Brazil in the Anthropocene

Conflicts between predatory development and environmental policies

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12 Pathways to a low carbon economy in Brazil[1]

Emilio Lèbre La Rovere, Claudio Gesteira, Carolina Grottera and William Wills

Introduction

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 percent 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 (La Rovere et al. 2013).

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 income per capita in 2005 was only $4,767. Inequality, as evidenced by Brazil's uneven income distribution, is a major problem. In 2005, the poorest 16 percent of the population had an average income per capita of $481 per year, or less than two times the national annual minimum wage. Meanwhile 60 percent of the population had an average income per capita of $1,819 per year, the equivalent of 2 to 10 times the national annual minimum wage. The richest 24 percent of the population had average annual income per capita of $10,848, or more than 10 times the annual minimum wage (IES-Brasil 2015). 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 social transfer programs (e.g. *Bolsa Família*). They 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 living in extreme poverty (Brasil 2015). 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 percent of urban households and 90 percent of rural households were electrified in 2010). Access to a clean water supply is also high (93 percent of the population in the largest 100 municipalities, in 2013). But important challenges remain in providing citizens access to basic services, most notably, Brazil has a housing deficit. Brazil has, in total, 65 million households, but 5.4 million houses are "missing." Some 2.7 million households lived in a residence with more than one family. In addition, nearly half the population had to build its own house. Water is expensive and subject to shortages, as was the case during the recent drought. The coverage of sanitation services is still poor: only 48 percent of the population benefits from sewage collection networks and only 39 percent 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 percent of domestic needs, mostly for the industrial and transportation sectors (oil products are not used significantly in electricity generation or 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 transportation modes that dominate urban and long-distance travel – freight as well as passenger. 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, imported oil accounted for 6 percent of domestic oil consumption; while 44 percent of natural gas domestic consumption was imported, 75 percent of coal's and 5 percent of electricity's, with 87 percent 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 percent of the oil rent to fund education and 25 percent for health. This assumes that the pace of growth of domestic energy consumption will be kept moderate, through continuing to produce renewable energy. Already, renewables accounted for 39.5 percent of energy consumption in 2014. Renewables include hydropower, sugarcane products (ethanol used as liquid biofuel in 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 and 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 traced the rapid growth in demand, 9.5 percent from 2013 to 2014, mainly for power generation and industrial use, creating a need to import gas through the pipeline from Bolivia or as liquefied natural gas (LNG) from other countries. Natural gas imports represent 41 percent of domestic supply in 2014, but it is expected to sharply decline, 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 highest 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 percent 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 22–25 percent ethanol. Domestically produced ethanol is also used for the pure ethanol and flex fuel 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 percent blend of biodiesel. Brazil also has important wind energy potential. Initial estimates of its potential for installing 150 GW have yet to be updated; this figure will grow due to 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 (EPE 2015). 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 percent and more than 23 million people were lifted out of poverty, while emissions dropped 52 percent, delinking economic growth from emission increase over the period (Brazil 2015). However, this was only possible thanks to a dramatic cut in Amazon deforestation, as 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 standards of all the population (La Rovere et al. 2013). 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 the country's huge potential to further expand production of renewable energy.

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 12.1).

As a consequence of the lower rate of deforestation, the share of CO_2 in the GHG emissions mix has declined sharply, from 73 percent to 57 percent 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 percent in 2005 to 32 percent in 2010. Fossil fuel combustion ranked second, after agriculture and livestock, in 2010 (see Figure 12.1). Among fossil fuels, oil is by far the dominant source of CO_2 emissions, followed by natural gas, and coal (in 2010, 220, 62 and 44 $MtCO_2$, respectively).

The Brazilian population increased from 145 million to 191 million people from 1990–2010. Population growth rates have declined, to a rate 0.9 percent per year today (from 1.6 percent per year in 2000). Economic growth has been an important driver of increased energy-related CO_2 emissions, as GDP nearly

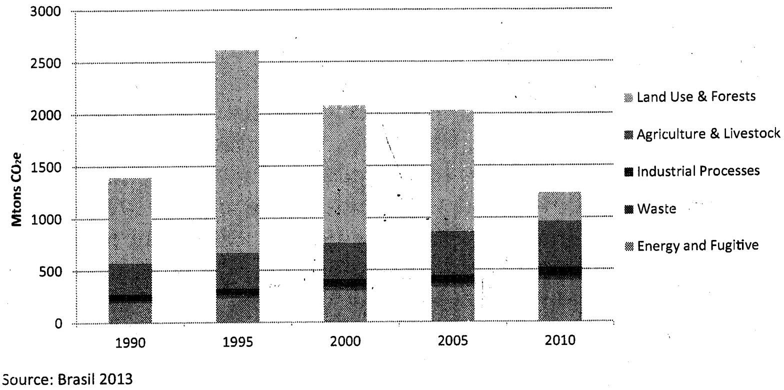

Figure 12.1 GHG emissions by source: 1990–2010

Source: Brasil 2013.

doubled from 1990 to 2010 (an 89 percent increase, in real terms). The carbon content of the energy supply has followed the ups and downs of the development of renewables: the share of renewables in total energy mix fell from 49 percent in 1990 to 41 percent in 2000 due to a slowdown in the deployment of hydropower and ethanol from sugarcane. Then it rose, after 2000, to reach 45 percent of total energy supply in 2010. In 2010, transportation was the largest energy-related CO_2 emissions source (162 $MtCO_2$), followed by industry (112 $MtCO_2$), electricity generation (31 $MtCO_2$) and buildings (21 $MtCO_2$). Roads play an overwhelming role in Brazil, both in intercity freight transport 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 declining now.

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 ("Instituto Brasileiro de Geografia e Estatística," a federal 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 of 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 Energy Long-Term National Plan, PNE 2050 (EPE 2014). Economic growth is assumed to be very strong through 2050, with a quadrupling of average GDP per capita to reach 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.

A Deep Decarbonization Pathway then, is designed to include mitigation policy actions and measures targeted to bring Brazilian GHG emissions per capita to 1.7 tCO_{2e} per year, of which 1.2 tCO_{2e} comes from energy-related emissions, consistent with a world average required to limit global warming to 2 degrees Celsius.

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 global climate target. The 2050 GHG emission target for Brazil is set at 367 $MtCO_2e$, a 70 percent reduction compared to 2010 (1,214 $GtCO_2e$). 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 (Economic and Social Implications of GHG Mitigation Scenarios in Brazil up to 2030),[2] outlined by a Scenario-Building Team (SBT) made up of experts from the government, academia, private sector and civil society. This IES–Brazil 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 $MtCO_2e$ emissions level in 2030 (483 $MtCO_2$ 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 $MtCO_2e$ 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 percent in the period, and a doubling of biomass-based thermopower, to producing almost 20 percent 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 percent, 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. This allows for fully emissions-free electricity generation by the end of the period.

Rail and water represent about 60 percent of total freight transport in ton-kilometers, in 2030. After 2030, reliance on rail and water increases to reach more than 70 percent 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 percent decrease of ton-kilometers from 2030–2050, in parallel with 80 percent 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 percent from 2030–2050.

Passenger transportation, by contrast, sees a growth in activity levels over the period, by about 30 percent, given the continued trend of the expansion of Brazil's urban centers. Urban growth triggers a 15 percent rise in energy needs from 2031–2050, essentially because of increased public transportation needs. 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, although passenger transportation activity increases over the period by about 30 percent, emissions fall, more than offsetting the activity growth and decreasing emissions by about 30 percent from 2030–2050. A comprehensive list of all mitigation actions per sector can be found in Table 12.2 on page 262.

The investment required for these transformations is assessed through a one-way soft-link in sectoral modules for 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 energy 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 CGE model IMACLIM-BR. 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). 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/tCO2e in 2030 and then to \$168/tCO_2e in 2050.[3] The tax revenues are fully recycled through lower social security taxes on labor, so that fiscal neutrality is ensured and 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 aligning of some key variables, such as population, GDP, GDP structure and final energy consumption. Most of the mitigation actions considered are cost-efficient 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 adopt, as an approximation, neglecting the effect on energy demand of economic feedback from IMACLIM-BR.

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 2 degrees Celsius-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 pillars of this Deep Decarbonization Pathway strategy: Agriculture and Livestock, Forestry and Land Use (AFOLU); biofuels and hydropower. Table 12.2 includes a list of all sectoral mitigation actions up to 2050 in the Deep Decarbonization Pathway (DDP).

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 percent of the estimated carrying capacity, which accounts for 274 to 293 million animal units. It is envisageable to increase pasture productivity to 49–52 percent 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 (Brasil 2012), 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 (Brasil 2004) and of the Action Plan for Prevention and Control of Deforestation and Fires in the Savannahs (Brasil 2009) 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 12.1).

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 the 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-2020s, 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.

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.

From 2030 to 2050, new mitigation technologies will become available, allowing for the deeper decarbonization of the Brazilian economy. 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. The sectoral mitigation measures up to 2050 are presented in Table 12.2.

Results and discussion

The quantitative results from the storyline of the Deep Decarbonization Pathway (DDP) described in the previous section are presented and discussed below.

Emissions pathways

In most countries, the key challenge to a deep decarbonization pathway is the combustion in fossil fuels. In Brazil, this is also true (see La Rovere et al. 2013) but the country is right now in a transition from deforestation to energy as the main source of GHG emissions, as explained in the Introduction. Moreover, carbon sequestration from reforestation and afforestation schemes has the potential to play an important role in the long-term decarbonization of the Brazilian economy. Therefore, in this section we first present the GHG emissions from AFOLU and its share of overall GHG emissions, before detailing the results for energy-related emissions in different sectors of the economy.

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

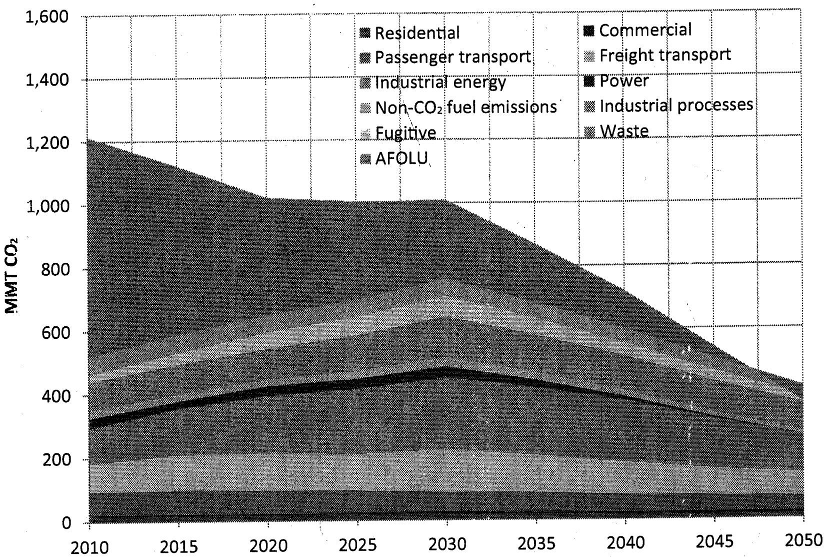

Figure 12.2 DDP: GHG emissions per sector 2010–2050

Source: La Rovere et al. 2015

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 12.2.

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 262 $MtCO_2$ a lower level than in 2010. Opposite trends drive these evolutions. On the one hand, the main driver of emission 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 transportation) 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 120 MtCO_2 in 2050. Emissions from buildings (22 MtCO_2 in 2050) and power generation remain very low throughout the 2010–2050 period.

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). 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.

Final energy, currently consumed mostly in the form of liquid fuels (almost 50 percent), 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.

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 percent 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.

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 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 percent 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 percent 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 percent (the government has just regulated an increase from 5 percent to 7 percent). 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 percent 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 standards 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. 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 percent to 70 percent 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 percent of all the passenger transportation needs in 2050, a significant increase from the current level of below 10 percent.

Buildings

Demand for energy in buildings rises strongly in the DDP scenario, reflecting 16 percent population growth, 267 percent 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 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 percent to about 5 percent to 10 percent by 2050, thanks to 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 percent of residences, will fall from its current level of 33 percent because of efficiency improvements. By contrast, air conditioners, used now by only about 15 percent of households, will be more widely adopted (by up to 75 percent 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 percent of residences and accounting for 27 percent of residential energy consumption on average, will be replaced mostly by solar heaters, so their share falls to no more than 10 percent 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 (hairdryers, microwave ovens, toasters, washing machines, vacuum cleaners, water purifiers, etc.). These appliances, now found in only 44 percent 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, decarbonization measures 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.

Industry

Several 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 percent from 2010–2050. The industrial sector's overall share of GDP would drop by 4 points (from 34 percent of GDP in 2010 to 30 percent 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 remaining constant at about 5–6 percent of GDP.

In most major industrial sectors, the share of electricity in total energy demand is expected to rise considerably by 2050. For generating heat in industry, biomass would partially replace fossil fuels, wherever possible. The share of natural gas to meet industry needs is expected to increase, 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.

In absolute terms, the energy demanded by industry would more than double by 2050, 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. Under the Deep Decarbonization Pathway, the growth in industrial energy emissions will be tempered 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 the aggregate across the industrial sector, this will result in a decrease of energy intensity per unit of value added of 21 percent in 2050, compared to 2010. 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 non-energy emissions of industrial processes will also increase, given the inflexibility of some of those processes.

A substantial effort will be required to reduce CH_4 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 the 2015 level.

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 percent 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. 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 the infrastructure and logistics in place for oil and 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.

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 above, 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 on page 000). 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 12.1 presents key macroeconomic and social indicators related to the DDP.

Table 12.1 Deep Decarbonization Pathway: key macroeconomic and social indicators

	2010	*DDPP-2030*	*DDPP-2050*
Population (millions)	191	223	221
GDP (trillion 2010 US$)	2.14	4.53	8.64
GDP growth per year (2010–2030; 2030–2050) (%)		3.81	3.28
Investment rate (% of GDP)	19.50	20.84	25.16
Total investments (trillion 2010 US$)	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 (2010 US$/barrel)		95.20	95.20
Carbon tax (2010 US$/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

Note: for monetary figures of this table, 1 2005 US$ = 1.12 2010 US$, and 1 BrR$2005 = 1.23 BrR$ 2010; therefore, 2010 US$ 95.20/barrel = 2005 US$ 85/barrel

Source: La Rovere et al. 2015.

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.

Brazil's GDP is expected to grow at an average rate of 3.5 percent per year from 2015–2050. GDP will grow from $2.14 trillion in 2010 to $4.53 trillion in 2030 to $8.64 trillion in 2050 (all in 2010 dollars). GDP per capita will also increase significantly, starting from $11,240 in 2010 to $20,800 in 2030 to $39,100 in 2050 (all in 2010 dollars).

In the Deep Decarbonization Pathway a partial but important decoupling between GDP growth and GHG emissions for Brazil takes place from 2005 to 2050, enabling the country to reach in 2050 a level of 30 percent of 2010 GHG emissions.

Carbon revenues collected by the government are used to reduce payroll taxes, to stimulate the creation of new jobs and 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 percent in 2005 to 3.8 percent in 2030, and then start to grow very slowly, to 5.5 percent in 2050, because of a combination of fewer full-time jobs and the demographic trend of a larger active population.

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 percent of GDP in 2010 to 0.8 percent in 2030 and to 0.5 percent in 2050.

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. For example, Brazil's lower-income class of up to two minimum wages (24 percent of population in 2005) increases real consumption by a factor of 3.7, the mid-income class of 2–10 minimum wages (60 percent of population in 2005) has a 2.6 increase, while the highest income class above 10 minimum wages (16 percent of population in 2005) increases real consumption by a factor of 2.1, indicating a significant reduction in income distribution inequality by 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 percent of GDP from 2010–2050. 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.

Economic implications and 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 timeframe (up to 2050), and a high growth of Brazilian economy throughout this period, a lower discount rate of 4 percent per year was chosen, instead of 8 percent 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 forests 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 percent 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 six days add up in 2050.

To increase power generation from sugarcane bagasse, storing some of the biomass is also necessary. This share will be used during the off-season, and hence must be dehydrated. The analysis considered that from 2031–2050, the share of sugarcane 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 12.2 depicts all mitigation actions considered, including their year of implementation, penetration rate in 2050 and investment levels. Monetary values are in 2010 constant US dollars, with a 2015 present value at a 4 percent 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 the analysis finds 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.

Implementing a deep decarbonization pathway in Brazil

As the long-term starts today, it is of utmost importance to discuss the requirements for a transition from current policies to the enabling conditions of a deep decarbonization in Brazil. This section addresses the need for connecting short- and long-term concerns.

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 exporting the bulk of the oil resources and channeling 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 wrong use would undermine current and future efforts to foster energy efficiency and the use of renewable energy sources.

Table 12.2 Mitigation actions, year of implementation, penetration in 2050 and investment levels

Sector	*Mitigation action*	*Year of implementation*	*Penetration in 2050*	*Total investment level (2015–2050) – million 2010 US dollars at 4% p.y. discount rate*
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 4,782 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	0,245
	Additional solar photovoltaic generation expansion (inc. storage)	2021	n/a	293,041
	Additional sugarcane 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%	1,996
	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: La Rovere et al. 2015.

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 outside, 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.

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. 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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Notes

1 This work is based on the second report about Brazil to the Deep Decarbonization Pathways Project, jointly coordinated by Columbia University and IDDRI (Sciences Po, Paris) in 2014-2015.
2 IES–Brasil (Implicações Econômicas e Sociais de Cenários de Mitigação no Brasil até 2030 / Economic and Social Implications of GHG Mitigation Scenarios in Brazil up to 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: www.mapsprogramme.org/.
3 These values correspond to 100 US$/tCO2e and 150 US$/tCO2e in 2005 values, respectively.

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