Deep decarbonization pathways in BRAZIL

February 2024
Lessons from the EU-funded research project IMAGINE

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Introduction

This work takes place in a context where:

- *in 2023, Brazil submitted NDC objectives for 2025 (1.32 Gt CO2e) and 2030 (1.2 Gt CO2e). Those objectives are actually from 2016, when originally joining the Paris Agreement, that Lula's administration re-signed after entering into power in 2023.*
- *The objectives include land sector emissions : Brazil needs to cut those emissions in order to meet NDC targets. The 2023 submission also mentions a zero illegal deforestation by 2030.*
- *Brazil has not submitted an LTS but mentions a target for 2050 neutrality (all GHG) in its 2023 NDC submission.*
- *Brazil is in the process of developing an indicative 2035 target and has indicated it will submit a second NDC in 2025*
- *Brazil famously managed a reduction of deforestation by >80% 2004-2012, from its peak levels in 2004, through a comprehensive policy framework including improved MRV, command and control policies, and finance to sustainable land projects (including via the Amazon fund). Deforestation has once again surged in the last years, and bringing it down to very low levels will be fundamental for reaching the climate targets.*

In this context and under the EU-funded research project IMAGINE, we defined a set of three development pathways :

- **The New Government Policy Scenario 1 (NGPS 1) :** this scenario illustrates current policies implemented, with a limited sucess in halting deforestation. It does not allow to meet either 2025 and 2030 NDC objectives, and does not increase long-term ambition up to 2050.
- **The New Government Policy Scenario 2 (NGPS 2) :** this scenario is identical to the NGSP1, except for its better performance on halting deforestation. Therefore it almost meets the 2025 NDC target and meets the 2030 target. Similarly to NGPS1, does not increase long-term ambition up to 2050.
- **The Deep Decarbonization Scenario (DDS) :** this scenario illustrates the transformations needed to reach net-zero all greeenhouse emissions before 2050. It also reaches 2025 & 2030 NDC objectives. It only uses already available technologies (no CCS or technologies in R&D stages). Most of the efforts of the reductions of GHG emissions comes from changes in land use and forestry, and from carbon pricing.

Research questions for scenario framing

1) What are the additional transformations required to reach net-zero CO_2 emission before 2050 in the current Brazil political context?

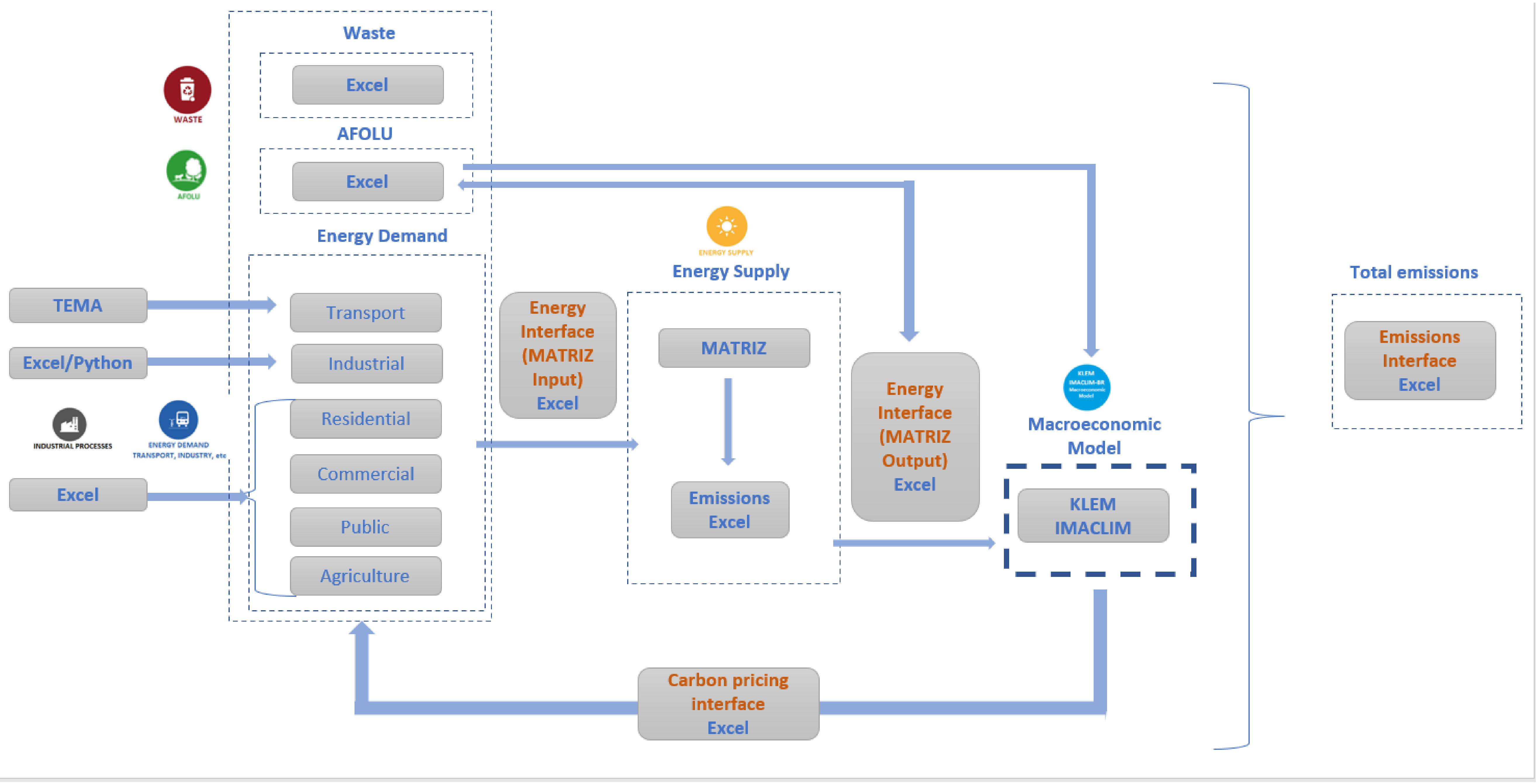
2) How does targeting land use and foresty emissions enable reaching mid-terms objectives (2025 & 2030 objectives)?

- The comparison of NGPS with DDS will inform us on the additional transformations to implement in order to reach net-zero GHG emissions in 2050.
- The comparison of NGPS1 with NGPS2 will inform us on the additional transformations needed to reach NDC objectives even with the current delayed implementation of mitigation policies.

Other key country-specific questions aim to be informed by this work:

- What are the main emitting sectors and what sectors should be particularly addressed if we include all greenhouse gas emissions in the carbon neutrality target?
- How could this work support the revision of national development and climate policies and future UNFCCC's commitments?
- What key global and sectoral transformations must be considered to enable national Paris-compatible pathways?
- What are the key international enablers and cooperation needs for these sectoral transformations?
- How to avoid negative impacts on the country's economic and social development due to the transition to a net-zero economyby 2050?
- What carbon policies and other tools need to be adopted to ensure a just transition towars a net zero economy by 2050?
- Are available "off-the-shelf" technolgies sufficient to deliver net-zero GHG emissions in Brazil by 2050?

Modelling architecture & improvements



Source: Adapted from

Wills, W., La Rovere, E.L., Grottera, C., Naspolini, G.F., Le Treut, G., Ghersi, F., Lefevre, J., Dubeux, C.B.S., 2021. Economic and social effectiveness of carbon pricing schemes to meet Brazilian NDC targets. Climate Policy, 2021, 22(1), pp. 48–63. https://doi.org/10.1 080/14693062.2021.1981212

Part 1

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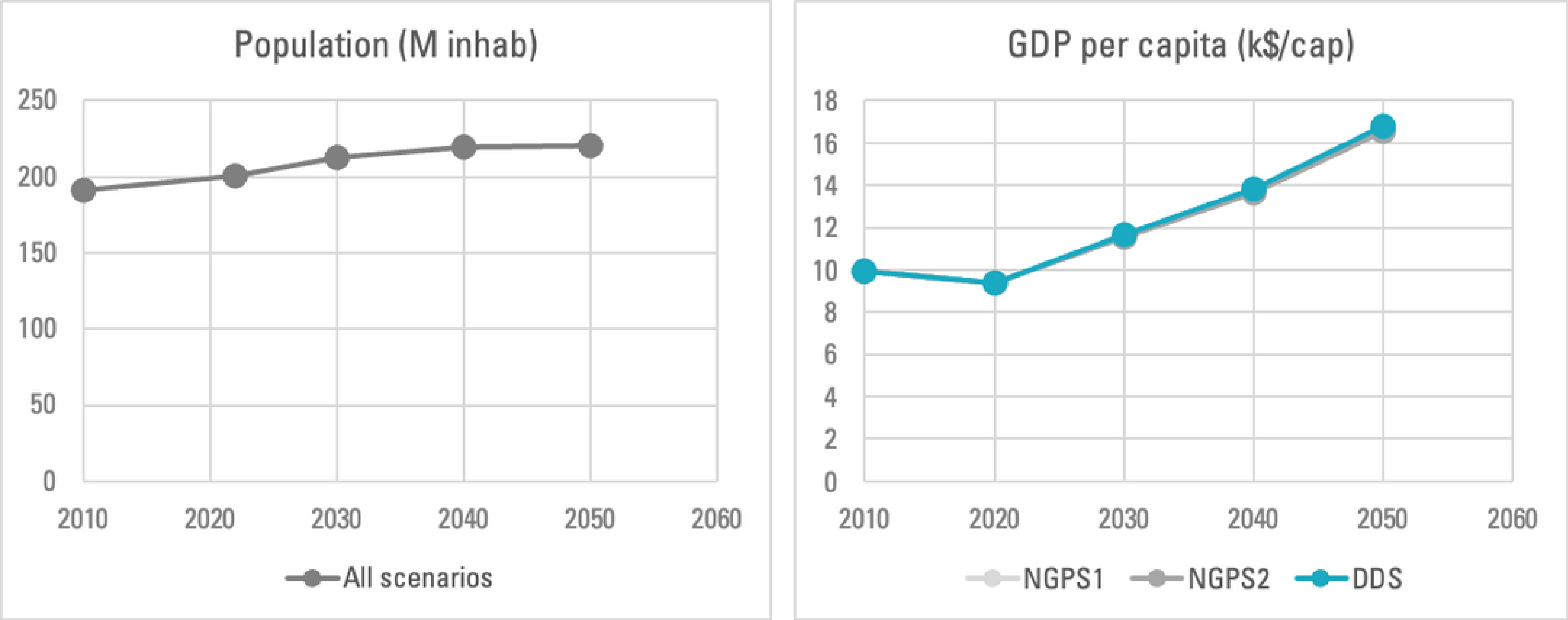
National overview of the deep decarbonization pathways

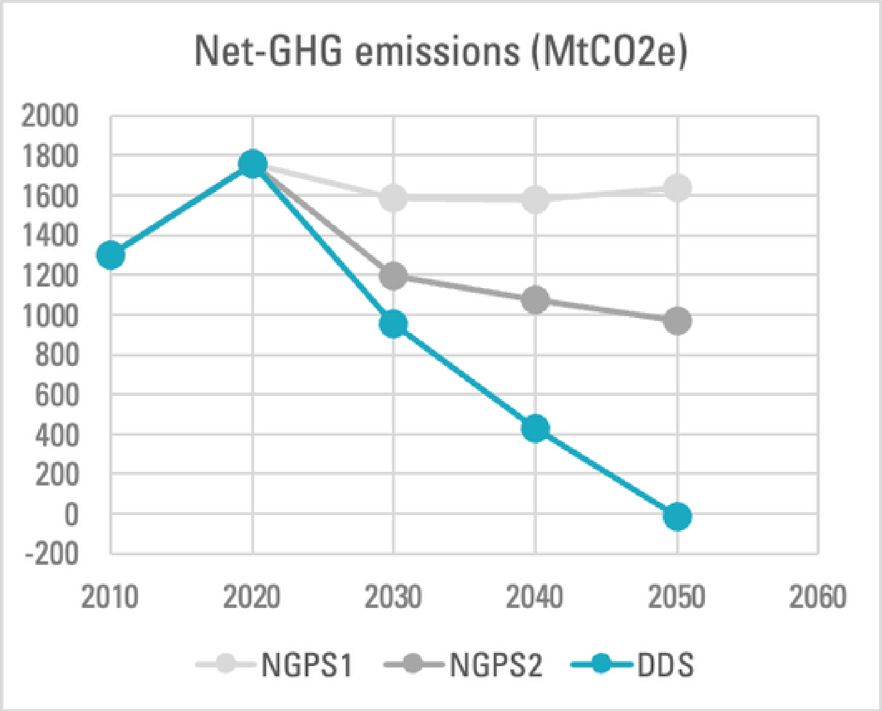
Reaching net-zero GHG emissions by 2050 is feasible, while ensuring socio-economic development

Figure 1. Socio-economic indicators (population, GDP per capita)



- The Brazilian population is expected to increase to 220 million inhabitants by 2050. An aging demographic due to lower fertility rates and a shift in population from rural to urban areas are also anticipated.
- The GDP per capita will grow after 2020, to reach 11.5k$/cap in 2030 and 16.5k$/cap in 2050; the GDP per capita will be slightly higher in the DDS (respectively 11,7 & 16.8 in 2030 & 2050).
- There's a gradual decline in primary industries with a notable rise in services and clean technology sectors. There could be potential improvements in trade balance due to increased exports, particularly in agribusiness and oil and a slow diversification of exported products, from raw materials to value-added goods.

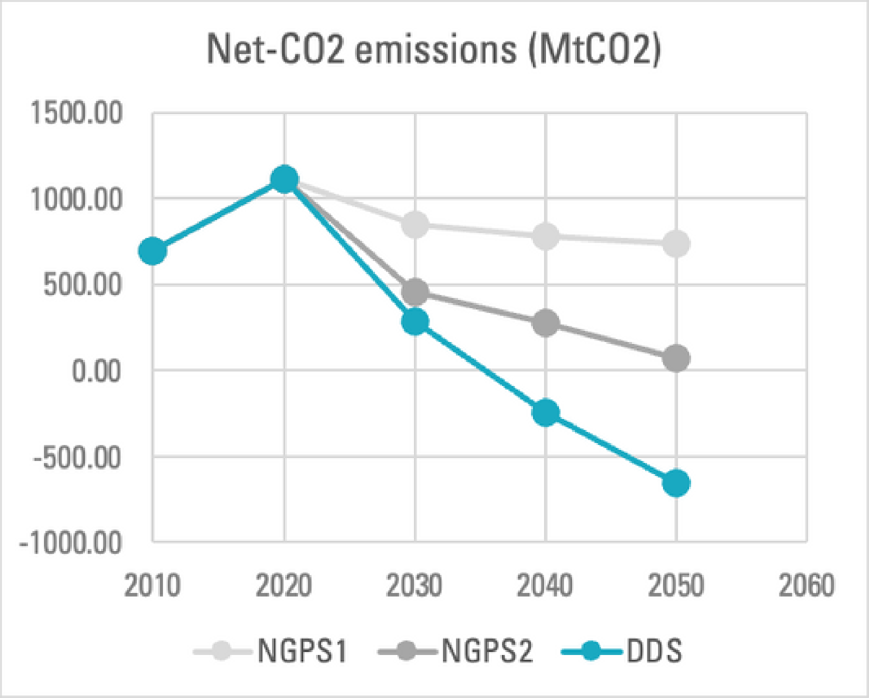
Figure 2. National net GHG emissions

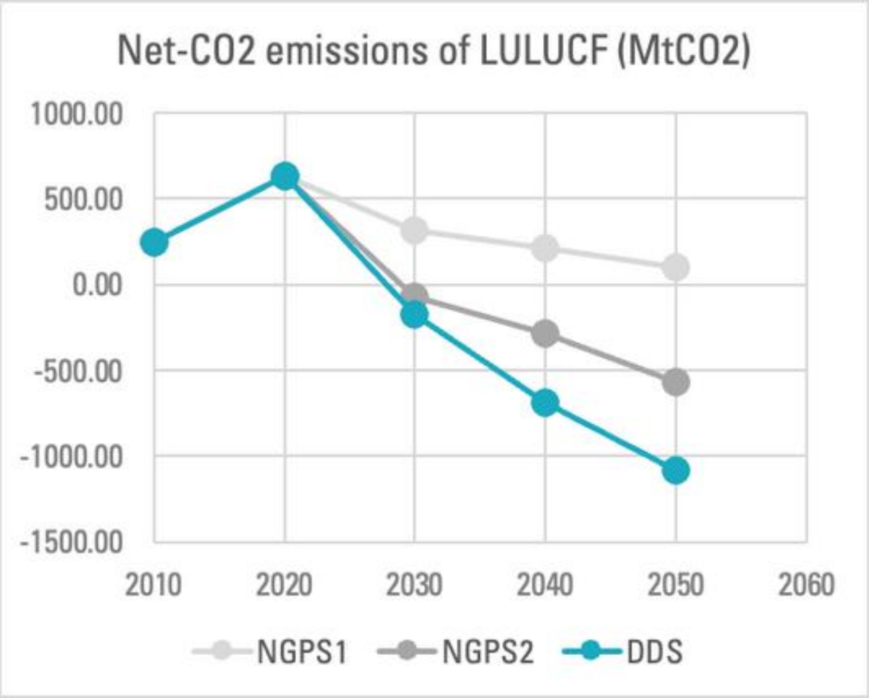


- All scenarios will peak in 2020 at 1755 MtCO2eq, before decreasing at different emissions levels in 2030: from 1600 MtCO2eq in the NGPS1, to 950 MtCO2eq in the DDS. NGPS2 reaches 1200 MtCO2eq, in between. Only NGPS2 & DDS reach the 1200MtCO2eq NDC 2030 obejctive.
- Only the DDS scenario allows to meet the net zero greenhouse emissions target in 2050.

Total net-CO_2 emissions represent about 63% of all net-GHG emissions and could become net-negative by 2050

Figure 3. National net-CO_2 emissions. Top: net-CO_2 emissions. Bottom: LULUCF net emissions.





- CO_2 emissions excluding LULUCF are similar in the NGPS 1 & NGPS 2, as defined in the scenario framing : the only mitigation effort that differ between the two are in the LULUCF sector. When emissions level are similar between NGPS 1 & NGPS2, we'll refer as NGPS.
- Excluding LULUCF, around 75% of CO_2 emissions comes from fuel combustion and are mainly driven by the energy consumption and the current reliance on fossil fuels notably on crude oil and natural gas. Emissions from industrial process represent around 19% of the CO_2 emissions. Agriculture and waste represent respectively 5% and 0,4% of the total CO_2 emissions.

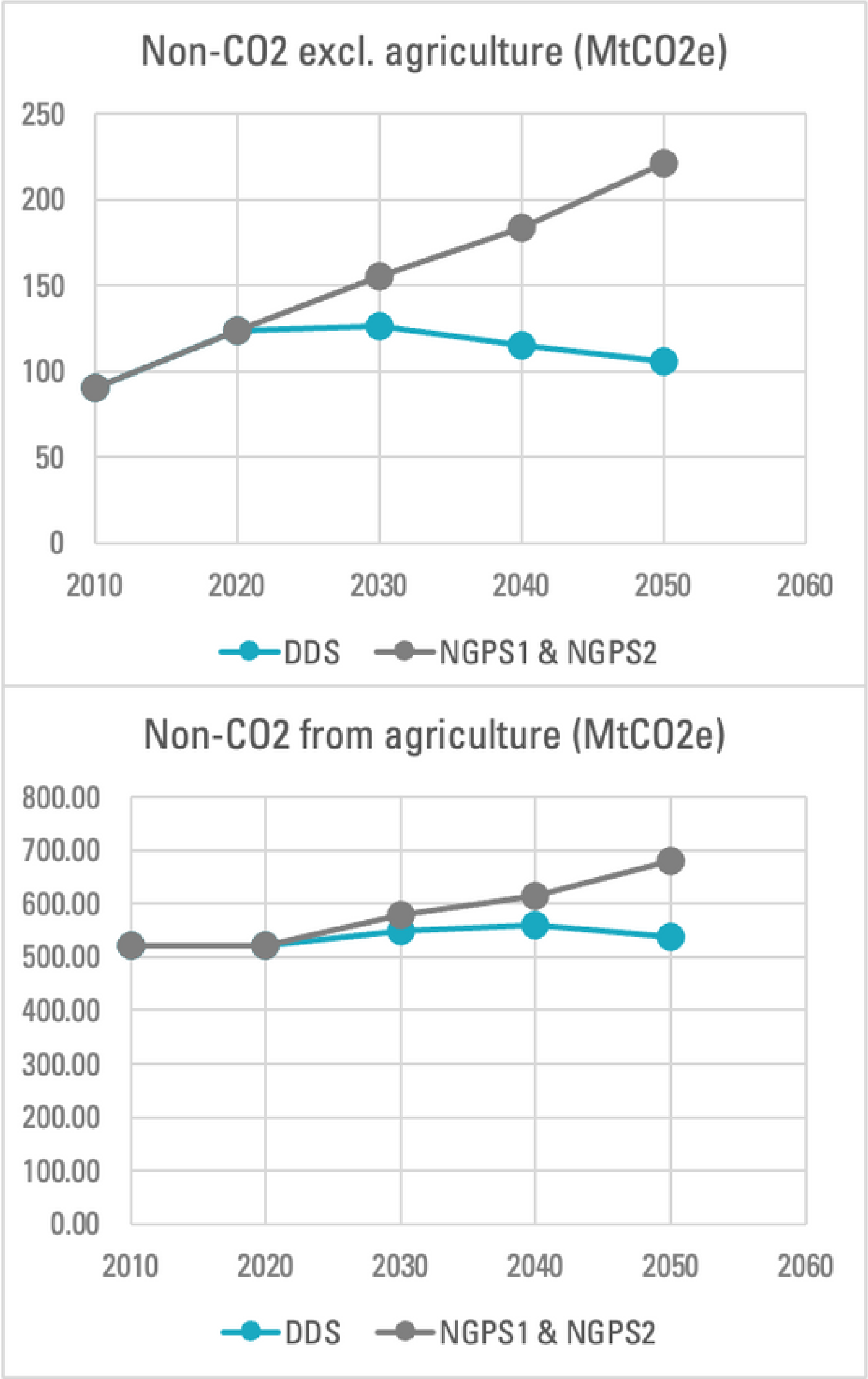
- CO_2 emission sources excluding LULUCF are expected to increase in the NGPS. Emissions decrease after 2022 in the DDS to reach carbon neutrality between 2030 & 2040.
- LULUCF emissions represent 57% of CO_2 emissions in 2020. They become negative in the NGPS2 and DDS between 2025 and 2030, with the DDS reaching negative emissions first. LULUCF emissions in the NGPS1 stay positive, even in 2050. Carbon capture and storable technolologies are not used in any scenario.

The main decarbonization drivers are :

- halting deforestation in the Amazon and a/reforestation.
- climate investments on green infrastructure and sustainable urban mobility & carbone revenues from carbon pricing implemented in 2030.
- the development of renewable energy production (mainly hydroelectric, wind and solar).

Total non-CO2 emissions represent 23% of all GHG emissions and could be reduced by 29% by 2050

Figure 4. National non-CO2 emissions.
Top: Non-CO2 emissions excluding Agriculture.
Bottom: Non-CO2 emissions of Agriculture



Non-CO2 emissions levels are similar in the NGPS 1 &2, as defined by the scenario framing.

Agriculture

·Agriculture makes up 4% of Brazil's GDP, and this share remains relatively stable until 2050 in all scenarios. The sector is more important for exports: 14% of exports came from agriculture in 2020, and 17.5% (NGPS) and 16.5% (DDS) in 2050.

·Agricultural production grows by relatively equal rates in the NGPS & DDS, while non-CO2 emissions increases by 30% in the NGPS and only 3% in the DDS. In the DDS, CH_4 reduces while N_2O increases.

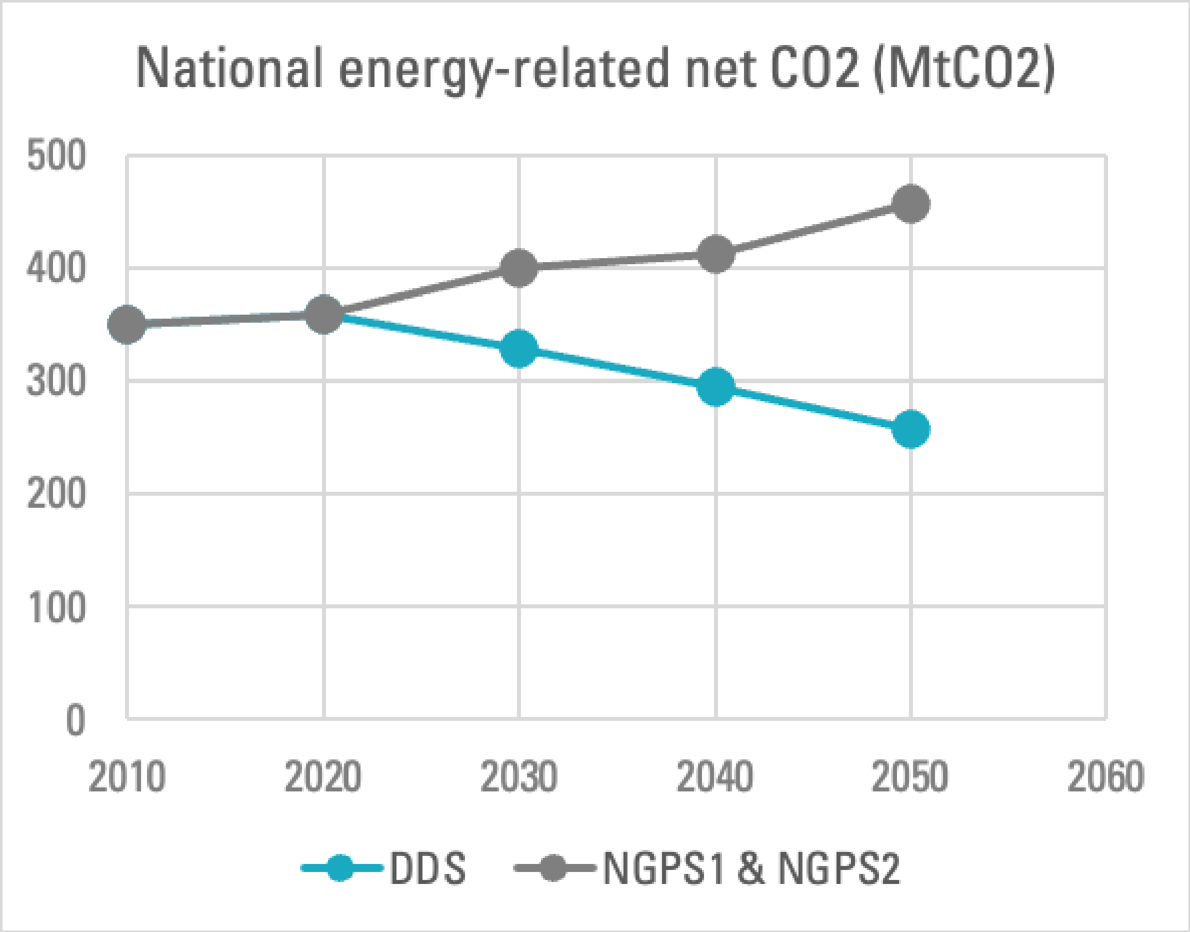
Waste

·Waste is the main other sector emitting non-CO2, both in 2020 and 2050. Other sectors include energy and IPPU.

·Waste management services are limited and don't cover a large share of the population. National policies focusing on solid waste and wastewater sectors will address and extend the coverage of services to all the population until 2040. In the DDS scenario, there is a more ambitious adoption of low emission technologies. Thanks to the higher share of methane (main component of biogas) captured and burnt, and also to some use of biogas as a fuel , GHG emissions are lower than in NGPS.

Total energy-related CO2 emissions represent 20% of all GHG emissions and could be reduced by 44% by 2050 (1/3)

Figure 5. National energy-related CO2 emissions



- Energy-related C02 emissions are similar in the NGPS 1 & NGPS 2, as defined by the scenario framing. Moreover, with this scenario framing, energy-related CO2 emissions are not the main emissions targeted by the mitigation policies in the DDS.
- Energy-related CO2-emissions represented in 2010 the majority of the CO2 emissions, the drivers of decarbonization are therefore similar, notably the increasing share of new and renewable energy sources. However, in 2020, CO2 emissions from LULUCF represent the majority of the CO2 emissions.
- In 2030, DDS shows a lower level of energy-related CO2 emissions than the NSGP, by 18%. It goes until a difference of 44% in 2050. However, energy-related emissions remain significant.
- Energy demand is expected to increase in the NGPS, leading to an increase of the energy-related CO2 emissions, due to a lack of additional climate policies. Those emissions will decrease in the DDS due to lower level of energy demand and to higher mitigation ambitions. Energy-efficiency measures also allow a reduction of the energy-related CO2 emissions.

Total energy-related CO2 emissions (2/3): Reducing energy-related CO2 emissions requires systemic and technological changes to improve energy efficiency and reduce the fuel carbon content

Figure 6 . Final energy consumption (GJ/cap)

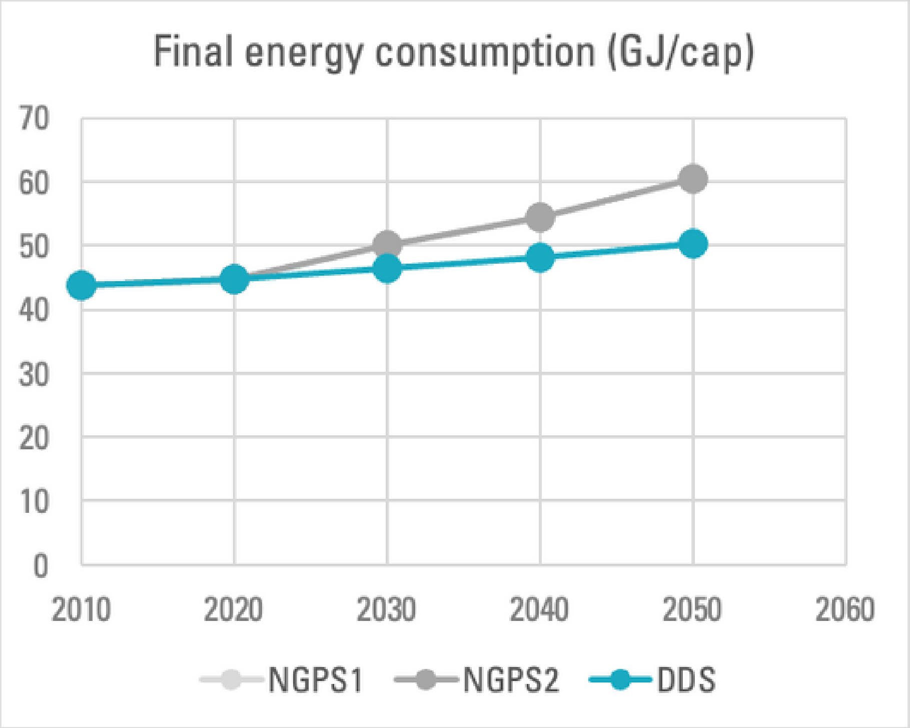
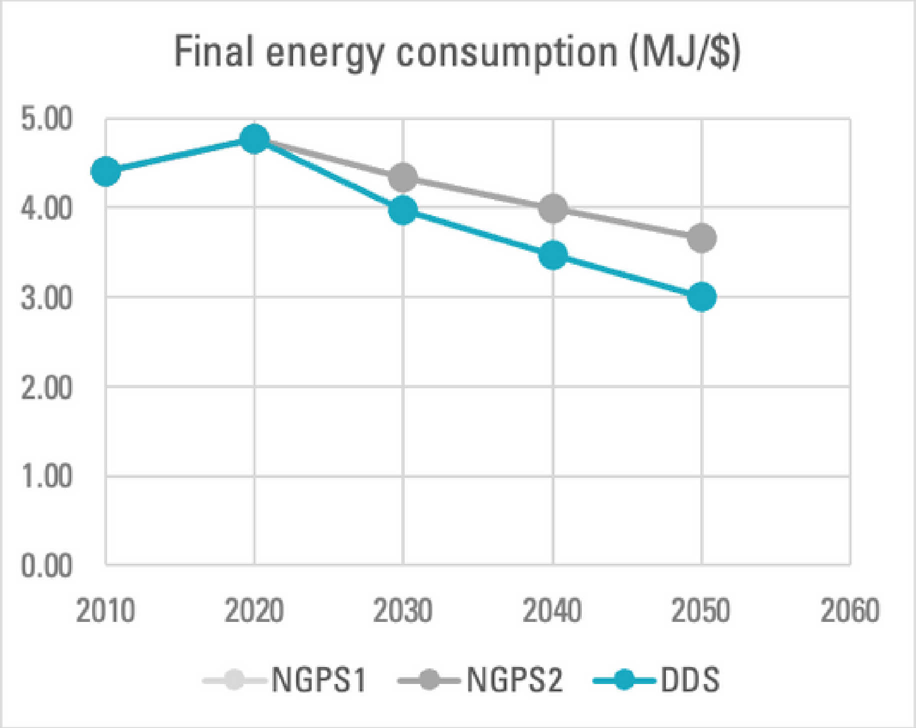


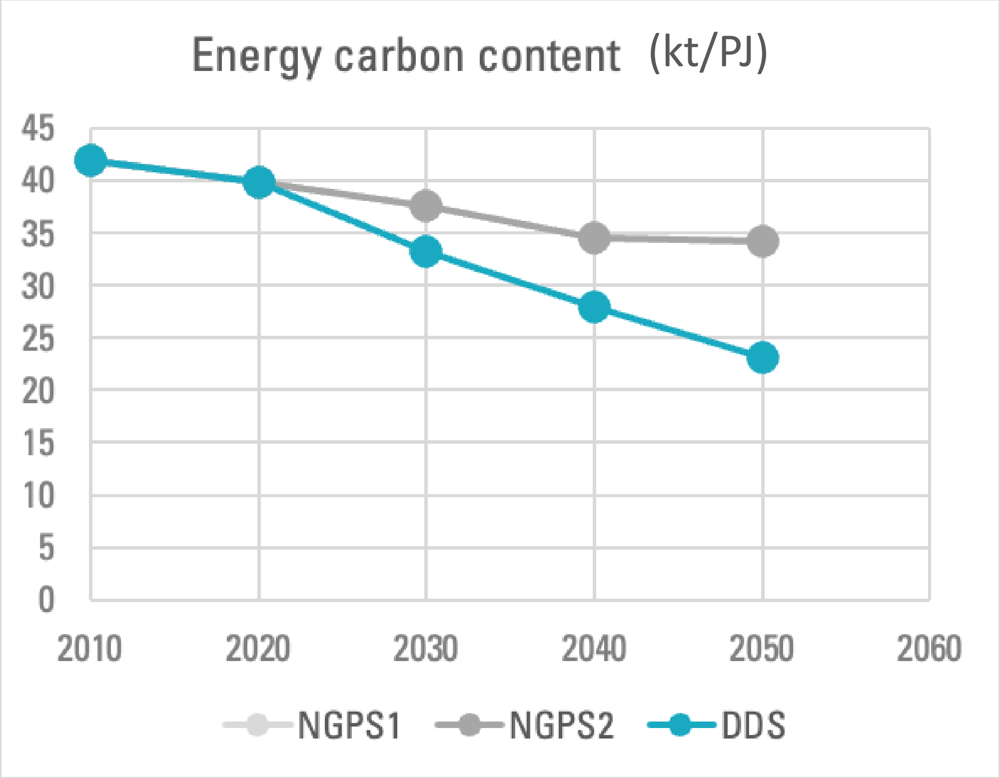
Figure 7. Final energy consumption (MJ/$)



- The energy consumption per capita is increasing in both scenarios by 2050. In the DDS, it stabilizes after 2030, and diverges from the NGPS pathway after 2040.
- Energy intensity reduces (MJ/GDP) increases until 4MJ/GDP unit in 2030 for both scenarios. Then it decreases, with a stronger decrease in the DDS, to reach 3MJ/GDP in 2050.

Energy demand increases due to an increasing energy consumption (building, transport, industries) following increasing GDP/cap.

Figure 8. Emissions per final energy unit (ktCO2/PJ)

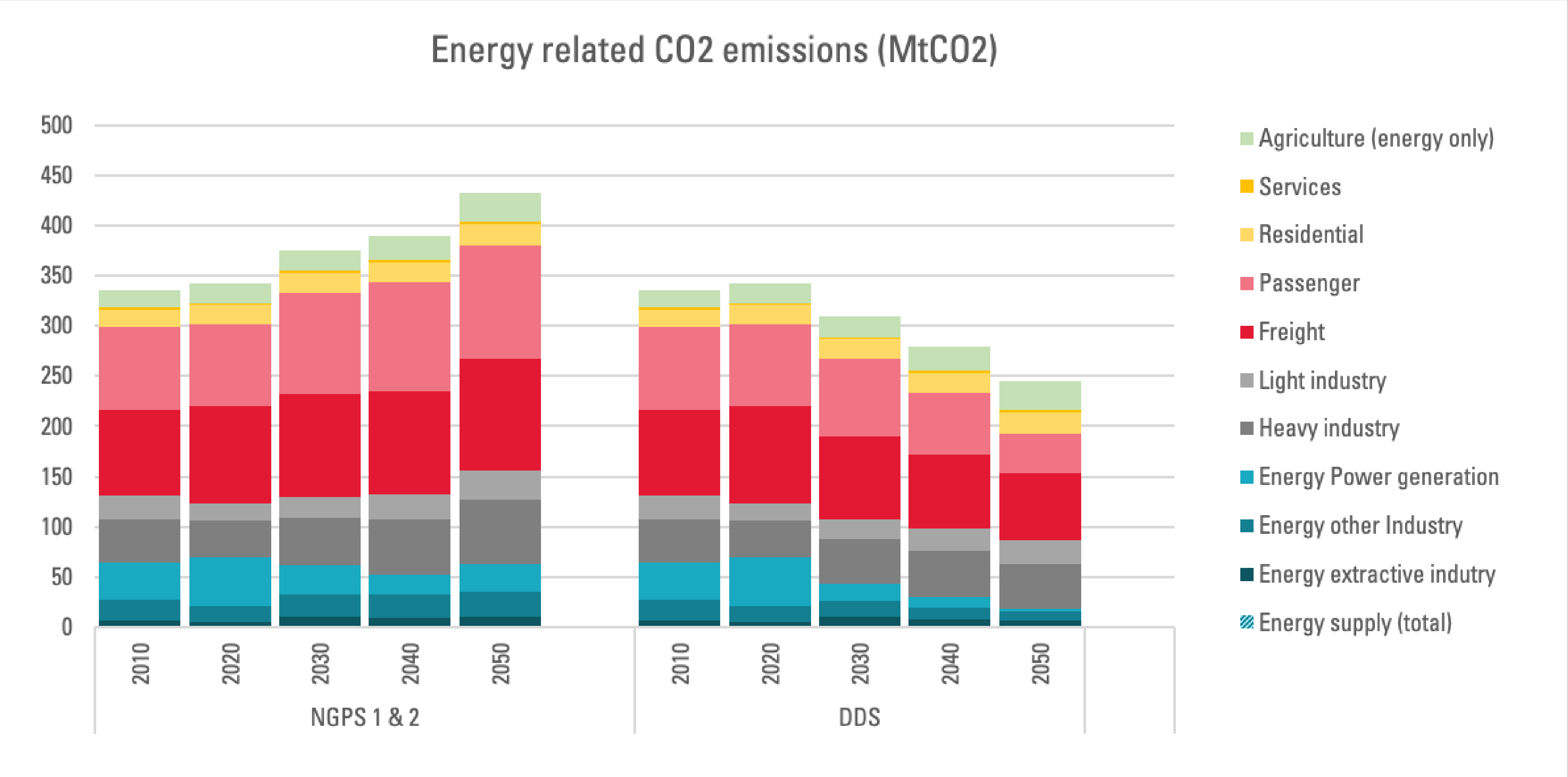


The shift towards zero-emission fuels will enable a decrease in the carbon content of fuels; there is no CCS technologies in the Brazilian scenario.

Carbon content decreases by 12% in 2030 in the DDS in comparison to the NGPS, and then by 32% in 2050.

Total energy-related CO2 emissions (3/3): The key energy-related sectors for deep decarbonization are freight and passenger sector

Figure 9. Energy related CO2 emissions



- Energy-related emissions across sectors are the same in the NGPS 1 & NGPS2.
- In the DDS, we see a clear reduction of the energy-related emissions achieving the overall goal of net-zero GHG emissions by 2050 relies mainly in reaching a zero annual deforestation rate and increasing forest sinks to compensate for residual energy-related GHG emissions. LULUCF emissions represent a high share of the national emissions in comparison to other countries.
- From now until 2030, the energy-consumption sectors with the highest emissions are transports, both freight and passenger and then the power sector, and a majority of mitigation efforts must be concentrated in these sectors to reach the NDC objectives. Mitigation efforts in these sectors in the DDS center on development of renewable capacities & the decarbonization of the fuel carbon content in transports. When comparing the NGPS and the DDS in 2050, we see that emissions cuts comes from the same main emitting sectors. No mitigation efforts are made in buildings or agriculture; little mitigation efforts are made in energy-intensive industry after 2030.

Part 2

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Sectoral deep decarbonization pathways in the DDS scenario

Part 2.1

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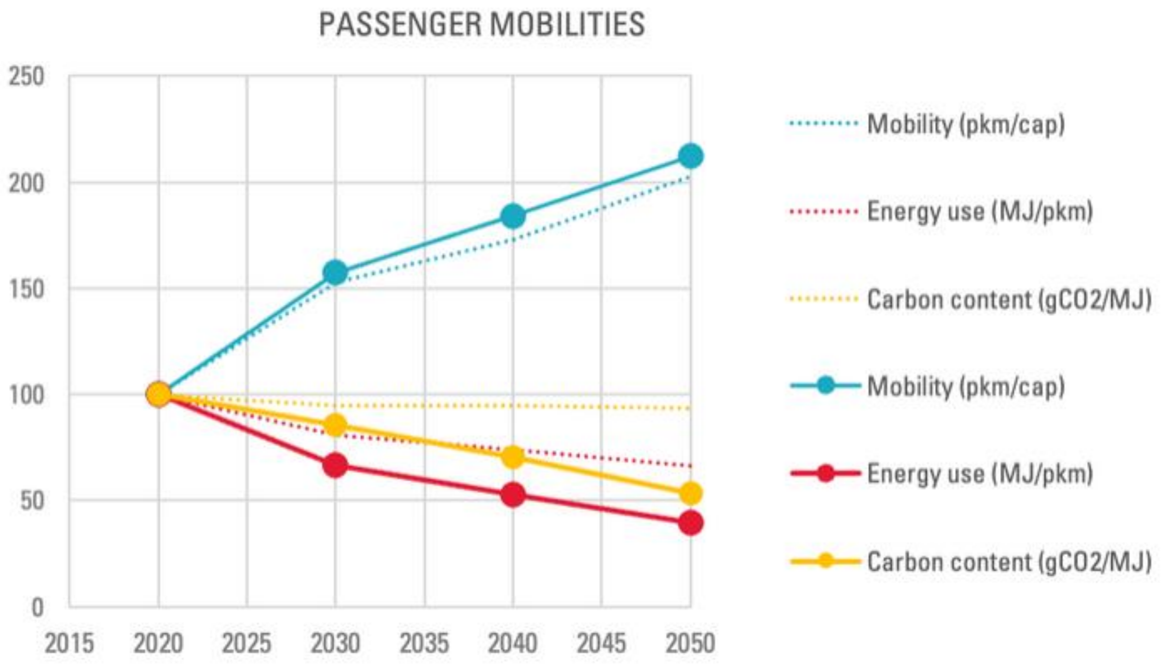
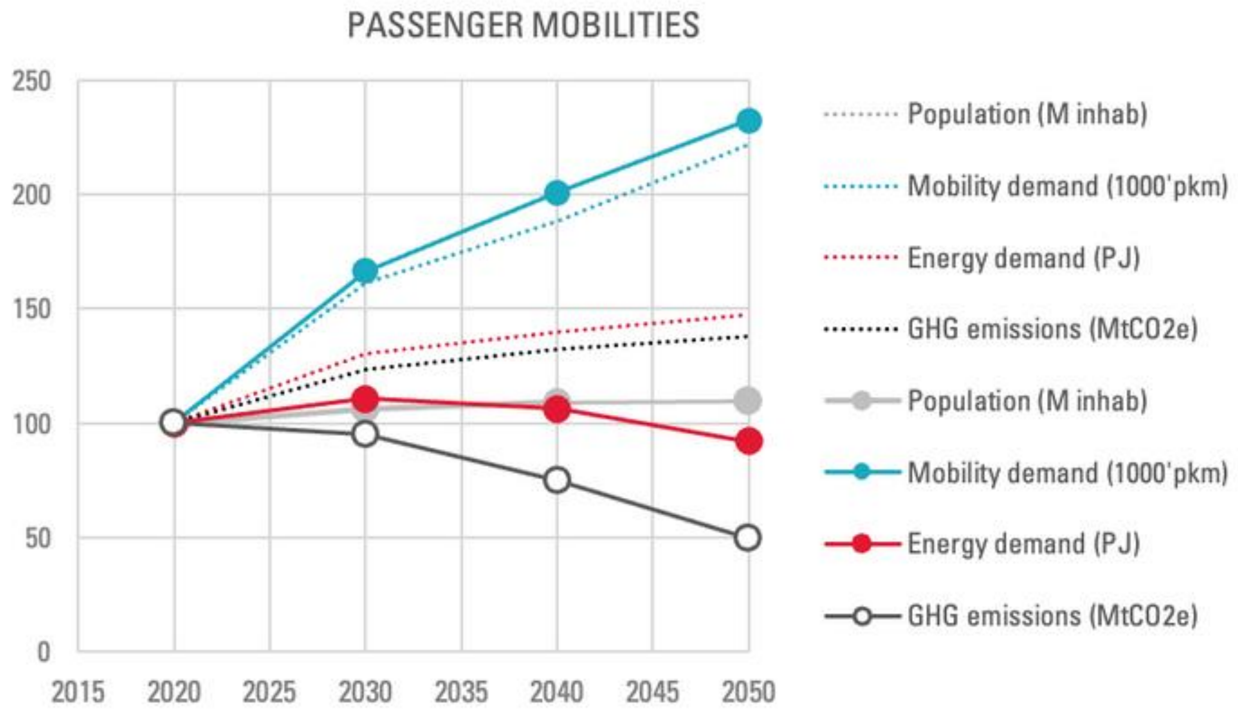
Transition of energy-related emission sectors: Transport, Buildings, Industries

Developing Paris-compatible PASSENGER MOBILITIES

Figure 12. Sectoral emission drivers and main aggregates (Index, 2020 base year)





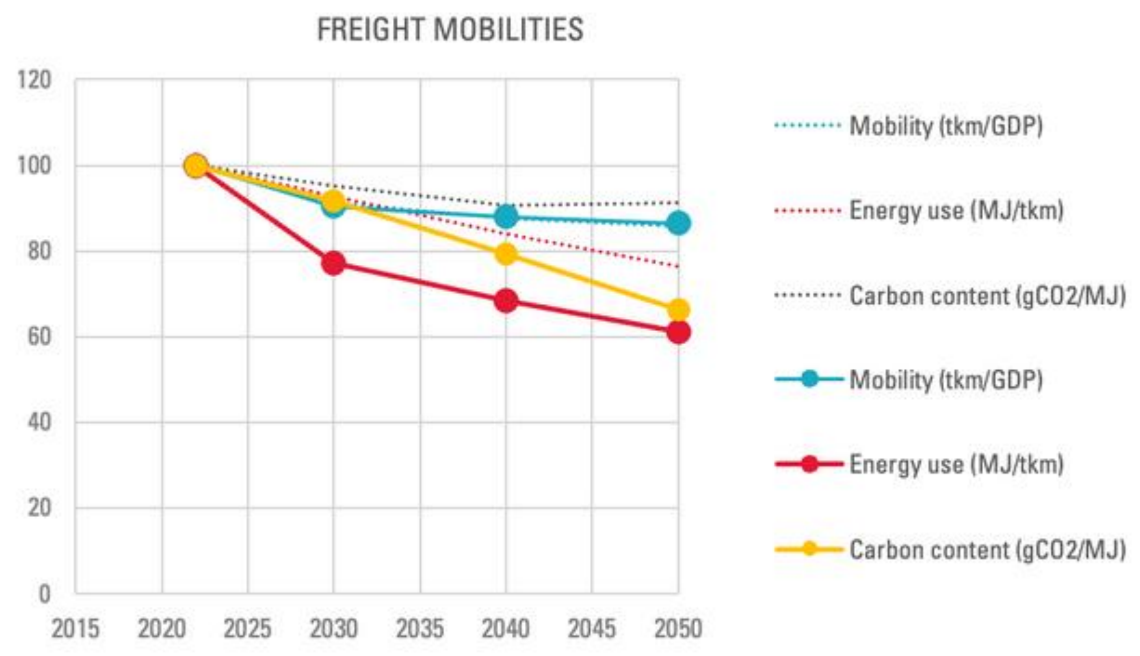
- In both scenarios, mobility demand is almost doubling between 2010 and 2050, but with different socio-organisational realities. In the DDS scenario, the urban, land use and transport systems are better planned together in densely populated urban areas. It supports a decentralization of activity centers aiming to alleviate commuting pressures and congestions, to facilitate access to jobs and services. It drives investments in public transport and pedestrian-friendly infrastructure environments to encourage an increase of walking, cycling (9,1% in 2050), and public transport (40,5% in 2050) and moderate private (cars and 2W) mobility development. While this approach contribute to diminish travel time, distances and household expenditures, it is assumed a rebound effect to more leisure activities and associated transport. However, these changes contributes to reduce energy consumption per pkm up to 56% by 2050.

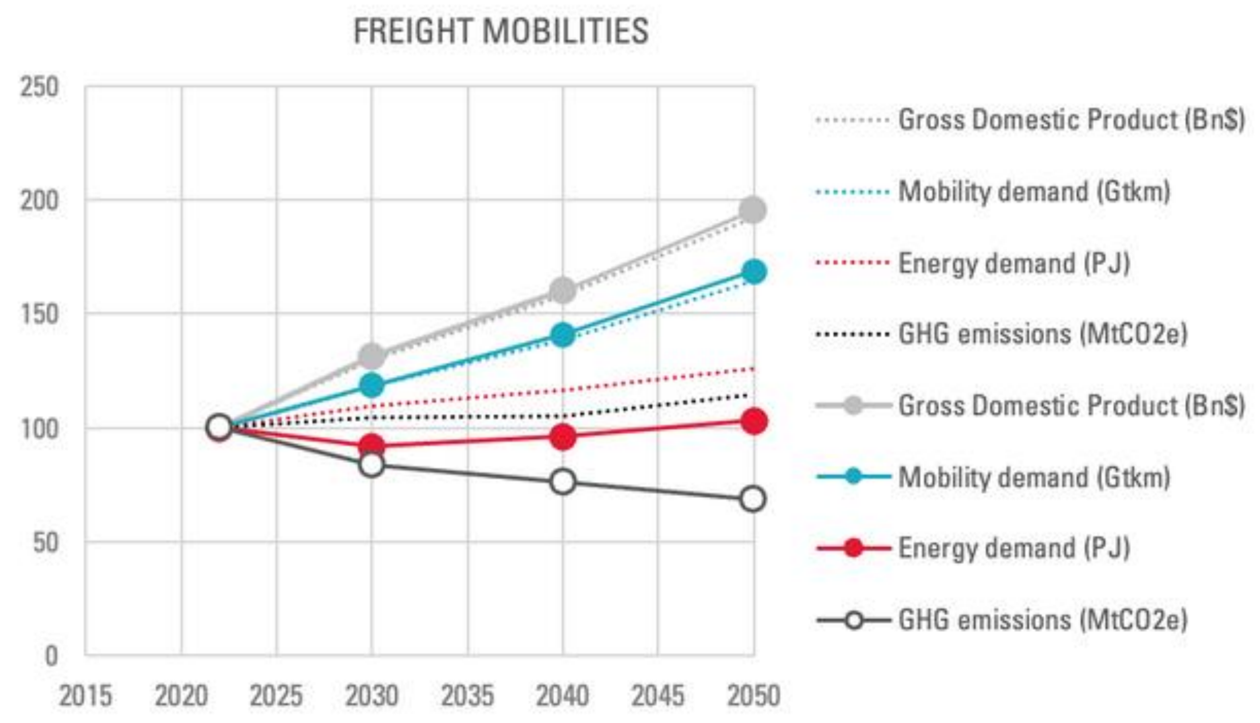
- Regarding the vehicle and fuel transition, the share of non-fossil fuels reaches up to 67% by 2050 compared to 41% in the NGS1. This is due to an increased electrification of cars and 2W mostly in urban areas. Brazil's advancement in standards, regulations, concession models, training programs, financing options, and business models from 2030 onwards mirrors the pace of electromobility adoption seen in leading regions such as Europe, the United States, and China. The emergence of new local manufacturers specializing in electric vehicles and components for cars and buses reshapes the industry landscape, resulting in price reductions and increased accessibility, negating the necessity for government incentives. Credit facilities aimed at financing electric vehicles, particularly for intensively used vehicles like those in e-hailing applications, further drive early adoption and the development of a second-hand market. Government incentives aimed at reducing the average age of light passenger vehicles and promoting the scrapping of older ICE vehicles. Electric utilities deploy new technologies to address the challenges of smart grids, paving the way for a gradual increase in the role of electricity in the transport sector. BEV sales represents 100% of 2W sales by 2050 and 59% of car sales, compared to 33% and 23% in the NGPS1.

- Combined these transformations enable to moderate passenger transport energy consumption, peaking around 2030 and coming back in 2050 to the level of 2010, compared to a 60% increase in the NGS1. In addition, it enables to cut emissions by half over the period 2010-2050, while the current policies would lead to a 37% increase of emissions by 2050.

Developing Paris-compatible FREIGHT MOBILITIES

Figure 13. Sectoral emission drivers and main aggregates (Index, 2020 base year)





- In both scenarios NGPS1 and DDS, the industrial and economic system remain based on a strong agriculture economy (ca. 10-15% of tkm) coupled with a strong manufacturing sector (45-50% of tkm), which drive GDP increase by 90% and total freight transport demand by ca. +120%.

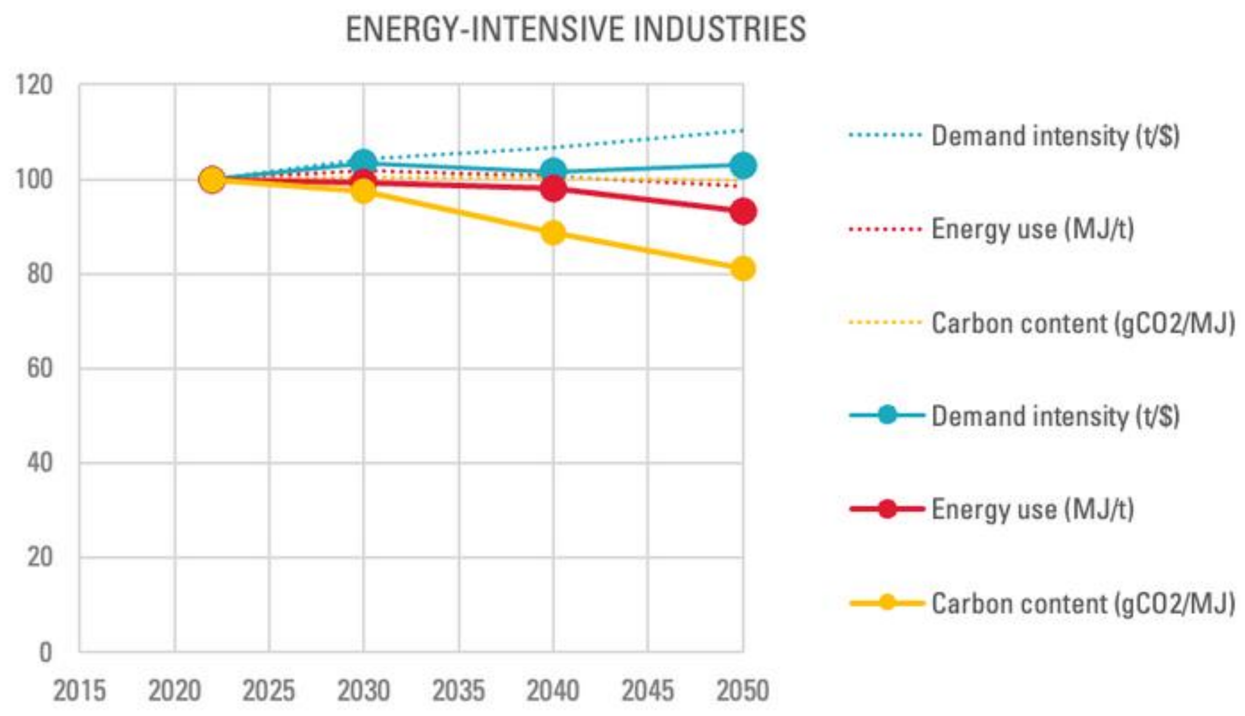
- However in the DDS scenario, two additional strategies enable a better improvement of energy efficiency. One rely on an acceleration of infrastructural and regulatory change to boost rail freight (up to 55% compared to 49% in NGPS1) for long-distance transport, and the other rely on better road logistics regulation and incentives to improve the loading factors and reduce empty running.

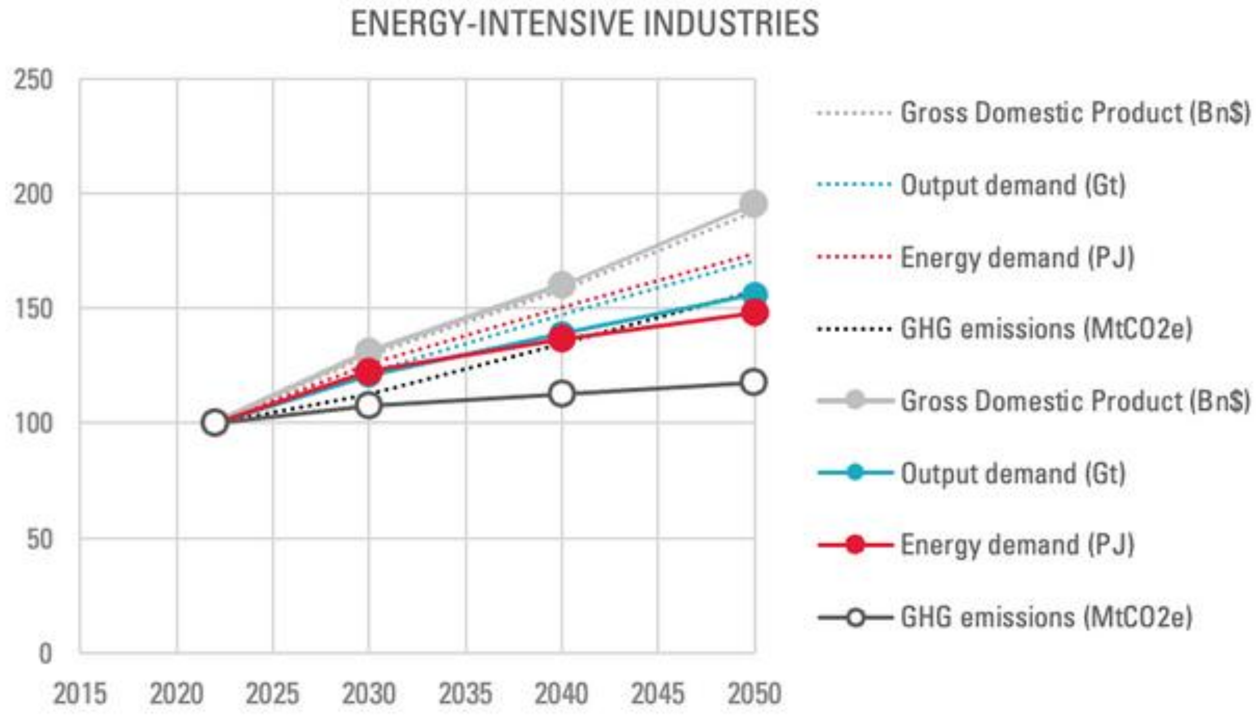
- Finally, the decarbonisation of fuels is accelerated compared to NGPS1 and non-fossil fuel energy represents up to 40% of final energy consumption by 2050 compared to 20%. This is mainly due to an acceleration of road freight electrification and increase production of liquid biofuels. Increased investments in local manufacturing for electric vehicle components as well as charging stations around main highways facilitate cost reduction and penetration of road battery electric vehicles for regional transport. In 2050, BEV sales represents 100% of LCV sales and 37% of HGV sales, compared to 65% and 11% in the NGPS1. The increased production of biodiesel is made possible through the reinforcement of the RenovaBio program.

- Combined these transformations enable to moderate freight transport energy consumption and to cut emissions by 22% over the period 2010-2050, while the current policies coud lead +31% increase of emissions by 2050.

Developing Paris-compatible ENERGY-INTENSIVE INDUSTRIES

Figure 14. Sectoral emission drivers and main aggregates (Index, 2020 base year)





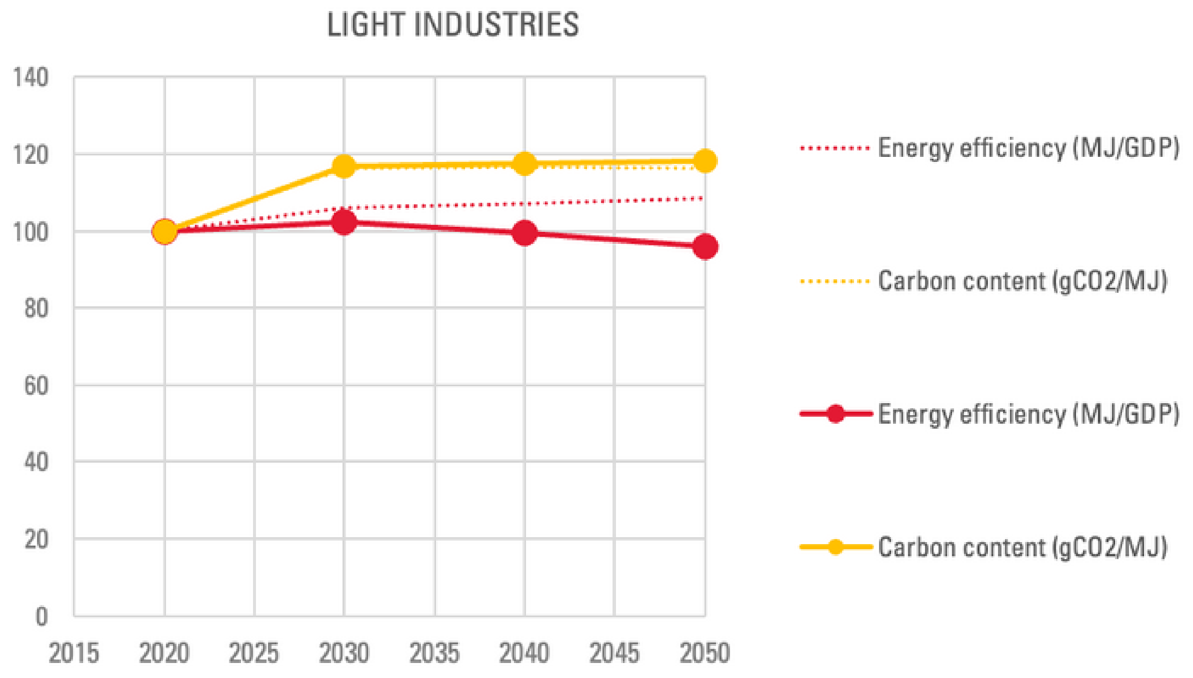
- The level of industrial activity in Brazil follows the trend of the country's GDP, although the industry sector's share of the national GDP is decreasing. The Brazilian industry has faced successive crises since the 2008 global economic downturn. The industry is expected to be in a recovery process until 2025.
- The main emitting energy intensive industries in Brazil are Iron & Steel, Cement, Chemicals, Non-ferrous and Other Metallurgical and Pulp and Paper.
- Emissions stay stable in the DDS in comparison to the NGPS where they increase : there is no major decarbonization strategy. However, in the DDS, both the efficiency gains and the shift from high-carbon to lower-carbon fuels are more pronounced than in the NGPS.
- The DDS net emissions for the EEI were 143 MtCO2e, 25% lower than the NGPS scenario, with EEI contributing to 68% of total industrial emissions in 2050. The goal was to achieve national net-zero without adding mitigation constraints on the Brazilian industrial sector.

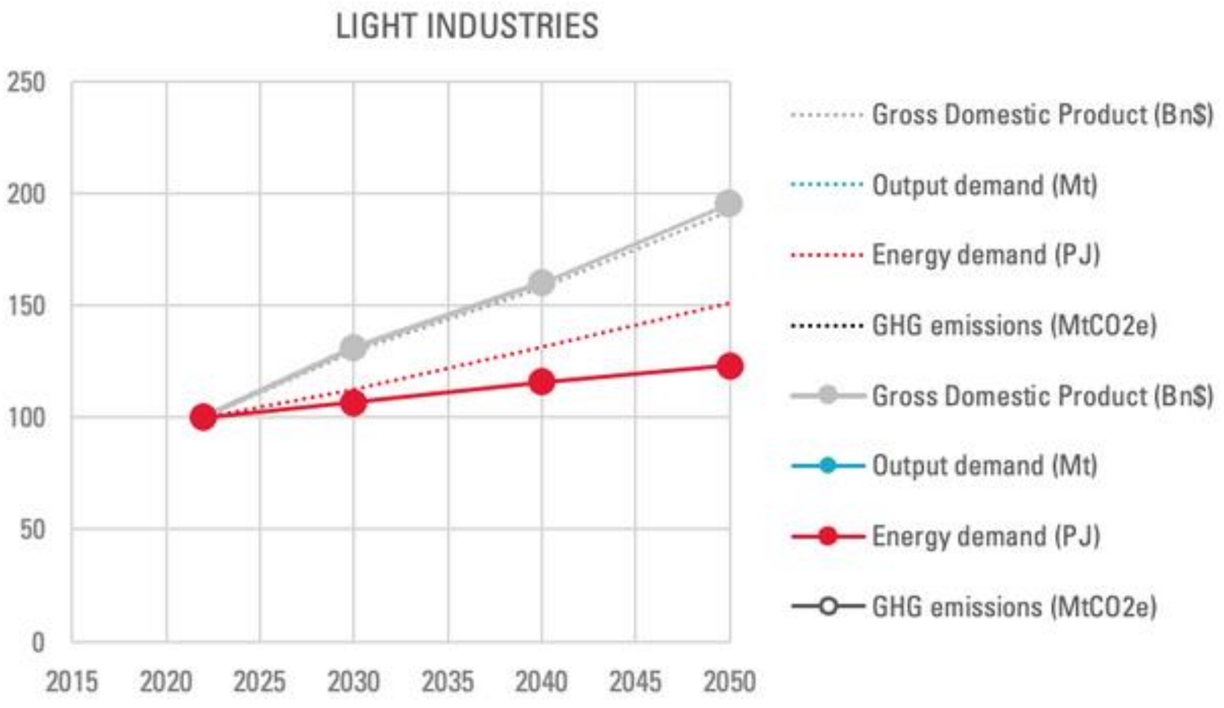
The main drivers of GHG emissions pathways are:

- the electrification in all energy-intensive industries and switching from fossil fuels and gas to renewable energies.
- energy efficient systems and process optimization.
- the key additional policies to compared to the BAU should focus on energy efficiency, fuel switching, and the introduction of new feedstocks in the industry

Developing Paris-compatible LIGHT INDUSTRIES

Figure 15. Sectoral emission drivers and main aggregates (Index, 2020 base year)





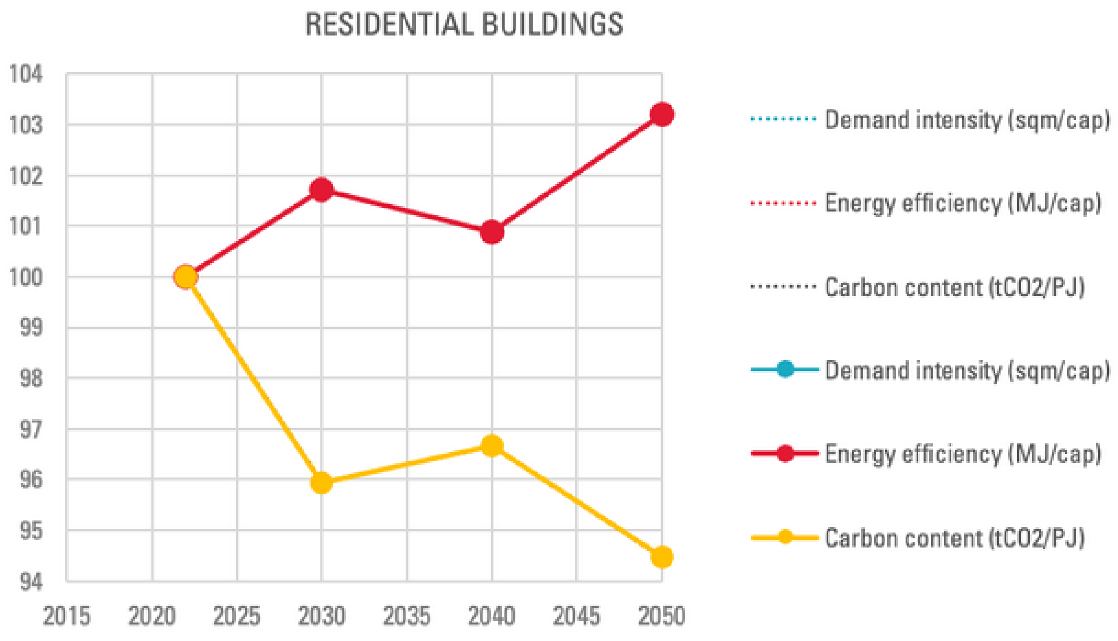
- The level of industrial activity in Brazil follows the trend of the country's GDP, although the industry sector's share of the national GDP is decreasing.
- The main emitting light industries in Brazil are Food and Beverage, Textiles and Other Industries.
- Same measures as for the energy-intensive industries, with no major mitigation strategy. The DDS net emissions for the light industries are 69 MtCO2e, 8% lower than the NGPS scenario in 2050.

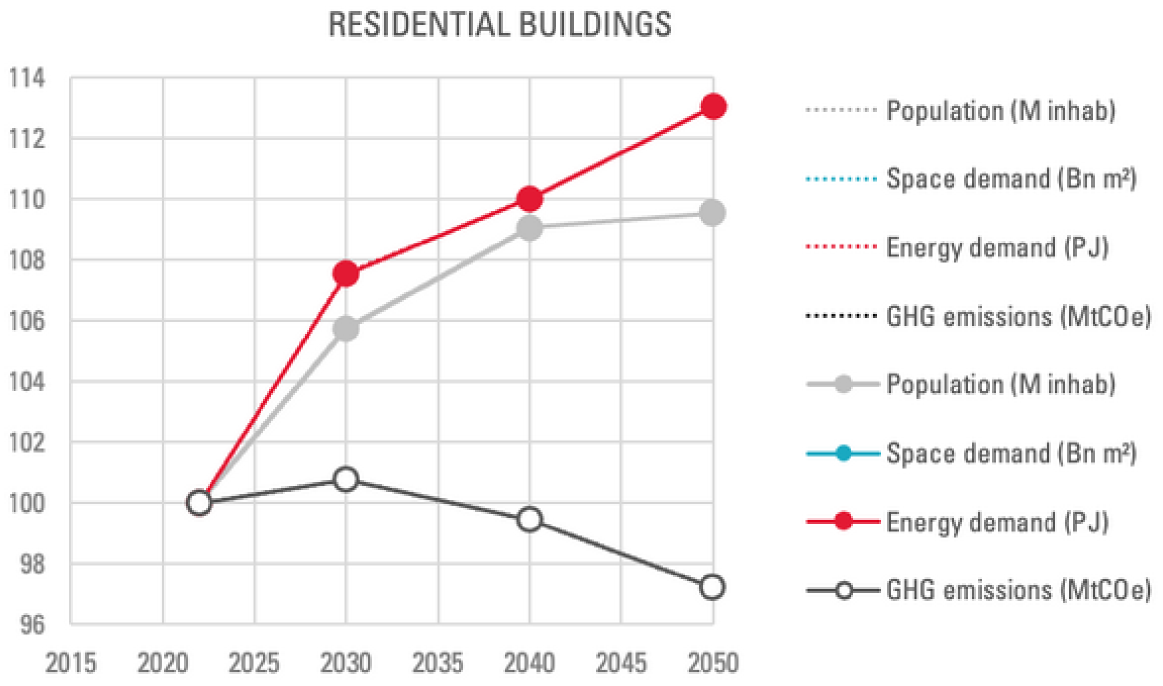
The main drivers of GHG emissions pathways are:

- the electrification in all energy-intensive industries and switching from fossil fuels and gas to renewable energies.
- energy efficient systems and process optimization such as combustion optimization and heat recovery.

Developing Paris-compatible RESIDENTIAL BUILDINGS

Figure 16. Sectoral emission drivers and main aggregates (Index, 2020 base year)





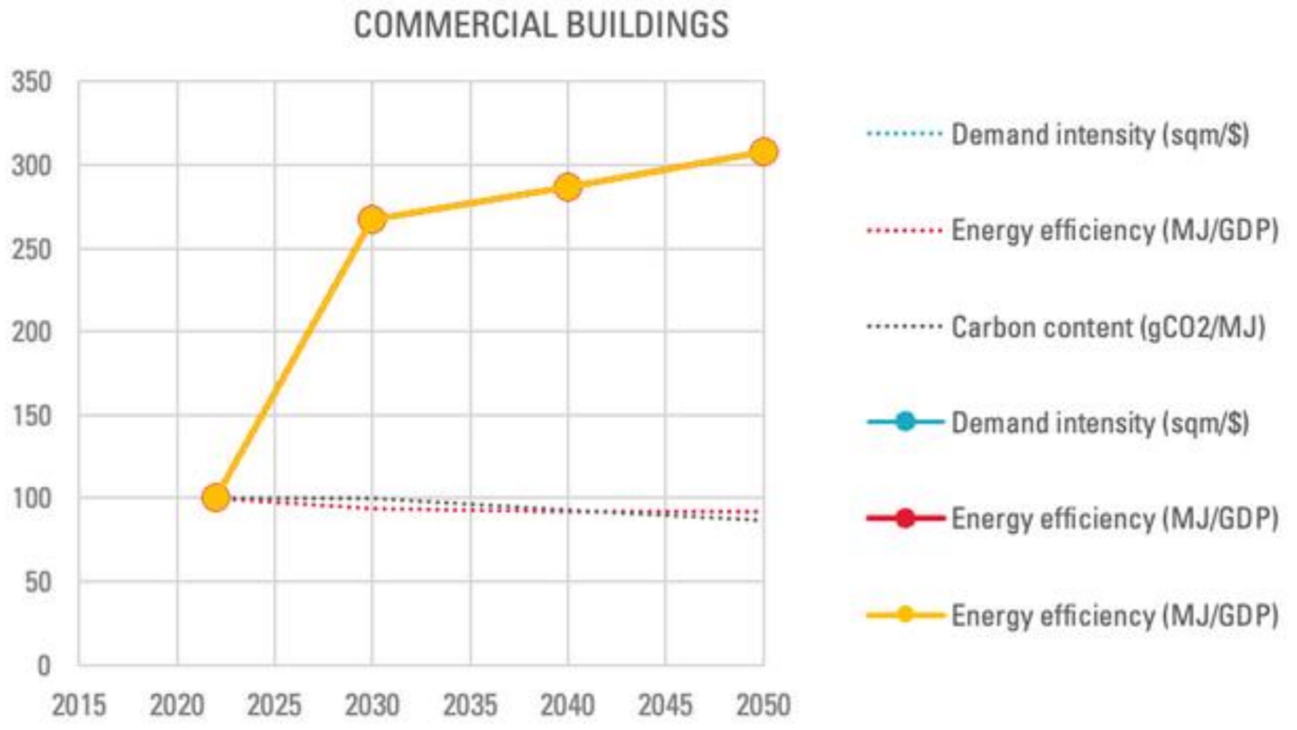
- Emissions from residential buildings account for 1.3% of the country's emissions in 2020.
- In this sector, 51% of energy use was for cooking, mainly from firewood, LPG, natural gas, and charcoal in 2022. Electricity contributed 46%, while solar thermal made up 3% of the energy mix.
- From 2012 to 2022, average electricity household consumption increased from 153 kWh/month to 179 kWh/month, a 17% growth. In the same period, per capita consumption went from 0.61 to 0.77 MWh/inhabitant an increase of 26%) and the total electricity demand increased by 32% due to the increase in the population growth in the period.

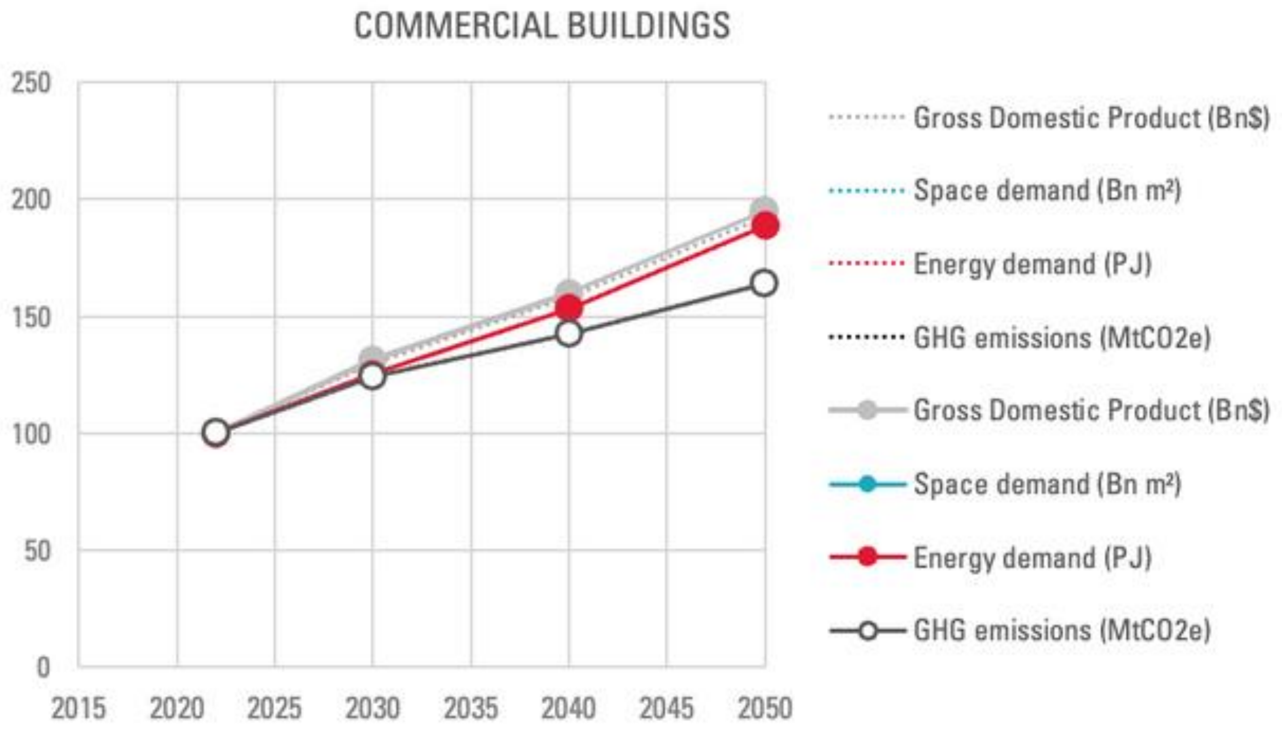
- LPG is the main emission source and will make up to 89% of the sector's emission by 2050. There is no decarbonization strategy for buildings in the DDS. Residential emissions are similar in the DDS and the NGPS : the study employed the per capita electricity consumption of Italy in 2020 as a proxy for Brazil's anticipated value in 2060.

The main driver of decarbonization is an increasing electrification in households to replace fuel use.

Developing Paris-compatible COMMERCIAL BUILDINGS

Figure 17. Sectoral emission drivers and main aggregates (Index, 2020 base year)





- The urban planning we anticipate is influenced by South Africa's significant urbanisation trend. More people are relocating to urban areas in pursuit of improved economic prospects. The growth rate of new building construction is gradual, reaching its peak around 2041 with the addition of 3.82 million m2 between 2040 in the REF / 4.78 million m2 in the 8GT. This indicator displays a two-year temporal lag in response to fluctuations in GDP.
- The decarbonization strategy relies on the reduction of the carbon content, the improvement of the energy efficiency & the reduction of the demand intensity.

The main drivers are :

- the decreasing carbon content due to a further acceleration of sustainable designs and renewable energy solutions.
- Increased adoption of sustainable and energy-efficient designs.
- Urban planning addressing spatial inequalities and fostering social cohesion. A more compact urban planning will lead to also reduce transportation needs.

The key additional transformations to compared to the REF should focus on developing on compact urban planning, increase the access to essential utilities,and developing sustainable designs and smart grid technologies

Part 2.2

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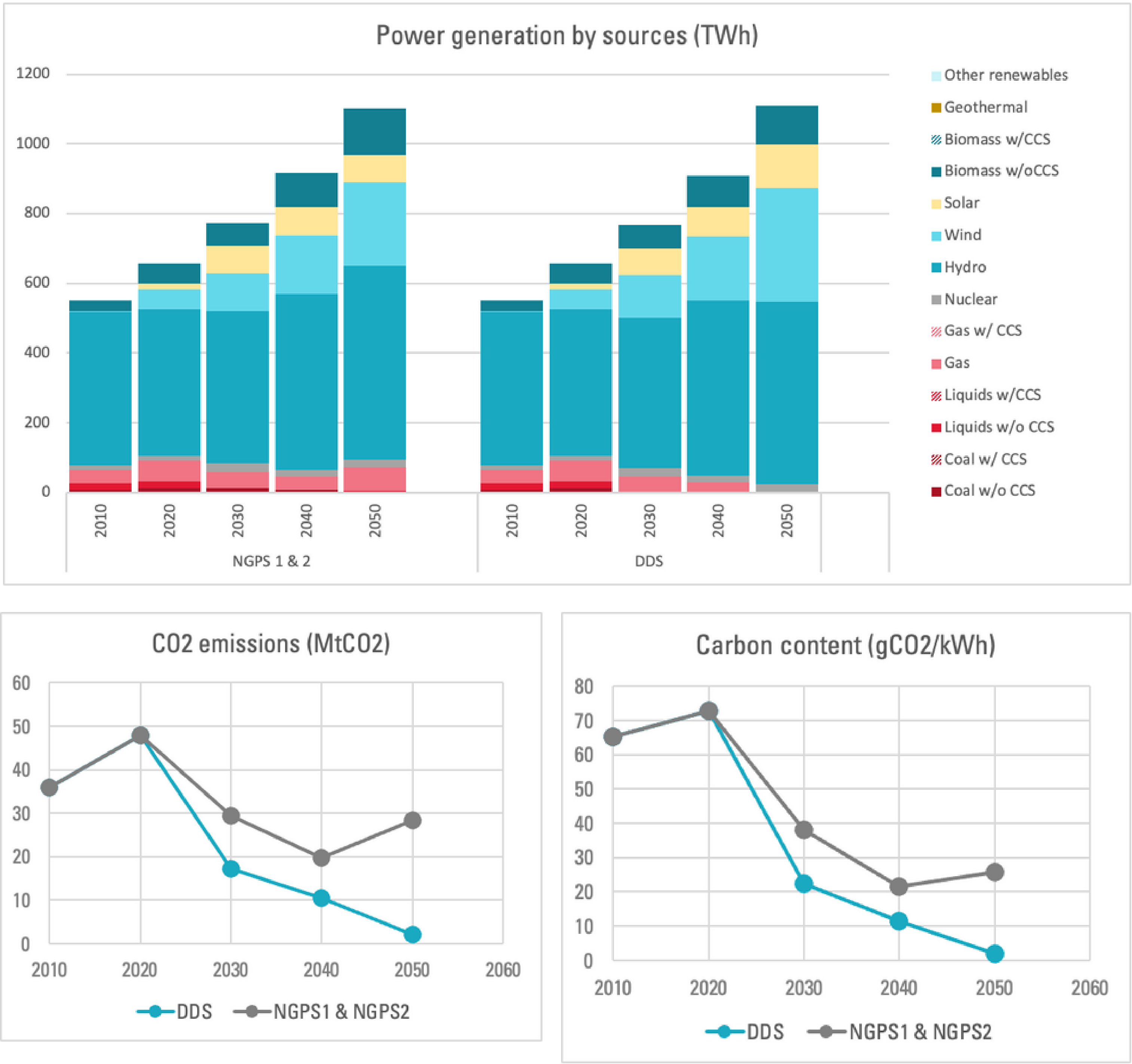
Transition of energy-related emission sectors: Power generation, Extractive energies, Other energy production

Decarbonizing POWER GENERATION

Figure 18. Power generation by sources (Top, in TWh) and production emissions / electricity carbon content (Bottom, in MtCO2 & gCO2/kWh) .



- Power generation is expected to increase similarly in all three scenario, to 5 TWh/cap in 2050. However, we observe in the DDS a strong decarbonization of the power production: Brazil continues to produce and import fossil primary energy, including coal and liquid fossil fuels, there is a concerted effort to diversify the power mix with renewables and replace fossil fuel power plants by renewable capacities.

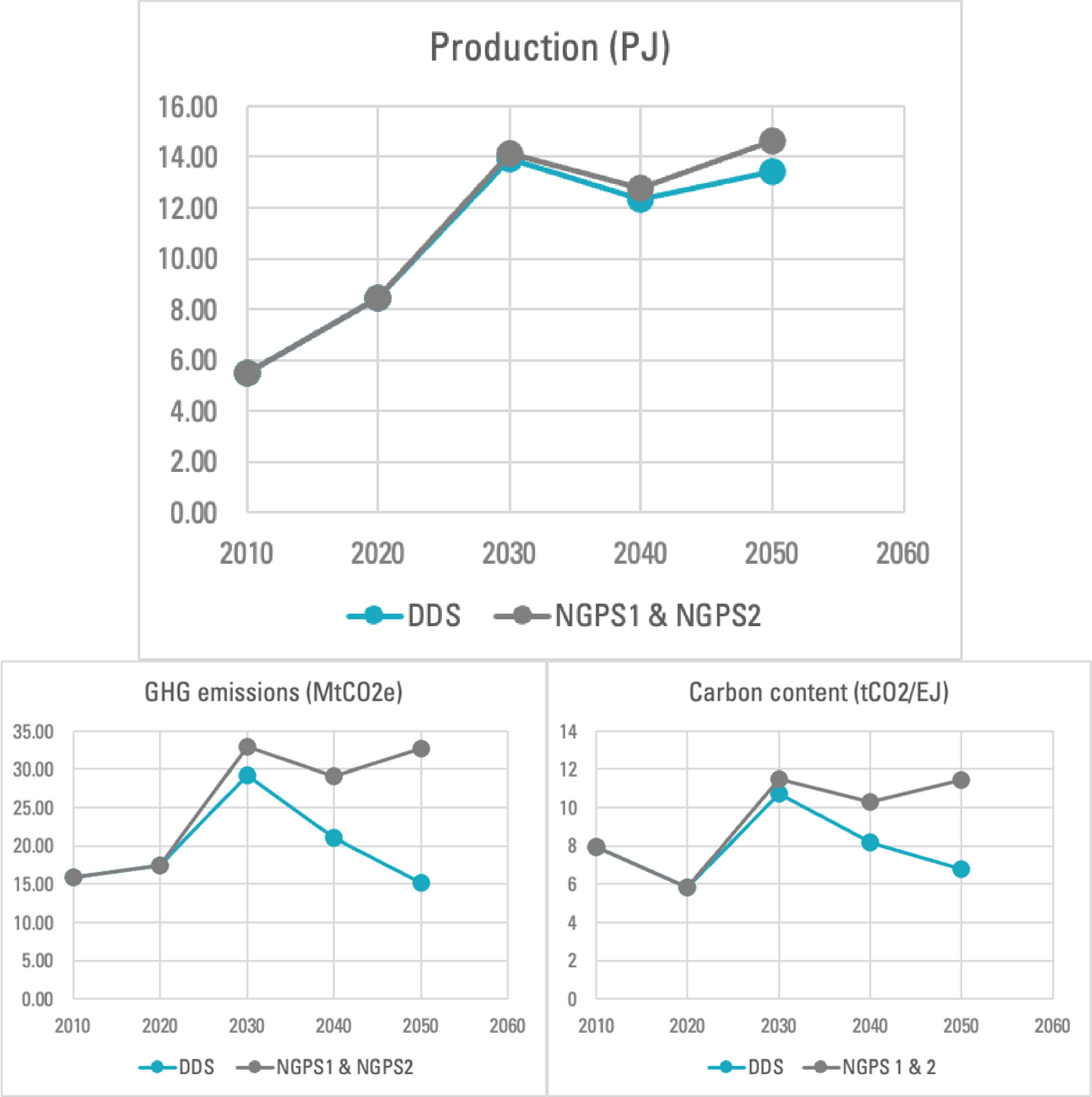
The main drivers are :

- a massive electrification, notably in the transport and industrial sector: total electricity demand increased by 24% from 2020 to 2030, by 45% from 2030 to 2050.
- the decarbonization of electricity production. This can be achieved with large-scale deployment of renewables :hydro, wind (onshore and offshore), and solar power. The carbon intensity has seen a substantial decline, dropping from 72 gCO2/kWh in 2020 to 22 gCO2/kWh in 2030, and it continues to decrease further, reaching 1.8 gCO2/kWh by 2050.
- the expansion of transmission infrastructures.

The key additional transformations to compared to the NGPS should focus on promoting energy efficiency and the electrification of sectors like transportation, to play a pivotal role in achieving a more effective utilization of electricity. Moreover, In this scenario, there is a carbon tax that reaches \$2/tCO2e in 2030, \$31/tCO2e in 2040 and \$44/tCO2e (\$2020 prices) by 2050. This carbon tax incentivizes significant gains in both energy efficiency and the use of lower-carbon energy sources.

Decarbonizing EXTRACTIVE ENERGY INDUSTRIES

Figure 19. Coal, Oil and Gas production (Top, in PJ) and production emissions / carbon content (Bottom, in MtCO2e & MtCO2/MJ).



- A substantial growth in Exploration & Production (E&P) activities is due to an important increase in offshore oil and gas production from the pre-salt layer. Increasing shares of oil production are progressively directed towards exports as production costs are kept low and remain competitive in the world market.

- The declining demand for coal in the Brazilian supply energy landscape is attributed to the diversification of the power mix. Government initiatives (historical- to incentivize the adoption of wind, small hydro, solar, and biomass technologies, various measures have been implemented, including discounted tariffs, reduced import taxes, and subsidies) and market dynamics (cost reduction) have facilitated the growth of renewable energy sources, further diminishing the demand for these high-carbon energy products.

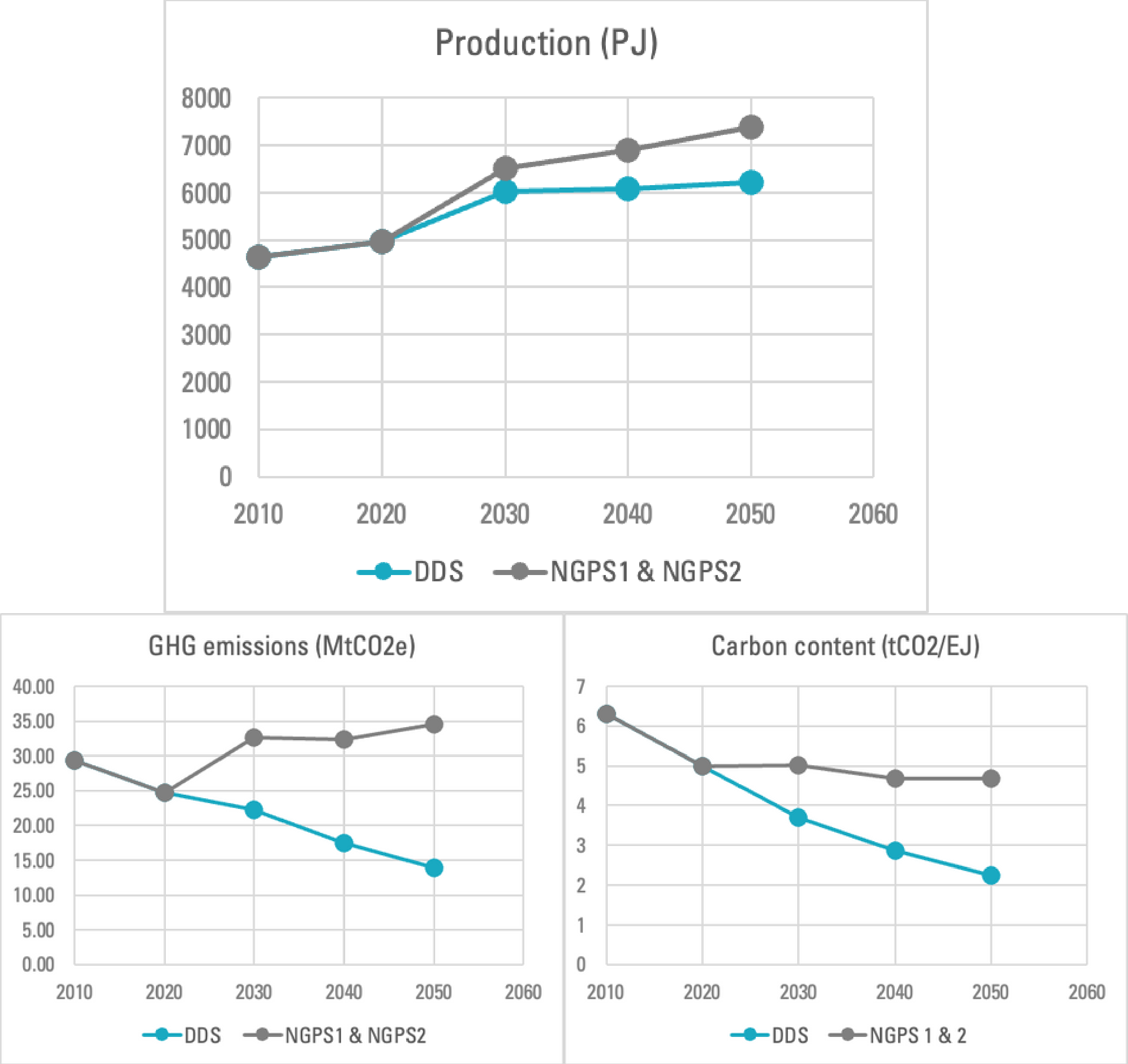
- The DDS shows an increase of emissions from extractive activities until 2030, and then a decrease, to eventually reach 2010 level of 15MtCO2eq . The main decarbonization strategy comes from a lower production of gas after 2030 (2J of gas instead of 3EJ). The DDS & NGPS have similar strategies in terms of coal assets decomissing and oil production for export, reaching similar production levels.

The key additional transformations should focus on accompany the strategic decomissioning of the coal power plants and the slow phasing down of natural gas.

According to the 2023 Petrobras Sustainability Report, the carbon intensity in the E&P sector is expected to decrease by 32% by 2025 compared to 2015 levels, a trend that will be maintained until 2030. The study also anticipates further reductions, reaching 41% by 2040 and 57% by 2050, all compared to 2015 levels. These reductions are attributed to autonomous energy efficiency improvements, transitioning to electrified upstream operations, fuel switches and the adoption of more efficient equipment.

Decarbonizing OTHER ENERGY PRODUCTION INDUSTRIES

Figure 20. All other final fuel production (Top, in PJ) and production emissions / carbon content of energy produced (Bottom, in MtCO2e & MtCO2e/MJ)



***All other solid, liquid, gaseous final fuel production activities (e.g. refineries, H2 generation, …)**

- In Brazil, there is a strategic diversification of the energy mix to reduce reliance on fossil fuels. This strategy focused on the development of biofuels and cleaner alternatives. This initiative has resulted in an overall reduction of demand for traditional liquid fuels, especially in the transportation sector, where demand of liquid fuel is primarily shaped.

- The DDS differs after 2030 in comparison to the NGPS: production stabilizes after 2030 instead of increasing. Production gets 16% lower than the NGPS in 2050, while it was only 7% lower in 2030. The main change before 2030 relies on a 10% reduction of crude oil production. By 2050, this crude oil reduction doubles, associated with a 26% reduction of coal production.

- In Brazil, main secondary energy sources imports are diesel oil, fuel oil, gasoline, LPG, kerosene, coal coke, electricity, non-energy petroleum products, and other secondary petroleum sources, with diesel oil leading in terms of import quantities. Brazil also exports secondary energy, including diesel oil, fuel oil, gasoline, kerosene and alcohol and other secondary petroleum sources, with fuel oil and alcohol being the most exported secondary sources. Brazil, renowned for its biofuel production, exports ethanol, primarily derived from sugarcane. Until 2050 Brazil will continue to import gasoline, LPG and kerosene to meet domestic energy demand in the transport sector, and LPG in buildings.

- In the Refining segment (refineries), the 2023 Petrobrás Sustainability Report targets a 16% reduction in carbon content by 2025 compared to 2015, and 30% by 2030. The DDS projects additional reductions, aiming for 42% by 2040 and 53% by 2050 compared to 2015 levels. These reductions are attributed to autonomous energy efficiency improvements, transitioning to electrified operations, fuel switches and adoption of more efficient equipment.

Part 2.3

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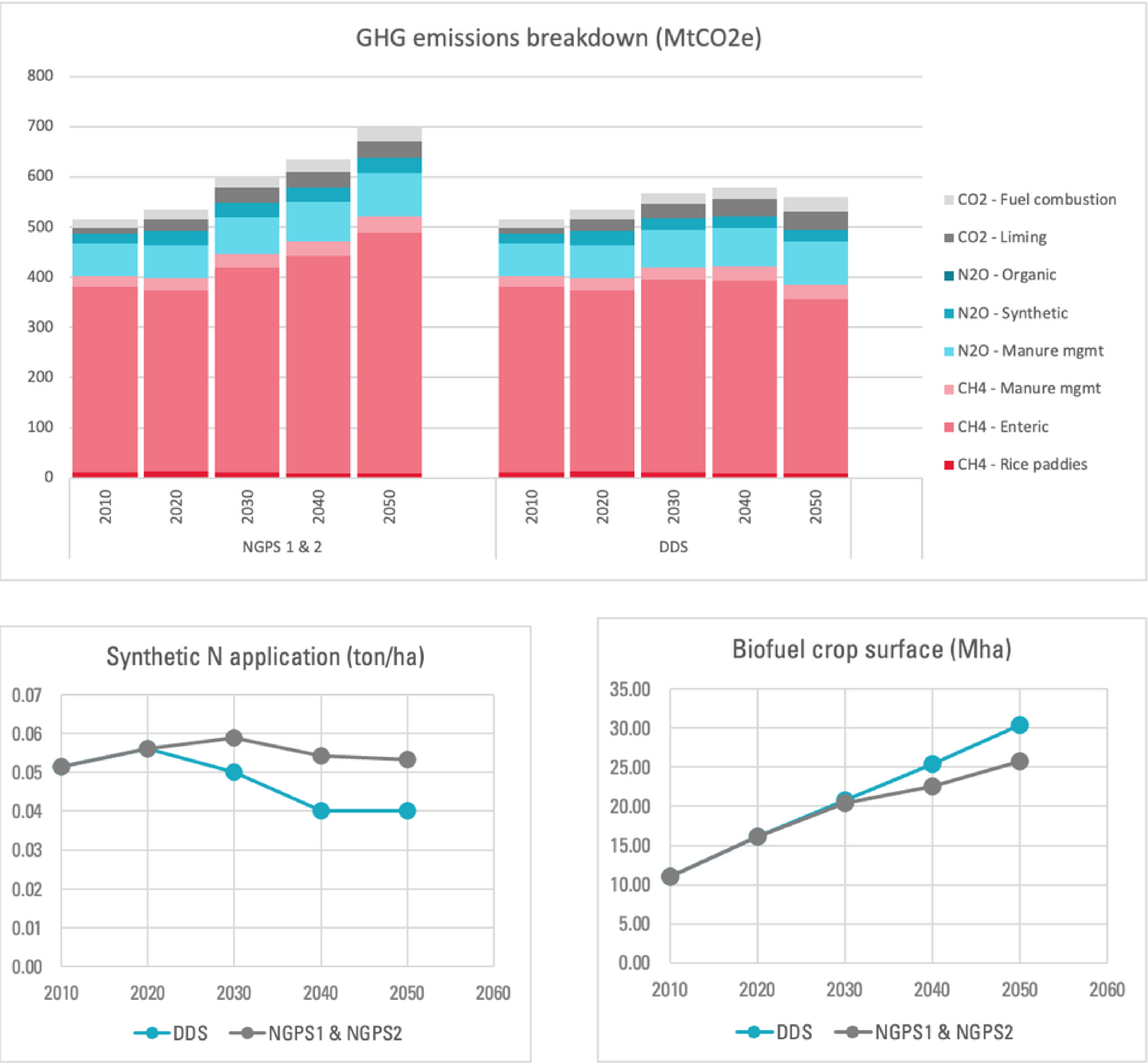
Transition of non-energy related emission sectors: Agriculture, Forestry and Land use change, Waste

Developing a Paris-compatible AGRICULTURE sector

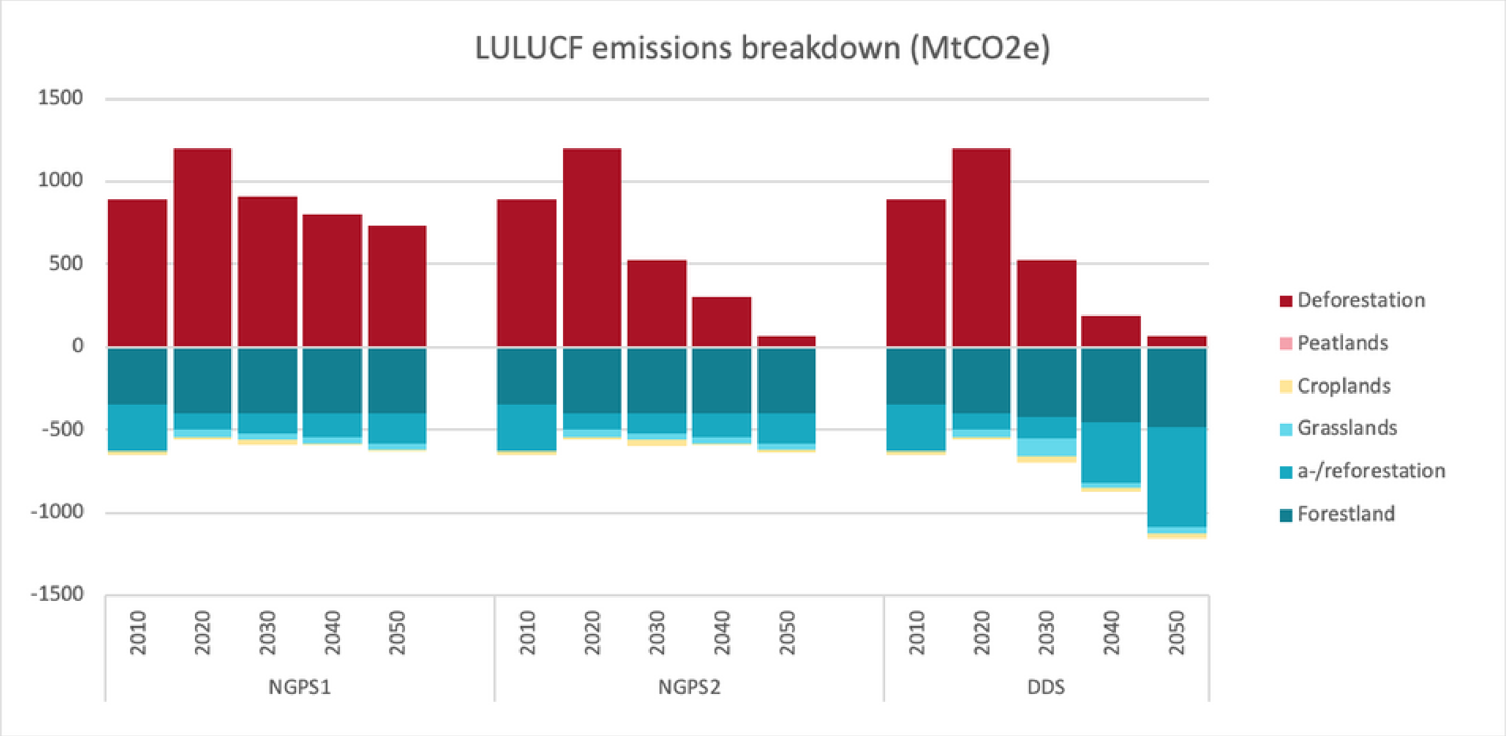
Figure 21. Sectoral emission drivers and main aggregates

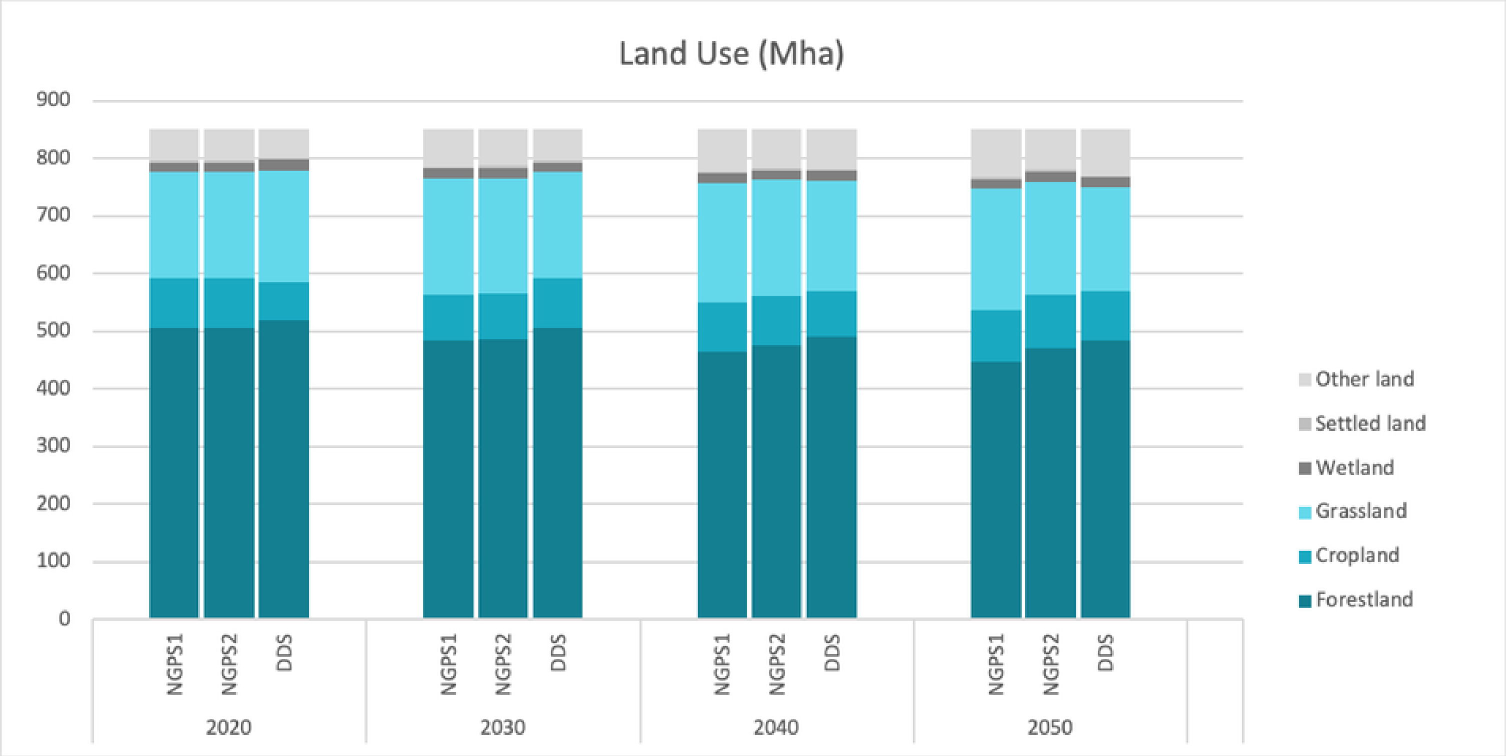


- In the DDS, the agriculture production increases significantly between 2020-2050 (82%) while the agricultural area rises moderately (6%), due to high productivity gains, both in crop production and animal production.
- The production meets both an increasing national and global demand for meat, following improved income inequality domestically and reductions in cross-country inequality internationally.
- The main drivers of increased productivity and consequently affecting the emissions intensity are:
  - Animal: genetic improvements of cattle, fattening diets, increase in average carcass weight, reduced slaughter age, the restoration of grazing lands which generates more feed to cattle. Cattle production remains extensive.
  - Crop: genetic improvement, an adjustment in planting times, selection of crop varieties, and improvement of irrigation efficiency. Application of synthetic fertiliser reduces further in DDS, as biological nitrogen fixation already widely used in soybean crops, expands to other crops as an alternative source of nitrogen.
- Reducing agricultural emissions is secondary to ensuring agricultural productivity increases that are 1) meeting an increasing demand for meat and bioenergy domestically and internationally, and 2) for minimizing agricultural land use to maximize the LULUCF sink.
- However, the DDS control the increase in emissions, comparing with the NGPS scenarios. The main strategies include reducing emissions from enteric fermentation by holding the cattle herd relatively stable (as opposed to in the NGPS where it grows significantly) and by reducing synthetic fertiliser application, by increased biological nitrogen fixation in different crops.

Developing a Paris-compatible LULUCF sector

Figure 22. Sectoral emission drivers and main aggregates

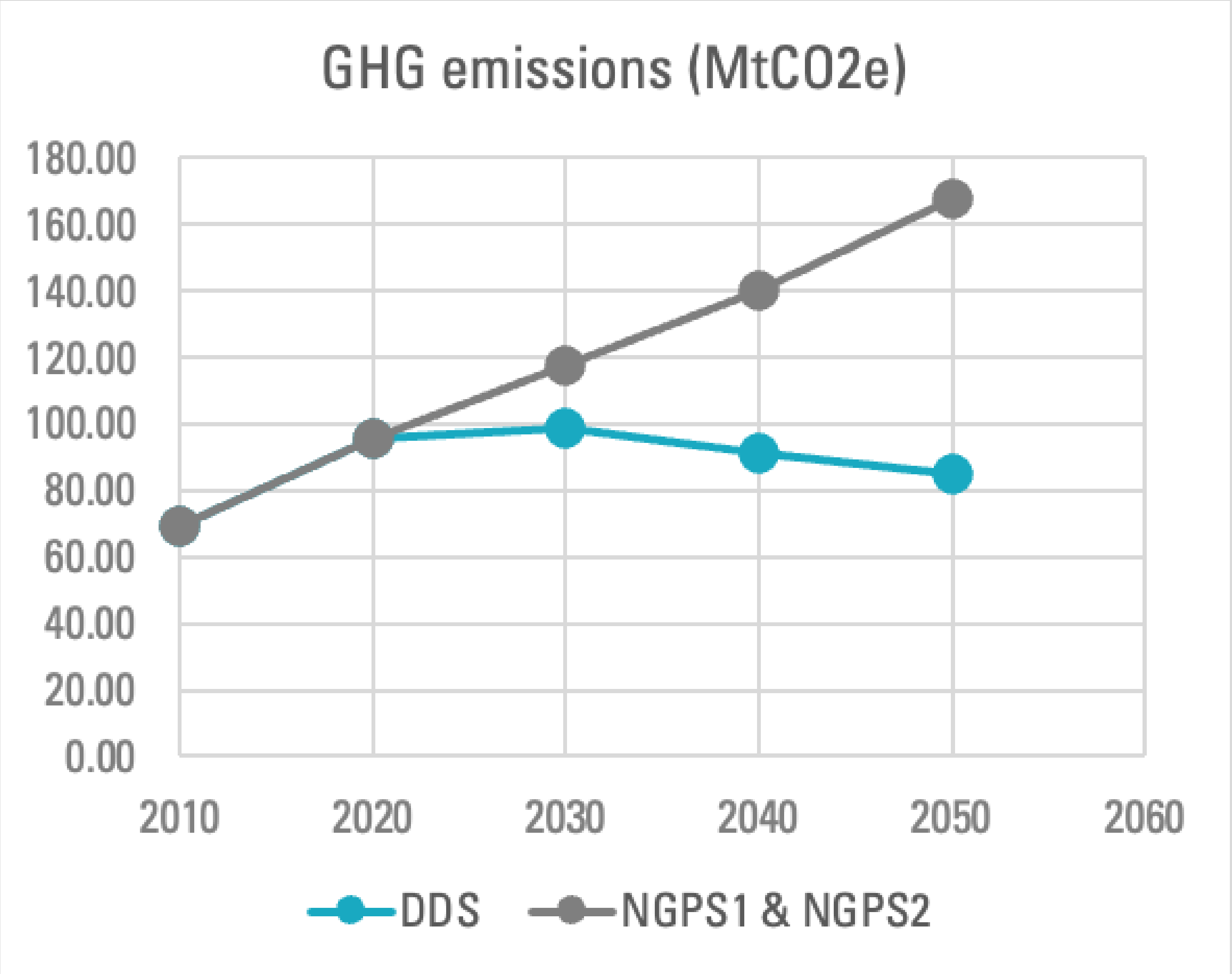




- Reducing the LULUCF net CO2 emissions is the main driver of overall national emission reductions, and plays an important role for biodiversity conservation. In the DDS, the annual net CO2 sequestration equals >1 GtCO2/yr in 2050.
- The main drivers are a rapid and lasting halt to deforestation (reducing from 2.3 to 0.35 Mha/year between 2020 & 2050) and an a/reforestation (plantation forests increase from 9,3 to 22.5 Mha 2020-2050) in the DDS.
- Underlying drivers include:
  - Improved land governance, especially improving land tenure, enhancing law enforcement, tackling illegal activities, and advocating for sustainable forest management;
  - Indigenous communities are protected by safeguarding land rights, offering legal protection, and supporting traditional livelihoods;
  - Promoting sustainable economic development includes encouraging practices such as sustainable agriculture, bioeconomy, eco-friendly tourism, and responsible supply chains;
  - Implementing advanced monitoring systems utilizing technology ensures accurate data, guiding decisions, and enabling timely interventions;
  - A transformation of agriculture with sustainable practices and without reduction of agricultural expansion into forest areas;
  - International pressures on controlling farming chains associated with degradation and deforestation. Countries that do not commit to reducing GHG emissions and controlling deforestation will face market barriers that will hamper exports

Developing a Paris-compatible Waste sector

Figure 23. Sectoral emission drivers and main aggregates



- Decarbonizing waste management in Brazil is a crucial step toward sustainable development, aligning with environmental and resource efficiency goals.
- In 2020, the waste sector accounted for 5.5% of the country's total emissions, with a trend toward increasing emissions as the coverage rate of services rises, especially considering the existing structural deficit.
- The DDS assumes that the national solid waste policy (PNRS) and the national sanitation plan (PNSB) goals regarding the extension of service coverage are met.
- The main drivers of emission stabilisation are
  - Increasing share of collected waste, which increases from 92% today to 100% in 2035 for solid waste, and 42% to 96% considering all generated wastewater
  - The implementation of biogas capture projects in sanitary landfills and sewage treatment plants
- The expansion outlined in national solid waste and basic sanitation policies can be partially financed through the sale of carbon credits, gate fees, and energy revenues.
- In DDS, the amount of collected solid waste sent to landfilling decreases from currently 57% to 29% in 2050due to the adoption of other advanced types of treatment (thermal and biological) , while in NGPS, it reaches 66%.

Conclusions

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Key lessons for national & international climate and development decision processes

Lesson 1 - Key areas or sectors which require additional transformations

- DDS is just one among many pathways for Brazil to reach climate neutrality by 2050.
- Underlying assumption: use of available technologies only; huge mitigation potential at low costs in Brazil even before the deployment of technological "breakthroughs".
- Sharp reduction of annual deforestation rate and native vegetation restoration in public and private areas have a significant abatement potential and lower costs than mitigation actions in other sectors.
- A pathway towards net-zero GHG emissions in 2050 can be reached with a carbon price starting now at 2 and going up to 44 USD/t CO_2e by 2050.
- DDS allows to reach carbon neutrality while keeping slightly better economic and social development results than in NGPS (smart recycling of carbon pricing revenues).
- From forecasting to backcasting: milestones for MRV -> embedding climate change in routine management.
- Modelling: co-benefits (SDGs), climate finance (capital costs), employment & labor market.
- Challenges: Zero deforestation; International oil prices; Political acceptability.

Lesson 2 - Key short-term national policy packages and priorities to enable them

- Resuming policies successfully adopted in the recent past (2004-2012) to sharply reduce annual deforestation rates, including both command-and-control and economic instruments.

- Developing smart financial mechanisms to foster the funding of investments in mitigation actions, and mainly in low-carbon infrastructure

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- Carbon Pricing: provide a long-term, stable signal to induce economic agents to choose low-carbon technologies through a well-structured cap-and-trade scheme for Industry and a carbon tax on other regulated sectors. A significant share of avoided emissions can be obtained at negative or very low costs.

- Relying on the AFOLU sector to reduce and capture the largest share of emissions in the first half of the century to achieve net-zero target by 2050, sharply decreasing annual deforestation rates in all biomes and boosting forest cover restoration; this would help reduce overall costs for Brazil and provide sufficient time for more ambitious decarbonization technologies to be economically viable.

- Substantial support from Annex I countries to foster financial flows targeted at mitigation actions in non-Annex I countries, including both the climate finance tools within UNFCCC (GCF, SDM) and international financial initiatives to channel private capital to low-carbon investments: key enabler of de-risking low carbon projects.

Lesson 3 - Key international conditions to implement them

- Strong international commitment to meeting the 1.5° - 2°C target of the Paris Agreement
- Increasing supply of international finance for investment and innovation over the period
- Improved access to low-cost (affordable) finance to enable low-carbon infrastructure investments in developing countries, consistent with global carbon neutrality
- Robust investment flows from Annex I to non-Annex I countries in mitigation and innovation.
- Continued technical progress in renewable energy, electric mobility, energy efficiency, H2, CCS and high emitting industrial processes (steel, cement, etc.).
- International cooperation and trade mechanisms support the Brazilian goal of zero net deforestation.
- Adoption of carbon pricing by most countries favours low carbon products in trade and finance.
- Voluntary carbon markets support the development of a latinamerican carbon market.
- Trade openness for low carbon products with preferential trade mechanisms that require traceability and proof of origin for agricultural and forestry product exports

Lesson 3 - Key international conditions to implement them

International Negotiations

- Linking existing and future carbon pricing schemes
- Harmonization and convergence of standards & regulations of voluntary and regulated carbon markets

International Finance

- Implementing smart financial mechanisms at the international level to reduce the WACC (weighted average cost of capital) in developing countries for low-carbon projects

•Just Energy Transition Partnerships

- Developing countries lead and own the investment plans and enabling policies
- Financial levers and mechanisms that re-orientate significant systemic financial flows
- Housing de-risking mechanisms (e.g. public guarantee funds) to leverage private finance
- based upon a pipeline of well designed projects to address country needs

Lesson 3 - Key international conditions to implement them

- Potential for EU/Brazil cooperation on **financial mechanisms to fund decarbonization actions** in Brazil.
- Besides the Amazon Fund, what would the design of a **potential JET-P initiative** for Brazil look like?
- How to make the design of the **upcoming cap-and-trade Brazilian industry carbon market compatible with CBAM**? What mechanisms would be required to adjust the level of border taxes, at what disaggregation level, what methodologies to use?
- **Cooperation around certification programs compatible with EUDR:** a variety of deforestation free certification programmes exist internationally (eg RSPO, PNCCS and CBS/FSC in Brazil), and ensuring coherence among programmes and cooperation around the certification methodologies and the underlying technology
- How to create within EUDR **positive incentives to reward good practices** in ranching and the production of agricultural commodities for export to Europe?

Lesson 4 - Fair national contributions to the GST outcome

Based on Article 28 of the GST outcome text of COP28

28. *Further recognizes* the need for deep, rapid and sustained reductions in greenhouse gas emissions in line with 1.5 °C pathways and *calls on* Parties to contribute to the following global efforts, in a nationally determined manner, taking into account the Paris Agreement and their different national circumstances, pathways and approaches:

(a) Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030;

(b) Accelerating efforts towards the phase-down of unabated coal power;

(c) Accelerating efforts globally towards net zero emission energy systems, utilizing zero- and low-carbon fuels well before or by around mid-century;

(d) Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 in keeping with the science;

(e) Accelerating zero- and low-emission technologies, including, inter alia, renewables, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production;

(f) Accelerating and substantially reducing non-carbon-dioxide emissions globally, including in particular methane emissions by 2030;

(g) Accelerating the reduction of emissions from road transport on a range of pathways, including through development of infrastructure and rapid deployment of zero- and low-emission vehicles;

(h) Phasing out inefficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible;

Lesson 4 - Fair national contributions to the GST outcome

(a) Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvement by 2030

Brazil already has a large renewable power capacity and will only triple it by 2040 in the DDS, excluding hydro.

NGPS (base year 2020=1)	2020	2030	2040	2050
Renewable w/o Hydro	1.00	2.24	2.97	3.64
Total Renewable	1.00	1.34	1.63	1.83

DDS (base year 2020=1)	2020	2030	2040	2050
Renewable w/o Hydro	1.00	2.31	3.07	4.69
Total Renewable	1.00	1.36	1.64	2.12

Energy efficiency gains

	2010	2020	2030	2040	2050
NGPS -Domestic Energy Supply/GDP (ktoe/(10^6 R$2020)	30.1	31.5	27.6	25.5	23.9
NGPS -Average annual rate of energy efficiency gain in the decade	-	-0.458%	1.321%	0.790%	0.651%
DDS -Domestic Energy Supply/GDP (ktoe/(10^6 R$2020)	30.1	31.5	25.4	22.3	19.5
DDS -Average annual rate of energy efficiency gain in the decade	-	-0.458%	2.149%	1.294%	1.348%

Lesson 4 - Fair national contributions to the GST outcome

(b) Accelerating efforts towards the phase-down of unabated coal power

In Brazil, there are only 8 coal-fired power generation plants, all concentrated in the southern region of the country, providing altogether 3.2 GW of installed capacity. This limited number and the regional concentration of coal plants reflect Brazil's broader energy mix, which heavily relies on renewable sources.
The lifetime of existing coal-fired power plants ends by 2030 in DDS and by 2040 in NPGS 1 and 2. In the NGPS scenarios, coal-fired power plants operate under partial flexibility conditions through take-or-pay clauses in their coal purchase contracts and continue to generate electricity from coal until 2040. In the DDS, there are no minimum conditions in the contracts, and other cheaper generation options become available.

Brazilian green electricity can be a central factor in the country's decarbonization efforts through the electrification of other sectors, such as transportation and industry. However, this depends on the evolution of the power generation mix toward renewable sources, and on the fate of energy policies that contradict decarbonization efforts. Such policies include Law No. 14.182/2021, which mandates the construction of 8 GW of inflexible natural gas-fired power plants, and Law No. 14.229/2022, which ensures contracts until 2040 for energy generated by coal-fired power plants, thereby continuing a subsidy for coal-fired electricity generation. Government action to revise these laws is crucial.

Lesson 4 - Fair national contributions to the GST outcome

(c1) Accelerating efforts globally towards net zero emission energy system, utilizing zero and low-carbon fuels well before or by around mid-century

Domestic energy supply: economy-wide values, including imports and excluding exports

			NGPS			DDS		
Zero and low-carbon fuels in Domestic Energy Supply (DES)	**2010**	**2020**	**2030**	**2040**	**2050**	2030	2040	2050
Total DES (in Mtoe)	269.1	289	336	378	431	312	335	356
Hydro (in Mtoe)	37.7	36.2	37.4	43.5	47.8	37.4	43.3	45.0
Woody biomass (in Mtoe)	26.0	26.5	26.7	29.7	34.5	26.7	29.7	34.5
Sugar cane products (in Mtoe)	47.1	54.9	68.5	80.7	92.6	65.6	73.2	74.6
Other renewables (in Mtoe)	9.6	23.3	38.5	48.4	57	39.8	52.6	74.5
% of renewables in DES	45%	49%	51%	53%	54%	54%	59%	64%
% of renewables without hydro in DES	31%	36%	40%	42%	43%	42%	46%	52%
Uranium (in Mtoe)	3.9	3.7	6.3	5.4	5.6	6.3	5.4	5.5
Total zero and low-carbon fuels (in Mtoe)	124	145	177	208	238	176	204	234
% of total zero and low-carbon fuels in DES	46%	50%	53%	55%	55%	56%	61%	66%

In the DDS, the use of total zero and low-carbon fuels in 2050 is projected to be 62% higher than in 2020 and its share in domestic energy supply reaching 66% against 55% in the NGPS by 2050.

Total DES by 2050 is 17% lower than in NGPS thanks to energy efficiency mainly

Lesson 4 - Fair national contributions to the GST outcome

(c2) Accelerating efforts globally towards net zero emission energy system: zoom on the Transport system

Transport system

Fuel use in Transport	2020	NGPS 2030	NGPS 2040	NGPS 2050	DDS 2030	DDS 2040	DDS 2050
Fuel use – Transport (Mtoe)	79	96	103	110	81	81	77
Ethanol	15.3	21.4	21.8	22.1	20.3	21.3	18.3
Biodiesel + HVO	4.1	6.8	9.2	9.8	7.4	11.5	14.9
SAF	-	-	-	-	-	0.5	1.2
Bio-oil	-	-	-	-	-	0.1	0.3
Electricity	0.2	0.4	1.2	3.7	0.8	2.9	7.3
Zero and low-carbon fuels	20	29	32	36	29	36	42
% of Ethanol	19%	22%	21%	20%	25%	26%	24%
% of Biodiesel + HVO	5%	7%	9%	9%	9%	14%	19%
% of SAF	0%	0%	0%	0%	0%	1%	2%
% of Bio-oil	0%	0%	0%	0%	0%	0%	0%
% of Electricity	0%	0%	1%	3%	1%	4%	9%
Subtotal % of zero or low-carbon fuels	25%	30%	31%	32%	35%	45%	55%
Fossil fuels - Transport (Mtoe)	60	68	71	75	53	45	35
% of fossils fuel in Total	75%	70%	69%	68%	65%	55%	45%

Biodiesel and HVO are used in regional freight transport (road, rail, and inland navigation) and to non-electrified buses.. Ethanol is exclusively used in individual passenger mobility. Bio-oil is used in cabotage. Electricity displaces diesel oil, natural gas and gasoline

Lesson 4 - Fair national contributions to the GST outcome

(d) Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050 and keeping with science

Domestic energy supply: Economy-wide values, including imports and excluding exports

Fossil Fuels in Domestic Energy Supply - DES (in Mtoe)	2010	2020	NGPS 2030	NGPS 2040	NGPS 2050	DDS 2030	DDS 2040	DDS 2050
Total DES (Mtoe)	269	289	336	378	431	312	335	356
Oil	103	97	105	116	127	88	84	79
Natural gas	28	34	36	36	45	34	31	27
Coal	15	14	18	19	21	15	16	16
Total fossil	145	145	159	171	193	137	131	122
% of fossil	54%	50%	47%	45%	45%	44%	39%	34%

DDS - total coal demand by industry sectors in Mtoe	2020	2030	2040	2050
Total industry demand	10	15	16	16
Iron & Steel	84%	84%	84%	84%
Non-ferrous metals	10%	8%	8%	8%
Rest of Industry	6%	7%	8%	8%
	100%	100%	100%	100%

In the DDS, the total of fossil fuels in domestic energy supply in 2050 is projected to be 16% lower than in 2020 and 37% below that of the NGPS by 2050

DDP

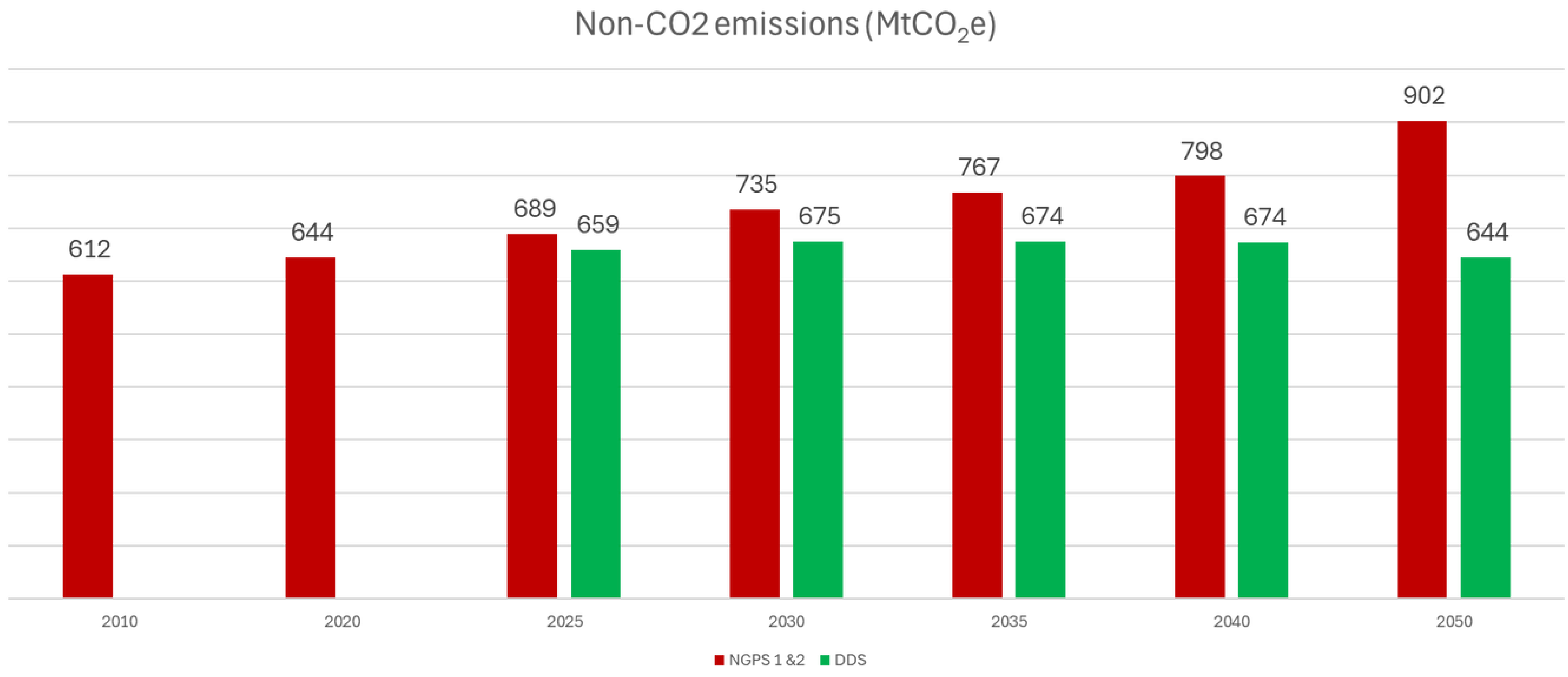
Lesson 4 - Fair national contributions to the GST outcome

(e) Accelerating zero- and low- emission technologies, including, inter alia, renewabes, nuclear, abatement and removal technologies such as carbon capture and utilization and storage, particularly in hard-to-abate sectors, and low-carbon hydrogen production

The scenarios do not anticipate an acceleration of nuclear energy, nor the use of CCS (Carbon Capture and Storage) and hydrogen technologies. In the DDS scenario, the deployment of renewable energy sources is the main decarbonization driver. The country meets its targets and achieves net-zero by 2050 solely with already available technologies, including the increased use of renewables, enhanced energy efficiency, and carbon removal via the expansion of vegetation stocks.

Lesson 4 - Fair national contributions to the GST outcome

(f) Accelerating and substantially reducing non-carbon-dioxide emissions globally, including in particular methane emissions by 2030



Despite the country's commitment to the Global Methane Pledge at COP26, reducing its methane emissions remains a formidable challenge due to the enormous scale of its cattle herd that feeds a large part of the globe, as well as the continued practice of using substantial sanitary landfills, which are significant methane producers.

In DDS, non-CO2 emissions are kept in 2050 at the same level recorded in 2020 (a 28% reduction of the NGPS level).

Lesson 4 - Fair national contributions to the GST outcome

(g) Accelerating the reduction of emissions from road transport on a range of pathways, including through development of infrastructure and rapid deployment of zero and low-emission vehicles

Transport Emissions

MtCO2e	2010	2020	2030	2040	2050
NGPS					
Passenger					
CO2	82.7	81.9	101.2	108.3	112.9
non-CO2	3.4	3.6	4.3	4.8	5.1
Freight					
CO2	85.2	97.3	101.7	102.3	111.6
non-CO2	1.4	1.4	1.6	1.8	2.1
Total	**172.7**	**184.2**	**208.7**	**217.1**	**231.7**
DDS					
Passenger					
CO2	82.7	81.9	77.6	61.1	40.3
non-CO2	3.4	3.6	3.8	3.4	2.6
Freight					
CO2	85.2	97.3	81.7	74.0	66.4
non-CO2	1.4	1.4	1.0	1.0	1.1
Total	**172.7**	**184.2**	**164.1**	**139.6**	**110.4**

Prioritize non-road transport and public transit: Boost modal shares for walking, cycling, and public transport to 40.5% by 2050.
Push for electric vehicles and biofuels: Non-fossil fuel usage to reach 67% by 2050, with BEV sales comprising 100% of 2W sales and 59% of car sales by 2050.
Achieve energy consumption reduction and emissions cuts: Moderate passenger transport energy consumption, cutting emissions by half from 2010 to 2050.

Lesson 4 - Fair national contributions to the GST outcome

(h) Phasing out ineficient fossil fuel subsidies that do not address energy poverty or just transitions, as soon as possible

Although a reduction in fossil fuel subsidies is not expected, the DDS scenario assumes the adoption of a carbon pricing strategy designed to effectively counterbalance these subsidies. This scenario introduces a carbon price across all sectors, excluding agriculture, LULUCF (Land Use, Land-Use Change, and Forestry), and waste, which is implemented via a cap-and-trade system.

The carbon price is established at $2 per tCO2e in 2030, escalating to $31 per tCO2e by 2040, and further to $44 per tCO2e in 2050. It allows for the use of a limited quantity of forest offsets within the cap-and-trade framework. The revenue generated from the carbon tax is primarily reinvested to foster employment, with a smaller share allocated to provide financial compensation to low-income households.

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