CEBRI
BRAZILIAN CENTER FOR INTERNATIONAL RELATIONS

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Empresa de Pesquisa Energética

cenergia

IDB

ENERGY TRANSITION PROGRAM

Final Report of the technical cooperation
ATN/OC-17965-BR

The energy transition program

Sponsored by the Brazilian Center for International Relations (CEBRI), the Inter-American Development Bank (IDB), the Energy Research Company (EPE) and the Center for Energy and Environmental Economics (CENERGIA), the program sought to identify paths for Brazil to reach carbon neutrality by 2050.

Sponsorship:

Support:

Note: The results of the Energy Transition Program reflect Cenergia's efforts to construct, develop and quantify exploratory scenarios which may not express the individual opinion of the institutions that participated in the Program and may not consider other work these institutions are developing. The decarbonization policies, works and analyses developed by the competent sectoral institutions/entities must be considered in relation to aspects and recommendations pertaining to specific sectors. The sectoral analyses and policy recommendations in this report are not exhaustive and are subject to review for validity and consistency with the regulatory, technical and policy frameworks of the industries involved and with those frameworks in the specific context of Brazil.

PROJECT PHASES

The program was divided into three phases, aiming to position Brazil in the process of global society's understanding of the consequences of climate change and of progress in the development of sustainable energy technologies.

DIVERGENCE

CONVERGENCE

SCENARIOS

1st
half of
2021

DIVERGENCE

Mapping of major trends and critical uncertainties through a series of virtual debates with experts, the public at large and stakeholders. Resulted in the publication of a white paper consolidating the insights obtained.

1st half of 2021

DIVERGENCE

GUIDING QUESTIONS

Which **alternatives** bring the greatest benefits to Brazil? What is each industry's contribution to this process?

What are the structural effects of the **pandemic** on the global energy sector and what are their consequences for Brazil?

What **technologies and energy sources** make the most sense for Brazil in its effort to comply with climate agreements?

2nd
half of
2021

CONVERGENCE

Consolidation of a vision of the future for the main explanatory variables identified in the previous phase.

2nd half of 2021

CONVERGENCE

CONVERSATIONS WITH BUSINESSES

- Online debates on major divergences identified in the first phase
- Institutions that sponsor the project and other entities

UNCERTAINTY PRIORITIZATION

- Prioritization by impact and uncertainty level
- Correlation matrix
- Validation by CEBRI, IDB and EPE

DEFINITION OF REFERENCES

- Future states of prioritized uncertainties
- Sensitivities (What-Ifs)
- Compatibility check with the COPPE model

NARRATIVE CONSTRUCTION

- Writing up the logic of each scenario
- Report preparation

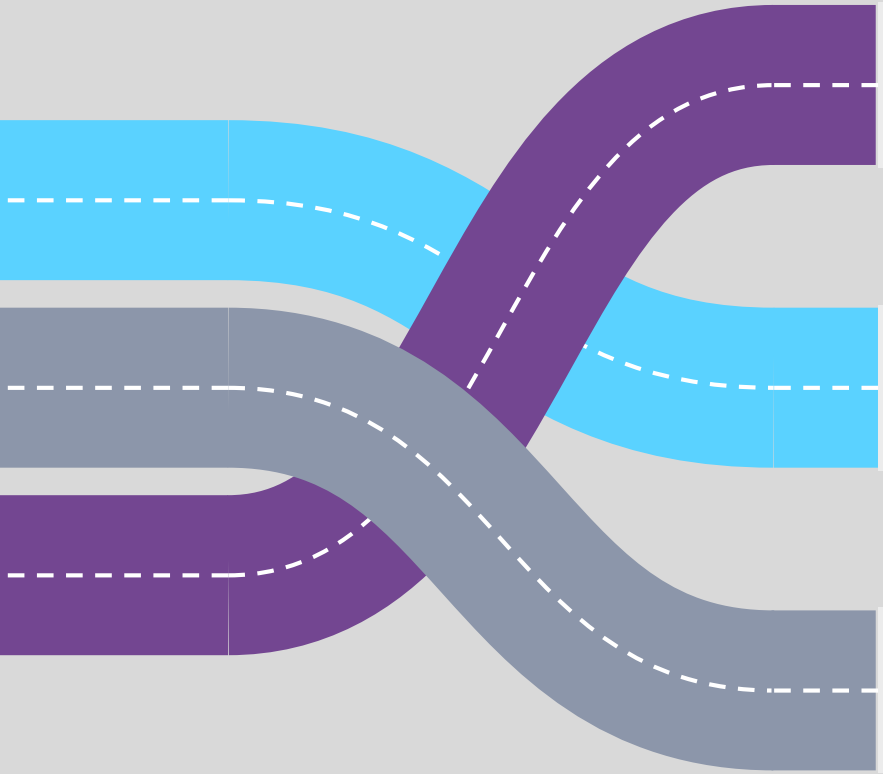
1st half
of
2022

SCENARIOS

Modeling future scenarios based on the methodology used by Cenergia/PPE/COPPE/UFRJ.

1st half of 2022

SCENARIOS



1	BRAZIL TRANSITION	Optimal cost-efficient trajectory (based on Brazil's commitments, resources, knowledge and cost expectations) to reach net carbon neutrality by 2050.
2	ALTERNATIVE TRANSITION	Alternative technological path for Brazil to achieve neutrality by 2050 considering the impacts of climate change itself on the energy sector and the uncertainties of new technologies.
3	GLOBAL TRANSITION	Brazil's contribution in a world that seeks to limit average increase in global surface temperature to 1.5°C in 2100 in reference to pre-industrial levels.

SCENARIOS

AGENDA

SCENARIO DESCRIPTION

	1 BRAZIL TRANSITION	2 ALTERNATIVE TRANSITION	3 GLOBAL TRANSITION
KEY DIFFERENCES BETWEEN SCENARIOS			
International environment	Limited cooperation ("regional blocks")		Global cooperation ("Global village")
Transition process in Brazil	Defined by the Brazilian context		Included in a global context
Emission neutrality in Brazil	CO2 in 2040 GHG in 2050	CO2 in 2040 GHG in 2050	CO2 in 2035 GHG in ~2050
Carbon budget (2010-2050)	24 $GtCO_2$	24 $GtCO_2$	15 $GtCO_2$
Rearrangement of global production chains	Production more regionally-oriented		Revitalized global value chains
Approach	Minimum cost to reach NetZero GHG	Minimum cost to reach NetZero GHG by 2050, with restrictions	Minimum cost to reach global 1.5º optimum

SCENARIO DESCRIPTION

	1 BRAZIL TRANSITION	2 ALTERNATIVE TRANSITION	3 GLOBAL TRANSITION
PUBLIC POLICY FOCUS			
Decarbonization of the O&G industry			
O&G participation in the energy mix			
Level of hydropower generation (as a result of climate change)			
Expansion of nuclear power generation			
Expansion of biofuels			
Hydrogen production			
Biomethane production			
Expansion of biomass participation in the mix			
STAKEHOLDER PREFERENCES/PRESSURE			
Improving land use (ending illegal deforestation)			
Gas as a vector for decarbonization (industry)			
Increased fleet electrification			

ENERGY MIX

Primary energy demand will go from 268 Mtoe in 2020 to around 400 Mtoe in 2050 in all scenarios.

The use of fossil fuels will decrease and the use of renewable sources will increase in all scenarios.

Renewables will exceed 70% share of primary energy demand.

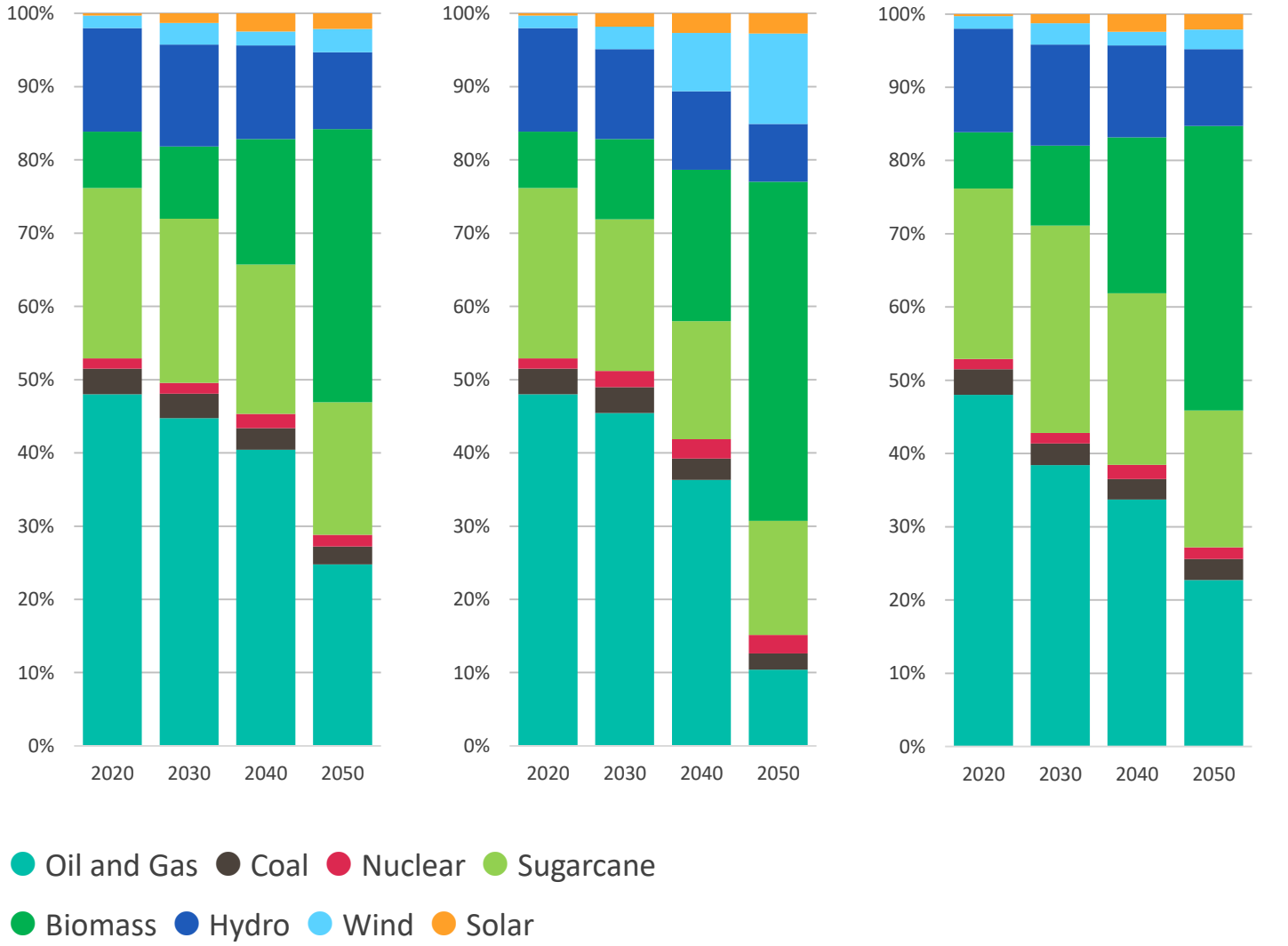
Biomass will be the source that will grow the most within Brazil's energy mix, followed by wind and solar.

Oil & gas will be the source that will diminish the most.

1 BRAZIL TRANSITION

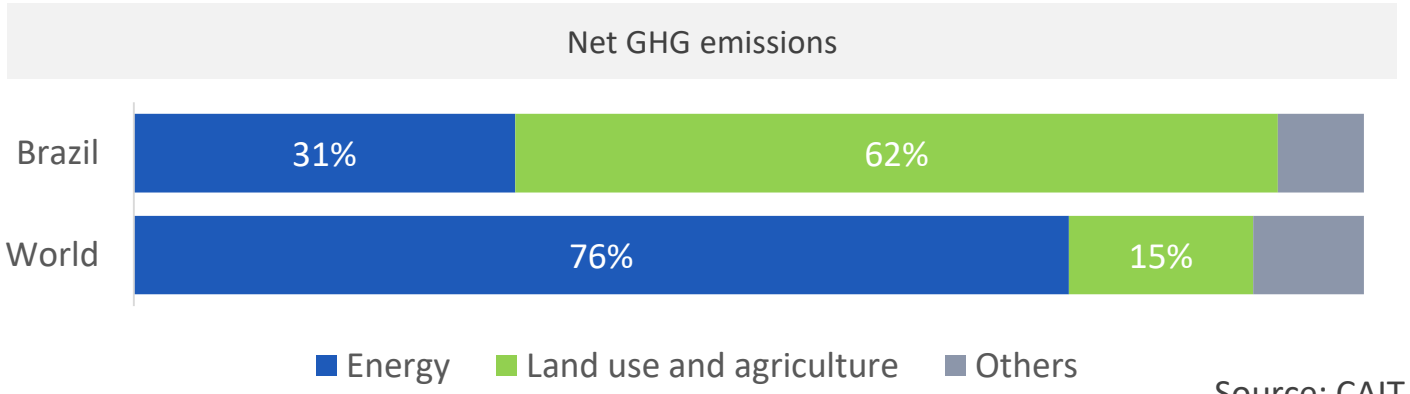
2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

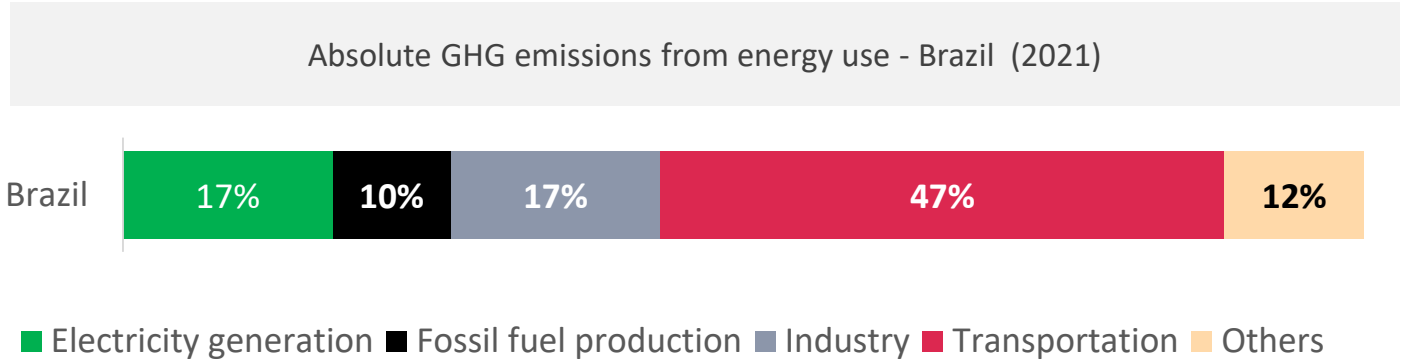


NET EMISSIONS

Brazil's emissions profile is completely different from the global profile, which implies reconciling the agricultural, energy and environmental agendas.



Source: CAIT (2019)



Source: SEEG (2022)

Challenges for neutrality

1. Expected growth in energy demand
2. Elimination of illegal deforestation as a necessary condition
3. Modernizing and creating regulatory frameworks for energy transition
4. New technologies and infrastructure require further development and more scale

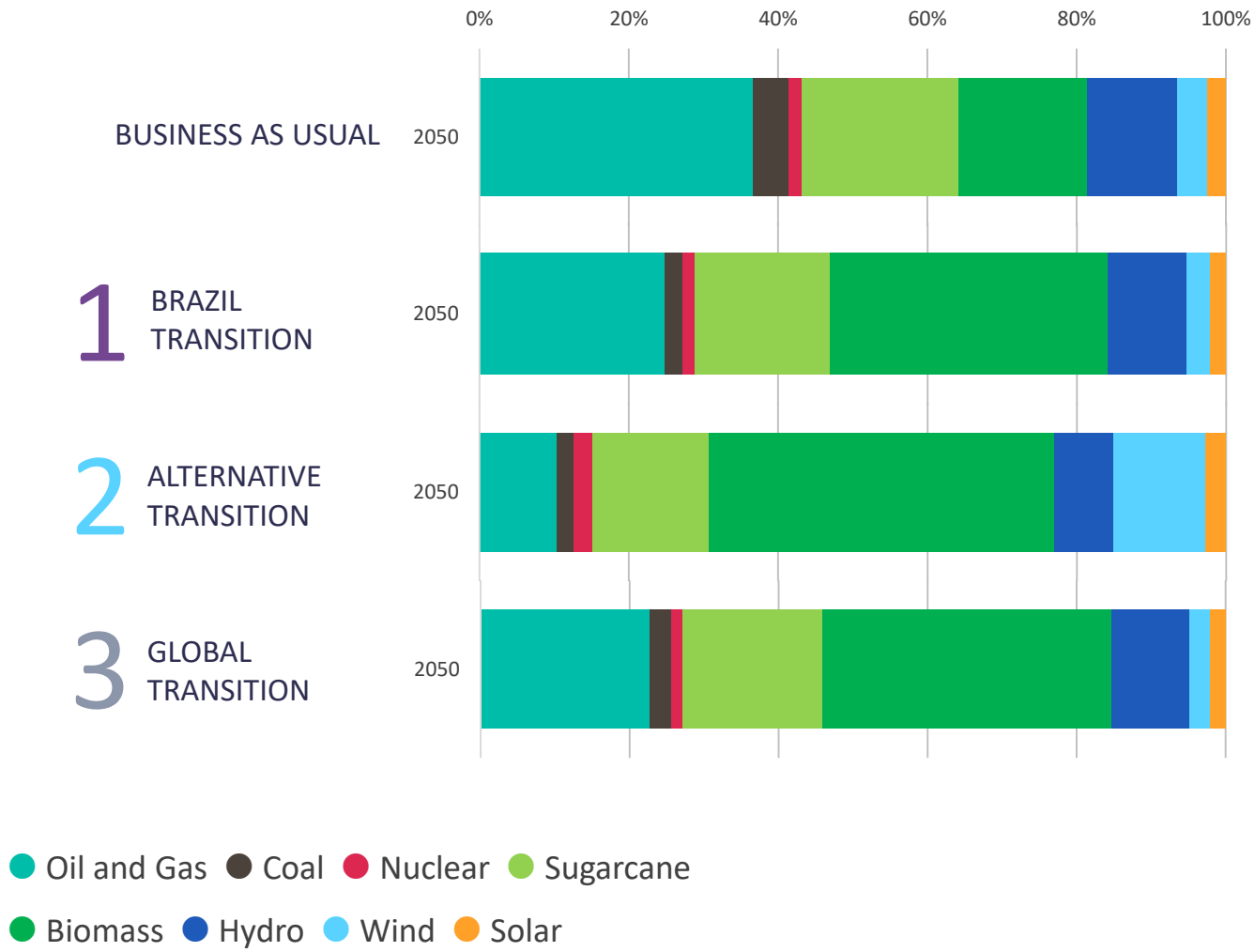
Notes: 1. Forest restoration and reforestation were deducted from land use - AFOLU (net emissions); 2. Energy answers for 18% of Brazil's total gross GHG emissions. Based on this criteria, forest restoration and reforestation by the energy industry removes carbon from AFOLU and not from energy.

ENERGY MIX

The comparison with the Business As Usual (BAU) trend, based on current policies and actions related to the energy system and to change in land use, shows a considerably smaller share for oil & gas and for coal in 2050 in all three scenarios.

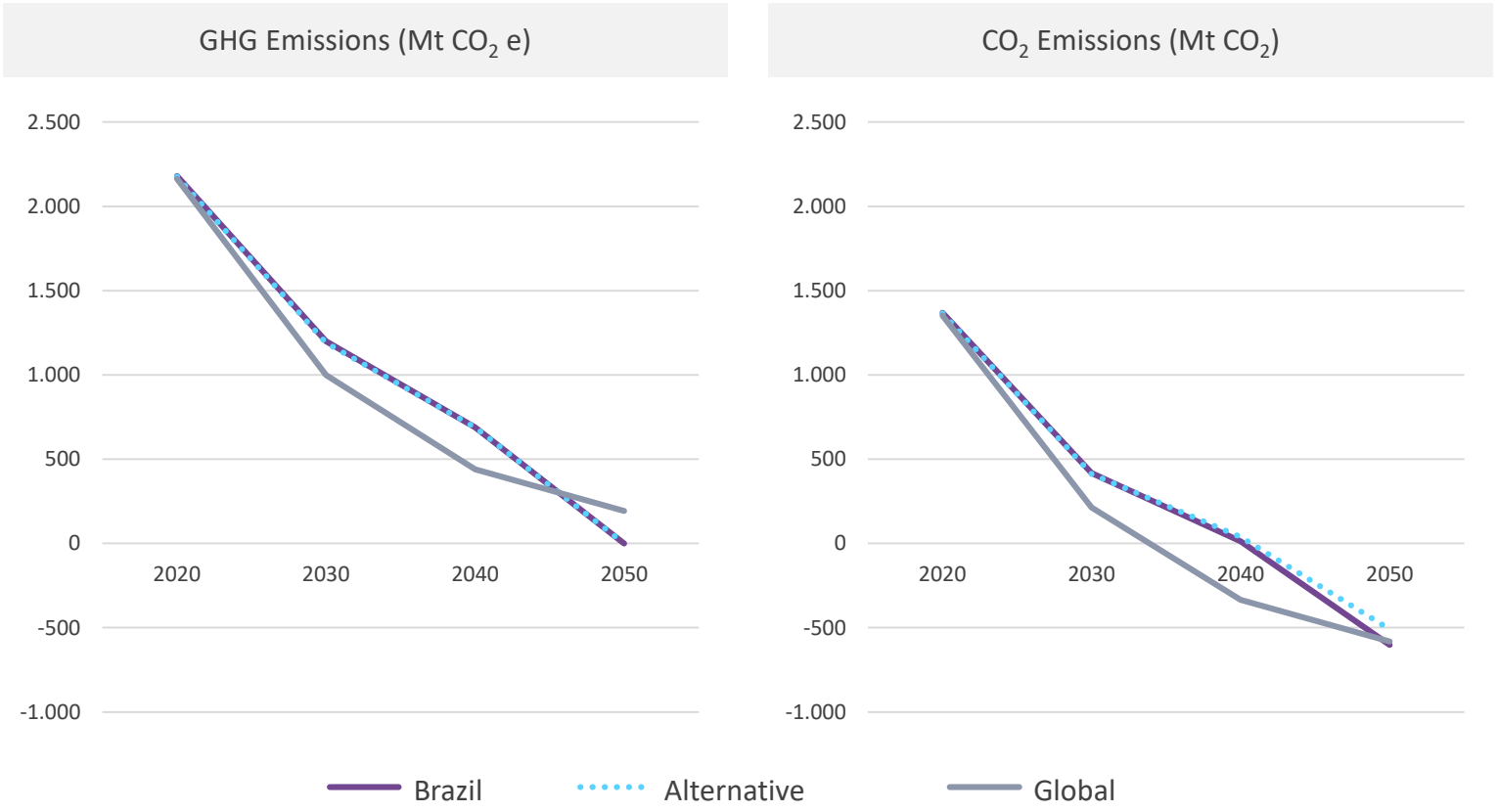
In comparison with current trends, biomass' share will grow and hydropower's will diminish in all scenarios.

Primary energy by source in 2050



EMISSIONS: URGENT ACTION

The scenarios focused on reaching greenhouse gas (GHG) neutrality by 2050, which implies reaching carbon neutrality (CO_2) ten years earlier, around 2040.



CONCERNS

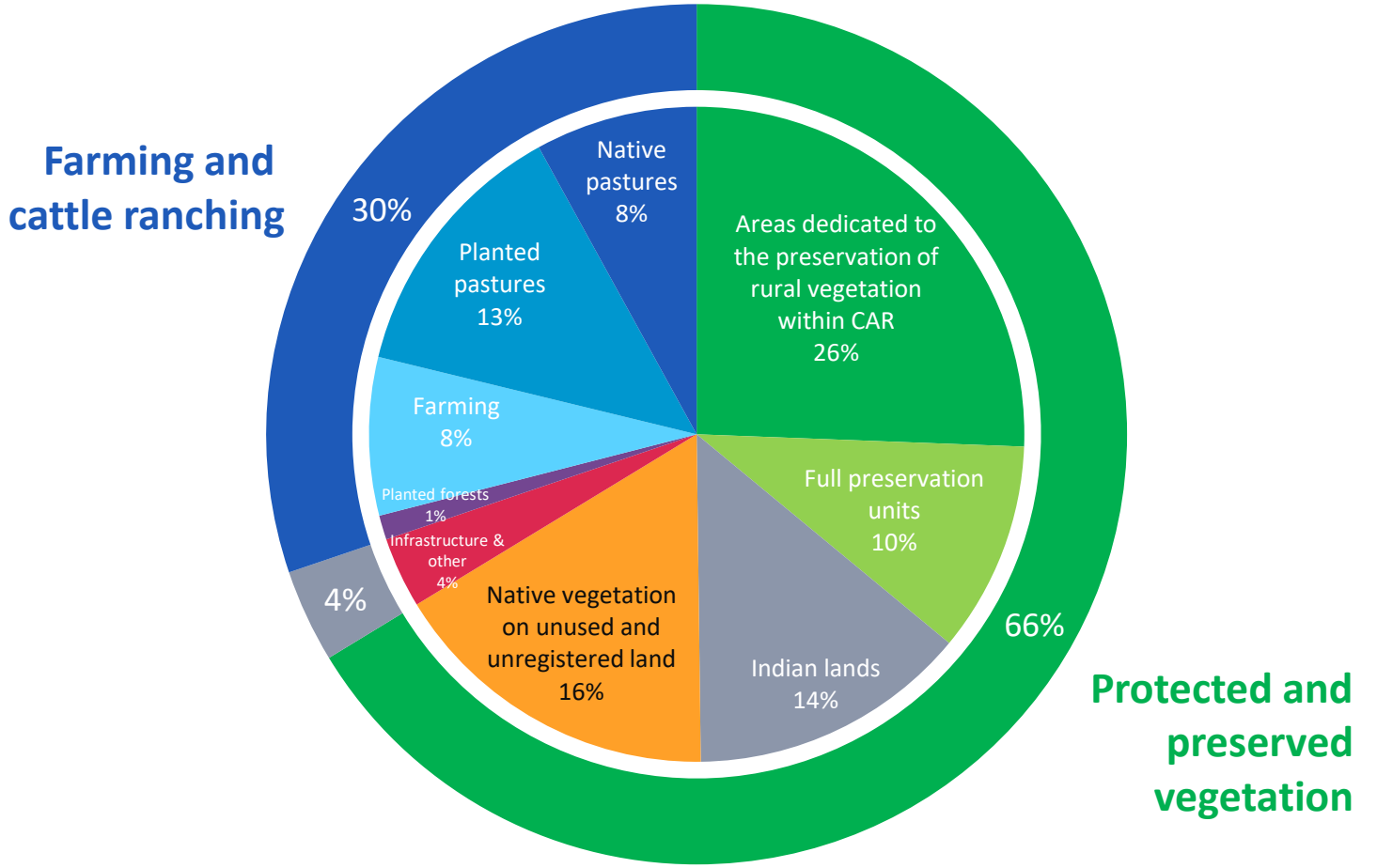
- The model could find no technically viable and realistic solution for neutrality in 2050 without eliminating illegal deforestation by the end of this decade. That is a **necessary condition for Brazil's neutrality**.
- Ending illegal deforestation will save 21 Gt CO_2 emissions by 2050.
- Without those savings, achieving neutrality will require up to US$ 3.4 trillion in compensation costs for Brazil to comply with its NDC commitments.

EMISSIONS: LAND USE

Areas dedicated to the preservation and protection of native vegetation represent a large share of total land use and occupation in Brazil.

There is no competition between agri-energy and food in Brazil today.

Territorial quantification of land use and occupation in Brazil, 2018



Sources: SFB, EMBRAPA, IBGE, MMA, FUNAI, DNIT, ANA end MPOG

EMISSIONS: OPPORTUNITIES

Brazil's path to neutrality can reconcile agricultural, power-related and environmental objectives.

CO_2 removal

30%

(IPCC)

Opportunities for nature-based solutions (NBS) in Brazil

20%

of the tropical country total

(Griscom *et al*, 2020)

Reforestation

40 Mha

AT Scenario

Recovery

27 Mha

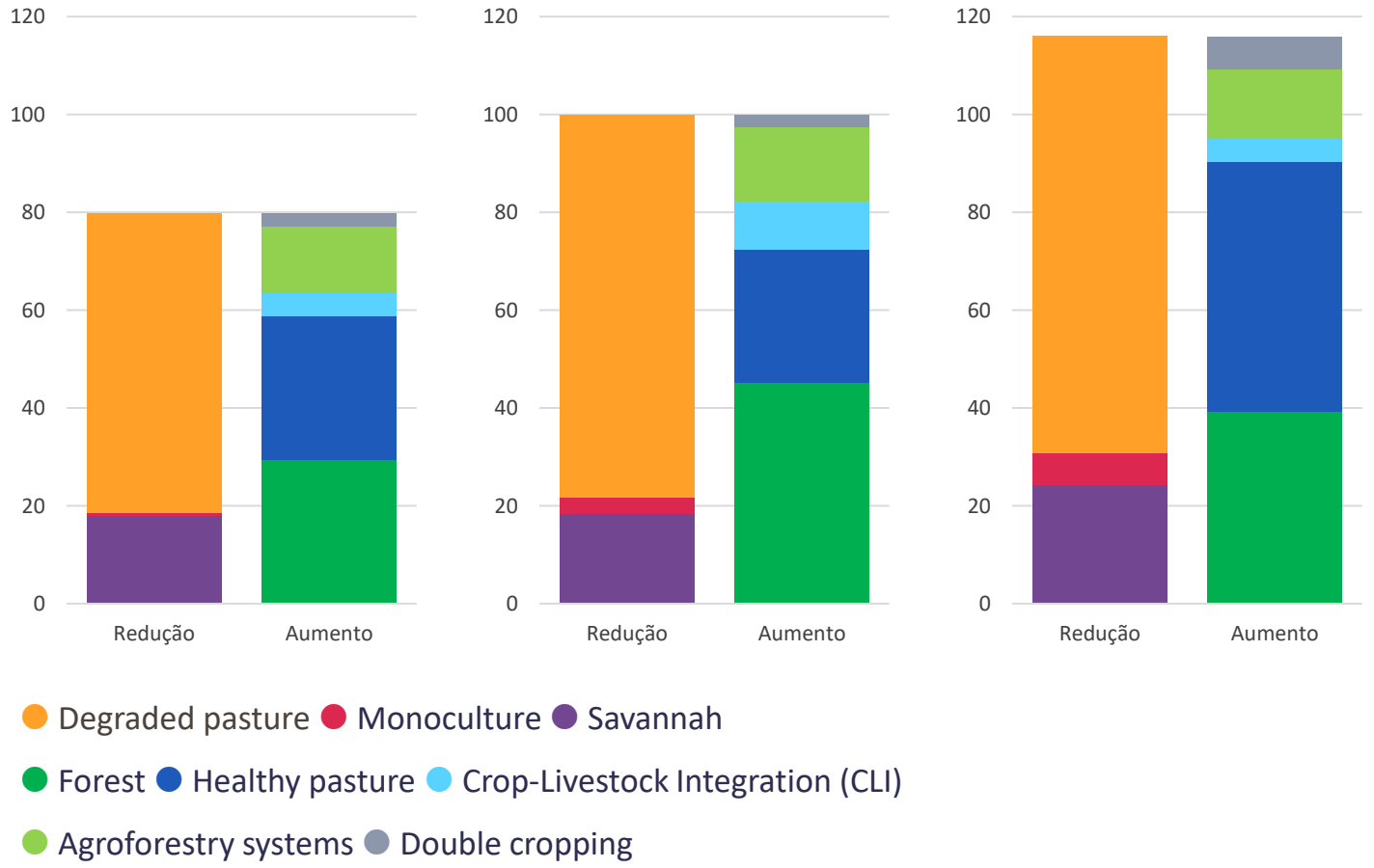
AT Scenario

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Changes to land use (Mha) by 2050

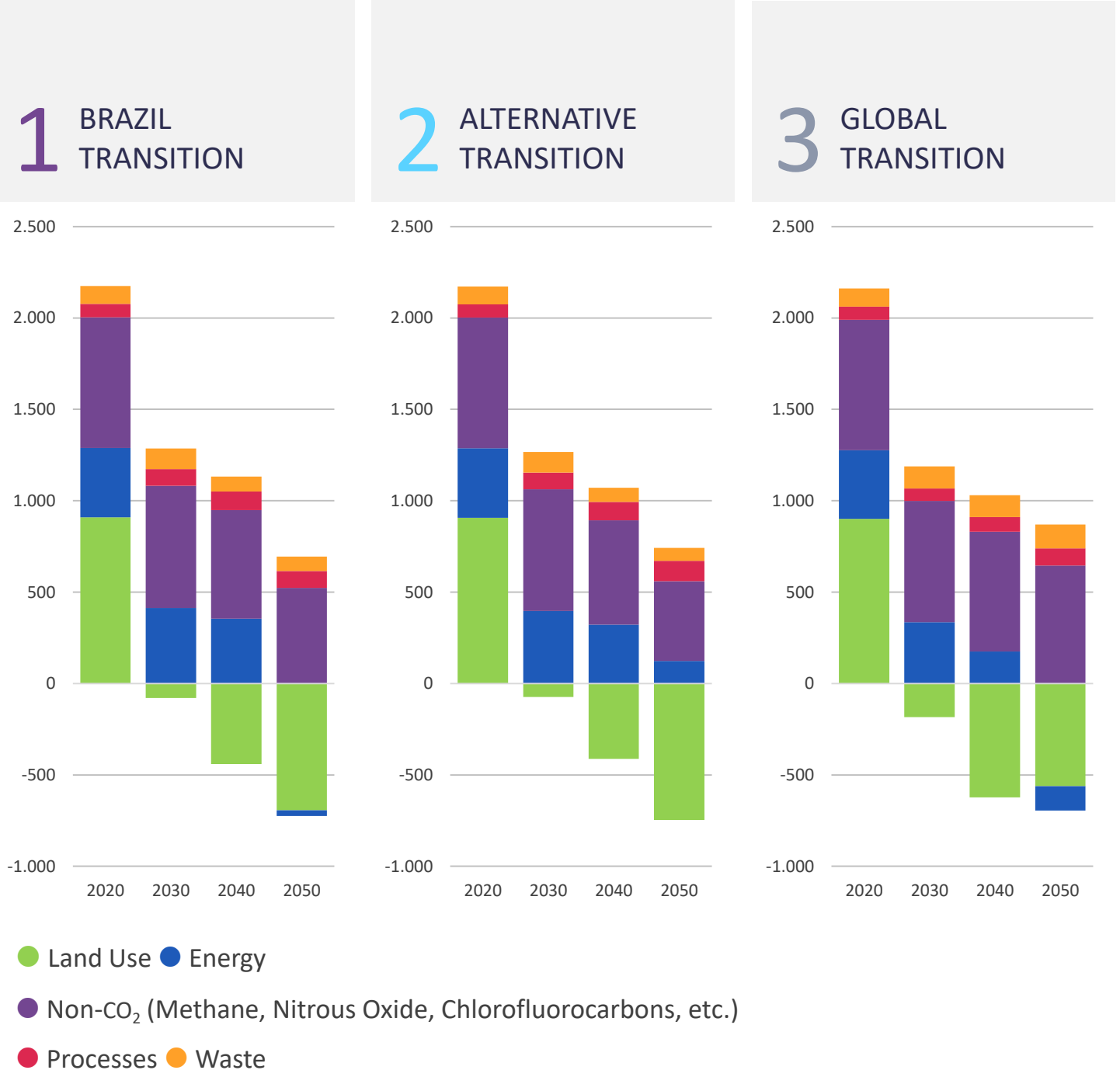


EMISSIONS

The energy transition needed to achieve climate neutrality must include structural changes in energy supply and demand.

Not only emissions from energy use must be eliminated, but NBS should also provide negative emissions to the tune of 562-747 Mtonnes by 2050.

The paths to neutrality will save some 30 billion tonnes of CO2 equivalent in the BT and AT scenarios and 40 billion tonnes in the GT scenario.



POWER INDUSTRY

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

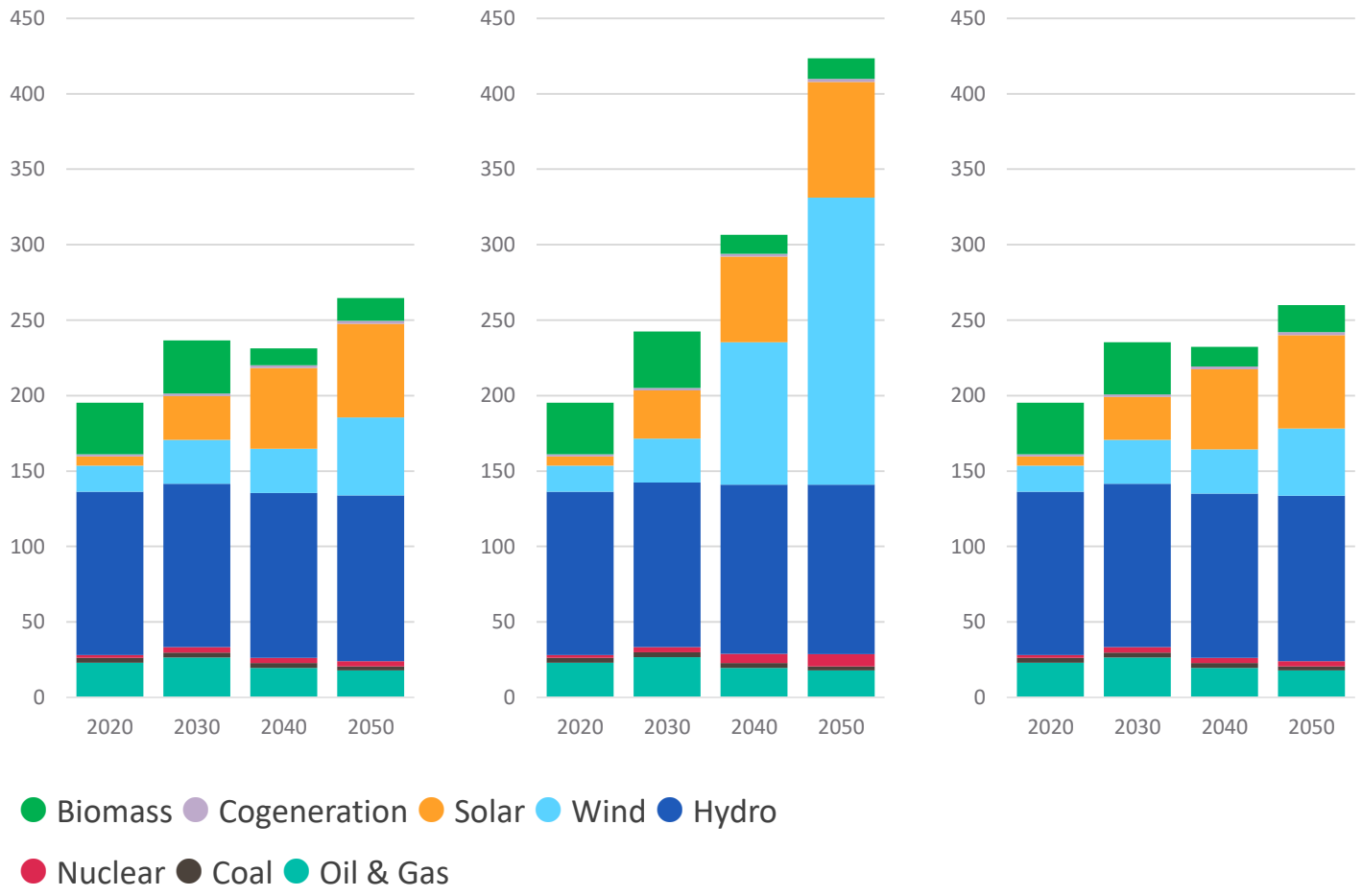
The Alternative Transition scenario involves higher electricity demand and lower hydropower dispatch, so that solar, wind and nuclear sources grow more in this scenario.

Solar capacity added 2020-50 (GW)

	BRAZIL	ALTERN.	GLOBAL
New solar	56	70	56
Centralized	15	30	15
Distributed	40	40	40
% of total net growth	81%	31%	86%

Nuclear sources reach 8 GW by 2050 in the AT scenario.

Installed Capacity (GW)



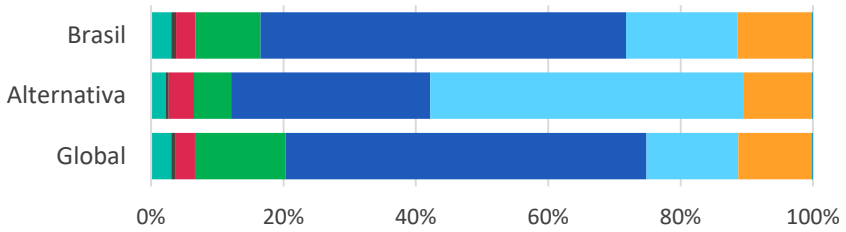
POWER GENERATION

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Generation breakdown in 2050



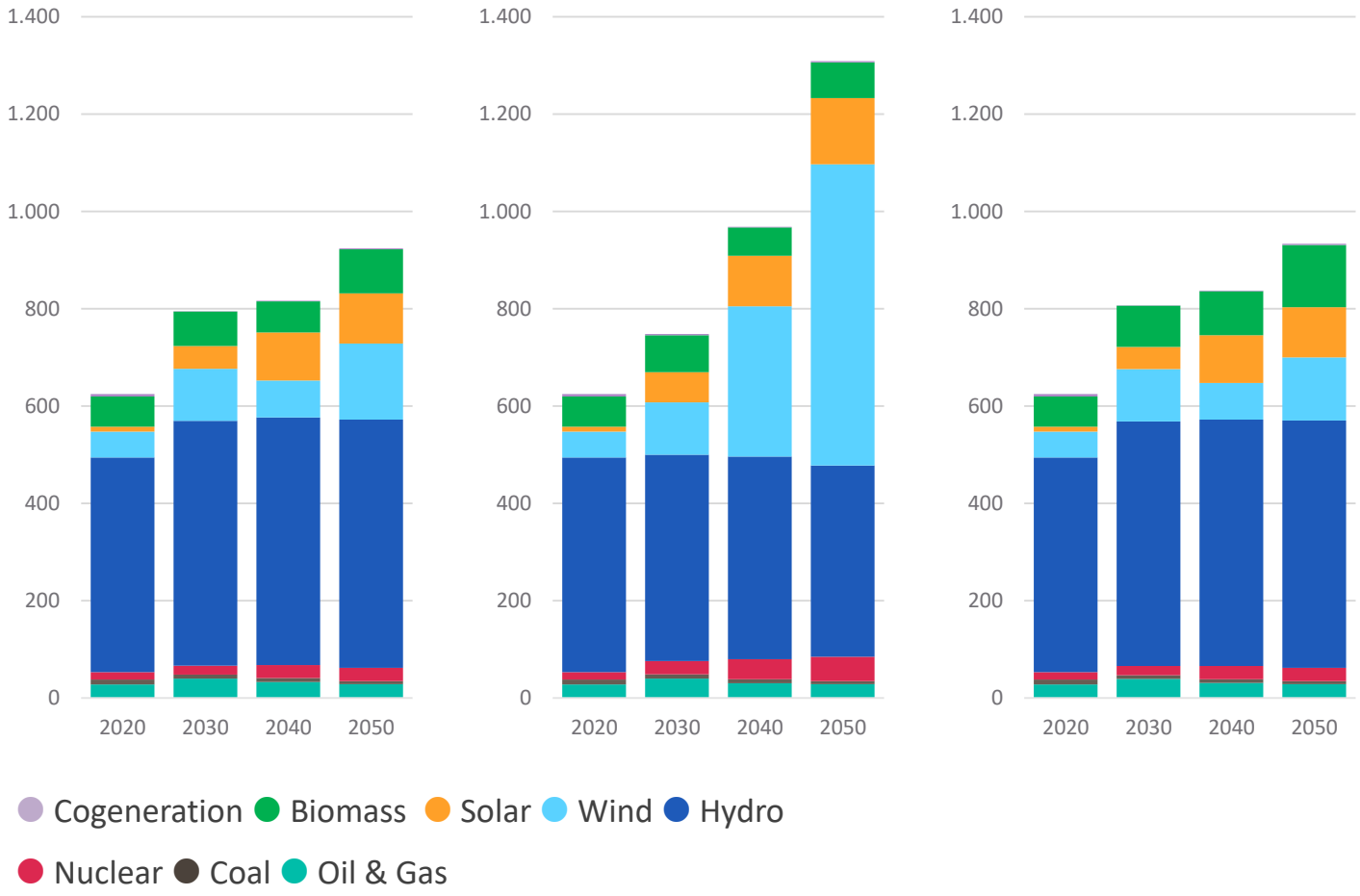
A portion of the generation from biomass in the Brazil and Global scenarios is associated with CCS.

New power generation 2020-2050 (TWh)

	BRAZIL	ALTERN.	GLOBAL
Biomass	+11	+12	-19
Biomass CCS	+18	-	+85
Wind	+102	+565	+76

In all scenarios, natural gas will in 2050 answer for a smaller share of the energy mix than in 2020 despite the growth in its absolute generation volume.

Power generation (TWh)



POWER INDUSTRY

Transmission lines must be expanded and the exchange of power between subsystems within the National Interconnected System (SIN) must improve.

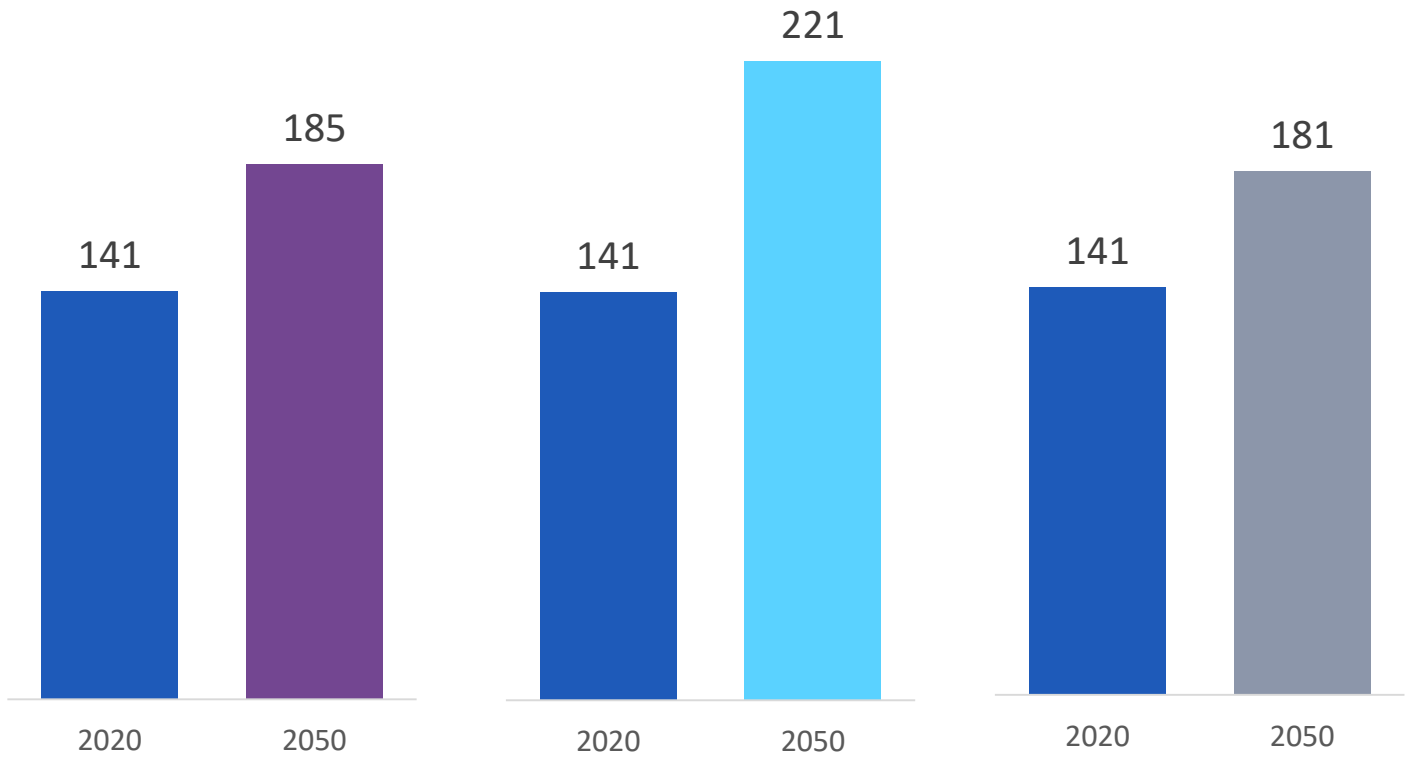
The transmission capacity required is a function not only of the flow of power but also of the type of generation. The Alternative Transition scenario, with more wind generation, requires greater expansion of transmission lines (57% growth from 2020 to 2050).

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Transmission Capacity (GW)

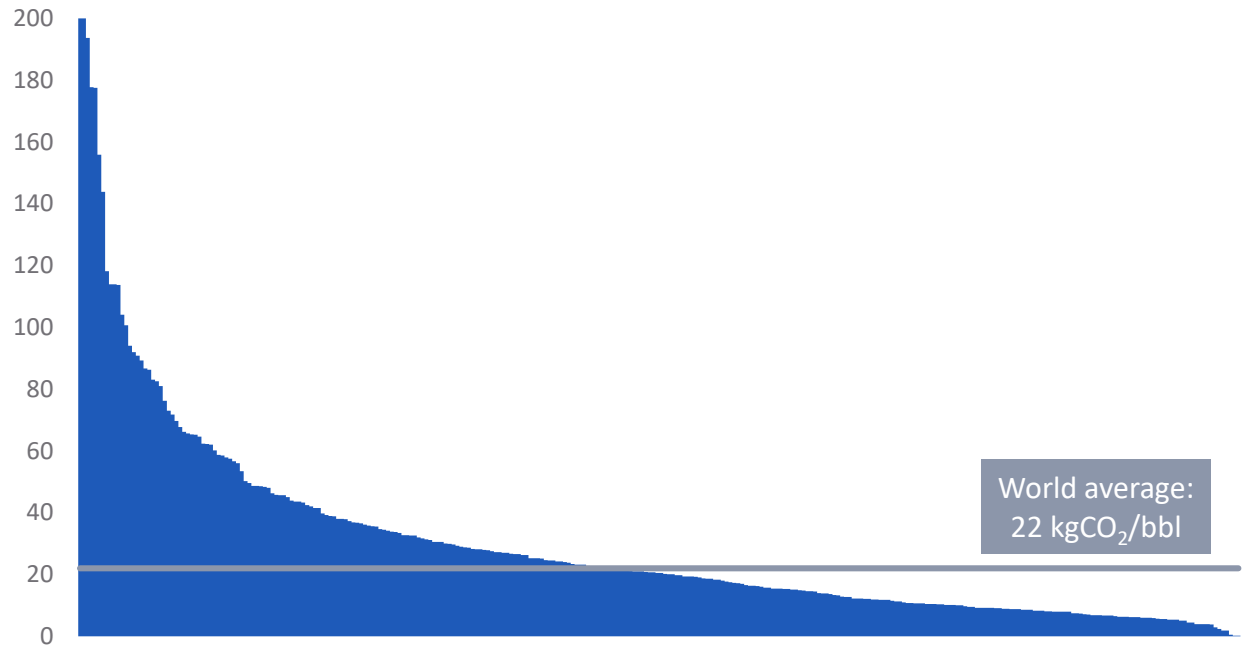


OIL

Brazilian oil is mostly medium grade and low sulfur content and shows triple resilience (technical, economic and environmental). It is the least carbon-intensive in the international market: the world average is 22kg of CO2 per barrel of oil equivalent produced (kg CO2 eq/b) and Brazil's is 15 kg CO2 eq/b (going as low as 10kg CO2 eq/b for oil from the pre-salt layer).

Oil will remain in use throughout the energy transition to meet national energy security needs. In the long run, global carbon neutrality scenarios project a residual demand for oil to serve hard-to-abate industries and non-energy purposes.

Worldwide oil carbon intensity (kg CO2 per barrel)



Source: Rystad, 2022

OIL

The Brazilian economy will use less oil but domestic production will likely grow to meet foreign demand.

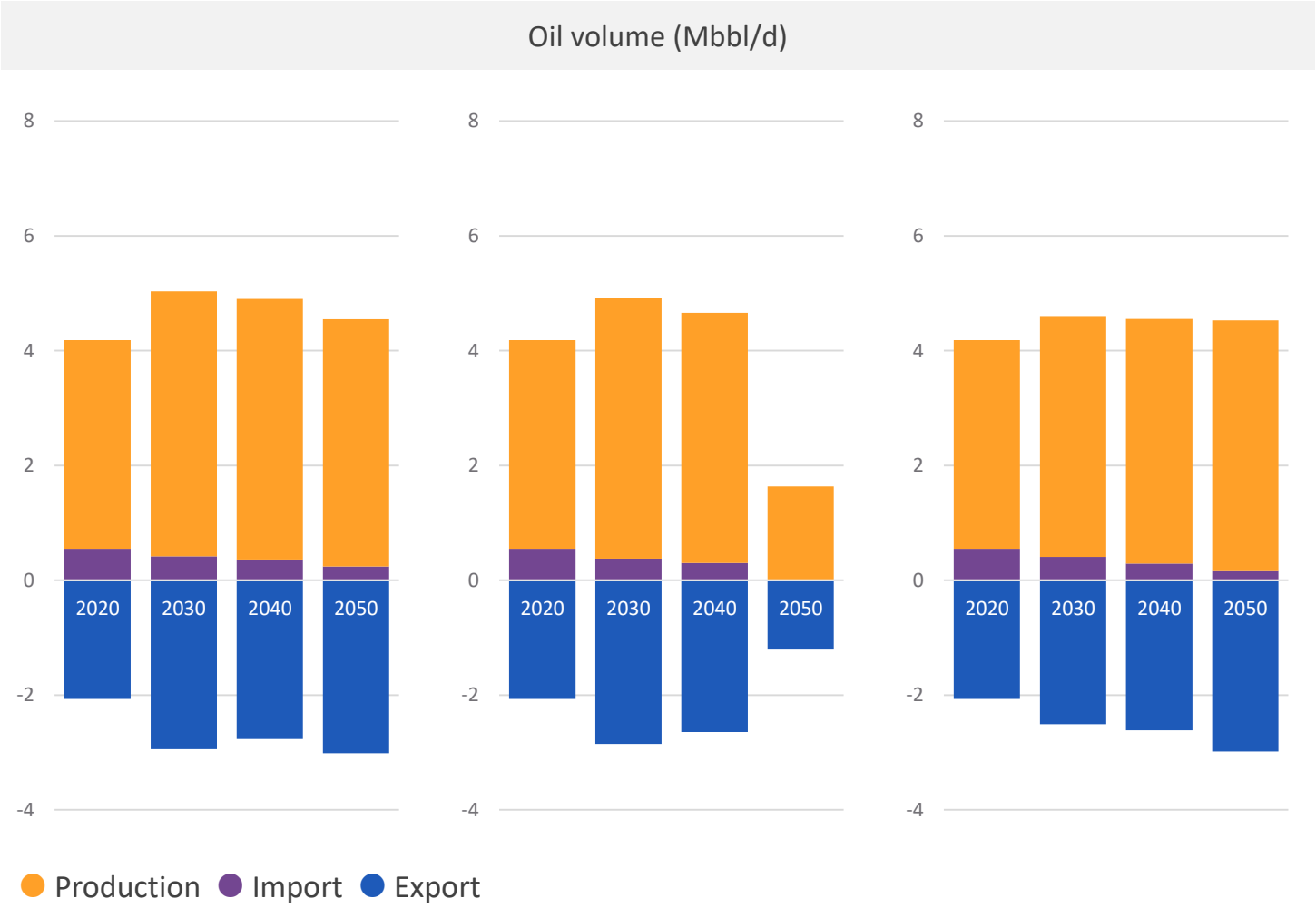
The increase in production is based on the triple resilience of Brazilian oil, which will crowd out oil from other countries with heavier carbon footprints, thus contributing to mitigate GHG emissions.

Non-energy uses will represent 12.3% of domestic demand for oil products by 2050.

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION



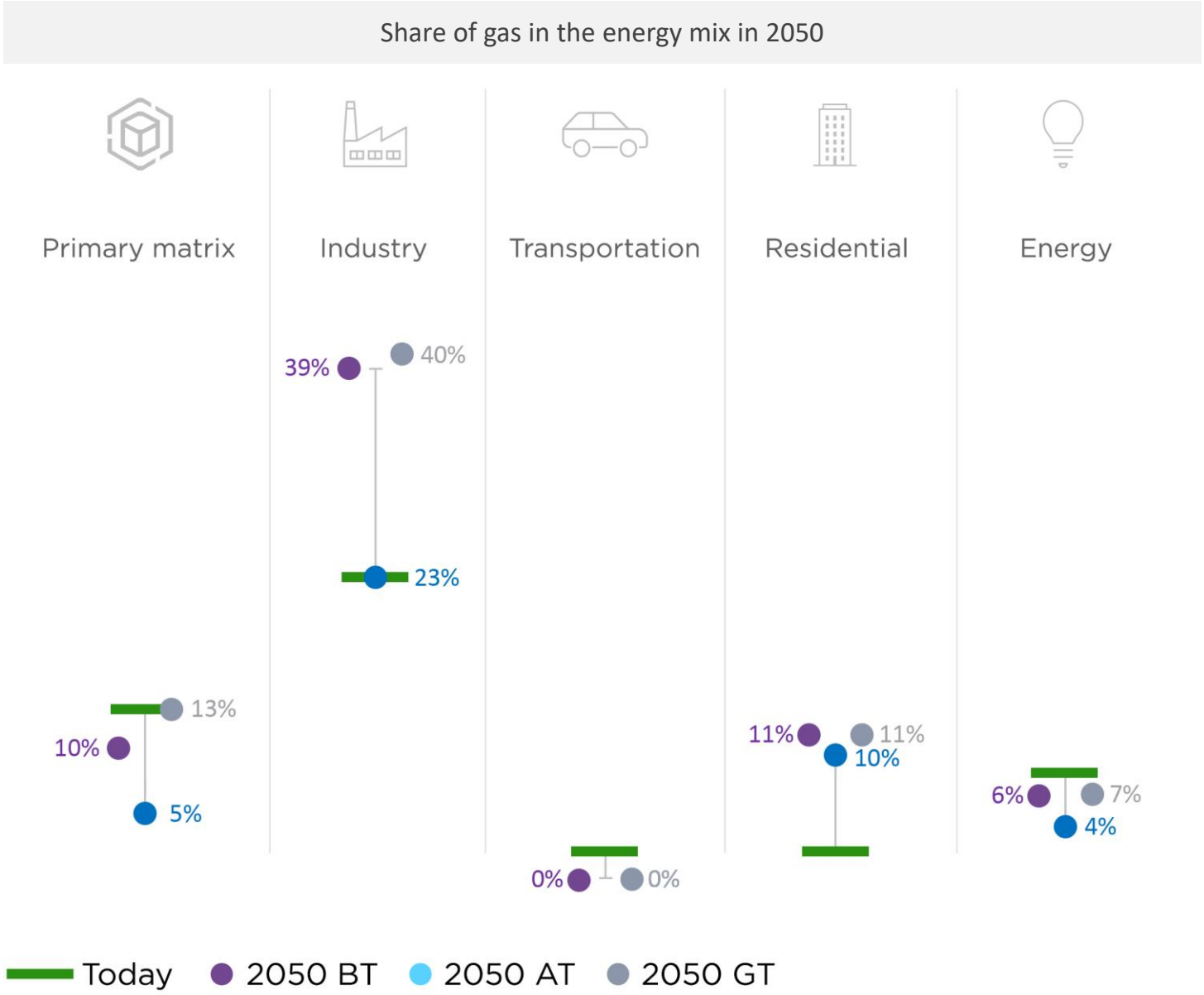
NATURAL GAS

As Brazilian natural gas is mostly associated, its production follows a similar pattern to oil production, growing between 2020 and 2050 in the Brazil and Global scenarios and decreasing in the Alternative scenario.

In all scenarios, production focuses on the domestic market.

Natural Gas will become less important for power generation purposes but more so in construction and industrial activities, driven by the chemical, cement, ceramics and other industries.

Gas will remain a marginal fuel in the transportation industry.



REFINERIES

1 BRAZIL TRANSITION

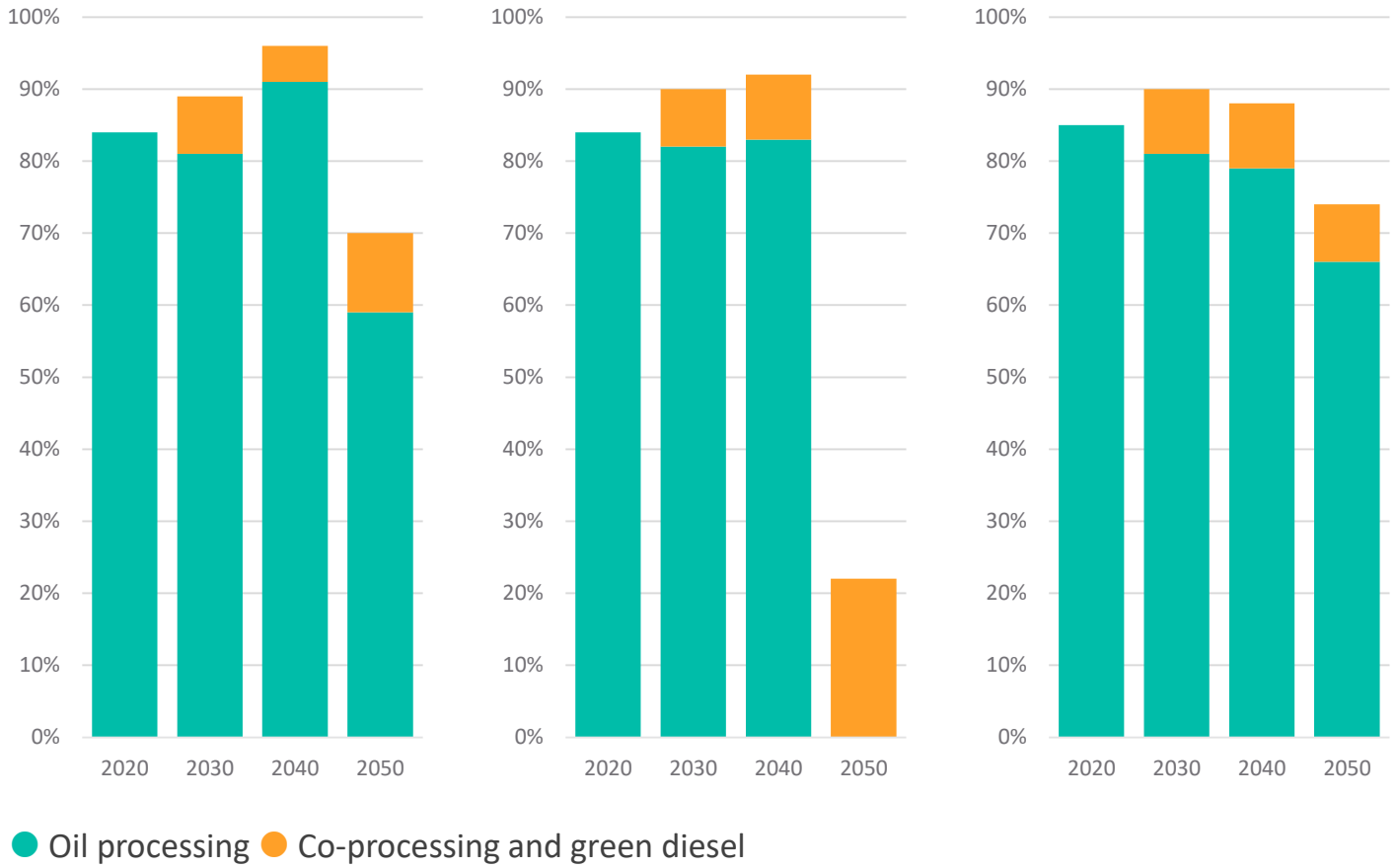
2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

The oil refinery use factor will drop from 84% in 2020 to 70% in the Brazil scenario and to 74% in the Global scenario in 2050. Fleet electrification will cause the use factor to go down significantly in the Alternative scenario.

The introduction of vegetable oil, residual oil (UCOS) and pyrolysis oil co-processing in refineries equipped with HDT and FCC units will push up the use factor. Co-processing inputs are expected to have around 10% biomass content by 2050.

Refinery use factor



BIOFUELS

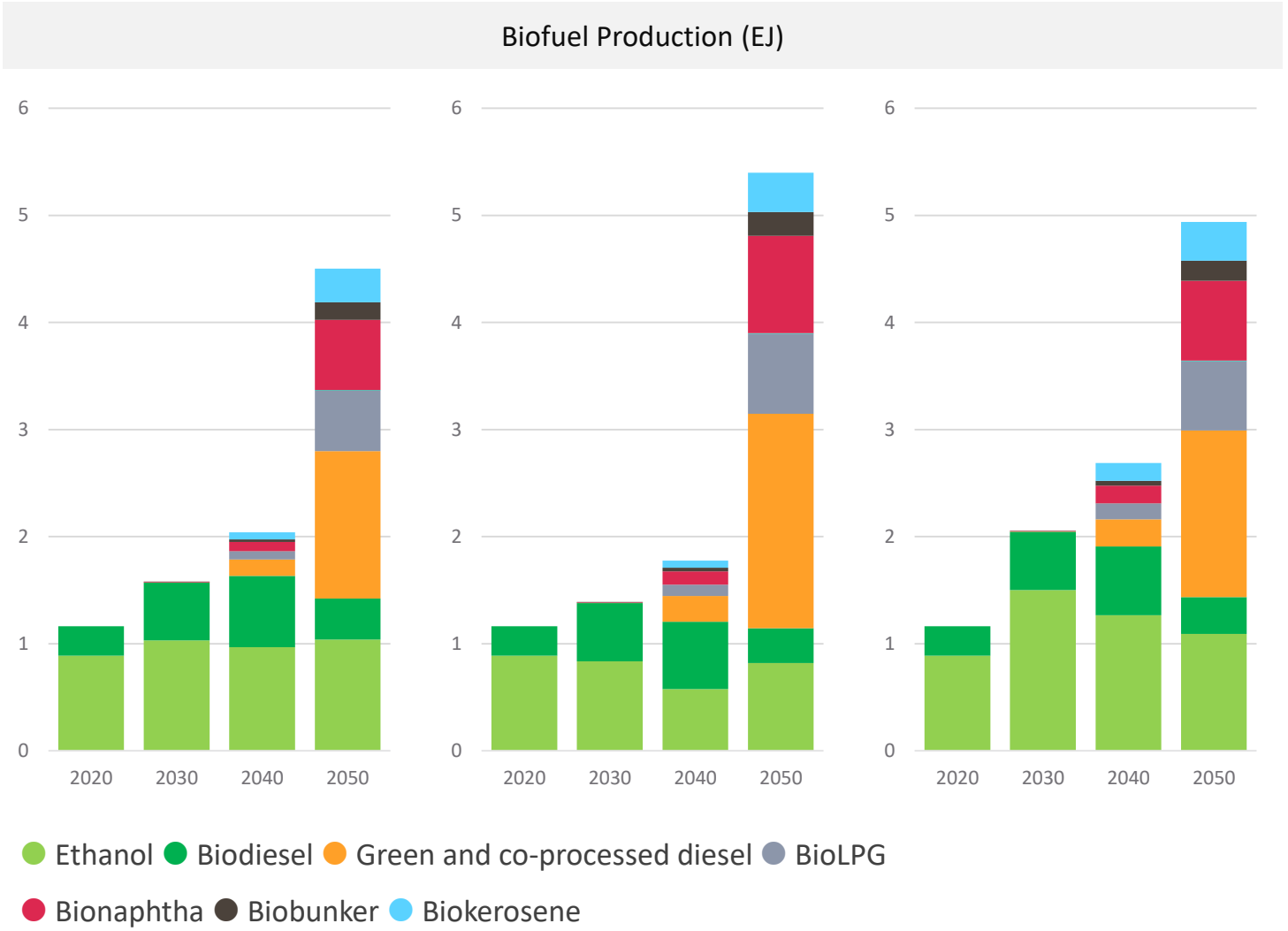
1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Conventional biofuels (ethanol and biodiesel) grow in almost all scenarios, accounting for the largest share of biofuels by 2040.

Advanced biofuels have grown significantly in the last decade, especially to meet the demand from hard-to-abate transportation activities such as freight, aviation and maritime.



BIOMETHANE

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

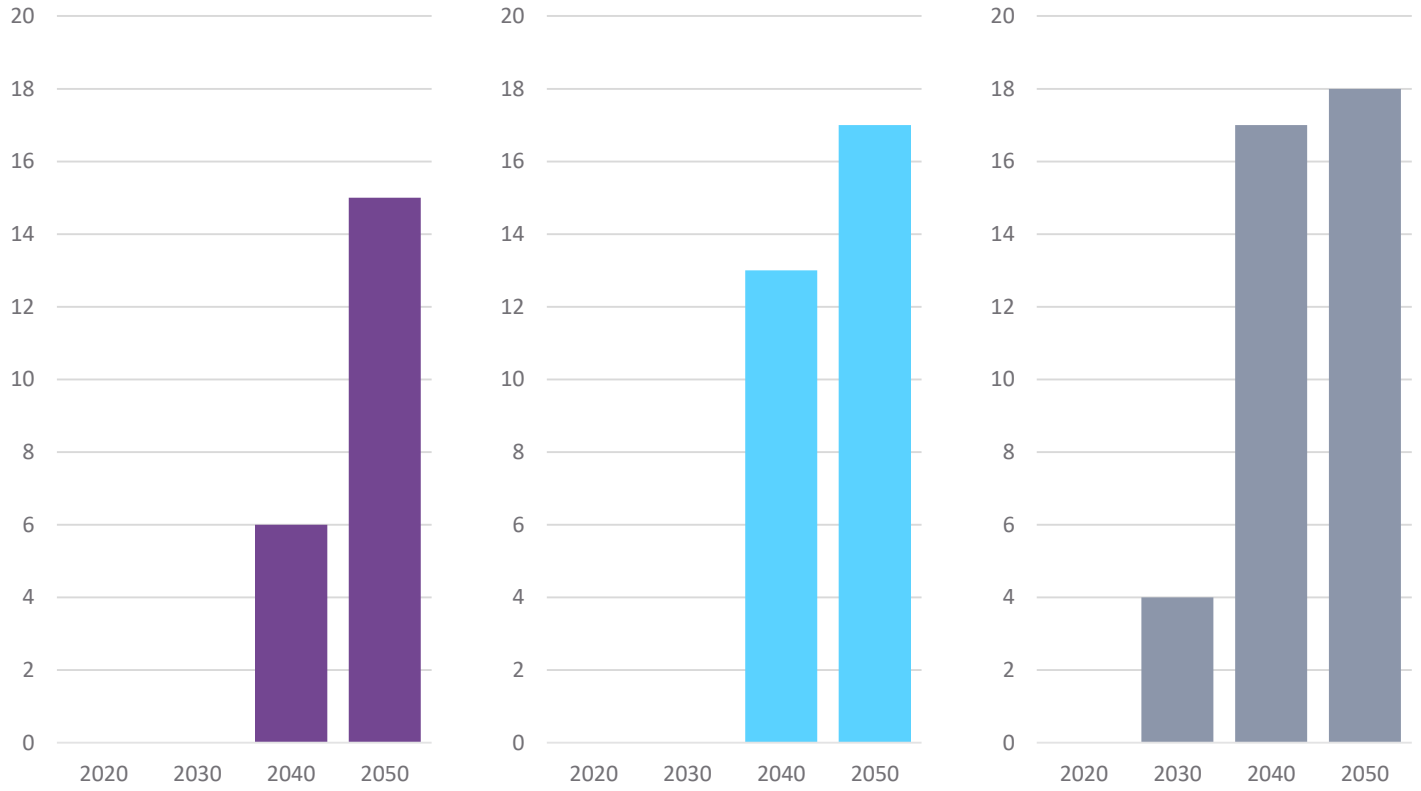
3 GLOBAL TRANSITION

Biomethane can significantly contribute to achieve climate goals, with production growing to between 17 and 18 Mm³/day by 2050 in the three scenarios.

Biomethane plays a role in the decarbonization of natural gas and contributes to give use to the fossil gas infrastructure.

Biomethane may boost the value of thermal plants, gas pipelines, etc. that stop using natural gas.

Increase in Biomethane Production (Mm³/d)



biomethane % share of gas demand

BRAZIL	ALTERN.	GLOBAL
10%	19%	11%

HYDROGEN

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

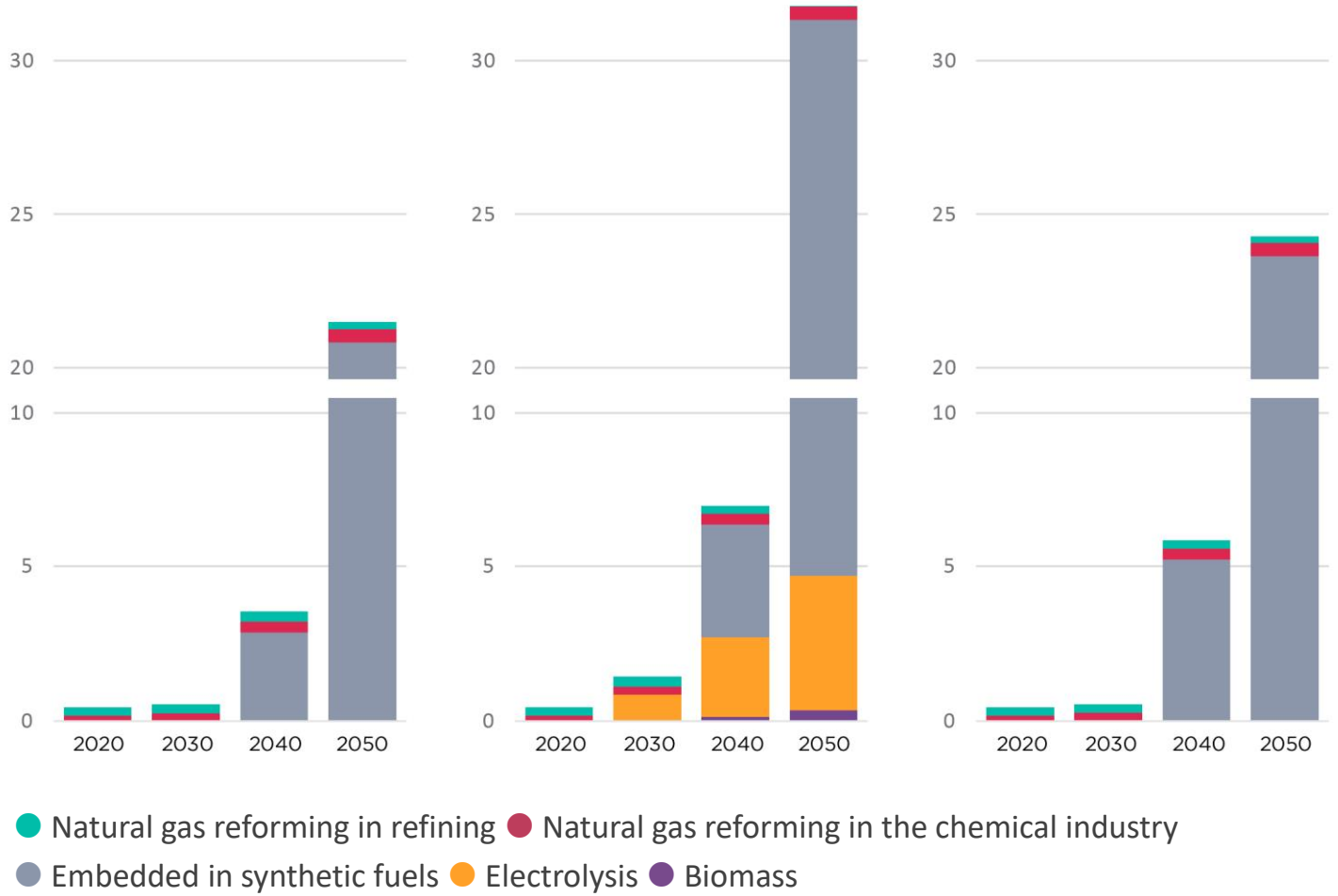
3 GLOBAL TRANSITION

H2 can be produced from different energy sources such as electricity, natural gas, biomass (via electricity, gasification or reforming, depending on the biomass and on the conversion chain).

H2 shows greater promise as a feedstock to generate syngas to be used in advanced biofuel production.

The Alternative Transition scenario projects significant production of electrolysis H2 for export.

Hydrogen Production (Mt)



TRANSPORTATION

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

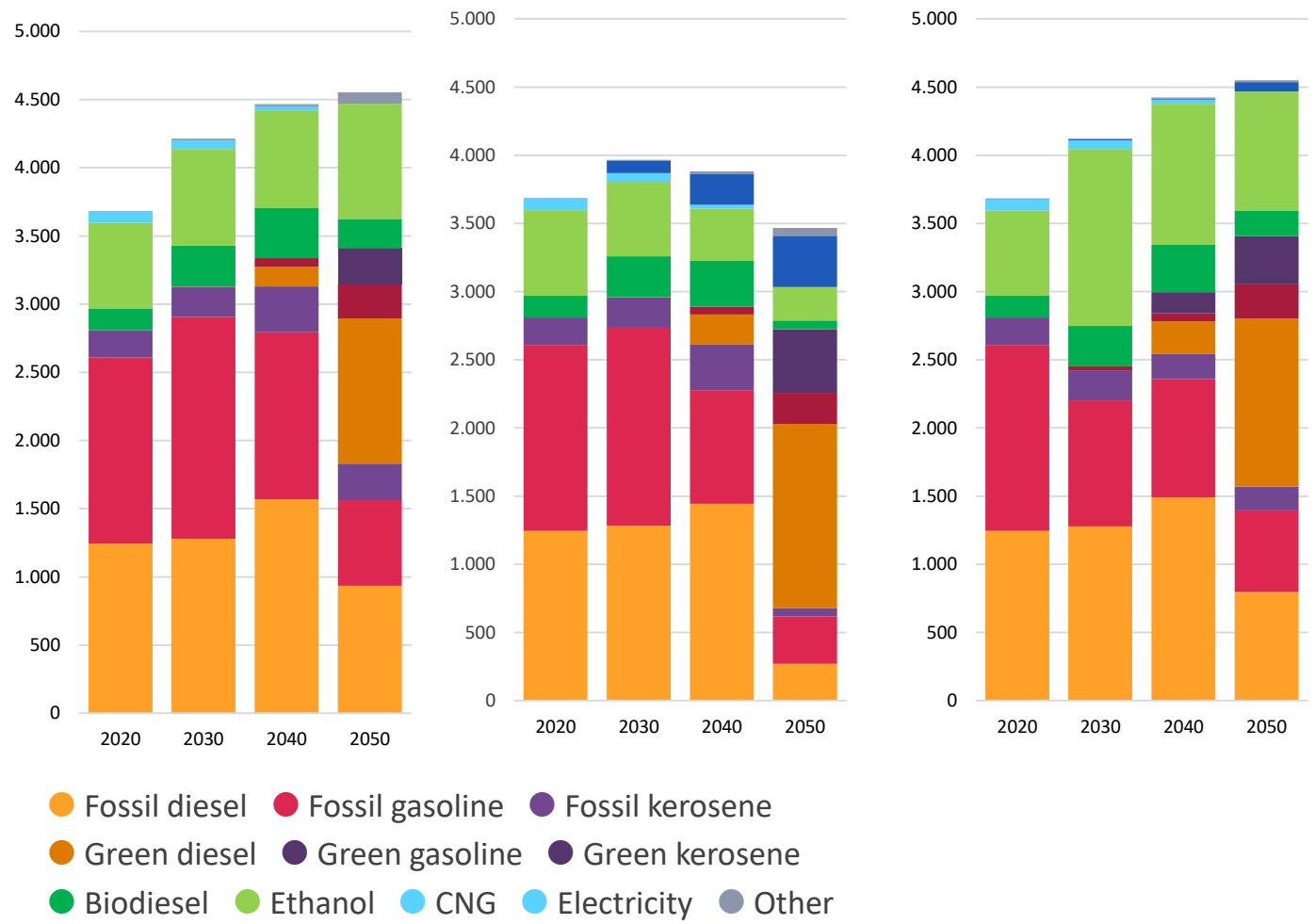
Two technological alternatives are available to decarbonize the industry:

(i) fleet electrification through the replacement of vehicles now in circulation;

(ii) replacement of fossil fuels with biofuels.

Those alternatives may complement each other in different market niches (luxury x economy) but also be combined (flex hybrid vehicles, ethanol fuel cell vehicles, etc.).

Total use in the transportation industry (PJ)



ROAD TRANSPORT: PASSENGERS

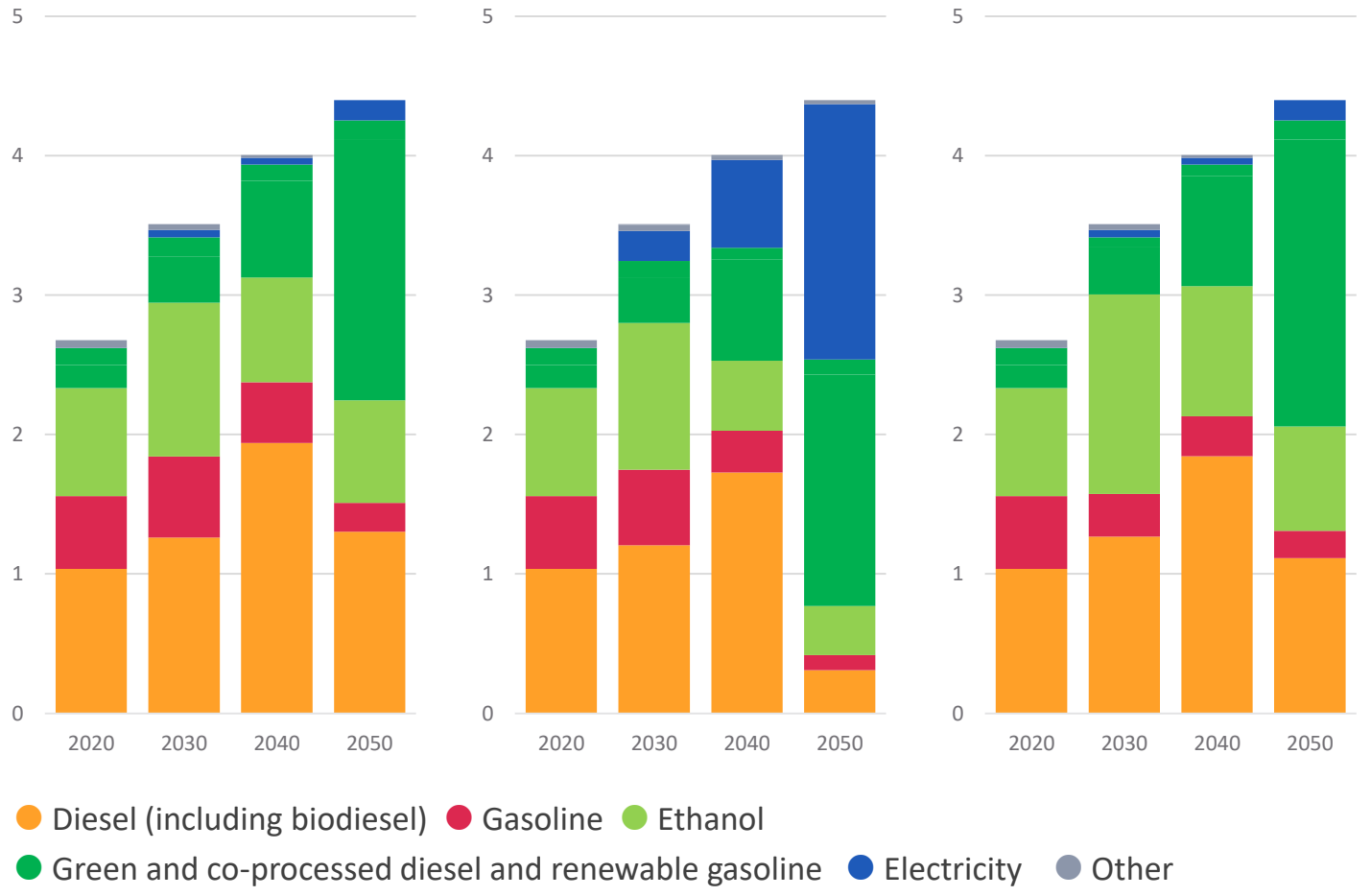
Urban buses and light commercial vehicles and motorcycles will give the greater contribution to the electrification of passenger road transportation, the former two thanks to the predictability of their routes and to their operating regimes and the latter because of short life-cycles and low replacement cost.

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Road passenger transportation (billion passenger-kilometers)



ROAD TRANSPORT: FREIGHT

1 BRAZIL TRANSITION

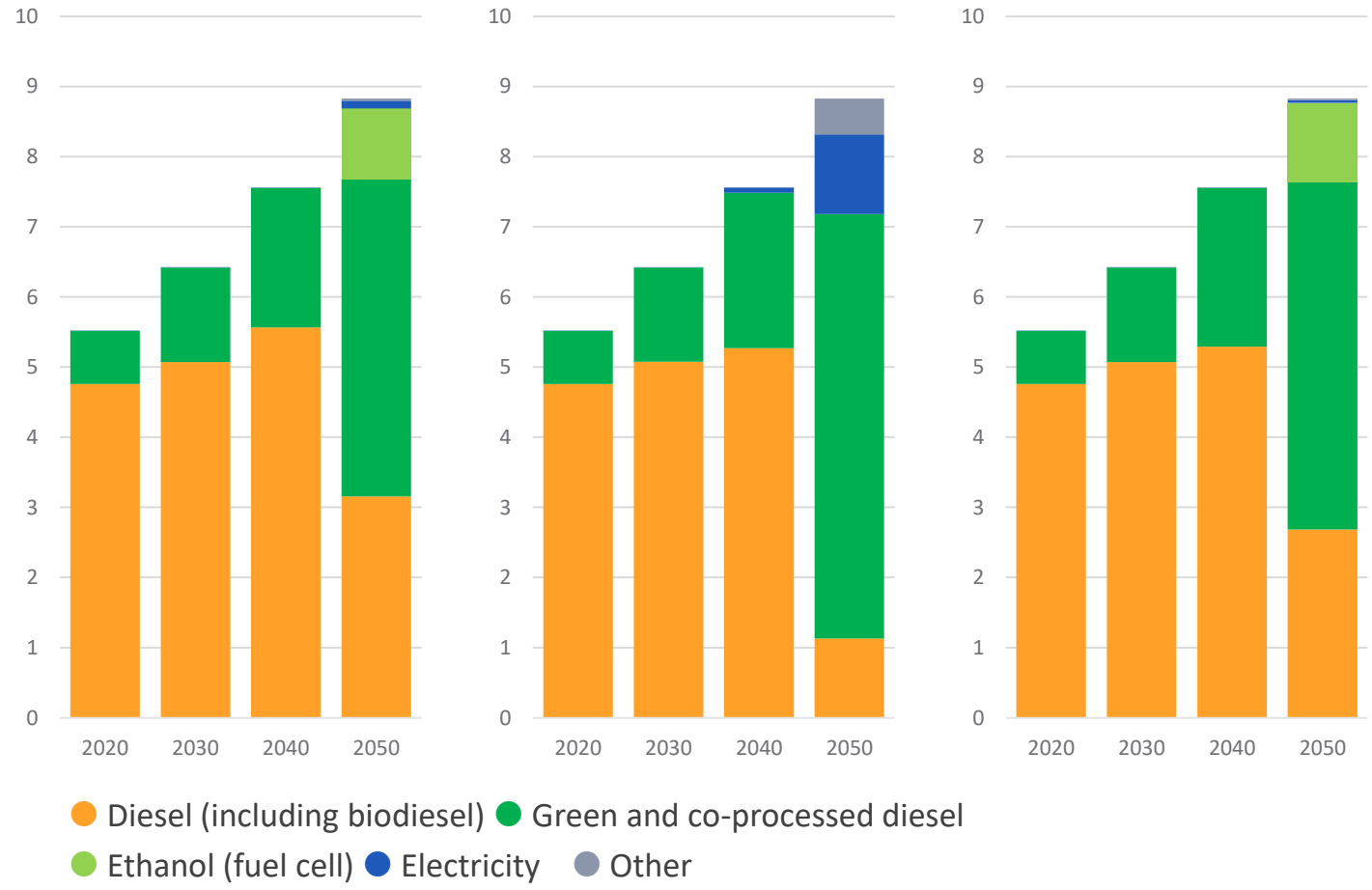
2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Energy use in road freight transportation is concentrated in high-capacity trucks driving long-haul. The energy density of the fuel source used is particularly important when moving freight over long distances.

The energy density of batteries is still significantly lower than that of liquid fuels, which makes fuel cells the preferred electrification alternative in the BT and GT scenarios. The use of batteries in freight transportation is restricted to the AT scenario and focuses on light trucks.

Freight transportation (billion tonne-kilometers)



INDUSTRY

1 BRAZIL TRANSITION

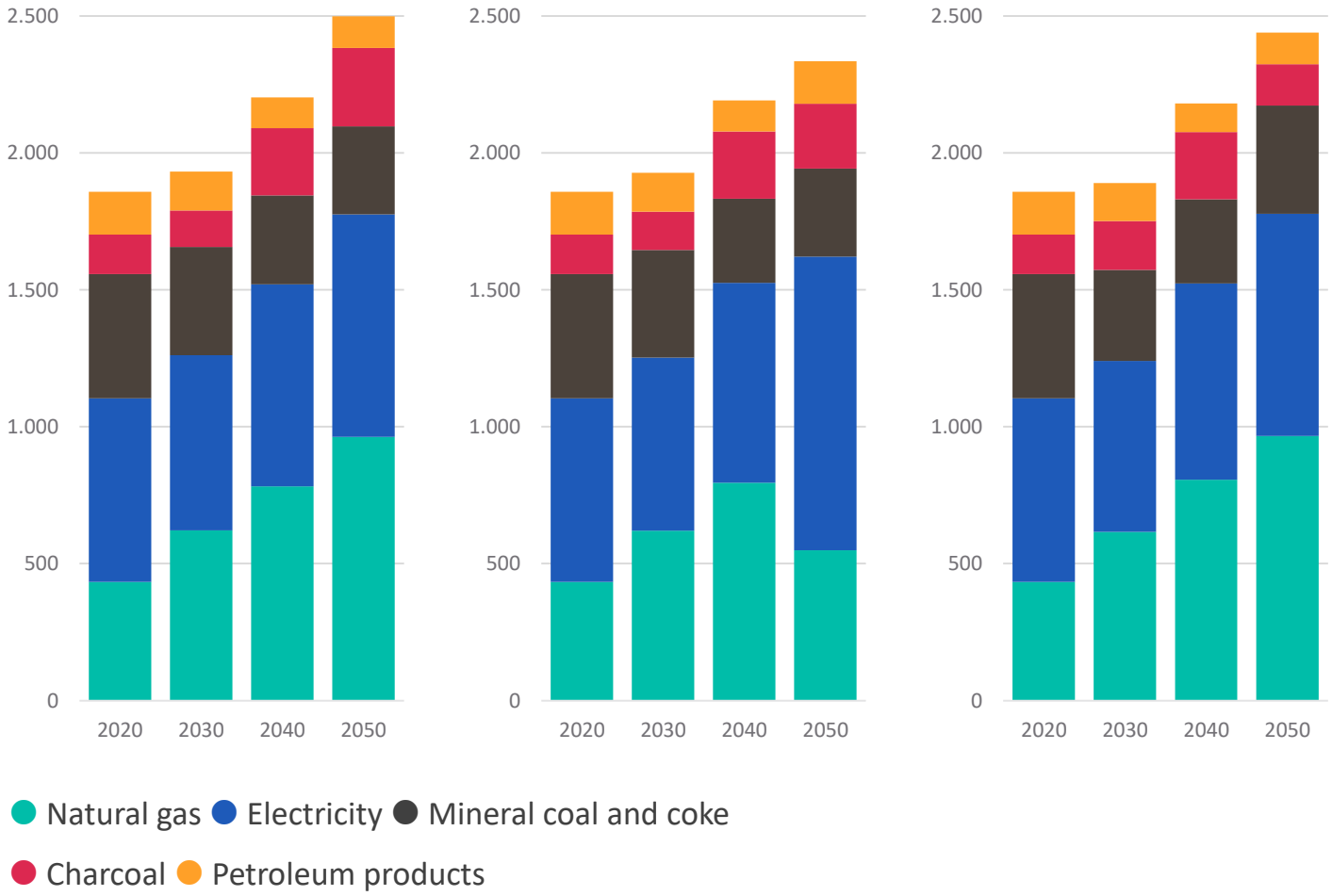
2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Industry adds to Brazil's total emissions both by burning fossil fuels and through industrial production processes.

In relation to the latter, the industries that emit the most are metallurgy and cement manufacturing. Those industries not only are the biggest emitters but also face the hardest technological hurdles to decarbonize because emissions are inherent to their manufacturing processes.

Total energy use by industry (PJ)



HOME AND SERVICES

Growing equipment ownership and use, magnified by income growth and by the widespread dissemination of mobile phones and of the internet, and the rapid expansion in the total built area in emerging countries such as Brazil, indicate that energy demand in these countries will increase.

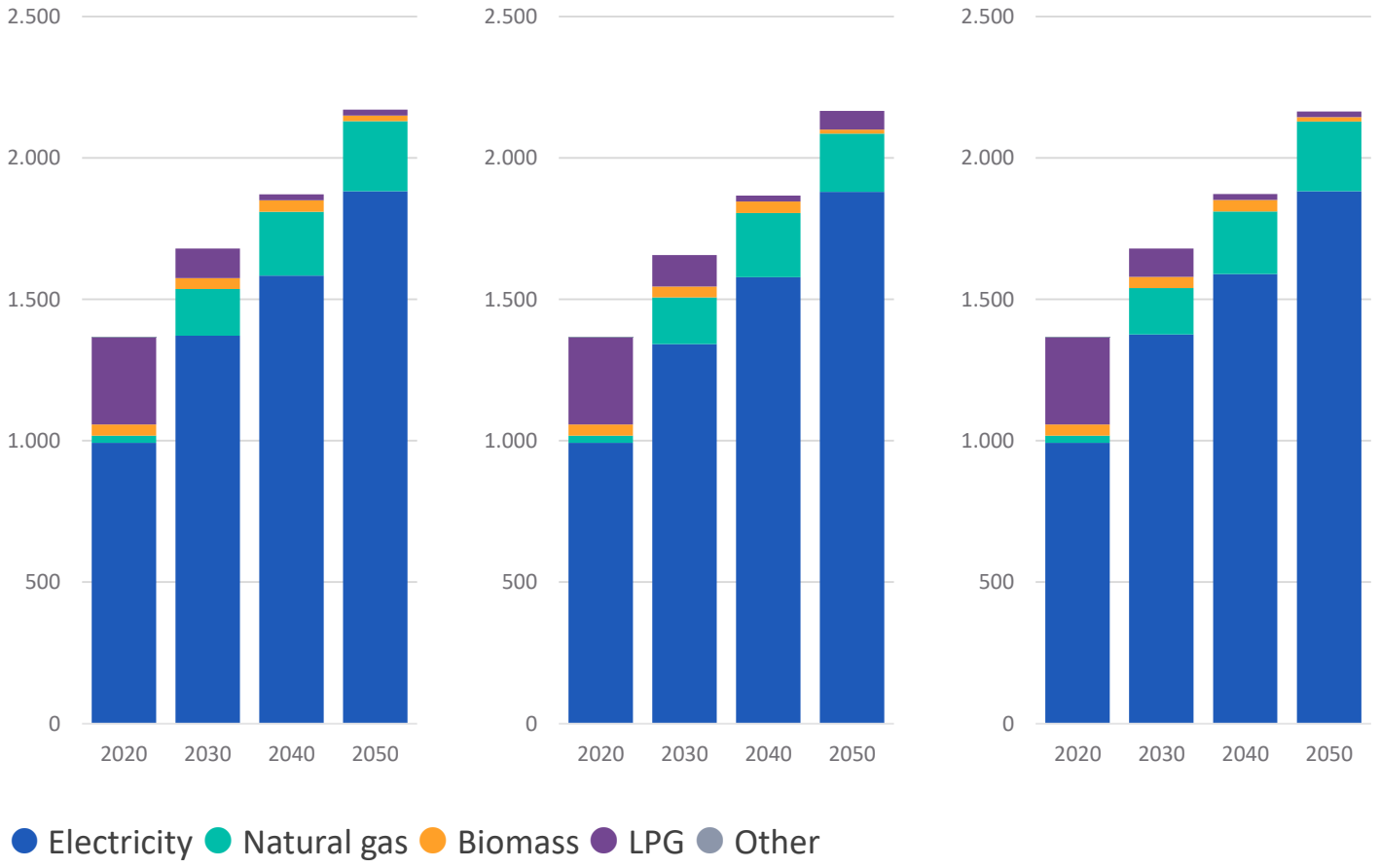
Electricity, which already is one of the main sources of energy for final home use, will gain ground in all scenarios. The increased purchasing power of an expanding middle class is a significant driver for growth in energy demand. The challenge of energy transition will be to reconcile this demand growth trend with sustainability.

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Total energy use in homes and in services (PJ)



FINAL COMMENTS

RECOMMENDATIONS (1/2)

1

Build an energy policy agenda and design markets that can open flexible decarbonization paths to address the technological and market uncertainties identified taking advantage of the synergies provided by Brazil's diverse energy resources, in line with an economy-wide approach to Brazil's NDC goals.

2

Minimize regrets through open, diverse and competitive market approaches and through the combination of and competition between different technological solutions (technological neutrality).

3

Harmonize sustainable development, energy transition and energy security objectives taking advantage of Brazil's resource potential and market and innovation opportunities.

4

Take advantage of Brazil's existing competitive advantages to build and fund the competitive advantages of tomorrow, upgrading assets and focusing expertise on the energy transition of the O&G, biofuels, renewables and nuclear industries (co-firing with renewables, new decarbonized energy sources, synergies with renewables projects, new uses for infrastructure and assets, funding new businesses, etc.).

5

Meet Brazil's current objectives/targets in line with (net) climate neutrality commitments, such as eliminating illegal deforestation by 2028, recovering degraded areas, reducing fugitive methane emissions, decarbonizing fuels and others.

FINAL COMMENTS

RECOMMENDATIONS (2/2)

6

Ensure that the transition of the Brazilian energy industry is fair, inclusive and cost-effective and does not involve offsetting GHG emissions associated with land use, forestry and extensive cattle ranching in any way that will cause higher costs for Brazilian society and economy.

7

Improve or establish institutional, legal and regulatory frameworks conducive to the development and use of technologies and business models focused on reducing emissions and on removing carbon from greenhouse gas emissions. In particular, it is critical to establish or improve frameworks for CCS (key to BECCS and to define the role of O&G in energy transition), renewables for power generation, advanced biofuels, new energy sources (low carbon hydrogen, synthetic fuels, etc.), energy storage and carbon pricing, as well as for the adoption of new end-use technologies (including the electrification of transportation, new industrial applications, etc.).

8

Map, supplement and disseminate information on the technical, economic and market potential of the alternatives identified in the different scenarios, especially CCS, renewables for electricity generation, advanced biofuels and hydrogen.

9

Further study the climate resilience of the energy solutions found in the project, especially hydro, wind and solar power and biofuels (energy agriculture).