brazilian power system and also contribute to the prospect of lower operating costs in the future.

The massive expansion of wind power, together with the hydrological conditions of São Francisco River basin, may yield a larger share of the wind power expansion to be located in the Northeast region to cope for the variability of wind energy. The resulting consequences for the operation of the regional power system will require further integrated generation and transmission studies.

Combined-cycle thermal power plants will have an expansion of almost 5,000 MW, from 2024 onwards.

The need of additional power capacity to cope with net peak load appears from 2022 onwards, totaling about 13,200 MW in 2027, which could be provided, for example, by storage technologies and TPPs. However, the implementation of hourly energy prices in the spot market may lead to reductions in this net peak load, mostly in the second half of the 10-year period.

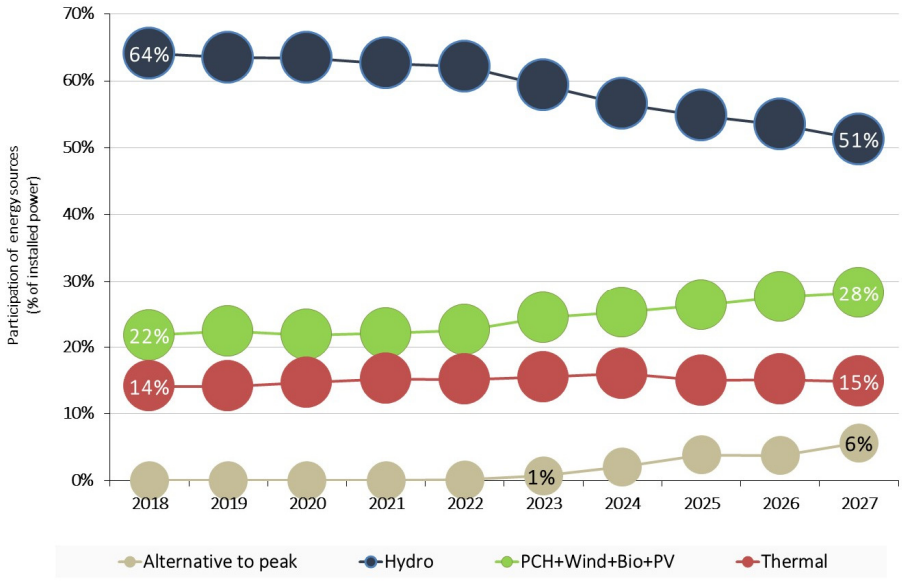
Furthermore, the IDM did not indicate any expansion of the transmission trunks capacity in addition to the already committed expansion. However, one shall bear in mind that this analysis is very coarse, since it considers only the average capacity of equivalent trunks between subsystems, not the actual transmission network.

The evolution of the installed capacity in the 10-year period is shown on Table 6 and the share of each source, in relation to the total installed capacity, is depicted on Figure 8.

Table 6. Evolution of the Installed Capacity

Source	2017	2022	2027
		MW	
Renewable Sources	125,861	141,463	164,171
Hydro	93,555	101,916	103,410
Other Renewable Sources	32,305	39,547	60,762
PCH and CGH	5,985	6,751	8,868
Wind Power	12,325	15,351	26,672
Biomass + Biogas	13,517	13,806	16,583
Centralized Solar Energy	479	3,639	8,639
Non-Renewable Sources	22,784	26,559	31,980
Uranium	1,990	1,990	3,395
Natural Gas	12,510	15,759	23,021
Coal	3,075	3,420	3,420
Fuel Oil	3,721	3,696	1,368
Diesel Oil	1,488	1,694	776
Indicative Peak Alternative	-	204	13,142
Total	148,644	168,227	209,294
ITAIPU 50Hz	7,000	7,000	7,000
Total Available	155,644	175,227	216,294

Figura 8. Evolution of the electricity mix



Notice that despite the hydroelectricity's share reduction, the system keeps the predominance of renewable and non-greenhouse gases emitting sources, amounting up to 80% of total capacity.

Regarding the expected generation, the system operation's simulations indicate a share of TPP about 9% of supplied energy. This generation results in GHG emission values of 39 million tons of equivalent CO_2 in 2027, which is lower than what has occurred in recent years.

The trend of increasingly low water storage level at the end of each year shows that TPP generation is required to keep reservoirs at safe levels and to protect the system against possible delays of wet season or even a dry year. To enhance the thermal power competitiveness, it is being proposed to allow seasonal operation inflexibility instead of a flat one throughout the year, removing the compulsory generation in the wet season.

In the beginning of the planning horizon, the required power to cope with peak demand is performed by the existing and already committed additional thermal power plants. However, that set of power plants do not have the required characteristics (flexibility) to comply with peak demand, thus it will be required to have operational measures that will increase the cost of operation. Later, part of the peak demand will be supplied by the added power resources that have the required characteristics. The expected value of additional supply should happen throughout the year, but the larger one will be needed from September to April (the wet season).

The large expected spilled water (hydropower capacity larger than the load) signals the opportunity to promote operational flexibility. Additionally, sources that also add energy to the system, such as quick-start thermal power plants, may contribute to serve the peak demand and also to recover reservoir levels in months of lower storage (September to December).

Other important issues for the capacity expansion in the horizon are: the implementation of the price system, demand response and the availability of natural gas.

The implementation of price signal mechanisms that properly values the peak demand will incite generators to increase their production at those moments. In this context, sources such as SHP, CGHs and biomass may have a competitive edge due to their energy and power supply capacities and flexibility and get a larger share of the expansion than indicated in the plan.

Demand response (DR) shall be mentioned as a resource to reduce peak demand, shave the load curve and even to de-stress the system in dry

periods. DR is one of the main active contribution of consumers to the electricity system.

The availability of natural gas and its transport and distribution infrastructure capacity is a key issue for the energy supply and also to provide operating flexibility.

Finally, the HPPs still represent an important drive for the expansion of power supply. Most of the unexplored potential is located in the North region, which has a number of challenges to overcome, mainly environmental, for its use. The trade-off between operation security, historically provided by the HPP's reservoirs, versus the environmental constraints for the deployment of new HPPs and greenhouse gas emissions by TPPs are issues that has to be addressed by the society.

WHAT-IF ANALYSIS

1. ALTERNATIVE DEMAND SCENARIO

Considering a load growth average rate of 3.9% per year, the energy load would be about 2,600 average MW higher in 2027 than in the reference scenario. This is equivalent to the anticipation of one year at the end of the 10-year period.

To cope with that load increase, the following assumptions were changed in relation to the reference case:

- Upper limit for the wind step of 2.500 MW per year;
- Upper limit for the solar PV step of 3,000 MW per year;
- Upper limit for the biomass step of 600 MW per year;
- Upper limit for SHP as follows: 400 MW/year in 2023 and 2024; 500 MW/year between 2025 and 2027 and maintained 600 MW/year after the 10-year horizon.

The resulting expansion leads to an increase in the installed capacity of the SIN of about 7,000 MW at the end of the 10-year period, with an estimated additional investments in generation of about R$ 26 billion in the period from 2020 to 2026, for the indicative expansion.

Wind power supply will make a large share of the additional expansion, expanding the indication to 2,500 MW per year in the period from 2023 to 2027. In the same period, the development of SHP is expanded to 250 MW and sugar cane biomass is expanded to 750 MW.

Even for a larger demand, the expansion of centralized solar PV power remained at 1,000 MW per year, indicating that, at the forecasted costs, this option still does not seem to be economically attractive for the system.

The IDM also added more 1,300 MW of combined-cycle thermal power plants and 2,200 MW of open-cycle thermal power plant.

Due to the restricted HPP supply offer, this case presented the indication of the same plants, but it has anticipated Ercilândia HPP by one year, to 2024.

2. RESTRICTION TO THE EXPASION OF NATURAL GAS (NG)

To analyze the impacts of a reduced availability of natural gas supply, the following assumptions were changed with respect to the reference case:

- Allowed for the expansion of coal up to 1,500 MW, between 2024 and 2027;
- Upper limit of the wind power supply up to 2,500 MW per year, maintaining the indication of a uniform expansion divided between Northeast (80%) and South (20%) regions from 2023.

Two cases were considered.

In the first case, limiting the expansion of natural gas to 7,000 MW until 2027, so that its relative share in the installed capacity of the SIN in 2027 is equivalent to that of 2018. The IDM decided to use all available natural gas, distributing the 7,000 MW between the open-cycle technology (4,300 MW) and the combined-cycle technology (2,700 MW). The reduction of approximately 2,500 MW of combined cycle was compensated by an increase of

1,500 MW of coal power and 800 MW of wind power. On the other hand, the reduction of approximately 7,900 MW of open-cycle thermal power plants was compensated by an increase of 6,000 MW of power storage technologies.

In the second case, the development of the open-cycle TPP was constrained to 5,200 MW until 2027. This new restriction forced a reduction of approximately 7,000 MW in the expansion of open-cycle TPP, replaced by an increase of 6,300 MW of power storage technologies.

Once again, the IDM decided for the expansion of coal-fired TPPs to what was available, 1,500 MW until 2027. There was a reduction of 950 MW of combined-cycle NG power plants and of just under 900 MW of wind power plants.

In both cases the IDM has answered by changing technologies with the same characteristics, thereby not changing the way the system would be served.

It is worth noting the importance that storage technologies may have to the system, especially if an expansion of NG TPPs is not viable in the amount necessary to meet the capacity requirements of the system. However, several aspects still have to be improved for the inclusion of these technologies in the expansion candidate set.

Another important conclusion is the discussion that must be conducted regarding the share of coal in the power supply. From an economic point of view, this sensibility analysis showed that coal may be an alternative to the natural gas. Positive aspects, such as employment and development for the local economy in the South region of Brazil, and negative aspects, such as GHG emissions should be considered, along with the gains for energy supply security and the economic viability.

3. EXPANSION CONSIDERING THE UTILIZATION OF PRE-SALT RESERVES OF NATURAL GAS

The exploration of the pre-salt layer reserves means an option to use the national resource, thus reducing the risk associated with the fluctuations of the international price. In addition, the use of TPP flexibility with low operating costs using NG from the pre-salt layer reserves may change the system operation, especially regarding the reservoirs.

Two cases were prepared considering the pre-salt TPP with the following characteristics:

- Minimum feasible date for 2025;
- Minimum generation of 80% of the installed capacity along the year;
- Operating cost of 140 R$/MWh, annually adjusted annually by the IPCA.

In the first case, low operating cost TPPs are available as candidate for expansion.

The IDM decided to reduce by 2,100 MW approximately the expansion of combined-cycle LNG thermal power, and add 3,300 MW of pre-salt TPP. The larger expansion of TPP with a lower operating cost adds more energy to the system and a higher degree of inflexibility. The IDM also reduced the wind power expansion by, approximately, 2,000 MW in the 10-year period; and reduced 1,100 MW of open cycle TPP that was added to serve peak load.

By injecting more energy into the system, the pre-salt low operating cost TPP increases the attractiveness of power storage technologies, although only 160 MW of those technologies was added, it is important to explore this indication.

Second case: not allowing the addition of open-cycle TPP.

The addition of pre-salt's NG fueled TPP was practically equal to the previous case, that is, of 3,300 MW. To offset the removal of 12,000 MW of open-cycle TPPs, for load peaking service, IDM indicated more than 6,700 MW of power storage technologies and more than 2,100 MW of flexible combined-cycle TPPs. Finally wind power plants total had a 3,000 MW reduction.

The first conclusion on this sensibility analysis is that inflexible TPPs, due to having, in general, lower variable operating cost than the flexible technologies, are good for the system, but the amount depends on the operating cost. Studied

cases has shown that pre-salt's NG fueled TPPs replaced part of the flexible supply, but not all of it. The level of attractiveness of the low operating cost TPP is related to the fuel prices for flexible and inflexible operation, the larger the difference, the more attractive is the expansion with the inflexible option.

To evaluate the effect of this competitiveness, the operating cost of the pre-salt's NG TPPs was changed from 140 R$/MWh to 249 R$/MWh, in constant prices. At this new level of operating cost, the inflexible TPP option is no longer attractive for expansion, and the model chose again for the fully flexible option.

Another important point is the impact that this option on the reservoirs operation. If, on the one hand, inflexibility tends to increase the water spilling, on the other hand, by preserving the water storage, they ensure the availability of power in the HPP.

4. EVALUATION OF SOLAR PV TECHNOLOGY

Due to the uncertainties regarding the load curve in the future, the reference case does not consider the contribution of PV generation to serve the peak load. In some months the peak load occurs in the afternoon, where the PV contribution would be high. However, in other months, the peak load occurs in early evening, when PV generation is almost null. Nowadays, the load forecasting studies estimates only the maximum and average values, not assessing possible changes that may affect the load curve.

In this sensibility analysis, we have considered the PV contribution to serve the peak load, the least 5% (P95) percentile of PV estimated production upon the peak demand time in 2015. The PV production estimate considered solar irradiation data for 11 years in chosen spots in Northeast and Southeast/ Midwest subsystems. It was found that the PV contribution to serve the peak load is null from May to August, when the peak load has occurred, mostly at night.

When the PV contribution to serve the peak load is considered, it reduces the expansion of other generation by 3,350 MW. However, the added PV did not changed from the reference expansion.

This result suggests that the assumption adopted for the reference expansion gives more security to the system without reducing the competitiveness of PV generation. We can also conclude that, that even if we consider that the current behavior of the load curve is maintained over the 10-year period, the required additional power generation to serve the peak load will be about 9,500 MW.

It is worth mentioning that a significant portion of the reduction of required additional power (about 1,300 MW) to serve peak load occurs in 2022–2023. On the other hand, due to the uncertainty inherent to planning, it is recommended to procure the indicated power amount in the first years.

Also, as a final case we have considered a 40% reduction on PV investment costs to approximately R$ 2,400/kW, besides considering the mentioned PV contribution to serve the peak load. In this case, the PV would become competitive against other options and the expansion to the reference market reaches 3,000 MW per year, which was the upper limit. This larger penetration of solar power mainly replaces part of the expansion of wind power and reduces the need of additional power to serve peak load.

POWER TRANSMISSION

The Power Transmission studies take into consideration the indicative nature of the generation expansion and the current contractual deadlines for deployment of transmission facilities (it may be of up to 60 months).

Thus, in addition to providing flexibility to accommodate different strategies to deploy the generation sources contracted in the auctions of energy, studies for planning the expansion of interconnections adopt a differentiated approach, seeking alternative solutions that result in minimum regret and, at the same time, can add attributes of controllability, reliability and safety to the system.

The EPE has conducted a proactive planning for the expansion of transmission through the development of prospective studies that aim to anticipate the transmission system for integration of the potential of the new renewable sources (e.g., wind and solar) based on the registrations for the power auctions (which is conducted by the EPE).

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 the 10 following prospective studies with influence on the connection of renewables: (i) a study aimed at allowing the marketing of the wind power potential of the southern region of the country; (ii) seven studies aiming at providing the system with capacity to market the various generation potential of the Northeast and North regions; and (iii) two prospective studies focused on marketing the PV generation potential of the North and Northwest regions of Minas Gerais, as well as of the northwest region of the state of São Paulo.

With respect to the potential for renewable generation in the Northeast region, the PDE 2027 maintains the forecast of a significant share of wind and solar power sources in that region. This amount already exceeds that considered in the assumptions of the previous transmission study, developed in 2014, which resulted in the expansion of the Northeast–Southeast/Midwest interconnection. Therefore, new prospective studies are conducted with focus on interconnections, in order to determine the need for further expansions, in addition to those already scheduled for deployment until 2023.

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

Methodological improvements and advanced mathematical tools used in the integrated planning of generation and transmission expansion should be sought to represent the new technologies more adequately. This issue involves not only the modeling of intermittent renewable sources, such as wind and PV power, but also of Smart Grids (SG) and Distributed Generation (DG).

Total investments are expected to reach about R$ 108 billion, with R$ 73 billion in transmission lines and R$ 35 billion in substations, including frontier facilities. Considering only the new installations of transmission lines and substations, the estimated total value is about R$ 38 billion, with about R$ 21 billion in transmission lines and approximately R$ 17 billion in substations, including frontier facilities. Of these R$ 38 billion, the approximate amount of R$ 24 billion corresponds to projects already recommended in planning studies, and the rest, about R$ 14 billion, corresponding to indicative expansion, which are those associated with the planning studies in progress or to be started, matched based on the historical average of the physical and investments evolution of the transmission facilities.

Table 7. Expansion of Transmission Lines

Voltage	±800 kV	750 kV	±600 kV	500 kV	440 kV	345 kV	230 kV	TOTAL
	km							
Existing in 2017	4,600	2,683	12,816	47,688	6,748	10,320	56,722	141,576
2018-2027 evolution	7,798	0	0	28,516	248	1,513	17,165	55,240
2018-2022 evolution	4,878	0	0	16,221	166	761	8,611	30,637
2023-2027 evolution	2,920	0	0	12,295	82	752	8,554	24,604
Estimate in 2027	12,398	2,683	12,816	76,204	6,996	11,832	73,887	196,816

Table 8. Expansion of Substations

Voltage	750kV	500kV	440kV	345kV	230kV	TOTAL
	MVA					
Existeing in 2016	23,247	142,808	26,352	51,195	89,665	333,267
2018-2027 evolution	1,650	109,650	12,924	25,339	49,615	199,178
2018-2022 evolution	1,650	51,752	6,749	13,315	21,808	95,274
2023-2027 evolution	0	57,898	6,176	12,024	27,807	103,905
Estimate in 2027	24,897	252,458	39,277	76,534	139,280	532,445

Figure 9. Total investment in transmission lines

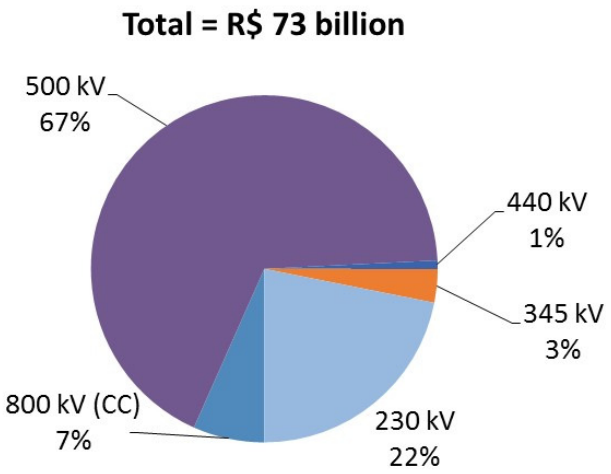
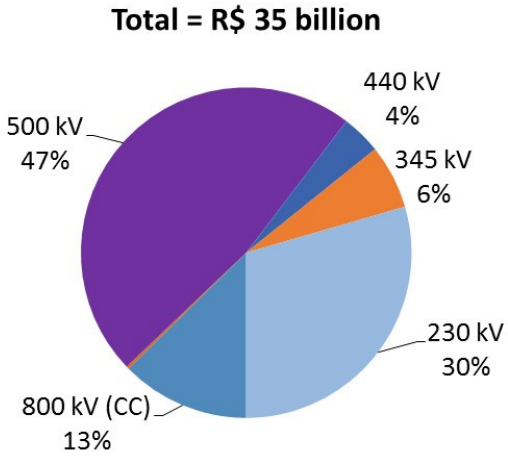


Figure 10. Total investment in substations

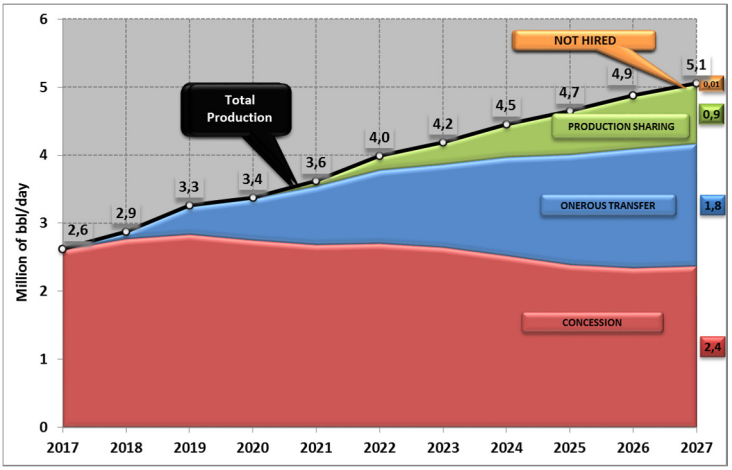


PRODUCTION OF CRUDE OIL AND NATURAL GAS

Oil production is expected to reach 5 million barrels per day (bpd) in 2027, approximately twice the value registered in 2017.

Oil production evolution related to the production of total reserves will reach the largest volumes in 2026, keeping the level around 4 million bpd to the end of the period, of which the areas related to the Onerous Transfer of Rights (OTR) are responsible for about 35%. The production estimated without contribution from the OTR areas would reach only 2.4 million bbl/day by 2027 (Figure 11).

Figure 11. National Oil Production by type of contract



Among the OTR fields, Búzios stands out with the entry of five production modules until 2022. It is expected a production of about 900,000 barrels per day in 2027.

Under contract of Production Sharing, the Mero field may also reach 900,000 bpd at the end of the horizon. These three units account for 35% of the oil production forecast for the end of the period.

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 92% of the total forecast for 2027, 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 of the Camamu-Almada, Parnaíba, Santos and Sergipe-Alagoas (deep water), and Solimões basins.

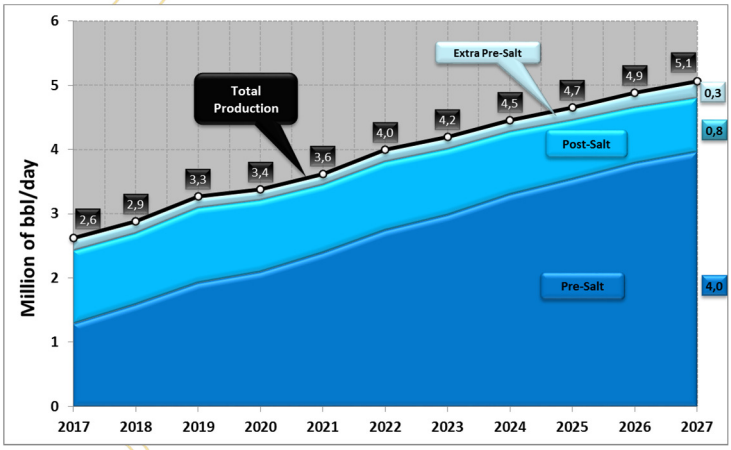
Natural gas production from total reserves reaches the largest volumes in 2025: 160 million m^3/day, followed by a mild decline until the end of the horizon, offset by contribution from the production of contingent and undiscovered resources. The greatest contributions are associated with the Santos, Campos, Solimões and Parnaíba basins.

In the gross natural gas production, it is expected that all OTR areas account for about 29% of the total. Concession Contracts contribute significantly with about 56% of the national gross natural gas production in 2027.

The behavior of the net production of natural gas does not follow the gross production, mainly due to the injection of gas from the pre-salt layer. These are considered high levels of injection, both to enhance oil recovery and for the lack of flow infrastructure, in addition to difficulties in processing related to the high rate of contaminants. In this case, anticipation of the oil production increases the profitability of E&P projects.

Thus, despite significant volumes, monetization of this gas depends on huge amounts of investments and the definition of a consumer market niche considering its high costs. Thus, although there is potential for production, the net production was not considered for the Mero field and Libra areas under evaluation (Figure 12).

Figure 12. National Oil Production by area

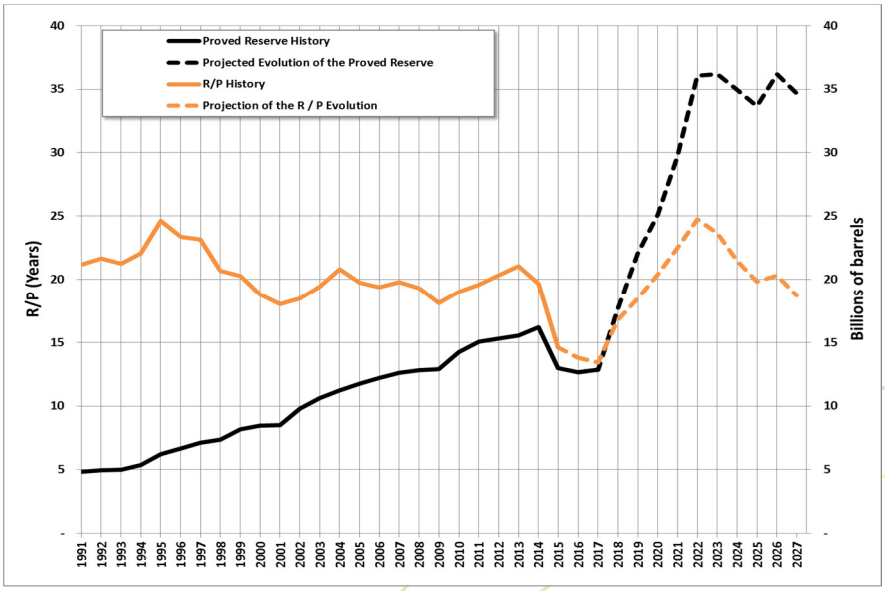


The proven oil reserves may reach about 35 billion barrels in 2024, considering all the estimated volumes mentioned above. The R/P ratio may reach relatively high levels for oil: between 17 and 23 years (Figure 13) – and for natural gas: between 16 and 29 years.

Investments for E&P activities in Brazil are estimated to remain between US$ 365 billion and US$ 406 billion in the 10-year period.

To support such production forecasts of this plan, the estimate for entry into operation of new Stationary Production Units (SPU) is 40 units up to 2027.

Figure 13. Oil: R/P ratio



Supply of Oil Products

Despite the short-term factors, it is expected that oil prices (Table 9) should continue their upward trend over the medium term until stabilizing in values close to breakeven prices of more expensive projects in fields today considered marginal.

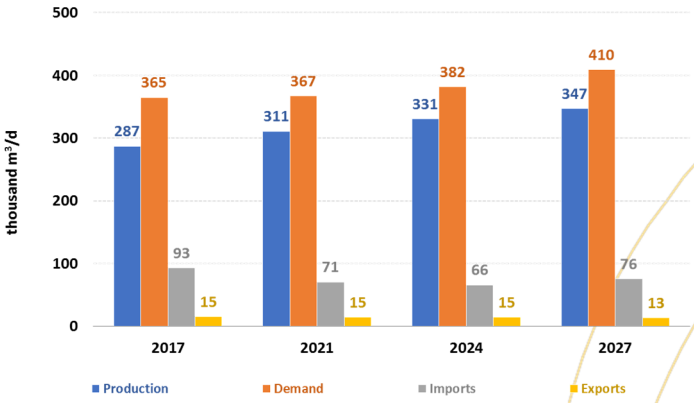
Table 9. Brent Oil Price

US$/barrel (Values of December, 2017)									
2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
70	71	72	74	75	78	81	82	83	83

Greatly affected by public policies, technologies and consumer preferences, the evolution of global demand should lead to an relative appreciation of cleaner fuels with lower sulfur content.

Brazil is expected to continue as a net importer of the main oil products (Figure 14), over the period under study, especially imports of naphtha, aviation kerosene (jet fuel), and diesel oil.

Figure 14. Balance of the Main Petroleum Products



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

As for gasoline, Brazil will continue to be an importer of this product, in small volumes.

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

In the case of diesel, the S10 diesel oil is more valued than the aviation kerosene (jet fuel), which economically favors domestic production of S10.

If there is an increase in the demand of 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 diesel oil "A") and the significant cabotage of gasoline "A" and diesel oil "A" 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 actors into the sector and free competition, in an objective and clear regulatory environment, as indicated in the *Combustível Brasil* (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.

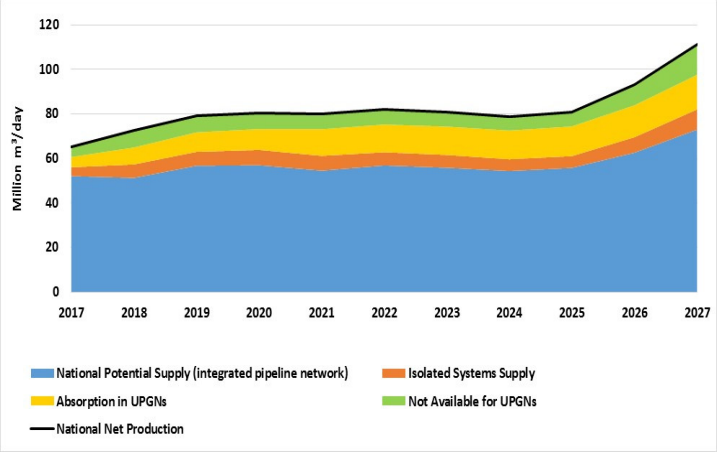
Supply Of Natural Gas

Changes in the regulatory framework resulting from the *Gás para Crescer* (Gas to Grow) initiative, 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 market of LNG.

The price of natural gas from LNG in Brazil, at first, will be affected by the international prices 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 thermal power.

The net production of natural gas will grow from 65 million m^3/day in 2017 to 111 million m^3/day in 2027. While the projected national potential supply of the integrated grid will grow from about 52 million m^3/day in 2017 to approximately 73 million m^3/day in 2027 (Figure 15).

Figure 15. Natural Gas Evolution

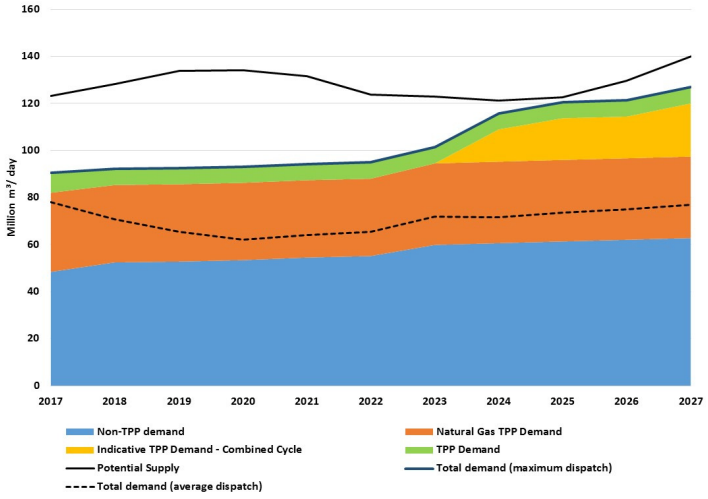


There is an increase in the production of associated gas, and the pre-salt layer will correspond to the level of 45% of the national supply in 2027. In addition, at the end of the period, there is an increase in domestic production of non-associated gas from the Sergipe-Alagoas basin.

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 onwards. The potential import of LNG corresponds to the installed capacity of the existing terminals, 47 million m^3/day, from 2018 to 2027.

At the end of the 10-year period, there may be a higher positive natural gas balance in the integrated grid balance (Figure 16) if either at least part of the indicative thermal power plants (TPPs) are located in isolated systems or there is interconnection to the integrated grid of LNG supply of the regasification terminals of Barra dos Coqueiros/SE or Porto do Açu/RJ forecast for the period.

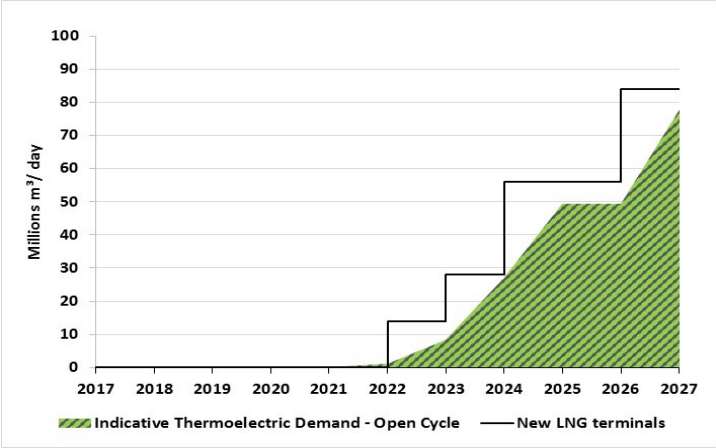
Figure 16. Natural Gas Balance in the Integrated Pipeline Newtwork



Expansion to meet the peak demand of the 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 78 million m^3/day in natural gas demand between 2022 and 2027.

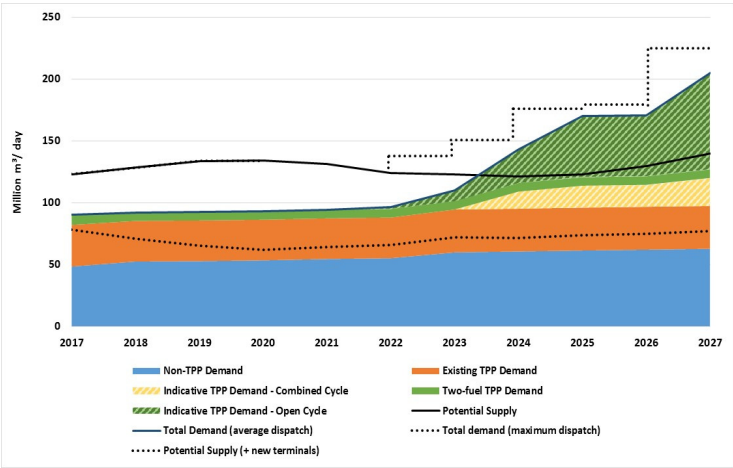
To meet this indicative demand, one of the proposed solutions would be the gradual installation of six new LNG terminals (indicative) until the end of the period, with capacity of 14 million m^3/day each (Figure 17). There would be, in this case, the challenge of developing a business model that adopt a situation of flexibility of the supply of natural gas.

Figure 17. Indicative thermal demand to meet energy peak and indicative LNG terminals



In the extreme and unlikely case of all peak demand being met by open-cycle thermal power plants connected to the integrated grid, the supply and demand balance of the grid would be considerably different in the second five-year span, doubling its levels of supply and demand (Figure 18).

Figure 18. The Balance of the Integrated Pipeline Network with open-cycle thermal power plants (TPP) for peak service



The behavior of the balance in case the open-cycle thermal power plants for peak service were connected to the integrated grid may be observed. This alternative presents several challenges, be they related to operation (variation of transported volumes and pressure variations in the integrated grid), to business models, or to financing.

With regard to operational issues, considering the connection of these thermal power plants to the existing grid will lead to a significant increase in volumes transported and in fluctuations in the flow of natural gas, which results in greater operational complexity and may require large investments in the grid.

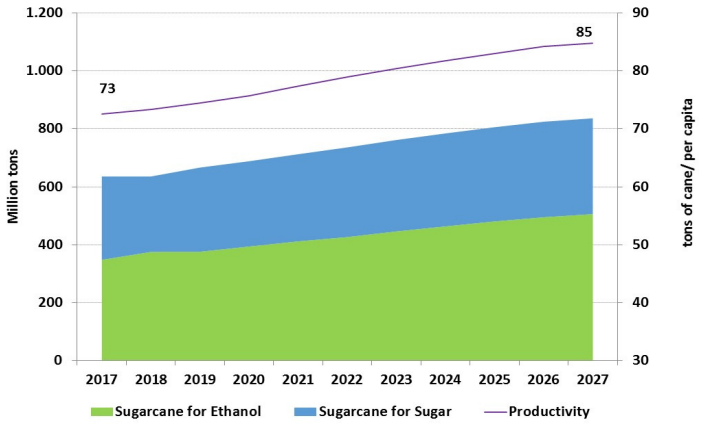
Investments related to the expansion of the natural gas supply are estimated at about R$ 8 billion, of which about R$ 3 billion in planned projects and R$ 5 billion in indicative projects. Among the indicative projects, it is considered the case in which the indicative open-cycle thermal power demand expected for the 10-year period is supplied by 6 new exclusive LNG terminals with capacity of 14 million m^3/day each, resulting in total investment of R$ 2.4 billion.

Supply of Biofuels

Biofuels will continue to have a relevant share in the Brazilian energy matrix in the next decennial period. The establishment of the National Biofuels Policy (RenovaBio) confirms the positive developments and the strengthening of the sector projected for the future.

With investments in renovation of the sugar cane crops, adequate cultural practices and adjustment between the mechanization of harvesting and planting of sugar cane, it is estimated a recovery of production indicators of this culture (agricultural productivity and industrial yield in ATR per tonnes cane).

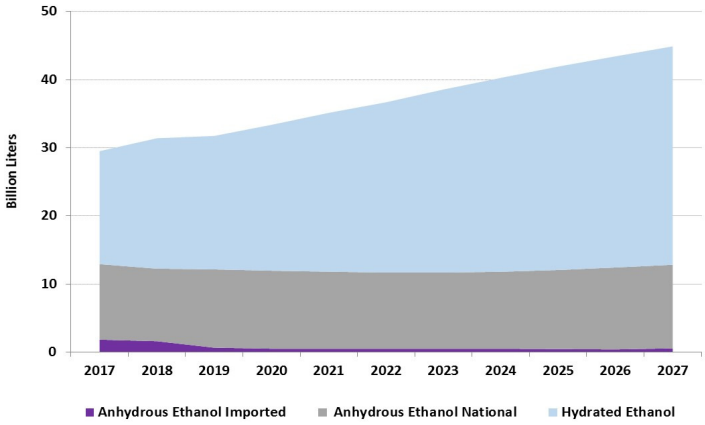
Figure 19. Productivity, harvested sugar cane and destination



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.

In the ethanol forecast it was considered the introduction of cane-energy 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 2 billion liters in 2027.

Figure 20. Total supply of ethanol



The total ethanol supply reaches 45 billion liters in 2027, with 32 billion liters referring to hydrated ethanol.

It is expected an expansion of the bioelectricity generation in the period, incorporating straws and tips and, in some cases, different sugar cane biomass. It is estimated that 6,800 MW will be available for marketing in 2027.

For biodiesel, soybean oil is expected to remain as the main raw material in the 10-year period. Demand for this biofuel is expected to remain within the mandatory limits set by law.

In strategic terms, developing alternative crops in relation to soybeans is important for the PNPB (*Biodiesel National Programme*). Among vegetable oils, palm oil presents the largest production volume in international markets, as well as more competitive prices.

Biogas from the biodigestion of vinasse and filter cake will have a higher share in the Brazilian energy matrix. Its production potential is estimated at 7.2 billion Nm^3 in 2027, and can be used to generate electricity, replacing diesel oil and mixed with fossil natural gas in pipeline grids.

Aviation biokerosene (BioQAV) is expected to reach a market share of 1% (91,000 m^3) of the total demand for aviation fuel in 2027, with specific airlines adopting certified technological paths.

Social and Environmental Analysis

The PDE 2027 social and environmental analysis aims to: 1) contribute to the definition of the expansion of the 10-year period; 2) assess the main environmental issues of the expansion in an integrated approach; 3) indicate the priority issues for the environmental management of the sector; and 4) analyze the greenhouse gas (GHG) emissions from the planned expansion.

First, in order to incorporate the environmental variable into the decennial expansion and contribute for the definition of the expansion, there are procedure analysis of the HPP plants and socioenvironmental complexity analysis of the oil and natural gas production units.

Then, based on the planned expansion, there is an integrated social and environmental analysis, which is based on the spatialization of the planned projects. It seeks to evaluate qualitatively the main interferences of the expansion with the socioenvironmental sensitivities that better represent the Brazilian regions, through socioenvironmental themes.

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 "Protected areas."

The theme "indigenous peoples and lands" was considered a priority due to the multiple associated challenges that comprise insufficient definitions about legal and regulatory devices in relation to the peoples affected.

The theme "Protected areas" was considered a priority due to the complexity intrinsic to the process of reconciling biodiversity conservation with electricity generation.

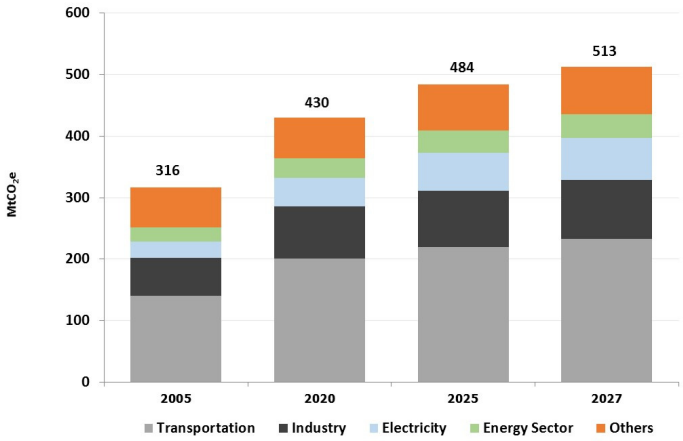
GREENHOUSE GASES (GHG)

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

Energy consumption per capita should increase substantially until 2030 and, thus, GHG emissions related to energy production and consumption will grow.

Considering Brazil's potential for electricity and fuel production from renewable sources, the main strategy of the industry for mitigating GHG emissions is precisely to maintain high the share of these sources in the matrix.

Figure 21. Evolution of the sector share in GHG emissions by energy production and use



The main sectors responsible for GHG emissions in energy production and consumption are the transportation and manufacturing sectors, which will remain responsible for most emissions of the energy sector, amounting to 64% in 2027.

In the electricity sector, generation from non-GHG-emitting sources will represent 91% of the total power generation in 2027. Therefore, additional efforts to mitigate GHG emissions should focus on sectors that the present opportunities with better cost-to-benefit ratio.

The expected expansion of the energy supply and consumption over the 10-year period meets and exceeds the goal for 2020 and the trajectory stipulated in the Brazilian NDC for the energy sector. Thus, it can be stated that PDE 2027 is fully aligned with the PNMC (*Climate Change National Policy*) and with the international commitments assumed by Brazil in the Paris Agreement.

CONSOLIDATION OF RESULTS

At the end of the 10-year period, the resident population is estimated to reach 221 million inhabitants, with average growth of 0.6% per year. The per capita GDP will reach R$ 39,000 in constant values of 2017, with growth of 2.2% per year.

Correspondingly, the final energy consumption grows at an average rate of 2.3% per year, reaching 325 million at the end of 2027.

It is estimated that the domestic energy supply reaches about 367 million toe, an average annual growth of 2.3%. The domestic electricity supply grows at an average rate of 3.6% per year, reaching an estimated supply of 889 TWh at the end of 2027. In per capita terms, the domestic electricity supply increases from about 3,000 kWh in 2017 to 4,024 kWh in 2027.

Table 10. Main indicators related to final energy consumption

Discriminação		2017	2022	2027	Average annual variation		
					2017 a 2022	2022 a 2027	2017 a 2027
Resident Population	(10^6 inhab.)	208	215	221	0.7%	0.5%	0.6%
GDP	(R$ 10^9 of 2017)	6,560	7,505	8,696	2.7%	3.0%	2.9%
	per capita (10^3 R$/inhab.)	31	35	39	2.1%	2.5%	2.3%
Domestic energy supply	(10^6 toe)	293	324	367	2.0%	2.6%	2.3%
	by GDP (toe/10^3 R$)	0.045	0.043	0.042	-0.7%	-0.4%	-0.5%
	per capita (toe/inhab.)	1,41	1,50	1,66	1.3%	2.0%	1.7%
Domestic electricity supply	(TWh)	624	752	889	3.8%	3.4%	3.6%
	by GDP (kWh/10^3 R$)	95	100	102	1.0%	0.4%	0.7%
	per capita (kWh/inhab.)	2,994	3,491	4,024	3.1%	2.9%	3.0%
Final energy consumption	(10^6 toe)	260	286	325	1.9%	2.6%	2.3%
	per capita (toe/inhab.)	1.25	1.33	1.47	1.3%	2.1%	1.7%
	by GDP (toe/10^3 R$)	0.040	0.038	0.037	-0.8%	-0.4%	-0.6%

Regarding the domestic supply of energy, renewables show an average growth of 3.2% per year, in particular, due to the average growth of 6.1% 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 to increase to 47% in 2027 (Table 11).

On the other hand, it is noted the reduction in the share of crude oil and its products in the total domestic supply of energy from 36% in 2017 to 31% in 2027. Despite the increased production of crude oil, prospects for the replacement of gasoline with ethanol and the substitution of fuel oil and LPG for natural gas are the main determinants for the decrease expected in the period.

Table 11. Domestic Energy Supply Evolution in the 10-year Horizon

	2017		2022		2027		2017-2027
	thousand. toe	%	thousand. toe	%	thousand. toe	%	Average Variation (% p.y.)
Non-Renewable Energy	**166,808**	**57**	**169,776**	**52**	**193,094**	**53**	**1,5**
Oil and Oil Products	106,276	36	107,547	33	113,830	31	0,7
Natural Gas	37,938	13	37,244	11	49,377	13	2,7
Mineral Coal and Derivatives	16,570	6	18,443	6	20,884	6	2,3
Uranium (U_3O_8) and Derivatives	4,193	1	3,918	1	6,877	2	5,1
Other Non-Renewable Sources	1,831	1	1,982	1	2,126	1	1,5
Renewable Energy	**126,685**	**43**	**154,685**	**48**	**174,263**	**47**	**3,2**
Hydraulic Energy and Electricity	35,023	12	45,333	14	46,761	13	2,9
Firewood and Charcoal	23,424	8	23,731	7	24,439	7	0,4
Sugar Cane Derivatives	51,116	17	61,476	19	72,072	20	3,5
Other Renewable Sources	17,122	6	24,145	7	30,990	8	6,1
Total	**293,492**	**100**	**323,819**	**100**	**367,356**	**100**	**2,3**

Although the Brazilian NDC is economy wide, the monitoring of NDC related to energy production and use shows that the country is set to fulfill the goals undertaken, as the PDE 2027 forecasts show (Table 12). It should be noted in particular the share of renewable sources (excluding hydro), for which a share of 34% is projected, and the share of bioenergy estimated at 21% (Table 12).

Thus, contrary to what occurs in most countries, in Brazil has a minor contribution from the electricity sector to total GHG 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 GHG should not focus on the power sector, but on sectors that present opportunities with better cost-to-benefit ratios.

Table 12. Monitoring of NDC measures x 2026 PDE Projections

INDICATORS		**NDC**	**PDE 2027**
		Reference year 2025	
Energy Efficiency	Electricity	8%	7%
Power matrix	Share of wind, solar and biomass energy, including DG and self-production	22%	22%
	Share of hydroelectricity in centralized generation	71%	73%
Energy matrix	Share of renewable sources, with the exception of hydro	32%	34%
	Share of bioenergy	18%	21%
	Total share of renewable sources	45%	48%

Nonetheless, emissions resulting from the production and consumption of energy will growth 62% between 2005 and 2027. This increase is lower than that expected for the gross domestic supply in the same period (70%). Thus, the indicator for the intensity of GHG emissions in

energy use in 2027 will be lower than that observed in 2005. The indicator for the intensity of emissions of the economy should also reach a value below that observed for 2005 in the end of 2027.

The estimated generation including self-production (representing almost 10% of the total generation in the period) is presented in Table 14. The share of wind power generation reaches more than 10% at the end of the period, while self-production using biomass almost doubles the expected generation in the period under analysis.

Table 13. Carbon intensity in the Brazilian economy due to the production and use of energy

Item	Unit	2005	2020	2025	2027
GHG emissions in energy production and use	$10^6 tCO_2e$	317	430	484	513
GDP	R$ billion [2010]	3,122	4,334	5,000	5,304
Gross Domestic Supply	10^6 toe	218	310	351	371
Carbon intensity in energy use	$kgCO_2e$/toe	1,451	1,389	1,381	1,384
Carbon intensity in the economy	$kgCO_2e$/R$ [2010]	101.3	99.2	96.8	96.7

Table 14. Total Electricity Generation

Centralized Generation	2017		2022		2027	
	TWh	%	TWh	%	TWh	%
Hydropower	404	65	523	69	539	60
Natural Gas	54	9	36	5	56	6
Coal	15	2	11	1	13	1
Nuclear	16	3	15	2	26	3
Biomass	25	4	31	4	38	4
Wind power	42	7	58	8	102	11
Solar (centralized)	1	0	9	1	18	2
Others	12	2	3	1	4	1
Subtotal	569	91	685	91	796	90
Self-production & Distributed Generation	**2017**		**2022**		**2027**	
	TWh	%	TWh	%	TWh	%
Biomass (biogas, sugar cane bagasse, black liquor and firewood)	26	4	41	5	51	6
Solar	0	0	2	0	12	1
Hydropower	3	1	5	1	7	1
Wind power	0	0	0	0	2	0
Non-renewable sources	26	4	18	2	21	2
Subtotal (Self-prodution & DG)	55	9	67	9	93	10
Total	624	100	752	100	889	100

In the course of the last few decades, the difference between the 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 a surplus in its energy matrix, reaching nearly 120 million toe in 2027, which will amount to approximately 23% of the country's total energy production (Table 15).

Table 15. Primary Energy Supply Evolution

Itemization	2017	2022	2027	2017-2022	2022-2027	2017-2027
	thous. toe			Variation (% p.a.)		
Total Energy Demand (A)	**304.615**	**341.645**	**396.668**	**2,3**	**3,1**	**2,7**
Final Consumption	260.010	286.340	325.296	1,9	2,6	2,3
Losses	44.605	55.305	71.373	4,5	5,2	4,8
Primary Energy Production (B)	**303.039**	**412.688**	**515.171**	**6,4**	**4,5**	**5,1**
Surplus Energy (B) - (A)	**-1.576**	**71.043**	**118.503**	**-**	**10,8**	**-**

Table 16 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 growth of 6.8%. Therefore, there is a detachment in relation to the energy demand of oil products, which shows 1.2% average annual growth. At the end of the 10-year period, energy surplus amounts to approximately 140 million toe in the Brazilian petroleum chain, which will be the main responsible for the significant expected surplus of the Brazilian energy matrix in the horizon of the plan.

Table 16. Crude Oil and Oil Products Supply Evolution

Itemization	2017	2022	2027	2017-2022	2022-2027	2017-2027
	thous. toe			Variation (% p.a.)		
Demand for Oil Products (A)	**117,093**	**119,458**	**131,702**	**0.4**	**2.0**	**1.2**
Final Consumption	110,291	115,841	127,932	1.0	2.0	1.5
Processing	6,802	3,617	3,649	-11.9	0.2	-6.0
Oil Production (B)	**144,161**	**212,919**	**272,811**	**8.1**	**5.1**	**6.6**
Crude Oil	135,907	206,243	261,458	8.7	4.9	6.8
Natural Gas Liquids	5,089	1,166	3,175	-25.5	22.2	-4.6
Biodiesel	3,166	5,510	8,178	11.7	8.2	10.0
Surplus Energy (B) - (A)	**27,067**	**93,461**	**141,230**	**28.1**	**8.6**	**18.0**

Table 17 presents the projected balance of natural gas. In the first five years, the processing in UPGN is expected to decrease due to the reduced need for thermal power dispatch. In the second five-year span, the supply from UPGN resumes expansion and comes close to 67 million m^3/day, in 2027, because of the increase in consumption as a whole.

As for the final consumption, it can be highlighted the growth acceleration in the second half of the decade, with emphasis on the residential and non-energy (raw material) sectors. The final consumption of natural gas is estimated to increase, on average, 2.3% per year over the next ten years, reaching 63 million m^3/day in 2027.

Table 17. Dry Natural Gas Balance

Itemization	2017	2022	2027	2017-2022	2022-2027	2017-2027
	thousand m^3/day			Variation (% p.a.)		
Expected Total Supply	**89,853**	**76,680**	**94,984**	**-3.1%**	**4.4%**	**0.6%**
UPGN	60,483	44,644	66,763	-5.9%	8.4%	1.0%
Import	29,370	32,036	28,221	1.8%	-2.5%	-0.4%
Expected Total Consumption	**85,169**	**76,680**	**94,984**	**-2.1%**	**4.4%**	**1.1%**
Electricity (1)	34,739	21,987	31,946	-8.7%	7.8%	-0.8%
Final consumption	**50,430**	**54,693**	**63,038**	**1.6%**	**2.9%**	**2.3%**
Non-energy consumption	2,133	7,019	9,733	26.9%	6.8%	16.4%
Energy consumption	48,297	47,675	53,305	-0.3%	2.3%	1.0%
Energy sector (2)	11,300	10,751	11,374	-1.0%	1.1%	0.1%
Residence	1,180	1,490	2,077	4.8%	6.9%	5.8%
Transport	5,400	5,362	5,738	-0.1%	1.4%	0.6%
Industry	29,997	29,114	32,818	-0.6%	2.4%	0.9%
Others (3)	420	958	1,298	17.9%	6.3%	11.9%

Notes: (1) Includes self-production;
(2) Does not include consumption in E&P;
(3) Includes the commercial, public and agricultural sectors.

Table 18 shows the quantitative values for domestic energy production over the horizon of the 2027 PDE, mainly explained by the huge increase in the oil production.

The next tables (19 to 21) indicate the physical expansion of the system in the 10-year period.

Table 18. Domestic Energy Production

Source	Unit	2017	2022	2027	2017-2022		2022-2027		2017-2027	
					Increment	%	Increment	%	Increment	%
Oil	thous. barrels/day	2,626	3,984	5,051	1,358	52%	1,067	27%	2,425	92%
Natural Gas	million m^3/day	109.9	123.5	192.1	13.7	12%	68.5	55%	82.2	75%
Diesel Oil	million m^3	40.6	47.9	51.1	7.3	18%	3.1	7%	10.4	26%
Fuel Oil	million m^3	12.2	11.5	11.9	-0.7	-6%	0.4	3%	-0.3	-3%
Gasoline	million m^3	27.7	27.0	26.4	-0.7	-2%	-0.6	-2%	-1.3	-5%
LPG	million m^3	10.4	12.2	14.6	1.8	17%	2.4	20%	4.2	40%
Kerosene	million m^3	6.2	6.6	7.0	0.4	6%	0.4	6%	0.8	13%
Ethanol	million m^3	27.7	34.7	42.4	7.0	25%	7.7	22%	14.7	53%
Electricity	TWh	624.1	752.0	888.9	128	20%	137	18%	265	42%

Table 19. Installed Capacity of Electricity Generation in the National Interconnected System

SOURCES	2017	2022	2027	2017-2022		2022-2027		2017-2027	
	GW			Increment	%	Increment	%	Increment	%
Installed Capacity of Electricity Generation	149	168	209	20	13%	41	24%	61	41%
Hydropower	94	102	103	8	9%	1	1%	10	11%
Thermal power	23	27	32	4	17%	5	20%	9	40%
Wind power	12	15	27	3	25%	11	74%	14	116%
Centralized Solar	0	4	9	3	-	5	137%	8	-
Open Cycle TPP + Storage Tech. Storage	0	0	13	-	-	13	-	13	-
Others	20	21	25	1	5%	5	24%	6	31%

Table 20. Power Transmission

ITEM	Unit	2017	2022	2027	2017-2022		2022-2027		2017-2027	
					Increment	%	Increment	%	Increment	%
Transmission Lines	km	141,576	172,213	196,816	30,637	22%	24,603	14%	55,240	39%
Substations	MVA	348,232	439,245	524,881	91,013	26%	85,636	19%	176,649	51%

Table 21. Natural Gas Pipelines

ITEM	Unit	2017	2022	2027	2017-2022		2022-2027		2017-2027	
					Increment	%	Increment	%	Increment	%
Gas pipelines	km	9,409	9,503	9,503	94	1%	0	0%	94	1%

Table 22. Investment Estimates in the Energy Industry

TYPE	R$ billion 2018-2027 period	%
Power Supply	**393**	**21.7%**
Centralized Generation	226	12.4%
Distributed Generation (microgeneration and minigeneration)	60	3.3%
Transmission	108	5.9%
Oil and Natural Gas	**1,382**	**76.1%**
Exploration and Production of Oil and Natural Gas	1,340	73.8%
Supply of Petroleum Products	34	1.8%
Natural Gas Supply	8	0.4%
Supply of Liquid Biofuels	**41**	**2.3%**
Ethanol – Production plants	34	1.9%
Ethanol – Pipeline and Port Infrastructure	4	0.2%
Biodiesel – Production plants	3	0.2%
TOTAL	**1,816**	**100%**
	1,816	**100%**

while Table 22 presents the estimate of the associated amount of investments.

Table 23 shows the list of HPP projects made available to the 2027 PDE to execute the expansion of centralized generation, while Table 24 finishes with the summary of the studies conducted in the Environmental Analysis. Finally, Table 25 presents the projection for the national energy matrix in 2027.

Table 23. List of HPP Projects Available for the PDE 2027

Earliest Date for Start of Operation	HPP	Power (MW)	Basin	River	State
2024	Apertados	139	Piquiri	Piquiri	PR
2024	Castanheira	140	Juruena	Arinos	MT
2024	Davinópolis	74	Paranaíba	Paranaíba	MG/GO
2024	Ercilândia	87	Piquiri	Piquiri	PR
2024	Tabajara	400	Ji-Paraná	Ji-Paraná	RO
2024	Telêmaco Borba	118	Tibagi	Tibagi	PR
2025	Comissário	140	Piquiri	Piquiri	PR
2025	Itaocara I	150	Paraíba do Sul	Paraíba do Sul	RJ
2027	Bem Querer	650	Branco	Branco	RR
After 2027	Alta Floresta	127	Teles Pires	Teles Pires	MT
After2027	Buriti Queimado	142	Tocantins	Almas	GO
After2027	Couto Magalhães	150	Araguaia	Araguaia	MT/GO
After2027	Formoso	342	São Francisco	São Francisco	MG
After2027	Foz do Piquiri	93,2	Piquiri	Piquiri	PR
After 2027	Foz do Xaxim	63,2	Uruguai	Chapecó	SC
After 2027	Itaguaçu	92	Paranaíba	Claro	GO
After2027	Itapiranga	724	Uruguai	Uruguai	SC/RS
After2027	Jatobá	1.650	Tapajós	Tapajós	PA
After2027	Maranhão	125	Tocantins	Maranhão	GO
After2027	Mirador	80	Tocantins	Tocantizinho	GO
After2027	Paranã	90	Tocantins	Paranã	TO
After2027	Porteiras	86	Tocantins	Maranhão	GO
After2027	Porto Galeano	81	Sucuriú	Sucuriú	MS
After2027	Santo Antônio	84	Uruguai	Uruguai	SC/RS
After2027	Saudade	61	Uruguai	Chapecó	SC
	Total	5.890			

Table 24. Summary of the Planned Expansion in the PDE 2027

SOURCE OR ACTIVITY	PDE 2027 EXPANSION
HPP	- 3,080 MW (13 HPPs), all regions of Brazil except in the NE - Contracted: 1,114 MW (4 HPPs). Indicative: 1,966 MW (9 HPPs) - Amazon Hydrographic Region (HR): 5 HPPs and 61% power, Paraná HR: 6 HPPs and 29% power, Uruguai HR: 1 HPP and 5% power, and South-East Atlantic HR: 1 HPP and 5% power
PCH	- 2,797 MW - Contracted: 747 MW (62 PCHs) in all regions of Brazil - Indicative: 2,050 MW in the S and SE/MW subsystems
Fossil fuel power plants (NG, coal) and nuclear power plants	- 24,690 MW - Contracted: 6,020 MW (6 NG TPP, 2 diesel TPP, and 1 coal TPP, in addition to 1 expansion of NG TPP) and 1,405 MW (1 nuclear power plant) - Indicative: 17,265 MW (64% in the SE/MW, 22% in the S, and 14% in the NE subsystem)
Biomass thermal power plants	- 3,141 MW - Contracted: 541 MW, 61% from burning sugar cane bagasse and straw, 32% from wood chips, 4% from biogas, 2% from vinasse biogas and 1% from rice husk, in the SE/MidW, NE and S subsytems - Indicative: 2,600 MW, of which 150 MW are from biogas in the SE/MidW subsytem
Wind power	- 14,006 MW - Contracted: 4,006 MW (164 facilities), predominantly in the NE region - Indicative: 10,000 MW, 80% the NE subsystem, and 20% in the S subsystem
Solar power	- 7,459 MW - Contracted: 2,459 MW (88 projects) with 71% in the NE and 29% in the SE - Indicative: 5,000 MW in the NE and SE/MidW subsytems
Transmission	- 55,240 km, in all regions of Brazil - Contracted: 284 LTs - Socioenvironmental analysis of 418 LTs amounting 41,415 km - N (8.647 km), NE (10.404 km), MidW (3.992 km), SE (10.221 km), and S (8.161 km)
Exploration and production of oil and NG	- 260 production units (PUs) of exploration and production of oil and natural gas will start production of conventional resources - Onshore PUs in the N, NE and SE regions - Offshore PUs are concentrated in the SE, with occurrence also in the NE and N
Refineries, UPGNs and LNG Terminals	- 1 refinery in the NE (PE), expansion - 2 regasification terminals, in the NE (Sergipe) and SE (Rio de Janeiro) - No UPGNs planned
Gas pipelines	- 2 gas pipelines, in the NE (Ceara) and SE (Rio de Janeiro)
Ethanol	- Expansion of etanol production by 49% in the 10-year period, from 30 billion liters (2018) to 44 billion liters (2027) - 20 planned power plants, 11 using sugar cane, 4 using corn, and 5 flexible (sugar cane and corn) - Midwest, West of Minas Gerais and Northwest of Paraná Regions
Biodiesel	- 3 new plants and 3 plants in expansion (NE, MidW and S regions)

Table 25. Energy Matrix Forecast (2027)

2027 (10^3tep)	PRIMARY ENERGY SOURCES										SECONDARY ENERGY SOURCES															
	CRUDE OIL	NATURAL GAS	STEAM COAL	METALLURGICAL COAL	URANIUM U_3O_8	HYDRO ENERGY	FIREWOOD	SUGARCANE PRODUCTS	OTHERS PRIMARY SOURCES	**TOTAL PRIMARY ENERGY**	DIESEL OIL	FUEL OIL	GASOLINE	LPG	NAFTA	KEROSENE	COKE-OVEN GAS	MINERAL COAL COKE	URANIUM CONTAINED UO_2	ELETRICITY	CHAR COAL	ANHYDROUS AND HYDRATED ETHANOL	OTHER OIL SECONDARIE	NON-ENERGY USE PETROLEUM PRODUCT	TAR	**TOTAL SECONDARY ENERGY**	TOTAL
PRODUCTION	261,458	69,625	3,342	0	6,877	45,193	24,439	71,121	33,116	515,171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	515,171
IMPORTS	6,663	9,065	5,464	10,644	***0***	***0***	***0***	***0***	***0***	31,836	11,488	***0***	2,895	705	5,194	3,090	***0***	1,433	***0***	1,569	***0***	951	1,265	64	***0***	28,654	60,490
VARIATION OF STOCKS	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	268,121	78,689	8,807	10,644	6,877	45,193	24,439	71,121	33,116	547,007	11,488	0	2,895	705	5,194	3,090	0	1,433	0	1,569	0	951	1,265	64	0	28,654	575,661
EXPORTS	-165,749	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	-165,749	-1,261	-7,072	-1	***0***	-10	-4,518	***0***	***0***	***0***	***0***	***0***	0	-382	***0***	***0***	-13,244	-178,993
NON-UTILIZED	0	-2,384	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	-2,384
REINJECTION	0	-26,928	0	0	0	0	0	0	0	-26,928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-26,928
GROSS DOMESTIC SUPPLY	102,373	49,377	8,807	10,644	6,877	45,193	24,439	71,121	33,116	351,946	10,228	-7,072	2,893	706	5,183	-1,428	0	1,433	0	1,569	0	951	882	64	0	15,410	367,356
TOTAL PROCESSING	-102,373	-25,180	-4,618	-10,644	-6,877	-45,193	-8,352	-31,561	-22,334	-257,131	51,574	11,073	20,354	8,899	1,583	5,731	1,799	8,318	0	74,881	4,059	20,907	11,142	6,119	325	226,764	-30,367
OIL REFINERIES	-102,373	0	0	0	0	0	0	0	-3,175	-105,547	43,302	11,411	19,441	4,612	4,914	5,731	0	0	0	0	0	0	10,182	5,487	0	105,080	-467
NATURAL GAS PLANTS	0	-7,707	0	0	0	0	0	0	975	-6,733	0	0	0	4,171	0	0	0	0	0	0	0	0	0	632	0	4,803	-1,929
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	-10,644	0	0	0	0	0	-10,644	0	0	0	0	0	0	2,282	8,318	0	0	0	0	-784	0	337	10,153	-491
NUCLEAR FUEL CYCLE	0	0	0	0	-6,877	0	0	0	0	-6,877	0	0	0	0	0	0	0	0	6,774	0	0	0	0	0	0	6,774	-103
UTILITY POWER PLANTS	0	-9,321	-4,367	0	0	-44,814	-351	-6,366	-9,749	-74,967	1,124	0	0	0	0	0	0	0	-6,774	66,873	0	0	0	0	0	61,223	-13,745
AUTOPRODUCING POWER PLANTS	0	-5,951	-251	0	0	-379	-342	-3,253	-5,819	-15,995	-621	-338	0	0	0	0	-483	0	0	8,008	0	0	-482	0	-12	6,072	-9,923
CHARCOAL KILNS	0	0	0	0	0	0	-7,659	0	0	-7,659	0	0	0	0	0	0	0	0	0	0	4,059	0	0	0	0	4,059	-3,600
DISTILLERIES	0	0	0	0	0	0	0	-21,942	0	-21,942	0	0	0	0	0	0	0	0	0	0	0	21,909	0	0	0	21,909	-33
OTHER PROCESSING	0	-2,200	0	0	0	0	0	0	-4,567	-6,767	7,769	0	913	116	-3,331	0	0	0	0	0	0	-1,002	2,226	0	0	6,691	-75
LOSSES IN DISTRIBUTION AND STORAGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11,693	0	0	0	0	0	-11,693	-11,693
FINAL CONSUMPTION	0	24,198	4,189	0	0	0	16,087	39,560	10,781	94,815	61,802	4,001	23,247	9,605	6,766	4,303	1,799	9,752	0	64,756	4,059	21,858	12,024	6,183	325	230,480	325,296
FINAL NON-ENERGY CONSUMPTION	0	3,126	0	0	0	0	0	0	0	3,126	0	0	0	0	6,766	2	0	0	0	0	0	687	511	6,183	209	14,359	17,485
FINAL ENERGY CONSUMPTION	0	21,071	4,189	0	0	0	16,087	39,560	10,781	91,689	61,802	4,001	23,247	9,605	0	4,301	1,799	9,752	0	64,756	4,059	21,170	11,513	0	115	216,122	307,811
ENERGY SECTOR	0	7,603	0	0	0	0	0	19,422	0	27,025	1,271	253	0	37	0	0	300	0	0	6,151	0	0	3,831	0	0	11,844	38,868
RESIDENTIAL	0	667	0	0	0	0	4,937	0	0	5,604	0	0	0	7,777	0	0	0	0	0	17,037	376	0	0	0	0	25,190	30,793
COMMERCAIL	0	376	0	0	0	0	95	0	0	471	15	35	0	340	0	0	0	0	0	11,215	90	0	0	0	0	11,695	12,167
PUBLIC	0	40	0	0	0	0	0	0	0	40	34	26	0	217	0	0	0	0	0	4,176	0	0	0	0	0	4,454	4,494
AGRICULTURE & LIVESTOCK	0	0	0	0	0	0	2,143	0	0	2,143	7,378	11	0	4	0	0	0	0	0	3,140	8	17	0	0	0	10,558	12,701
TRANSPORT	0	1,843	0	0	0	0	0	0	0	1,843	51,653	1,296	23,247	0	0	4,300	0	0	0	278	0	21,153	0	0	0	101,927	103,771
INDUSTRIAL	0	10,541	4,189	0	0	0	8,913	20,139	10,781	54,563	1,451	2,379	0	1,230	0	1	1,499	9,752	0	22,759	3,585	0	7,682	0	115	50,454	105,017