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# pathways to deep decarbonization in Brazil

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A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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## Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

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# 1 Introduction

## *1.1 The National Context for Deep Decarbonization and Sustainable Development*

Brazil occupies a unique position among the major greenhouse gas (GHG) emitting countries due to its low per-capita energy-related GHG emissions (2.4 tons $CO_2$ in 2014), attributable to Brazil's abundant clean energy sources. The sources of major emissions have historically been concentrated in agriculture, forestry, and other land use (AFOLU), and are related mostly to deforestation, crop growing and livestock. Recently, deforestation in Brazil has slowed considerably, to the point where forestry has ceased to be the major source of emissions. Thanks to reduced deforestation, Brazil has reduced its overall GHG emissions by 41% from 2005 to 2012, and its total GHG emissions per capita decreased from a high in 2004 of 14.4 $tCO_2e$ to an estimated 6.5 $tCO_2e$ in 2012.

Brazil achieved this reduction in emissions per capita through recent governmental policies combining command-and-control tools (enforcing laws and regulations, such as the Forest Code, through inspecting rural properties and roads spotted by satellite imagery) and economic instruments (requiring agricultural and cattle-raising projects to demonstrate compliance with environmental regulations to be eligible for public bank soft loans that supply most of the credit to this sector).

Before this recent decline, earlier agriculture and livestock emissions growth was driven by the expansion of the agricultural frontier that pushed crop and cattle-raising activities into the *cerrado* (savannah) and Amazon biomes. Brazil is one of the world's most important suppliers of commodities such as soybeans and meat, with 210 million heads of cattle in 2010. Deforestation in the Amazon peaked at 2.8 Mha (million hectares) in 2004. Governmental efforts have succeeded in bringing Amazon deforestation down to 0.7 Mha in 2010 and 0.5 Mha in 2014. On the other hand, emissions related to fossil fuel combustion for energy production and consumption have continued to increase significantly, in parallel with the growth of the Brazilian economy. Fossil fuel combustion for energy production and consumption have reached nearly the same level of those from agriculture plus cattle breeding, and due to this fast growth rate are expected to become the dominant source of GHG emissions over the next decade.[1]

Brazil faces the challenge of building upon its historically low energy-related GHG emission levels through new decarbonization strategies, while pursuing higher living standards for its population. Average annual per capita income in 2005 was only $4,767. Inequality, as evidenced by Brazil's uneven income distribution, is a major problem. In 2005, the poorest 16% of the population had an average per capita income of $481 per year, or less than two times

1 La Rovere, E.L., C.B.S. Dubeux, A.O. Pereira Jr; W.Wills, 2013; Brazil beyond 2020: from deforestation to the energy challenge, Climate Policy, volume 13, supplement 01, p.71-86.

the national annual minimum wage. Meanwhile 60% of the population had an average per capita income of $1,819 per year, the equivalent of 2 to 10 times the national annual minimum wage. The richest 24% of the population had average annual per capita income of $10,848[2] (or more than 10 times the annual minimum wage). Brazil has made some progress in reducing income inequality in the last decade, thanks to the government consistently increasing the minimum wage faster than the inflation rate and to social transfer programs (e.g. *Bolsa Família*). This decreased the Gini coefficient from 0.57 in 2005 to 0.53 in 2013. But inequalities are still a leading concern: In 2013, 15.5 million people in Brazil were living below the poverty line, of whom 6.2 million were in an extreme poverty condition.[3] Inequality between regions is also a problem; reducing these is the object of some regional incentive programs.

Electricity access is very high and increasing (99% of urban households and 90% of rural households were electrified in 2010). Access to a clean water supply is also high (93% of the population in the largest 100 municipalities, in 2013). But important challenges remain in providing citizens access to basic services and, most notably, Brazil has a housing deficit. Brazil has 65 million households in total, but 5.4 million houses are 'missing.' Some 2.7 million families lived in multiple family dwellings. In addition, nearly half the population had to build their own house. Water supply is expensive and subject to shortages, as was the case during the recent drought. The coverage of sanitation services is still poor: only 48% of the population benefits from sewage collection networks and only 39% of the population had its sewage properly treated in 2012. Building a low-carbon infrastructure to meet all these demands remains a huge challenge.

At the time of the 1973 oil shock, Brazil was strongly dependent on oil imports. It relied on imported oil for 83% of domestic needs, mostly for the industrial and transportation sectors (oil products are not used significantly in electricity generation nor in the residential sector; ambient heating is needed only sparingly in the south of Brazil). Oil imports have been important particularly to fuel the on-road modes that dominate urban and long-distance transportation, for freight and passengers. In 1980, after the second oil shock, more than half of Brazilian hard-currency earnings from exports were used to pay its oil import bill. Brazil has found large off-shore oil reserves during the last four decades, allowing for a substantial increase in oil production, and sharply reducing the country's dependence on oil imports. (As of 2014, 6% of domestic oil consumption was supplied by imports, while the corresponding import shares for natural gas, coal and electricity were 44%, 75% and 5%, respectively, with 87% of overall energy use secured by domestic production.)

More recently, the discovery of large offshore oil reserves in the pre-salt layer has created expectations that Brazil will become a major oil exporter, since the size of the reserves exceed the country's own consumption needs. Current government plans envision doubling domestic production by 2030 (from the 2014 level of 2.25 billion barrels oil/day), and using half of future production for export. Congress has approved a law to use 75% of the oil revenues to fund education and 25% for health. This assumes that the growth of domestic energy consumption will be supplied mostly by renewable energy. Renewables already accounted for 39.5% of energy consumption in 2014. Renewables include hydropower, sugarcane products (ethanol used as liquid biofuel in

2 IES-Brasil Project Team, 2015; "Economic and Social Implications of GHG Mitigation Scenarios in Brazil up to 2030"

3 Source: MDS. Data Social 2.0. Available at http://aplicacoes.mds.gov.br/sagi-data/METRO/metro.php?p_id=4, accessed on 24 September 2015.

transport and bagasse for cogeneration of heat and power), and, more recently, the fast growth of wind energy.

Brazil is not endowed with large coal reserves. Its small reserves are of a low-grade variety, with its demand limited to the few industries that use it for specific processes (e.g. coke for steel mills; ceramics, cement) and some complementary electricity generation. The volume of natural gas produced in the country is equivalent in 2014 to 24 Mtoe (net of losses and reinjection). It has not followed the rapid growth in demand, 9.5% from 2013 to 2014, mainly for power generation and industrial use, creating thus a need to import gas through the pipeline from Bolivia or as liquefied natural gas (LNG) from other countries. Natural gas imports represent 44% of domestic consumption in 2014, but it is expected to decline sharply, or to be eliminated entirely in the future as recent discoveries are fully exploited. If the country embarks on a low-carbon path, it will allow the country's natural gas to be diverted from power generation towards its noblest use, as an industrial feedstock.

Brazil is endowed with a huge renewable energy potential that makes a growth trajectory with low energy-emissions appear entirely technically feasible, with a wide spectrum of options. In 2014, hydropower provided 65% of the country's electricity needs and hydropower's full potential is still untapped, although not all of it will be used, due to concerns over local environmental impacts in the Amazon region. Brazil also has an abundance of land that can be sustainably used to produce biofuel feedstocks, especially sugar cane for ethanol. Since the launch of the Brazilian Ethanol Program in 1975, all the gasoline used in the country is blended with 22%–27%ethanol. Domestically produced ethanol is also used for the pure ethanol and flex fuel-run engines of light-duty vehicles. A learning curve over the last 40 years has allowed Brazilian producers to increase yields from 4,000 to 7,000 liters/ha/year of ethanol from sugarcane, while production grew from 0.7 billion liters in 1975 to 27 billion liters in 2010. The first new plants producing second-generation ethanol from cellulosic materials (e.g. sugarcane bagasse) have already reached 25,000 liters/ha/year, illustrating the huge potential for increasing ethanol production. Biodiesel production reached 3 billion liters/year in 2010, mainly obtained as a byproduct of soybean oil production., Overall, diesel oil used in the country includes a 7% blend of biodiesel.

Brazil also has an important wind energy potential. Initial estimates of its potential for installing up to 150 GW have yet to be updated; this figure will grow because of technical progress. In 2014, wind power installed reached 4.9 GW, with power generation increasing from 1.2 TWh/year in 2008 to 12.2 TWh/year in 2014.[4] Solar energy is also widely available at high levels throughout the country. Therefore, keeping a low energy-emissions growth trajectory appears technically feasible, with a wide range of options of renewable energy sources.

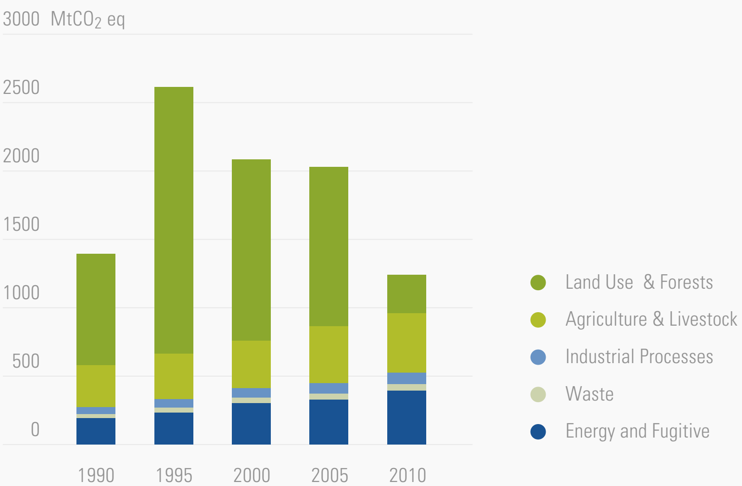
In the period 2004–2012, Brazil's GDP increased by 32% and more than 23 million people were lifted out of poverty, while emissions dropped 52%, delinking economic growth from emissions increase over the period.[5] However, this was only possible thanks to a dramatic cut in Amazon deforestation, since energy-related GHG emissions have increased in the same period. The challenge now is to decouple economic growth and social gains from the use of fossil fuels, ensuring a sufficient supply of renewable energy to fuel economic growth and increase the living stand-

4 EPE (2015), 'Balanço Energético Nacional' ; Available at: https:// ben.epe.gov.br/downloads/Relatorio_Final_BEN_2015.pdf

5 MDS, op.cit.

ards of all the population.[6] The good news is that the long-term deep decarbonization of the Brazilian economy will receive a boost from a relatively advanced starting point, an already comparatively low-carbon energy system, and also the country's huge potential to further expand renewable energy production.

Figure 1. Brazilian Emissions by Source 1990-2010




*Source: MCTI, 2013: Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil.*

## 1.2 GHG Emissions: Current Levels, Drivers and Past Trends

Brazilian GHG emissions increased from 1.4 billion metric tons $CO_2$ equivalent ($GtCO_2e$) in 1990 to 2.5 $GtCO_2e$ in 2004, followed by a substantial reduction (by half) to 1.25 $GtCO_2e$ in 2010, thanks to the sharp fall of deforestation (see Figure 1 below).

As a consequence of the lower rate of deforestation, the share of $CO_2$ in the GHG emissions mix has declined sharply, from 73% to 57% between 2005 and 2010. The recent upturn in GHG emissions has been driven, notably, by methane emissions from the enteric fermentation of Brazil's large cattle herd (numbering 213 million heads in 2012). Also, the share of fossil fuel combustion in total GHG emissions has been steadily increasing in recent years, from 16% in 2005 to 32% in 2010. Fossil fuel combustion ranked second, after agriculture and livestock, in 2010 (see Figure 2a). Among fossil fuels, oil is by far the dominant source of emissions, followed by natural gas, and coal (see Figure 2b).

6 La Rovere et al, op.cit.

Figure 2. Decomposition of GHG and Energy $CO_2$ Emissions in 2010

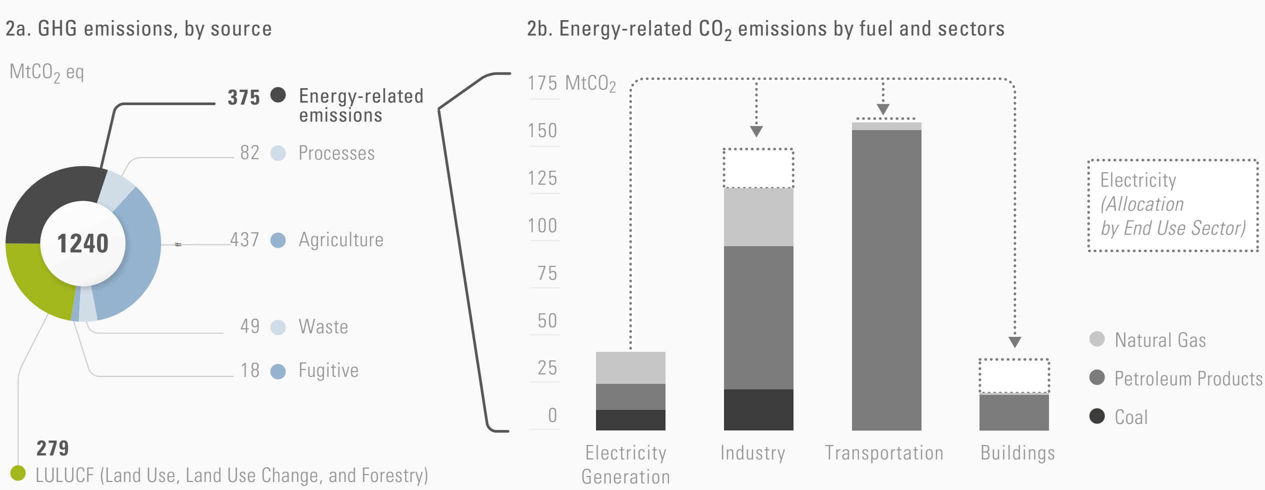


Figure 2c. $CO_2$ energy emissions ($MtCO_2$) and drivers

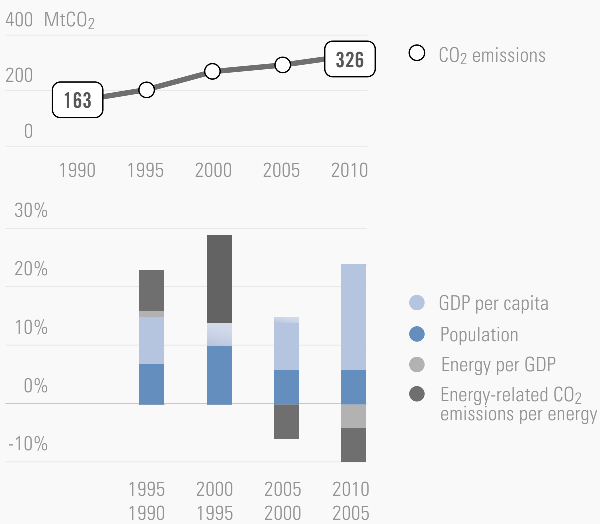
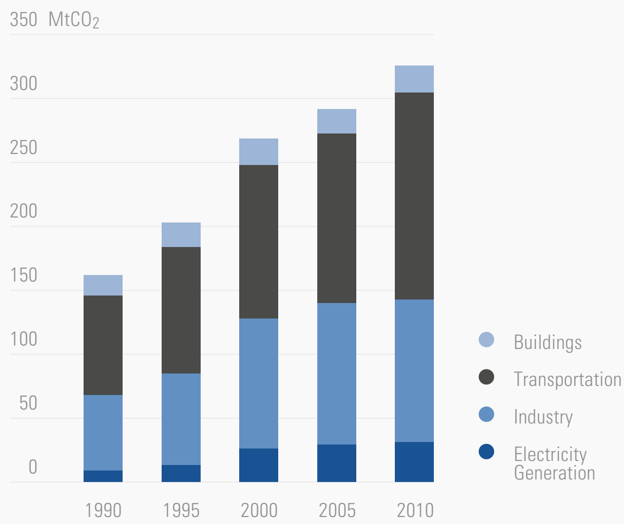



Figure 2d. $CO_2$ energy emissions ($MtCO_2$) by sector




The Brazilian population increased from 145 million to 191 million people from 1990–2010. Population growth rates have declined, to a rate of 0.9 percent per year today (from 1.6% per year in 2000). Economic growth has been an important driver of increased energy-related $CO_2$ emissions, as GDP nearly doubled from 1990 to 2010 (an 89% increase, in real terms). The carbon content of the energy supply has followed the ups and downs of the development of renewables (see Figure 2c): the share of renewables in the total energy mix fell from 49% in 1990 to 41% in 2000 due to a slowdown in the deployment of hydropower and ethanol from sugarcane. Then it rose, after 2000, reaching 45% of total energy supply in 2010. Transportation is the largest energy-related emissions source, followed by industry, electricity generation and buildings (see Figure 2d). Roads play an overwhelming role in Brazil, both in intercity freight transport and intra and intercity passenger traffic, and the growth of air travel and car ownership are also important drivers of energy-related GHG emissions. Energy intensive industries (iron and steel, pulp and paper, cement, petrochemicals) are important drivers of GHG emissions, but their share of GDP in the Brazilian economy is presently declining.

## 1.3 Brazil's Future Development Pathway: An Overview

The general methodological approach in designing the Deep Decarbonization Pathway Project (DDPP) scenario for Brazil was to highlight the implications of deep decarbonization strategies, embedded in a pathway of rapid economic and social development.

Demographic assumptions up to 2050 are based on IBGE's ("Instituto Brasileiro de Geografia e Estatística", a national body) projections of Brazilian population changes. From 2015–2050, Brazil will experience a major shift in its demographic profile, mainly because of a decrease in fertility. From 200 million people in 2015, the population is expected to grow to a peak around 225 million between 2030 and 2040, before slowly falling to about 221 million in 2050. This shift will bring about its own challenges, including the projected rise in the already significant deficit of the public retirement pension system.

Development assumptions are based on government plans, particularly the National Long Term Energy Plan, PNE 2050 (EPE, 2014). Economic growth is assumed to be very strong through 2050, with a quadrupling of average GDP per capita, reaching about $19,000 (2005 US dollars) by 2050.

Our macroeconomic reference scenario follows the government plans (the Governmental Plan scenario, or GPS). We build on it, with some assumptions to complement and extend the GPS to 2050. Then, a Deep Decarbonization Pathway is designed to include additional mitigation policy actions and measures targeted to bring Brazilian GHG emissions per capita to 1.7 t $CO_2$e per year by 2050, of which 1.2t$CO_2$e comes from energy-related emissions, consistent with a world average required to limit global warming to 2 degrees Celsius (2ºC).

# 2 Methods - Modeling Methodology and Economic Consistency

The construction of the Deep Decarbonization Pathway scenario uses a framework that aligns national development goals with the 2 degrees Celsius (2ºC) global climate target. The 2050 GHG emissions target for Brazil is set at 367 Mt$CO_2$e, a 70% reduction compared to 2010 (1,214 Gt$CO_2$e). To reach this goal, the designed pathway includes a number of mitigation actions in various sectors.

Initially, the Deep Decarbonization Pathway (DDP) follows the most ambitious scenario up to 2030 designed in the IES-Brasil project (Social and Economic Implications: GHG Mitigation Scenarios 2030),[7] outlined by a Scenario-Building Team (SBT) made up of experts from the government, academia, private sector and civil society. This IES-Brasil scenario considers additional mitigation measures that go beyond an extension of current government plans. Hence the DDP from 2010 to 2030 considers assumptions virtually identical to the IES-Brasil project, reaching a 1,009 Mt$CO_2$e emissions level in 2030 (483 Mt$CO_2$ from energy-related emissions). After 2030, a number of additional mitigation actions, which are foreseen to be economically feasible by that date, are introduced in the energy and transport sectors, to achieve a 367 Mt$CO_2$e emissions level in 2050.

In the energy sector, these actions include a strong expansion of solar power, its share of total energy generation growing from close to zero to 11.3% in the period, and a doubling of biomass-based thermopower, up to producing almost 20% of all electricity in 2050. The growth of solar and biomass power sources results in a lower reliance on hydropower, down to a share of little more than 50%, although it continues to expand in absolute terms. Until 2050, the complete replacement of natural gas by biofuels, the last fossil fuel still in use for power generation by 2030, is completed.

7 IES-Brasil (Implicações Econômicas e Sociais Brasil or Social and Economic Implications: GHG Mitigation Scenarios 2030) is an initiative of the Brazilian Forum on Climate Change, mandated by the Brazilian Minister of Environment, in collaboration with the MAPS Programme. More can be found in: http://www.mapsprogramme.org/

This allows for fully emissions-free electricity generation by the end of the period.

Rail and water represent about 60% of total freight transport in ton-kilometers, in 2030. After 2030, reliance on rail and water increases to reach more than 70% of total ton-kilometers in 2050. In addition, better geographical distribution of production, consumption and import/export hubs create logistical efficiency gains. Those improvements permit a decoupling of freight transport needs from production (14% decrease of ton-kilometers from 2030–2050, in parallel with 80% increase of GDP). The modal shift, combined with reduction of transport activities, translates directly into a sizable drop in road transportation activities, reducing overall energy needs. Freight transport emissions decrease further through the increased use of biodiesel. Together, these measures permit Brazil to cut sectoral emissions by almost 50% from 2030–2050.

Passenger transportation, by contrast, sees a growth in activity levels over the period, by about 30%, given the continued trend of the expansion of Brazil's urban centers. Urban growth triggers a 15% rise in energy needs from 2031–2050, essentially because of increased public transportation. The DDP assumes the electrification of passenger transport, through a shift from the use of passenger cars to rail, and from fossil-fuel run vehicles to electric cars. The result is that emissions fall, although passenger transportation activity increases over the period by about 30%, more than offsetting the activity growth and decreasing emissions by about 30% from 2030–2050.

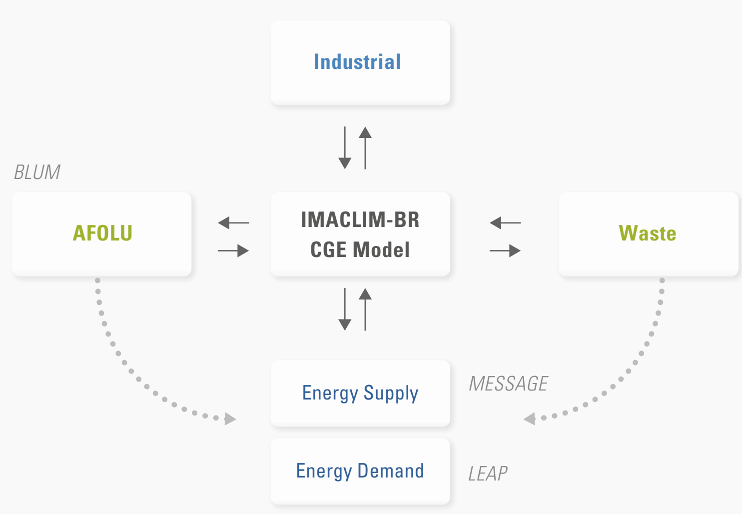
A comprehensive description of all mitigation actions per sector can be found in Section 3.4.

The investment required for these transformations is assessed through a one-way soft-link to sectoral modules to which a series of mitigation actions are associated. Each mitigation action presents, for a given level of specification, a cost and an energy-use profile. For example, energy-efficiency actions show a reduction in their energy-use profile, whereas mitigation actions related to biofuels consist of switching from fossil to renewable energy. Mitigation actions that are not related to energy demand or supply in the AFOLU and waste sectors are assessed directly through their associated emissions.

These sectoral results provide inputs to the IMACLIM-BR CGE model. In this model, the technical coefficients of the DDP are calibrated according to the percentage variation of energy use compared to the reference scenario, the Governmental Planning Scenario (GPS). The monetary values are the total investment requirements for all mitigation actions considered, per sector.

The IMACLIM-BR model is also used to simulate the introduction of a carbon tax on burning fossil fuels. The tax level increases linearly, from \$0/$tCO_2e$ in 2010 to \$112/$tCO_2e$ in 2030 and then to \$168/$tCO_2e$ in 2050[8]. The tax revenues are fully recycled through lower social security taxes on labor, so that fiscal neutrality is ensured and

Figure 3. The Modelling Framework




8 These values correspond to 100 US\$/$tCO_2e$ and 150 US\$/$tCO_2e$ in 2005 values, respectively.

the overall tax burden is kept at the same level as before the carbon tax.
The model ensures macroeconomic consistency between the sectoral modules and the IMACLIM-BR framework through the alignment of some key variables, such as population, GDP, GDP structure and final energy consumption. Most of the mitigation actions considered are cost-efficient (refer to Section 4.4) and their effects on GDP and total investment rate over GDP are minor (especially if compared to the substantial long-run uncertainties) so that we chose to neglect, as an approximation, the effect on energy demand of economic feedback from the IMACLIM-BR.
Figure 3 illustrates the modelling approach adopted.

# 3 Decarbonization Strategy

Given the huge potential of natural resources in Brazil, there is a wide range of possible decarbonization strategies that may be proposed. The analysis conducted in this report starts from the Deep Decarbonization Pathway presented in the DDPP 2014 report (La Rovere and Gesteira, 2014) and further explores the possibility of an earlier and more pronounced peak of GHG emissions, in order to make it more consistent with a 2ºC-compatible global emissions trajectory. Through 2030, this Brazilian Deep Decarbonization Pathway assumes that a majority of the economy-wide emission reductions will be realized through actions outside of the energy sector. However, actions will need to be taken in the near-term to set in motion the major infrastructure changes that would allow energy-related emissions to fall significantly after 2030, thanks to major investments in renewables, energy efficiency and low carbon transportation. Thus, Brazil`s energy-related emissions are expected to grow in the immediate future, peak around 2030, and then decline through 2050. This report outlines a Deep Decarbonization Pathway of the energy system that would be achieved through efficiency gains and fuel switching, as well as new technologies such as electric vehicles and energy storage for intermittent sources. Clean power generation would be provided by hydropower, complemented by bioelectricity (to ensure reliability) along with emerging onshore and offshore wind, as well as solar photovoltaic energy. In the productive sector, increased use of green electricity and biomass coupled with an interim substitution of natural gas for coal and petroleum products would be required.
Since Brazil has sizable biological $CO_2$ sinks, which are expected to increase until 2050 through substantial reforestation and afforestation efforts, the decarbonization strategy will be strongly complemented by initiatives promoting $CO_2$ sinks to compensate for energy-related GHG emissions.
The following Sections describe the three main areas of this Deep Decarbonization Pathway strategy: Agriculture and Livestock, Forestry and Land Use (AFOLU) (Section 3.1); biofuels (Section 3.2) and hydropower (Section 3.3). Section 3.4 includes a list of all sectoral mitigation actions up to 2030 in the government plan scenario (GPS) and the Deep Decarbonization Pathway (DDP).

## 3.1 Agriculture and Livestock, Forestry and Land Use

According to Strassburg et al (2014), "Brazil's existing agricultural lands are enough to sustain production at levels expected to meet future demand (including both internal consumption and exports) for meat, crops, wood and biofuels until 2040 without further conversion of natural habitats."

The cattle breeding subsector has the greatest mitigation potential, because its emissions account for approximately half of all Brazilian GHG emissions (Bustamante et al., 2012). The total area reserved for pasture lands comprises 170 million hectares, versus 60 million for crops. However, current productivity (94 million animal units) is 32–34% of the estimated carrying capacity, which accounts for 274 to 293 million animal units. It is feasible to increase pasture productivity to 49–52% of the carrying capacity, while maintaining the present geographical patterns of production, allowing to produce more food from the same area with lower environmental impact.

Insofar as agriculture (including livestock) is currently Brazil's most important source of GHG emissions, the DDP assumes the extension of the policies and measures of the Plan for Consolidation of a Low Carbon Emission Economy in Agriculture,[9] launched to meet the voluntary goals set by the Brazilian government for 2020. It thus assumes mitigation actions, such as the recovery of degraded pasture land. Moreover, both the Plan above and the DDP assume there will be an increase in land used by agroforestry and intensive cattle-raising (integrated agriculture/husbandry/forestry activities), while the planted area under low tillage techniques would also be expanded. In addition, areas cultivated with biologic nitrogen fixation techniques will be increased, replacing the use of nitrogenous fertilizers, and there would be greater use of technologies for proper treatment of animal wastes.

In forestry and land use, the DDP assumes the extension of the policies and measures of the Action Plan for Prevention and Control of Deforestation in the Amazon[10] and of the Action Plan for Prevention and Control of Deforestation and Fires in the Savannahs,[11] launched to meet the voluntary goals set for 2020. These action plans include a number of the initiatives, combining economic and command-and-control policy tools, that have succeeded in bringing down the rate of deforestation in recent years (see Figure 1).

Moreover, the proposed decarbonization pathway assumes the successful implementation of afforestation and reforestation activities, which would lead to a dramatic increase of forest plantations using eucalyptus and pine trees, not only for the pulp and paper industry but also for timber as well as for charcoal used in the production of pig iron and steel. In fact, huge areas of degraded land are available in the country where these afforestation programs would be developed, achieving both environmental and economic benefits. Given the likelihood that such initiatives will continue and expand in the coming decades, it is expected that as early as the mid 2020's, land-use change and forestry will become substantial net carbon sinks, and will, by 2050, be capable of offsetting a substantial share of the emissions from the energy sector.

The waste management system will require large investments in sewage pipelines, waste disposal facilities and industrial effluents treatment units, with methane capture and burning facilities that may curtail emissions. The capture of methane creates a renewable fuel source, and biogas would be used to replace some fossil natural gas.

9 Available at: http://www.mma.gov.br/images/arquivo/80076/Plano_ABC_VERSAO_FINAL_13jan2012.pdf

10 Available at: http://www.mma.gov.br/florestas/controle-e-prevenção-do-desmatamento/plano-de-ação-para-amazônia-ppcdam

11 Available at: http://www.mma.gov.br/florestas/controle-e-prevenção-do-desmatamento/plano-de-ação-para-cerrado-ppcerrado

## 3.2 Biofuels

Brazil is endowed with vast tracts of land suitable for agriculture, animal breeding and sustainable forestry exploitation, and it has sought to leverage these natural resources in fields beyond food production. The production of biofuels, especially ethanol and biodiesel, has been increasing since 1975, when it began as a response to the country's then-strong dependence on oil imports. The recent trend of sugarcane areas doubling 2004–2011 (from 5 million to 10 million hectares) has happened in parallel with a notable fall of the deforestation rate in the Amazon (from nearly 3 million hectares per year to less than 1 million). Actually, sugarcane production areas are far from forests, and most production occurs more than 2,000 kilometers away from the Amazon.[12],[13]
Biodiesel production from palm oil could also increase, given the potential to grow the feedstock on the huge surfaces of degraded land available in the country.[14]

Ethanol from sugarcane is manufactured through a highly energy-efficient and land-efficient process with further potential gains through second-generation manufacture. Brazil's ethanol adoption strategy is in a very advanced stage. On the one hand, anhydrous ethanol is currently added to all gasoline sold in the country, forming gasohol in a mandatory 27% proportion (25% for premium gasoline), the maximum level now technically possible. On the other hand, hydrated ethanol is also available everywhere as a standalone fuel, powering the country's large fleet of flex fuel cars. These vehicles, which boomed in Brazil in the last decade, now represent the bulk of cars sold domestically, and it is reasonable to envision an even greater potential for the further expansion of ethanol use.

By contrast, biodiesel from soybeans and animal fat is a less-efficient channel for the production of biofuels. Biodiesel is currently added to fossil-based diesel oil in a B7 (7%) proportion. This is expected to rise at least to B22 (22%) in the next decades as long as lower production costs keep biodiesel economically profitable—an important prospect for expansion that does not depend on demand conditions.

The production of sugarcane ethanol and soybean biodiesel compete with food usage of the same plants. Eventually, a rise in international sugar prices may divert producers away from ethanol, resulting in market shortages and price hikes that may ultimately reduce the market share of ethanol-run cars. This is what actually happened in the 80's and 90's and, temporarily, practically closed down the market for such cars. The temporary slump in ethanol sales in 2009–2012 shows that the market remains very responsive to price variations. Nevertheless, interestingly, while the recent discovery of large offshore oil reserves is quickly turning the country self-sufficient in crude oil and its products, biofuels' clear environmental benefits (not limited to climate-change mitigation) have influenced the current official mid-range policy of directing all the additional oil production to export, while promoting an expanded role for biofuels domestically.

12 While some second generation biofuels from sugarcane, such as biokerosene and farnesene ("diesel oil"), are accepted given demonstrated feasibility, they see limited growth in the transportation sector due to the low levels of current use.

13 Sources: INPE; IBGE; UNICA; NIPE-UNICAMP; CTC; in ICONE, 2012; Nassar et al, 2008 in Sugarcane Ethanol: Contributions to Climate Change Mitigation and the Environment. Zuurbier,P.; Vooren, J.(eds). Wageningen: Wageningen Academic Publ.

14 Estimates vary from 20 million to 60 million hectares, according to the level of degradation (high, medium and low); see PPCDAm, PPCerrado and Strassburg et al, 2014.

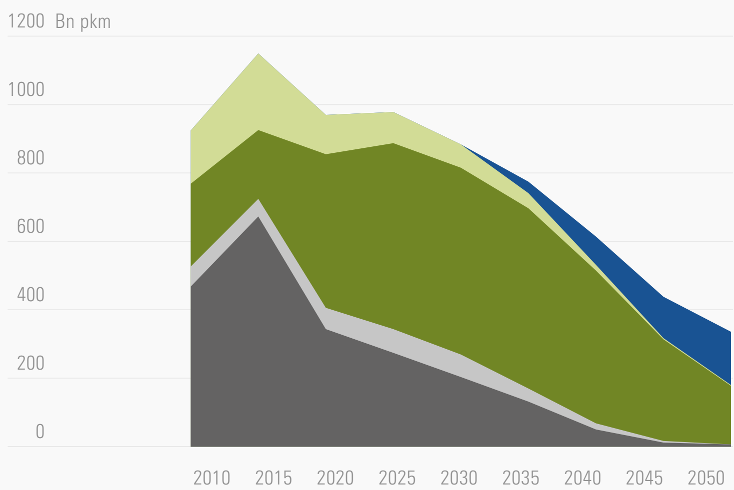
Both fuel change strategies, although not designed primarily for climate mitigation, have proven very successful in decarbonizing the transport sector. But their continued success depends on consistent government policies over the next decades, including removing subsidies for fossil fuels and using the added revenues to promote similar fiscal policies for biofuels. Adhering to a strict implementation of such policies is a precondition for reaching deeper decarbonization with Brazil's current fuel strategy.

In the Brazilian DDP scenario, the use of cars will continue to grow, induced by the rise in per capita income and increased urbanization; but the total fossil fuel consumption by cars would be largely decoupled thanks to efficiency gains and preference for ethanol in flex fuel cars (Figure 4). This trajectory requires that the government system of taxing biofuels and fossil fuels be fine tuned to ensure their competitive advantage: the final price per volume of hydrated ethanol must always be kept below 70% of the price of gasoline, given gasoline's higher car mileage per volume.

If the price gap between the two fuels widens further, car buyers might have an extra incentive not to buy gasoline-only cars, which would also contribute to increasing ethanol's market share. Through the combined use of these strategies, gasoline would be much less consumed by cars, down to about 5% (by volume) of overall direct fuel consumption by cars in 2050. It is noteworthy that the DDP also considers increasing the share of electric vehicles. These are developing as a substitute for both gasoline and ethanol cars, given their important advantages such as less noise and air pollution. From the beginning of the 2030's, the share of electric cars is envisioned to expand vigorously, reaching almost half the fleet by 2050. This rise will not imply in increased indirect emissions, since it would be associated with a fully decarbonized power sector in 2050.

It must be noted that the recent years have shown strong departure from the pattern proposed in the DDPP 2015 scenario, with gasoline usage increasing by more than 40% from 2010 to 2014, while hydrated ethanol sales slumped. The fuel tax policies adopted in this period, and the resulting relative prices, were the opposite of what is needed to reach a desirable share of renewable fuels by 2020. A sharp trend reversal must happen if a Deep Decarbonization Pathway is to be pursued, and this reversal can only be achieved with adequate taxation rules. The government should also adhere to its plans to export the extra crude oil produced in the next few years and resist the temptation to divert it to the internal market when international prices drop.

Figure 4. Passenger Cars and Taxis - Activity per energy source




| | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|
| Electric | 0 | 0 | 0 | 0 | 0 | 28 | 69 | 101 | 130 |
| Ethanol-anhydrous | 130 | 187 | 96 | 76 | 57 | 37 | 14 | 3 | 2 |
| Ethanol-hydrated | 202 | 168 | 375 | 454 | 456 | 440 | 373 | 248 | 143 |
| Compr. Nat. Gas | 49 | 43 | 52 | 58 | 55 | 32 | 15 | 4 | 0 |
| Gasoline | 391 | 562 | 287 | 229 | 170 | 110 | 42 | 10 | 5.5 |

*Source: MCTI, 2013: Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil.*

### 3.3 Hydropower

Of all nations worldwide, Brazil is among the five with the largest hydropower potential. In 2015, there are 197 hydroelectric power plants and 741 small hydropower plants (SHP)[15] in operation, which represent, respectively, 61.6% and 3.5% of the 138 GW of the country's total installed power generation capacity (ANEEL, 2015). The Brazilian technical hydropower potential is estimated at 247 GW (see Table 1), of which 180 GW–200 GW have been assessed as economically feasible. However, these projects face a number of controversies and challenges, including the potential disturbance of the Amazon biome, their location far from the large consuming centers and social and environmental hazards associated with their construction.

Other relevant energy sources are base load nuclear power plants and thermal plants used primarily as supplements when other sources are insufficient to satisfy the power demand. Wind and solar energy, even though still incipient, are expanding fast. Wind energy, in particular, is well suited to complement hydropower, since periods of low rainfall coincide with higher wind energy production.

When analyzing the composition of the electricity generation mix in the Deep Decarbonization Pathway, striking features appear. First, the share of hydropower in the electricity mix decreases over time. This is the logical outcome of the very fast increase in electricity production (growing 3.6 times from 2010–2050), when a sizable share of the overall hydropower potential was already deployed in 2010. (Installed hydropower capacity can reach only 180 GW, or a multiplication by 2.6 times, over the same period.) Nonetheless, hydropower remains the major source of electricity even in 2050, demonstrating the crucial role this energy source will keep playing over the next decades, even when taking the deployment constraints into account. Therefore, the development of hydropower is a necessary condition for deep decarbonization, but not sufficient. The development of other renewables, wind and solar, account for most of the residual production under DDP (see Figure 5).

Hydro energy's importance to Brazil's economic development is unquestionable. But these ventures sometimes have significant impacts. The negative outcomes of dam construction in the Amazon region are primarily due to the effect of the decomposition of the terrestrial vegetation in the vast areas flooded for reservoirs, impacting native flora and displacing wildlife. Other negative impacts include the deterioration of water quality and the loss of services that can be provided by terrestrial and aquatic ecosystems, affecting biodiversity (Tundisi et al., 2006).

Table 1. Hydropower potential per basin*

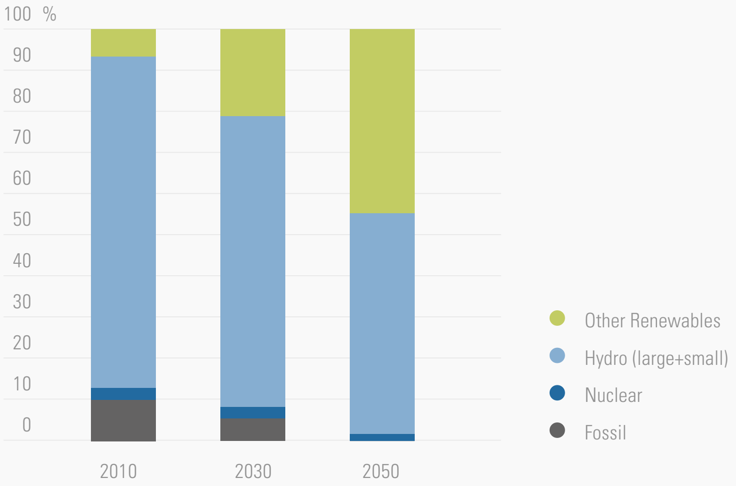
| Stage/Basin | Eastern Atlantic | Northern/ Northeastern Atlantic | South-eastern Atlantic | Amazon river | Paraná river | Sao Francisco river | Tocantins river | Uruguai river | Total per stage |
|---|---|---|---|---|---|---|---|---|---|
| Remaining | 767 | 525 | 941 | 17,584 | 3,414 | 694 | 1,780 | 12 | 25,717 |
| Individualized | 655 | 182 | 1,090 | 15,391 | 2,296 | 867 | 128 | 404 | 21,013 |
| Estimated total | 1,423 | 707 | 2,031 | 32,976 | 5,710 | 1,561 | 1,908 | 416 | 46,730 |
| Inventory | 5,567 | 1,183 | 1,756 | 38,164 | 9,275 | 3,883 | 7,897 | 4,017 | 71,743 |
| Viability | 725 | 408 | 2,218 | 774 | 1,760 | 6,140 | 3,738 | 292 | 16,055 |
| Basic Project | 852 | 55 | 366 | 2,156 | 2,593 | 289 | 134 | 598 | 7,043 |
| Construction | | | 25 | 13,458 | 32 | | | | 13,515 |
| Operation | 5,393 | 587 | 3,709 | 8,882 | 43,335 | 10,724 | 13,193 | 6,333 | 92,156 |
| Total | **13,960** | **2,941** | **10,105** | **96,410** | **62,705** | **22,596** | **26,869** | **11,656** | **247,242** |

* December 2014.

*Source: SIPOT/Eletrobras (2015)*

15 A small hydropower plant is defined as a facility with between 1 MW and 30 MW of installed capacity and a reservoir area no larger than 3 square kilometers.

Figure 5. Deep Decarbonization Pathway: Power generation sources




The related greenhouse gases emissions, mainly methane, are also estimated to be relevant in several instances (Abe et al, 2005).

There are also impacts on other uses of the water resources. Reconciling electricity generation with other river uses, such as waterways, irrigation, fishery and tourism, may also pose a challenge. So does the need to respect the rights of indigenous populations and other traditional communities such as the *ribeirinhos*, riverine people or those living on rivers, who rely strongly on the available natural resources. New power plants address some of these issues by using a "run-of-river" design, with smaller reservoirs. However, their operational efficiency may be compromised, since these dams are incapable of storing enough water to keep producing a significant amount of electricity in seasons with weaker river flows.

## 3.4 The Transition Strategy

Up to 2030, the DDP suggests that a number of available technologies can be deployed at a larger scale than proposed in governmental plans, bringing about a further lowering of carbon emissions. From 2005 to 2030, the Deep Decarbonization Pathway is based upon the same assumptions as the most ambitious mitigation scenario of the IES-Brasil project, regarding additional mitigation actions and their investment requirements. Thus, the DDP includes all mitigation actions approved or already under implementation by the government (per the governmental plan scenario or GPS), extended up to 2030 at higher penetration rates. It includes, as well, a set of extra mitigation actions, leading to further decarbonization. The sectoral mitigation measures up to 2030 are presented in Table 2, below.

From 2030 to 2050, new mitigation technologies will become available, allowing for the deeper decarbonization of the Brazilian economy, as presented in Section 4. Given the uncertainties about winners and losers in the technological race by 2050, the deployment of mitigation actions included in this period in the DDP must be seen as an illustration of what a deeply decarbonized domestic energy system could look like at that time horizon. Indicative costs are also presented in Section 5.

Table 2. Mitigation Measures

| | GPS - 2030 | DDP - 2030 |
|---|---|---|
| **Mitigation Measures in AFOLU** | | |
| Low Tillage | 100% of soybean and corn surface (first harvest) | Same |
| Nitrogen Biological Fixation | 2 million hectares | 2 million hectares + 100% of corn surface (first harvest) |
| Swine Residues Management | 4.4 million cubic meters of residues | Same |
| Restoration of Pasture Land | 15.5 million hectares | 20 million hectares |
| Agroforestry schemes | 4.2 million hectares | 6 million hectares |
| Planted forests | 11.5 million hectares | 13.9 million hectares |
| Agricultural land frontier<br>(cultivable + pasture land) | 278.5 million hectares (increase<br>of 43.5 million hectares to 2010 level) | 190.1 million hectares (reduction<br>of 44.9 million hectares to 2010 level) |
| Restoration of Atlantic Forest | - | 9.7 million hectares |
| Ethanol production from sugarcane (including constant exports level of 5 billion liter/year) | 62 billion liters / year in 7.5 million hectares | 79 billion liters / year in 8.5 million hectares<br>(7 billion liters / year of second generation biofuels) |
| Biodiesel production (including exports of 6.5 billion liter/year) | 6.4 billion liters / year (5.1 from soybean + 1.3 from wastes) | 11.6 billion liters / year<br>(7.3 from soybean + 1.3 from wastes + 3.0 from palm oil) |
| **Mitigation Measures in Energy Supply and Use in Households, Services and Agriculture** | | |
| Reduction of Installed Capacity of Thermopower from Fossil Fuels | Coal-fired:4,705 MW<br>Natural gas-fired: 24,330 MW | Coal-fired: 3,705 MW<br>Natural gas-fired: 14,134 MW |
| Expanding power generation<br>from sugarcane bagasse | Installed Capacity: 17,170 MW | Installed Capacity: 27,170 MW |
| Expanding wind power generation | Installed Capacity: 24,325 MW | Installed Capacity: 31,325 MW |
| Expanding solar power generation<br>Concentrated PV power plants<br>Decentralized PV generation | <br>Installed Capacity: 6,500 MW<br>Installed Capacity: 10,000 MW | <br>Installed Capacity: 8,500 MW<br>Installed Capacity: 10,000 MW |
| Expanding hydropower generation | Installed Capacity: 134,086 MW | Installed Capacity: 144,086 MW |
| Improvements in oil refineries | 2.68 million barrels oil/day processed | 3% increase of energy efficiency in existing refineries up to 2025 |
| Improvements in the energy efficiency<br>of the Households sector | Energy consumption: 33.7 Mtoe/year | Improved LPG cookstoves, solar water heating, higher LEDs use |
| Improvements in the energy efficiency<br>of the Services sector | Energy consumption: 24.0 Mtoe/year | Higher use of improved fluorescent lamps |
| Use of biofuels in the agricultural sector | Energy consumption: 14.6 Mtoe /year | 15% Blend of biodiesel in diesel oil from 2020 (up from 7% in 2015) |
| **Mitigation Measures in Transport** | | |
| Expanding ethanol use | Consumption: 57 billion liters / year | Consumption: 74 billion liters / year |
| Expanding bike lanes | - | 3,825 km new bike lanes |
| Improving energy efficiency in light duty vehicles | Energy efficiency average level: 1.82 MJ/km | Energy efficiency average level: 1.22 MJ/km in 2025 (EU target) |
| Urban traffic optimization | - | 3.45% reduction in the number of urban travels in big cities |
| Investments in Bus Rapid Transit systems (BRTs) | - | 1,149 km of BRTs in operation |
| Improving energy efficiency in heavy duty vehicles | | 6% increase of energy efficiency of new trucks and buses in 2025 |
| Expanding the blending of biodiesel in diesel oil | 7% blend (6.4 billion liters / year) | 15% blend (5.1 billion liters / year) |
| Electric city buses | - | 8% of electric buses in big cities |
| Investments in light tramways | - | 269 km of new light tramways |
| Investments in railways and waterways | 32% of railways and 18% of waterways in total freight transport | 36% of railways and 20% of waterways<br>in total freight transport |
| Investments in subways | - | 194.9 km of new subway lines |
| **Mitigation Measures in Industry** | | |
| Improved thermal efficiency of cement industry | Average consumption of 3.8 GJ / ton of clinker (0.064 toe / ton of cement, against 0.077 in 2010) | Average consumption of 3.35 GJ / ton of clinker |
| Co-firing in cement kilns | 7% of energy supplied by co-firing | 14% of energy supplied by co-firing |
| Improved thermal efficiency of the steel industry | Average consumption of 0.39 toe / ton of steel, against 0.48 in 2010 | Additional 2% improvement in energy efficiency |
| Expanding the use of charcoal from planted forests | | 1.8 million hectares of eucalyptus plantations for charcoal production |
| **Mitigation Measures in Waste** | | |
| Biogas capture and flaring in landfills (70% efficiency)<br>Small cities (< 100,000 inhabitants)<br>Medium cities (100,000 – 500,000)<br>Big cities (> 500,000 inhabitants) | 100% collection and disposal in sanitary landfills<br>50%<br>100%<br>100% in 2020 | 100% collection and disposal in sanitary landfills in 2020<br>70%<br>100% in 2020<br>100% in 2016 |
| Biogas capture and flaring in garbage dumping sites and controlled landfills | Stopping garbage disposal in dumping sites and controlled landfills | Stopping garbage disposal in dumping sites and controlled landfills in 2020, 30% equipped with biogas capture and flaring systems |
| Expanding biogas capture and flaring in sewage treatment units (50% efficiency)<br>Small cities (< 100,000 inhabitants)<br>Medium cities (100,000 – 500,000)<br>Big cities (> 500,000 inhabitants) | <br><br>40%<br>40%<br>60% | <br><br>60%<br>70%<br>85% |

# 4 Results and Discussion

## 4.1 Emissions Pathways

*Non-Energy Related GHG Emissions*

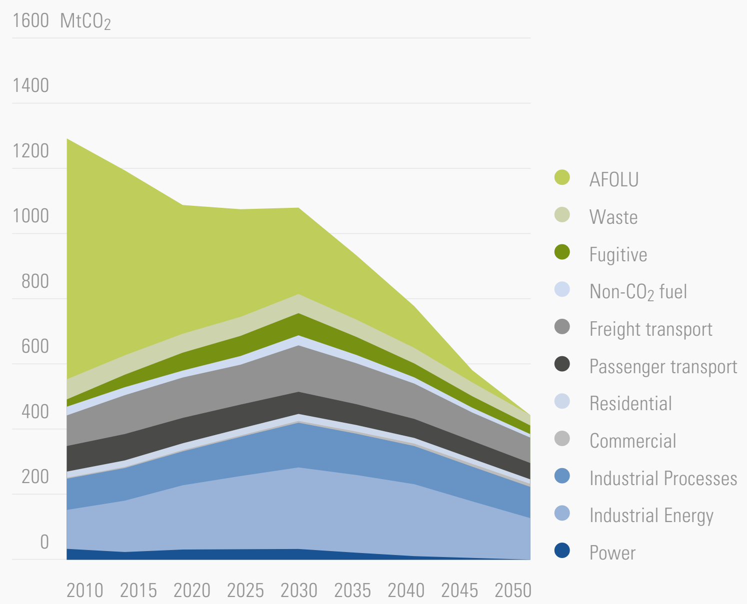
The DDP anticipates a deepening of already successful strategies in AFOLU (as previously described), ensuring the continuous decrease of non-energy related GHG emissions until AFOLU becomes a net sink before 2050. Those strategies—exerting control over deforestation, coupled with an increase in forest restoration and afforestation—compensate for the growth of energy-related GHG emissions until 2030.Thanks to the policies and measures under implementation to meet the voluntary targets announced in Copenhagen, overall GHG emissions decline until 2020, stabilize through 2030 and resume a downward path from 2030 to 2050, as shown in Figure 6.

*Energy-Related GHG Emissions*

By 2050, under the DDP scenario, total final energy needs increase considerably, due primarily to economic development and secondarily, population growth. Renewables and biomass become the dominant source of primary energy and are used to meet the majority of these energy needs, notably through the direct use of biomass and zero-carbon electricity generation. Brazil has a strong potential for energy efficiency; the government recently introduced several energy-saving initiatives that will be extended across the board, such as the replacement of incandescent light bulbs, energy efficiency labeling of home appliances and incentives for establishing less energy-intensive urban mobility infrastructure.

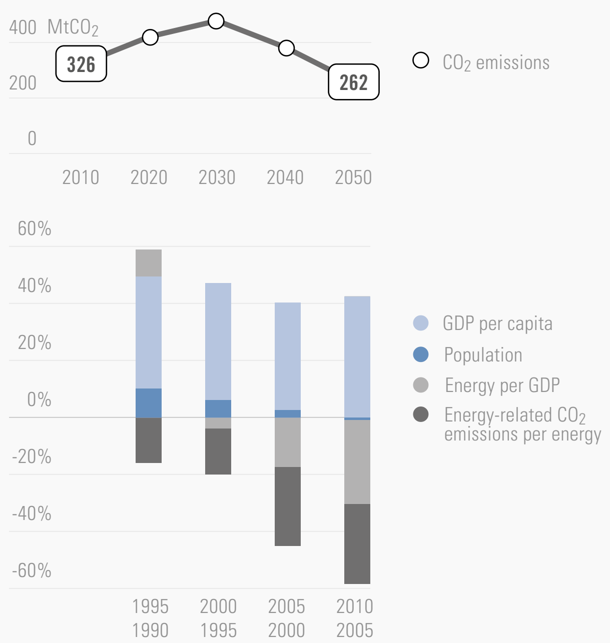
Under the DDP scenario, energy-related $CO_2$ emissions peak by 2030 and decline thereafter, to reach in 2050 emissions levels lower than those in 2010 (see Figure 7a). Opposite trends drive these evolutions. On the one hand, the main driver of emissions increase is the strong growth of GDP per capita and, to a lesser extent, population growth—which stops when the population stabilizes by 2040. On the other hand, a downward push on emissions is exerted by a substantial shift towards a renewable energy supply (especially through the increased use of hydropower, wind, solar energy and biomass to produce electricity and industrial heat, as well as the use of biofuels and electricity for transporta-

Figure 6. Emissions per Sector



tion) and a decrease in final energy intensity per unit of GDP, induced by structural shifts in the transportation and industrial sectors. The transportation and industrial sectors will be responsible for the bulk of emissions. Transportation emissions will dominate in the near future, and industry will become the dominant source in the mid-term; both sectors reach almost identical levels in 2050. Emissions from buildings and power generation remain very low throughout the 2010–2050 period (see Figure 8).

Figure 7a. Energy-related $CO_2$ emissions and drivers

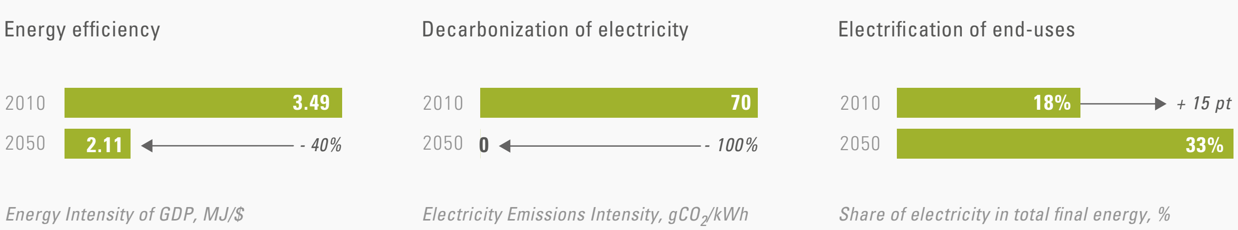



## 4.2 Final Energy and Energy Demand

Industry has historically been the most important source of energy demand, corresponding in 2010 to almost half of final energy consumed, followed by transportation (about one-third) and buildings (less than one- fifth). As illustrated in Figure 9, energy demand from buildings is supposed to increase slowly but steadily up to 2050, due to improved overall living standards, which more than offset efficiency gains. Energy demand from the transportation sector is expected to peak in 2030, and the industrial sector in 2040. The reversal of the energy-consumption trends happens later in industry because of a greater rigidity in some of its processes, which do not allow for fuel replacement and structural changes as easily or thoroughly as the transportation sector does. By 2050, buildings would be consuming more energy than transportation, while the largest demand will continue to come from industry.

Figure 10b shows that final energy, currently consumed mostly in the form of liquid fuels (almost 50%), will undergo a shift towards electricity and biomass, both with a more than threefold increase up to 2050, with electricity becoming the prevailing energy source. Natural gas consumption will also increase considerably, albeit less than electricity and biomass, while coal consumption will decrease.

Figure 7b. Pillars of decarbonization



Primary energy increases about proportionately to final energy, pushed by two opposite drivers. On the one hand, losses in electricity distribution drop as a result of technological improvements and the better spatial distribution of generation (notably, lower dependence on hydropower produced far from consumption centers). Both of these improvements contribute to proportionally reducing primary energy needs. On the other hand, a greater reliance in biomass, with less than 100% transformation efficiency (as opposed to hydro), will increase the amount of primary energy required to meet the base load.

The emissions impact of primary energy will be curtailed strongly by the considerably higher share of renewables and biomass, as seen in Figure 10a.

Figure 8. Energy related $CO_2$ emissions by sector ($MtCO_2$)

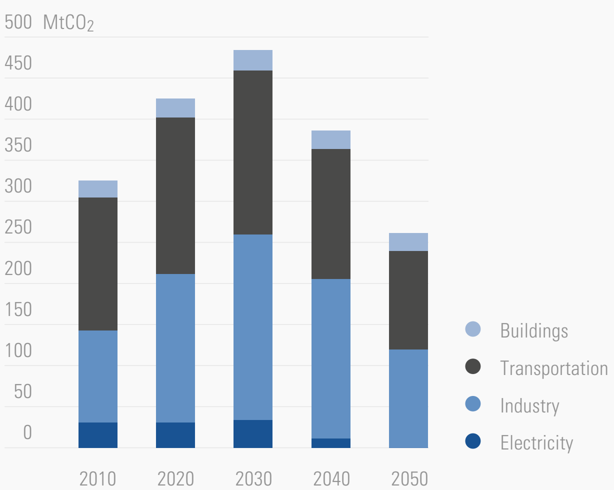



Figure 9. Final Energy Consumption by sector

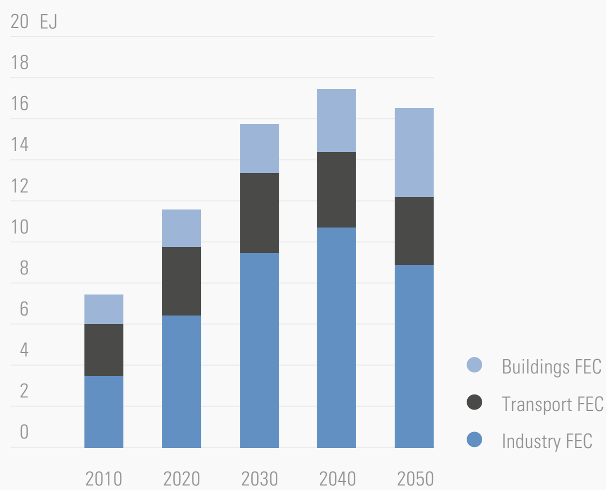



Figure 10a. Primary Energy

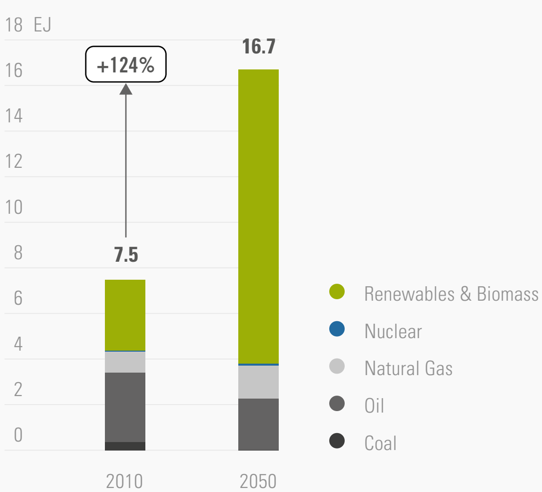
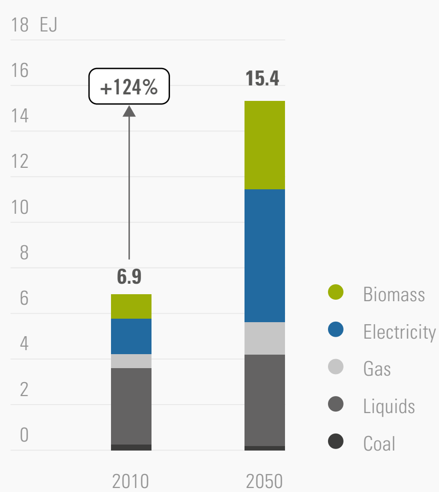



Figure 10b. Final energy



*Transportation*

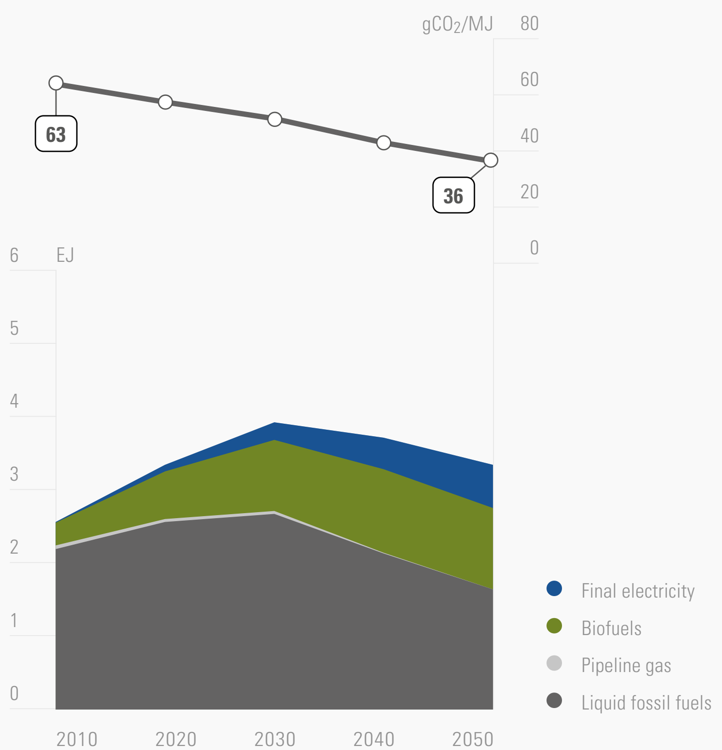
The DDP projection sees demand for transportation services increase considerably over the period 2010–2050. Passenger transportation increases by a factor of 2.6 due to increased urbanization, which not only results in more people relying on urban transportation but also (given the geographical expansion of metropolitan areas) longer commuting distances. Freight transportation, which in some areas of the country nowadays is identified as a major bottleneck for the expansion of industrial and agricultural production, is also expected to increase considerably.

In the transportation sector, the reliance on renewables, especially ethanol, will increase. Regular gasoline sold in the country will continue to have the current 27% mandatory ethanol content (anhydrous ethanol), and most new cars manufactured for the domestic market will continue to be flex fuel, capable of running solely on ethanol (hydrated ethanol with up to 5% water content). An ambitious biofuel program will increase the production of ethanol from sugarcane and biodiesel and biokerosene from a combination of sugarcane and palm oil. This would allow renewable ethanol to substitute for a significant amount of gasoline as it begins to fuel most of the light-duty vehicle fleet (along with some natural gas, used mostly by taxicabs in major cities). The amount of biodiesel blend in diesel, used by trucks and buses, would be further increased to 25% (the government has just regulated an increase from 5% to 7%). Through these combined measures, more than half the total energy used in transportation would be renewable.

In addition, electric vehicles will be an alternative/complementary option that grows in importance over time, notably given these vehicles' benefits aside from lower GHG emissions—such as producing less urban air pollution and noise. By 2050, almost half of the light-vehicle fleet is expected to be electric-powered and 30% of the bus fleet is expected to be electrified. Altogether in 2050, the carbon intensity of fuels used in transportation per unit of energy would be reduced by almost half.

Higher national standards for energy efficiency would be used to increase the fuel economy of all vehicles (cars, buses and trucks) and current tax incentives, for cars with smaller motors and lower fuel consumption, will be strengthened and expanded, further increasing the already large current share of one-liter motors. At the same time, a shift towards railways and waterways would be promoted (wherever possible) for a deep decarbonization of the transportation sector. Deep decarbonization of passenger transport thus implies strong investment in

Figure 10c. Energy and emissions intensity in Transportation




*Note: Carbon intensity includes indirect emissions related to electricity production.*

long-distance rail transportation, which has been resumed recently after a long period of neglect. For deep decarbonization of freight transport, the current share of transport by trains, ships and barges could be intensified, so it rises from a level now below 50% to 70% in 2050. The DDP scenario also includes the significant extension of urban mass transportation infrastructure (subways and trains, bus rapid transport systems, etc.), which should correspond to close to 50% of all the passenger transportation needs in 2050, a significant increase from the current level of below 10%.

*Buildings*

Demand for energy in buildings rises strongly in the DDP scenario, reflecting 16% population growth, 267% economic growth, and the drive for social inclusiveness. While the analysis envisions Brazil pursuing energy efficiency, it has only moderate impacts on energy demand (compared to countries with colder climates), given Brazil's almost non-existent heating needs. Fuel shifts in household energy consumption focus on increasing solar thermal for hot water, with some replacement of LPG by natural gas, ethanol and grid electricity. The use of firewood for cooking would be further curtailed from its already low level today (with less than 15% of the population living in rural areas and wood rarely obtained from deforestation but mostly from branches and other wood residues). The adoption of solar photovoltaic panels in residences would be stimulated by a proper regulatory framework and smart grid infrastructure, allowing for an increasing share of photovoltaic power.

The share of lighting in household electricity consumption will be reduced from the current level of about 20% to about 5% to 10% by 2050, thanks to a more intensive adoption of compact fluorescent light bulbs (CFLs) and light-emitting diodes (LEDs). At the same time, consumption from electronic equipment and electric appliances would increase by a factor of more than five. More specifically, the share of residential electricity consumed by refrigerators and freezers, already used in more than 90% of residences, will fall from its current level of 33% because of efficiency improvements. By contrast, air conditioners, used now by only about 15% of households, will be more widely adopted (by up to 75% of houses), and despite the addition of more efficient technologies (such as split units, central air conditioning and heat pumps), their total consumption of electricity will increase roughly four-fold.

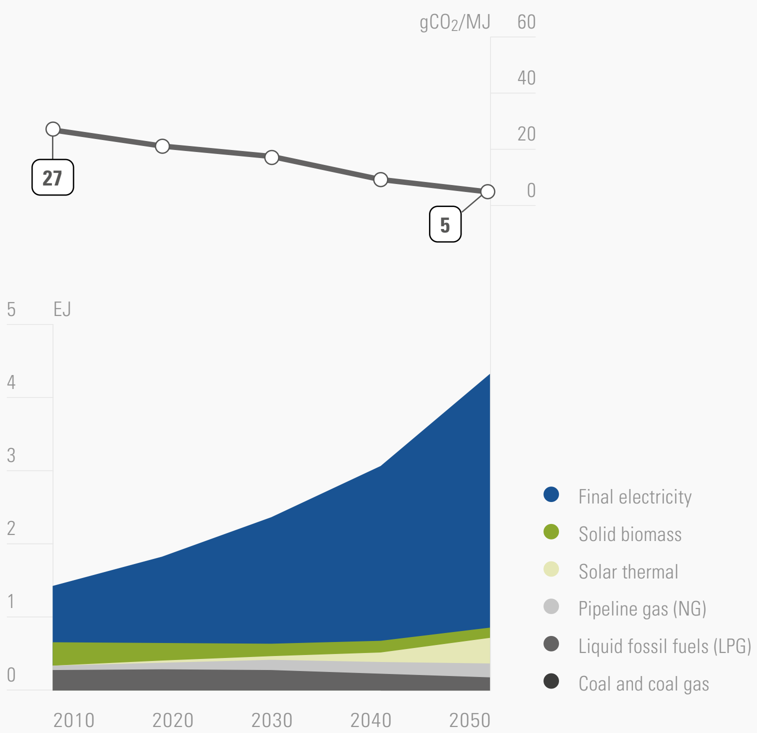
Electric showers, now present in about 72% of residences and accounting for 27% of residential energy consumption on average, will be replaced mostly by solar heaters, so their share falls to no more than 10% of household consumption by 2050. For cooking purposes, households would transition from LPG to natural gas in urban settings, and from firewood to LPG in rural areas. Although this last transition goes against decarbonization, it is necessary because of the social benefits of replacing firewood as a domestic cooking fuel.

However, by far the highest growth in energy consumption would come from household uses not specified above, such as entertainment and telecommunications equipment (TVs, computers, internet links, cellphones) and other electric appliances (hair dryers, microwave ovens, toasters, washing machines, vacuum cleaners, water purifiers, etc.). These appliances, now found in only 44% of households, will be present in almost all residences by 2050, and their relative use is likely to be intensified so they become the source of more than half of residential energy demand.

In the commercial sector (including private businesses and public institutions), energy consumption and the associated emissions expand in tandem with economic growth, since the service sector's share of the economy is already very high and determines GDP more than industry or agriculture. Decarbonization measures that can be adopted in the commercial sector are similar to those in the residential sector, with more weight given to energy efficiency in air conditioning installations, which are used extensively in modern shopping centers and malls, office buildings, hospitals, universities, etc.

In both the residential and commercial sectors, the Deep Decarbonization Pathway includes increasing the energy efficiency of all LPG uses (cooking and water heating), and greater energy efficiency in all electricity uses to reduce the growth in demand. In the end, energy use in buildings is expected to triple and the bulk of this increase will be satisfied by low-carbon electricity.

Figure 10d. Energy and emissions intensity in Buildings




*Note: Carbon intensity includes indirect emissions related to electricity production.*

### *Industry*

In the accounting of GHG emissions used in the DDPP, industrial GHG emissions include emissions from agriculture and livestock and oil and gas processing (normally accounted separately in Brazilian statistics). A sizable amount of CH4 emissions come from livestock, comparable to or higher than overall energy emissions (in terms of GWP). Industrial processes are also a major source of GHG emissions, of the same order of magnitude as the emissions from fossil fuels burnt in manufacturing.

Some industrial sectors have essentially domestic markets, which are expected to grow considerably in response to economic growth. Notably, an expansion in housing should be the main driver of demand for cement, and an important one for steel. All the non-agricultural sectors, which depend more on exports, are assumed to grow roughly at the same rate, slightly below GDP growth, increasing 224% from 2010–2050. The industrial sector's overall share of GDP would drop by 4 points (from 34% of GDP in 2010 to 30% of GDP in 2050), mostly due to a relative decrease of manufacturing and mining. This shift captures a structural change in the Brazilian economy towards the service sector; the share of agriculture and livestock in GDP remains constant at about 5%–6% of GDP.

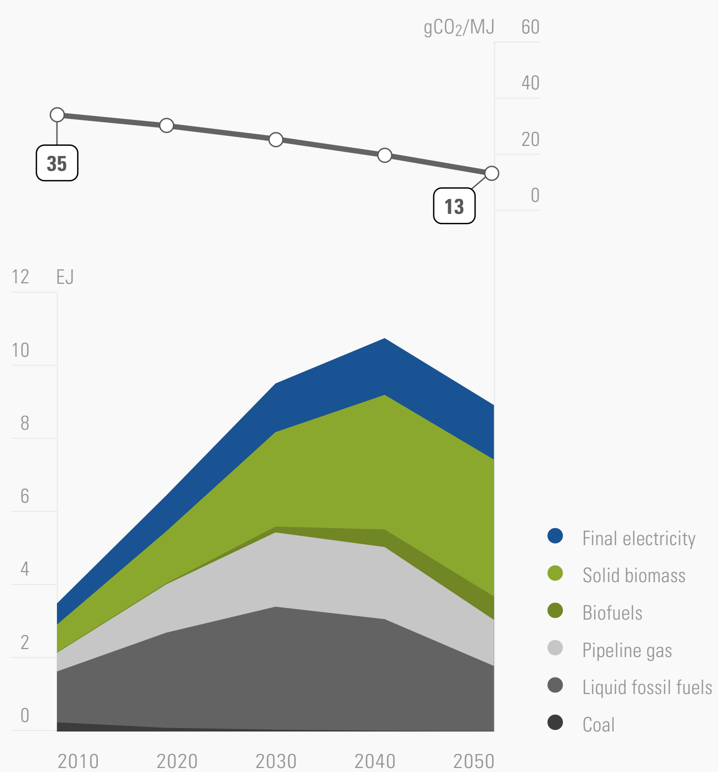
In most major industrial sectors, the share of electricity in total energy demand is expected to rise considerably by 2050, especially in oil and gas, where electricity would replace several fossil fuels, and in agriculture and livestock, where electricity (and also LPG) would take the place of firewood. For generating heat in industry, biomass would partially replace fossil fuels, wherever possible. The share of natural gas to meet industry needs, both for generating heat and for other chemical reactions (already intensely used in the chemical industries), is expected to increase further, while fuel oil and other oil products would be phased out. In steel manufacturing, a greater share going to charcoal would imply lowering the demand for coke from coal. And in the cement industry, emission reductions would be achieved through changes in the industrial process, partially substituting clinker by blast-furnace slag and/or fly ash (both abundantly available in Brazil), which at the same time reduces process emissions and the associated energy needs.

The share of industry in energy demand, which amounted to about 47% in 2010, peaks in 2030-2040 at 60%-61%, and then drops to 54% in 2050. In absolute terms, the energy demanded by industry would more than double by 2050 (Figure 9 above), despite the assumption of widespread adoption of energy efficiency measures, such as more efficient furnaces. As a consequence, the share of industrial sectors as a whole in energy-related emissions would grow through 2040 (see Figure 8 above), partly because switching from fossil fuels to biofuels is not always feasible with current technologies in some industrial sectors, especially in the oil, gas, cement and steel industries, which are all major emitters. The non-energy emissions of industrial processes will also increase, given the inflexibility of some of those processes, in spite of the envisaged gains in cement manufacturing with the increased replacement of Portland clinker by industrial byproducts.

Under the Deep Decarbonization Pathway, the growth in industrial energy emissions will be tampered by a reduction of both the energy intensity of industrial products and the emission factors, especially in the steel and cement industries. This will be permitted by a substantial rise in energy efficiency in all uses of petroleum products, natural gas and electricity. In the aggregate, across the industrial sector, this will result in a decrease of energy intensity per unit of value added of 21% in 2050, compared to 2010. As mentioned before, this reduction in energy intensity is complemented by a transition to the greater use of renewable energy sources, such as charcoal in steel furnaces and biomass for heat generation in several industries.

A substantial effort will be required to reduce CH4 and $CO_2$ fugitive emissions from the oil and gas production system (platforms and transport facilities), as the huge resources of the pre-salt layer are exploited. With the deployment of new infrastructure and some technical progress, in addition to the Petrobras program already under implementation, it is expected that the rate of natural gas venting and flaring can be reduced. Under this assumption, much higher levels of production can be obtained, with overall fugitive emissions reaching their peak of 64 $MtCO_2$ in 2030, and then falling back to around 25 $MtCO_2$ by 2050, equivalent to today's (2015) level.

Figure 10e. Energy and emissions intensity in Industry and Agriculture & Livestock

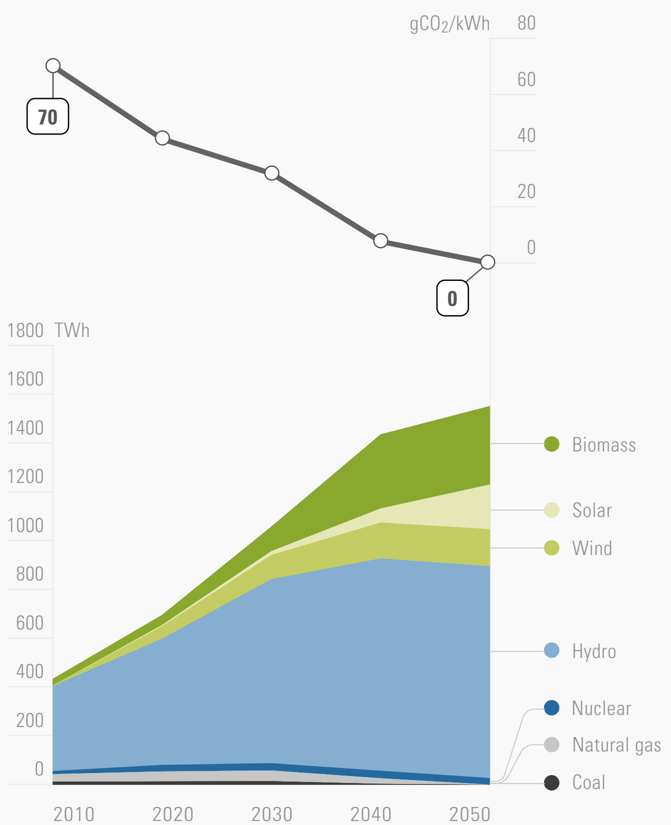



*Note: Carbon intensity includes indirect emissions related to electricity production.*

Carbon capture and storage (CCS) in Brazil is not important to reduce GHG emissions from coal, since coal's use is very limited. However, CCS coupled with the use of natural gas could support deeper decarbonization. CCS could also be helpful for lowering emissions from the future expansion of Brazil's oil and gas production, with the exploitation of the country's pre-salt resources. CCS is already being developed by Petrobras through the injection of $CO_2$ for enhanced offshore oil recovery, but the feasibility of large-scale deployment of CCS remains unclear.

In Brazil, the bulk of GHG emissions associated with agriculture and livestock is not related to energy use. The relatively small energy-related emissions in this sector that do exist will be curbed by adopting several decarbonization measures: the progressive replacement of diesel electric generators with grid electricity, locally produced biomass, small hydropower or solar energy, and increased energy efficiency.

Figure 11a. Energy and Carbon Intensity of Electricity




## 4.3 Energy Supply

Brazil's Deep Decarbonization Pathway includes further expanding the country's hydropower, tapping the potential for more than doubling the installed capacity with environmentally acceptable projects, along with an expansion of bioelectricity, wind and solar photovoltaic generation. Nuclear energy currently provides only 2.7% of total electricity in Brazil, and no further increase of this output level is considered in the DDP, aside from the operation of the Angra 3 plant that is already under construction. This is because of its high operational and investment costs compared to other electricity generation options, especially hydropower, and its uncertain social acceptance.

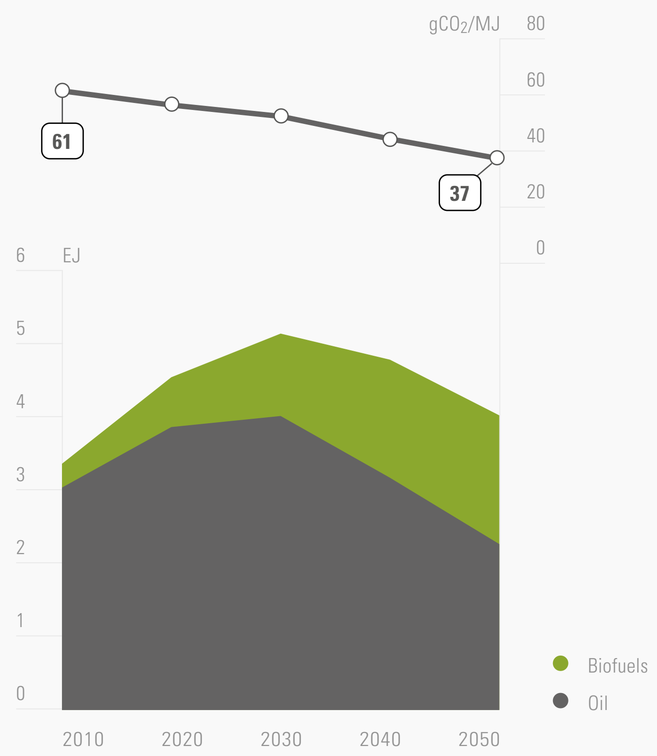
Further utilizing Brazil´s hydropower potential requires improving the design and construction of hydropower plants with reservoirs, while simultaneously meeting local environmental concerns (see Section 3.3). In recent years, hydropower plants have been constructed with minimal reservoirs (i.e. mostly run-of-the-river plants), limited energy storage capacity and without dispatchable generation. Improved designs are needed to improve the reliability of this intermittent resource. In addition, the DDPP analysis includes using the huge potential for renewable biomass, mainly from wood and the sugarcane byproducts of ethanol production (i.e. bagasse, tops and leaves and stillage).

This renewable electricity mix can be designed to match the country's variable electricity demand by exploiting the complementarity between the renewable resources. Offshore wind farms may become a relevant option, given the abundance of offshore sites, thanks to a potential synergy with the huge effort on offshore oil and gas drilling that would help reduce its costs (construction and operation of off-shore wind farms would strongly benefit from the infrastructure and logistics in place for oil&gas platforms).

Advanced batteries, as they become available, together with bio-thermoelectricity, could help overcome the challenge posed by non-dispatchable, intermittent renewable power sources such as solar and wind. If the challenge is overcome, renewable sources could replace natural gas as the base load supply, thereby further reducing GHG emissions from power generation. The resulting scenario leads to a completely decarbonized power sector in 2050.

In the transportation sector, Brazil has already succeeded in decarbonizing part of its energy demand, through the use of biodiesel and especially ethanol (see Section 3.2). The current mandatory blend of renewable fuels is 7% in diesel oil and 27% in gasoline (by volume). Furthermore, more than half the fleet of light vehicles in the country are of the flex fuel type, capable of running on 100% ethanol. Given the proper tax incentives to spur ethanol consumption, ethanol can displace a very large proportion of the car fleet's gasoline demand. This change, coupled with an increased proportion of biodiesel in trucks and buses, would lead to biofuels approaching 50% of the total liquid fuel demand by 2050 (see Figure 11b).

Figure 11b. Liquid Fuel Production




## 4.4 *Macroeconomic Implications*

This section, an analysis of the macroeconomic and social implications of the Deep Decarbonization Pathway, was prepared based on IMACLIM-BR runs especially calibrated for this study. As mentioned in Section 2.1, IMACLIM-BR is a hybrid CGE model, developed to assess the macroeconomic and social implications of climate policies in the medium- and long term.

For this DDP analysis, in order to limit GHG emissions, a carbon tax on the burning of fossil fuels was simulated, growing linearly from \$0/t$CO_2$e in 2015 to \$112/t$CO_2$e in 2030, and then to \$168/t$CO_2$e in 2050. This carbon tax would stimulate the introduction of a number of mitigation measures, carefully chosen to compose the DDP. They represent investments adding up to almost \$2.8 trillion (2010 US dollars) from 2015–2050 (see details in Section 5). The IMACLIM-BR assessment of macroeconomic trajectories demonstrates that those investments will help to deeply reduce GHG emissions without harming the country's economic growth potential.

Table 3 exhibits key macroeconomic and social indicators related to the DDP.

From 2015–2050, Brazil will experience a major shift in its demographic profile, mainly because of a decrease in the fertility rate. Growing from 200 million people in 2015, Brazil's population is expected to hit a peak between 2030 and 2040, and slowly fall to about 221 million in 2050. This will bring other kinds of challenges, such as the projected growth of an already significant deficit in the public retirement pension fund. Figure 12 illustrates the behavior of total population in Brazil from 2010–2050.

Brazil's GDP is expected to grow at an average rate of 3.5% per year from 2015–2050. GDP will grow from $2.14 trillion in 2010 to $4.53 trillion in 2030 and $8.64 trillion in 2050 (all in 2010 dollars). Figure 13 diplays the Brazilian GDP growth per year, according to IMACLIM-BR, from 2010–2030 and 2030–2050.

GDP per capita will also increase significantly, starting from $11,240 in 2010 to $20,800 in 2030 up to $39,100 in 2050 (all in 2010 dollars). Figure 14 below shows an important decoupling between GDP growth and GHG emissions for Brazil from 2005 to 2050 under the Deep Decarbonization Pathway. This figure illustrates a dynamic future with partial decoupling between economic growth and the evolution of GHG emissions in Brazil, which could enable the country, in 2050, to reach a level of 30% of the 2010 emissions.

Carbon revenues collected by the government are used to reduce payroll taxes, to stimulate the creation of new jobs and to offset the recessive effect of tax-induced price increases. The number of full-time jobs in the Brazilian economy under the DDP is expected to grow from 91 million in 2005 to 128 million in 2030, and then to experience a decrease to 116 million in 2050, notably due to continued labor productivity gains. As a result, unemployment rates decrease from 7.0% in 2005 to 3.8% in 2030, and then start to grow very slowly, to 5.5% in 2050, because of a combination of fewer full-time jobs and the demographic trend of a larger active population (Figure 15).

In terms of trade, oil exports from the pre-salt layer are expected to grow until 2030, and then slowly decrease until 2050. During this period, industry will improve its efficiency and increase competitiveness thanks to importation of capital goods, so the trade balance remains positive. However, the trade surplus experiences a relative decrease, from 0.95% of GDP in 2010 to 0.8% in 2030 and to 0.5% in 2050 (see Figure 16).

Prices rise in the DDP scenario, with the carbon tax and all the investment in mitigation measures, but even considering the higher price index, families experience a significant rise in real consumption.

Table 3. Deep Decarbonization Pathway: key macroeconomic and social indicators

| | 2010 | DDPP-2030 | DDPP-2050 |
|---|---|---|---|
| Population (millions) | 191 | 223 | 221 |
| GDP (trillion 2010 US$ dollars) | 2.14 | 4.53 | 8.64 |
| GDP growth per year (2010-2030; 2030-2050) | | 3.81% | 3.28% |
| Investment rate (% of GDP) | 19.50% | 20.84% | 25.16% |
| Total investments (Trillion 2010 US$) | 0.14 | 0.94 | 2.17 |
| Number of full time jobs (million) | 94.1 | 128.0 | 115.9 |
| Unemployment rate (%) | 6.70% | 3.81% | 5.49% |
| GDP per Capita (Thousand 2010 US$) | 11.2 | 20.8 | 39.1 |
| GINI | 0.53 | 0.42 | 0.33 |
| Income share of 16% poorest households | 2.1% | 2.9% | 5.7% |
| Income share of 60% middle class households | 28.7% | 35.1% | 40.0% |
| Income share of 24% richest households | 69.2% | 61.9% | 54.3% |
| Accumulated Price index | | 1.17 | 1.31 |
| Trade Balance (Billion 2010 US$) | 20.3 | 35.9 | 44.6 |
| Trade Balance (% GDP) | 0.95% | 0.79% | 0.52% |
| Exchange rate (BrR$ / US$) | 1.76 | 2.42 | 2.42 |
| International oil price (US$/barrel)[1] | | 95.20 | 95.20 |
| Carbon tax (US$/t$CO_2$e) | 0 | 112 | 168 |
| % of Agriculture in GDP | 5.3% | 5.6% | 6.1% |
| % of Industry in GDP | 28.1% | 26.5% | 24.2% |
| % of Services in GDP | 66.6% | 68.0% | 69.7% |

1 Equivalent to 85 US$/barrel in 2005 US dollars (for monetary figures of this table, 1 US2005 dollar = 1.12 US2010 dollar, and 1 BrR$2005 = 1.23 BrR$2010).

Figure 12. Population (millions)

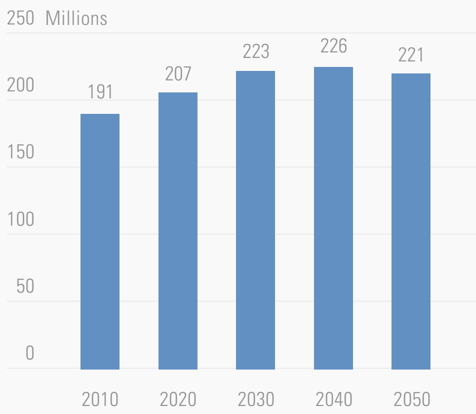



Figure 13. GDP growth per year

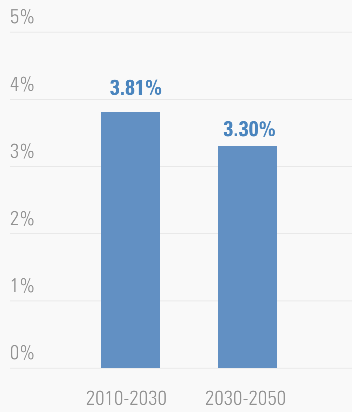



Figure 14. GDP, Polulation and GHG Emissions (Base 2010 = 100)

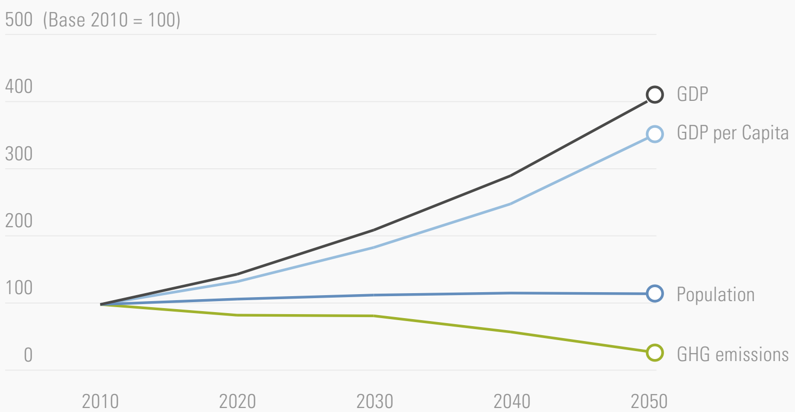



Figure 15. Unemployment rate

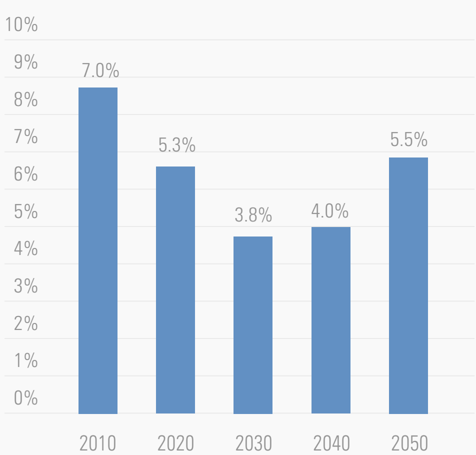
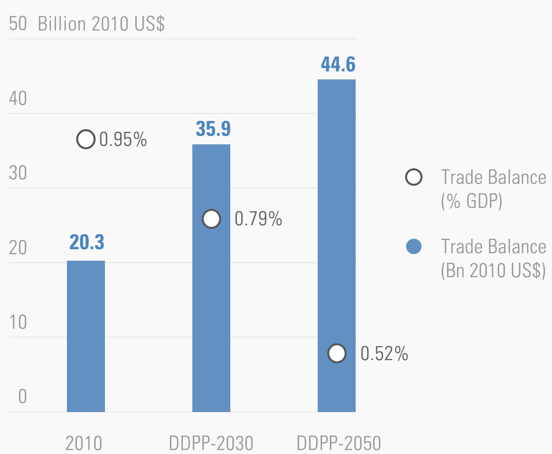



Figure 16. Trade Balance



For example, Brazil's lower-income class increases real consumption by a factor of 3.7, while the highest income class increases real consumption by a factor of 2.1, indicating a significant reduction in income distribution inequality by 2050. Table 4 compares the average household total consumption per income class, corrected by the price index of the period, in 2010 and in 2050. It is clear that the poorest households' consumption increases much faster than the richest. This happens due to an explicit government policy aimed at reducing income distribution inequality in Brazil through better public education for poor families, translating into better productivity of those workers, and thus higher salaries. Also, public transfers to poor families are expected to follow GDP growth, remaining at a level of about 0.5% of GDP from 2010-2050.

Table 4. Household consumption per income class

| | 2010 | DDPP-2050 | Consumption 2050/2010 |
|---|---|---|---|
| Class 1 (2010 US$) | 2,606 | 9,642 | 3.7 |
| Class 2 (2010 US$) | 5,959 | 15,493 | 2.6 |
| Class 3 (2010 US$) | 21,298 | 45,720 | 2.1 |

In aggregate, this reduction of income distribution inequality, allows for a fall of the GINI index from 0.53 to 0.334.

In conclusion, it is possible to significantly reduce emissions in the coming decades without jeopardizing Brazil's strong economic growth and social development.

# 5 Costs and Investment Requirements, Implications and Opportunities, Co-Benefits

The DDP analysis includes assessing the investment requirements for a series of mitigation actions. Different sectors present a range of possibilities, notably the AFOLU sector, a historically high emitting sector due to the deforestation associated with cattle raising and agriculture.

When it comes to mitigation actions and the associated investment requirements to 2030, from the base year 2010, the DDPP analysis considers circumstances virtually identical to those in the most ambitious scenario posited by the IES-Brasil project. This scenario includes all mitigation actions already agreed upon and foreseen by the government, and considers higher penetration rates, as well as a set of extra mitigation actions, leading to great decarbonization efforts. Since the DDP analysis takes into account a longer time frame (up to 2050), and a high growth of the Brazilian economy throughout this period, a lower discount rate of 4% per year was chosen, instead of 8% per year used in the IES-Brasil study.

After 2030, saturation levels on existing actions are considered, when applicable. For example, the modernization of existing refineries takes place before 2030, therefore it is not necessary to continue investing in these improvements after 2030, even if refineries are still in operation. Also, there is a threshold for commercial forest areas: above approximately 2.5 million hectares, their rate of expansion is slowed.

Furthermore, some extra mitigation actions are implemented:

- Transportation sector: Light electric vehicle use grows steeply, reaching 46% of the total fleet in 2050, as their costs gradually come to equal those of fuel-powered cars.
- Energy sector: Lithium-ion batteries used to

store energy were considered for offshore and onshore wind, as well as for solar energy. As more intermittent sources come online, energy storage becomes essential to assure the supply. The amount of energy guaranteed through batteries grows proportionally to the share of solar and wind power, reaching up to additional six days in 2050.

To increase power generation from sugarcane bagasse, storing some of the biomass is also necessary. This portion will be used off-season, and hence must be dehydrated. The analysis considered that, from 2031–2050, the share of sugar cane bagasse that requires dehydration gradually increases. Moreover, the analysis considered that an increasing part of the sugarcane straw would be used in cogeneration. This becomes possible due to the growing mechanization of sugarcane crops and efforts to abolish the practice of burning the straw in the fields.

Table 5 depicts all mitigation actions considered, including their year of implementation, penetration rate in 2050 and investment levels. Monetary values are in constant 2010 US dollars, with a 2015 present value at a 4% annual discount rate.

Assessing co-benefits from mitigation actions makes an even stronger case for climate action. Co-benefits can also justify some of the high investment levels that the analysis finds that will be required for a few mitigation actions. Subways are an iconic case: even though investment requirements are high, shifting from cars to urban rail improves air quality and mobility in general. Expanding bicycle lanes also generates health benefits.

Other actions bring about positive co-benefit impacts, for example, in the energy sector: Increasing the share of renewables in electricity generation guarantees energy security and may help improve the balance of payment terms as less fuel must be imported. The preserved biodiversity resulting from action in the AFOLU sector ensures the provision of environmental services.

**Table 5. Mitigation actions, Year of implementation, Penetration in 2050 and Investment levels**

| | | | Total Investment Level (2015-2050) - million 2010 USD at 4% p.y. discount rate |
|---|---|---|---|
| **Mitigation Action** | **Year of implementation** | **Penetration in 2050** | |
| **Services** | | | |
| Efficient light bulbs (Services) | 2015 | 100% | 32,520 |
| **Residential** | | | |
| Efficient LPG stoves | 2015 | 100% | |
| Efficient light bulbs (Residential) | 2015 | 97% | 10,231 |
| Thermosolar Water Heating | 2015 | 45% | 31,553 |
| **AFOLU** | | | |
| Planted forests | 2021 | average 5.9 million ha | 4,000 |
| Biological Nitrogen Fixation (corn crops) | 2021 | average 5.3 million ha | 874 |
| Agroforestry Systems | 2026 | average 1.8 million ha | 122 |
| Degraded Pasture Recovery | 2026 | average 4782 properties | 204 |
| Atlantic Forest Restoration | 2015 | average 16.0 million ha | 9,040 |
| Swine Waste Management | 2021 | average 16.0 million ha | 90,231 |
| **Transportation** | | | |
| Bicycle lanes | 2015 | n/a | 22 |
| Increased consumption of ethanol | 2015 | n/a | 673 |
| Traffic Optimization | 2015 | n/a | 343 |
| Heavy Electric Vehicles | 2020 | n/a | 37,265 |
| Light Electric Vehicles | 2031 | n/a | 661,983 |
| BRT Systems (Bus Rapid Transit) | 2015 | n/a | 14,261 |
| VLT Systems (Light Urban Train) | 2015 | n/a | 15,738 |
| Railways and Waterways | 2015 | n/a | 41,032 |
| Increased consumption of biodiesel (15% in the diesel mix) | 2020 | n/a | 169,533 |
| Subways | 2015 | n/a | 199,450 |
| Energy Efficiency - Light vehicles | 2021 | n/a | 2,139 |
| Energy Efficiency - Heavy duty vehicles | 2017 | n/a | 58,252 |
| **Energy** | | | |
| Additional hydroelectric generation expansion | 2021 | n/a | 194,932 |
| Additional onshore wind generation expansion (inc. storage) | 2021 | n/a | 239,977 |
| Additional offshore wind generation expansion (inc. storage) | 2031 | n/a | 110,245 |
| Additional solar photovoltaic generation expansion (inc. storage) | 2021 | n/a | 293,041 |
| Additional sugar cane bagasse generation expansion (inc. dehydration) | 2021 | n/a | 297,089 |
| Improvements in refineries - Energy Integration and Heat Reduction | 2021 | n/a | 56,040 |
| **Waste** | | | |
| Methane Destruction in Landfills | 2015 | 100% | 71,996 |
| Methane Destruction in Dumpsites and Controlled or Remediated Landfills | 2015 | 59% | 18,165 |
| **Industry** | | | |
| Carbon Intensity Reduction by 2% - Steel | 2015 | 100% | 1,257 |
| Eucalyptus incorporation for charcoal - Steel | 2015 | 100% | 66,621 |
| Carbon intensity reduction and increased co-processing - Cement | 2015 | 100% | 35,784 |

*Source: authors*

# 6 Implementing a Deep Decarbonization Pathway in Brazil

## 6.1 Challenges and Enabling Conditions

A fundamental, society-wide transformation is implied in decarbonizing the country's economy, which will certainly have its winners and its losers. Some preconditions will be necessary to obtain the political resolve necessary to muster the forces for change. The first precondition is solid public awareness of the potential dangers of climate change—and the dangers of inaction. Brazil will clearly benefit from a decarbonized world, given the abundance of non-fossil natural resources in the country.

The main risk is the temptation to channel the recently discovered huge offshore oil and gas resources to expand domestic use, through a low pricing policy aimed at helping curb inflation. So far, the announced government policy, confirmed by Congress, points in the opposite direction; the stated objective is to export the bulk of the oil resources and to channel oil revenues to finance government investments in health and education. It is imperative, if a low-carbon future is to be feasible in Brazil, to stick to this policy, avoiding the wrong use of the newfound oil resources. Such inappropriate use would undermine current and future efforts to foster energy efficiency and the use of renewable energy sources.

The main technological challenges for the country are designing and building a new generation of hydropower plants in the Amazon that would avoid disrupting ecosystems, and using dispatchable bioelectricity to replace fossil-fuel generation.

Many of the strategies will require structural changes and high upfront costs. The barriers to their implementation are related to pricing, funding and vested interests, especially in two fields: power generation and transportation (long distance transportation and urban mobility). The huge upfront costs and long construction times involved in tapping the hydropower potential and building low-carbon transportation infrastructure will require substantial financial outlays and upgraded institutional arrangements (e.g. public/private partnerships) to provide adequate funding. The financial flow will need to come largely from abroad, given the low savings capacity of the Brazilian economy.

Internationally, a set of technical and policy actions with a realistic chance of delivering on the promise of a climate-stable planet, together with a convincing argument for the perils of inaction, will be required to mobilize the resources needed for crucial initiatives. These actions will include: accelerated research to develop safe, energy-dense renewable fuels; research on industrial processes and materials that will bring down the investment costs of renewable power sources; and establishing mechanisms for technology transfer. It will also be crucial for governments worldwide to adopt carbon taxation schemes and to cut fossil fuel subsidies.

## 6.2 Near-Term Priorities

There are a number of immediate policy and planning measures that can be recommended to engage Brazil in a deep decarbonization process. Reinforcing the initiatives aimed at curbing deforestation is one such measure, to ensure there will be no major deviations from a trajectory that ends in zero deforestation within a decade, at most. Another policy priority should be substantially expanding forest plantations on degraded land, with appropriate financial schemes to meet the upfront costs. Another measure must be expending effort to pass legislation so the net effect of the taxes and subsidies on energy markets favor widespread adoption of renewable energy and energy efficiency options. To this end, in the near-term, it is essential to cut subsidies on gasoline and diesel, and to restore the financial health of the electricity generation sector.

Extending the coverage of current incentives to invest in renewable energy in order to encompass other types of equipment, such as photovoltaic and solar heaters, can produce short-term returns. Prompting electricity providers to adopt smart-grid technologies and drafting a detailed and economically meaningful plan for restructuring long-distance transport in Brazil is another measure. This will involve prioritizing an infrastructure that allows for the most energy and emissions-efficient modes of transportation, such as railways and waterways. This could both cut emissions and respond to the business community's concerns. A similar initiative should also be undertaken, in collaboration with local authorities, with respect to urban mobility—an aspect of Brazilian infrastructure that needs urgent improvement and is thus currently high on the political agenda.

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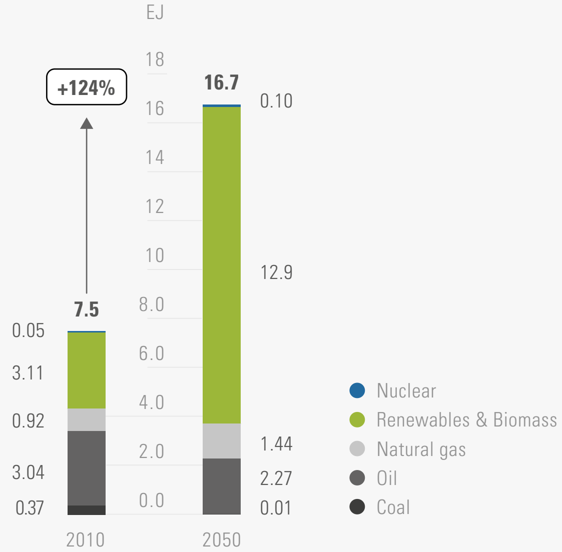
# Standardized DDPP graphics for Brazil scenarios

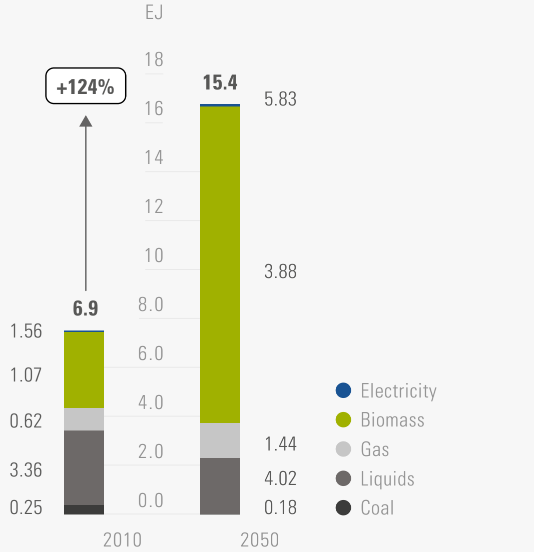
## BR – DDPP Scenario

# BR - DDPP Scenario

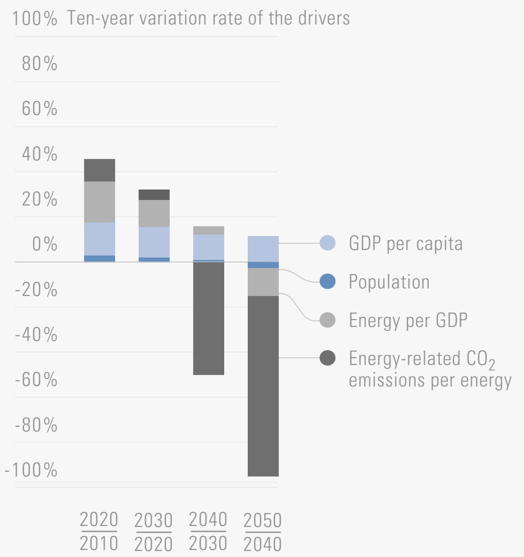
### Energy Pathways, Primary Energy by source



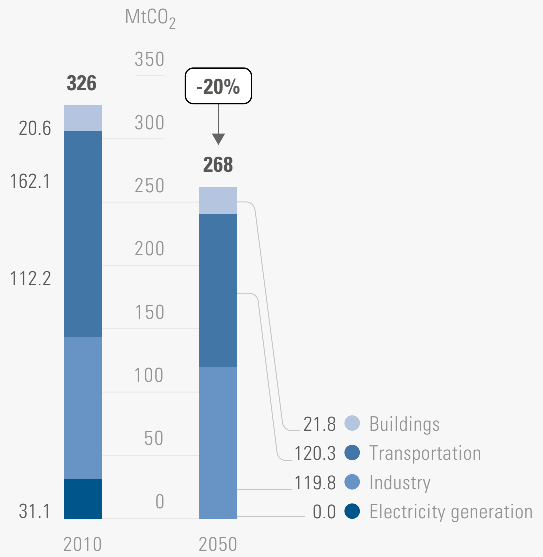

### Energy Pathways, Final Energy by source




### Energy-related $CO_2$ Emissions Drivers, 2010 to 2050

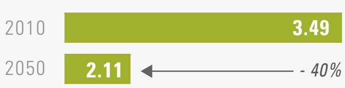



### Energy-related $CO_2$ Emissions Pathway, by Sector



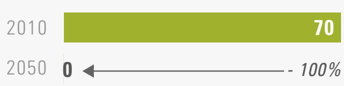

### The Pillars of Decarbonization

**Energy efficiency**



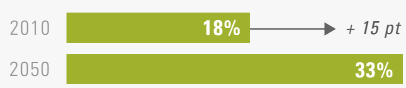

*Energy Intensity of GDP, MJ/$*

**Decarbonization of electricity**



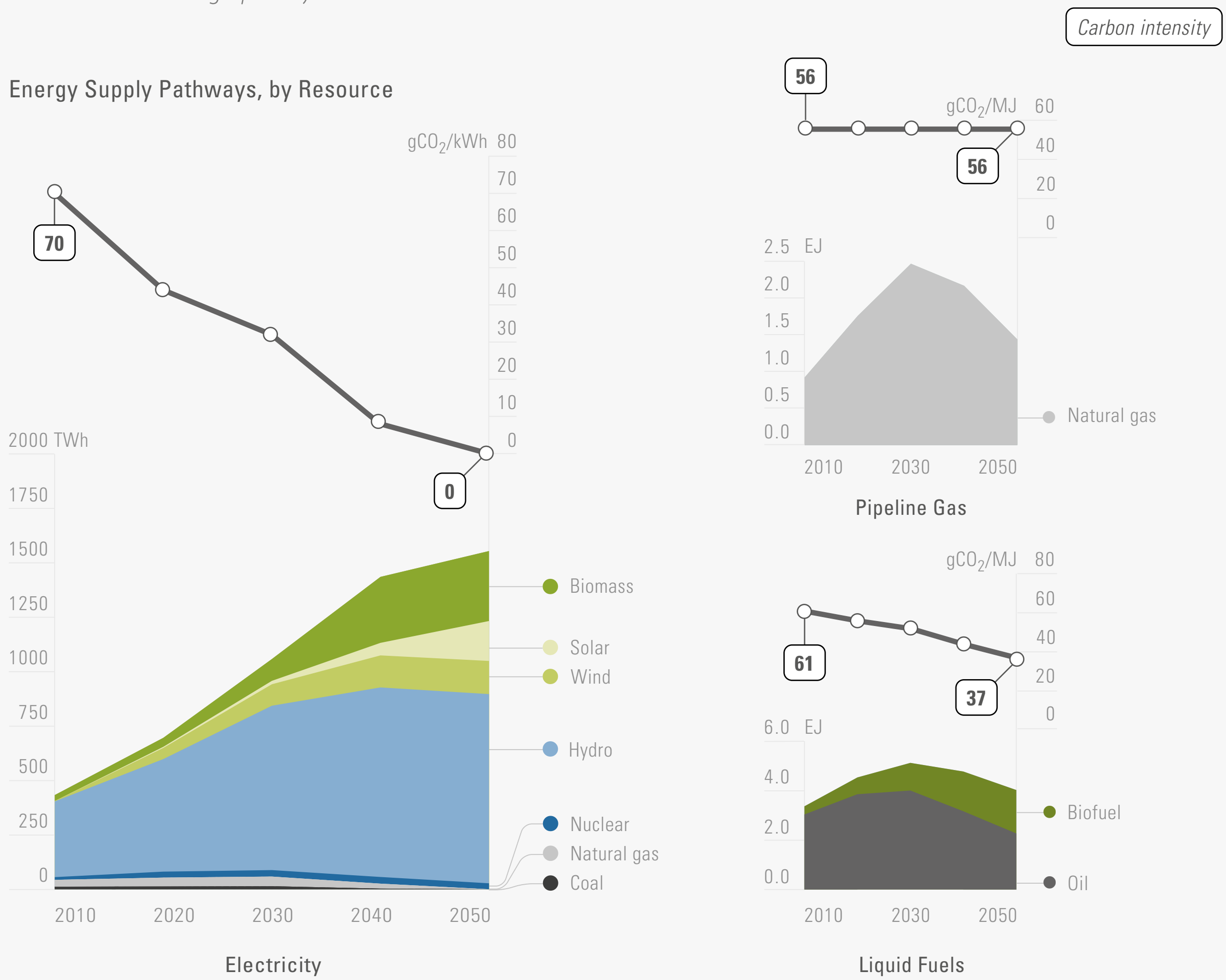

*Electricity Emissions Intensity, $gCO_2$/kWh*

**Electrification of end-uses**




*Share of electricity in total final energy, %*

## Energy Supply Pathways, by Resource




## Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050