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# The Challenge of Sustainable Development through a Low Carbon Pathway

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## Introduction

Climate change implies a two-fold challenge for sustainable development for Brazil. On one hand, the vulnerability of the Brazilian population and economy to climate change is high: poverty and social inequality, and Brazil's reliance on natural resources and commodities for economic growth aggravate potential impacts of climate change on the country's population, ecosystems and economy. The potential social and economic damage is particularly important in the northeastern region, and in the Amazon, where "hot spots" of environmental, social and economic vulnerability are mostly located.[1]

On the other hand, confronting the specter of climate change requires a Brazilian contribution to a global effort of strongly mitigating the emission of greenhouse gases (GHG)[2] into the atmosphere. Keeping global warming below the 2$^{o}$C limit, the goal established by the 193 countries that are parties to the United Nations Framework Convention on Climate Change (UNFCCC), will require that global net GHG emissions approach zero by the second half of the century.[3] Like other developing and emerging economies, Brazil is thus faced with the huge challenge of embarking in a transition towards a low carbon society without jeopardizing its sustainable development goals.

This work explores the potential of a climate compatible sustainable development model for Brazil, through the design of an illustrative pathway that would meet the challenge of a transition to a low carbon society while addressing the country's social equity and economic growth goals.[4]

## The Brazilian Context for Sustainable Development and a Low Carbon Future

Brazil has been in a unique position among major GHG emitting countries due to relatively low per capita energy-related GHG emissions, which is attributable to the use of abundant clean

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[1] Margulis, S., Dubeux, C.B.S. (eds), 2011; Economia da Mudança do Clima no Brasil, Rio de Janeiro, Ed. Synergia.
[2] Three main GHG account for the bulk of GHG emissions : carbon dioxide ($CO_2$), methane ($CH_4$) and nytrous oxyde ($N_2O$).
[3] Intergovernmental Panel on Climate Change (IPCC), 2014; Summary for Policymakers. In: Climate Change 2014: The Synthesis Report. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[4] This work is based on the research conducted by the authors for the Deep Decarbonization Pathways Project. The authors would like to thank the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI) for their support. See SDSN&IDDRI, 2014; Pathways to deep decarbonization. The full report is available at deepdecarbonization.org

energy sources. Major emissions have been historically concentrated in agriculture, forestry, and other land use (AFOLU), related mostly to deforestation, crop growing and livestock. In Brazil, deforestation has recently slowed down considerably, to the point where forestry has ceased to be the major source of emissions. The agriculture and livestock emissions have been driven by the expansion of the agricultural frontier in the "cerrado" (savannah) and Amazon biomes for crop and cattle raising activities, as Brazil is an important world supplier of commodities such as soybeans and meat. In parallel, as the economy grows, emissions related to the combustion of fossil fuels for energy production and consumption have been increasing significantly and are expected to become the dominant source of GHG emissions over the next decade.[5] Brazil faces the challenge of building upon its low historical GHG emission levels with new decarbonization strategies while simultaneously working to improve the standard of living.

In the past, Brazil had been strongly dependent on oil imports, mostly for the industrial and transportation sectors (oil products are neither used significantly in electricity generation—mainly supplied by hydropower—nor in the residential sector, as ambient heating is needed only sparingly in the south of Brazil). Oil imports have in particular fueled on-road modes of transportation that dominate both urban and long distance travel, whether freight or passenger-related. Over the last decade, large off-shore oil reserves were discovered, raising the expectation that Brazil can become a major oil exporter as these reserves exceed the country's own consumption needs and current governmental plans do not envision using these reserves for domestic consumption. The country is not endowed with large coal reserves, having only a low-grade variety and coal consumption is limited to a few industries specific processes (e.g. coke for steel mills, cement) and to some complementary electricity generation. Natural gas produced in the country has not matched the rapid growth in demand, creating a need to import gas either through a pipeline from Bolivia or as liquefied natural gas (LNG). The need to import natural gas may be eliminated in the long-term as new discoveries are fully exploited.

Brazil is also endowed with a large renewable energy potential. Hydropower provides more than 70% of the country's electricity and has still a great untapped potential, although not all of it will be exploited due to concerns over environmental impacts. Brazil also has an abundance of land that can be sustainably used to produce biofuel feedstocks, especially sugar cane for ethanol, which is already widely used as a fuel for light-duty vehicles. The country also has significant wind and solar potential and the last five years have witnessed an increase in the use of wind for electricity generation.[6] Therefore, keeping a low energy-emissions growth trajectory appears feasible, and, if carefully planned and prioritized, can combine continued economic growth with declining fossil fuel consumption, excluding perhaps natural gas.

Income inequality is another major concern, and although the level remains high, there has been a visible improvement in recent years, with the lower income strata of the population witnessing a greater increase in income than the national average. Regional inequality is also high, and is the subject of some regional incentive programs. On this point, the need to provide enough energy to fulfill the needs of the whole population while decarbonizing the economic activity remains a key challenge, although not an insurmountable one.

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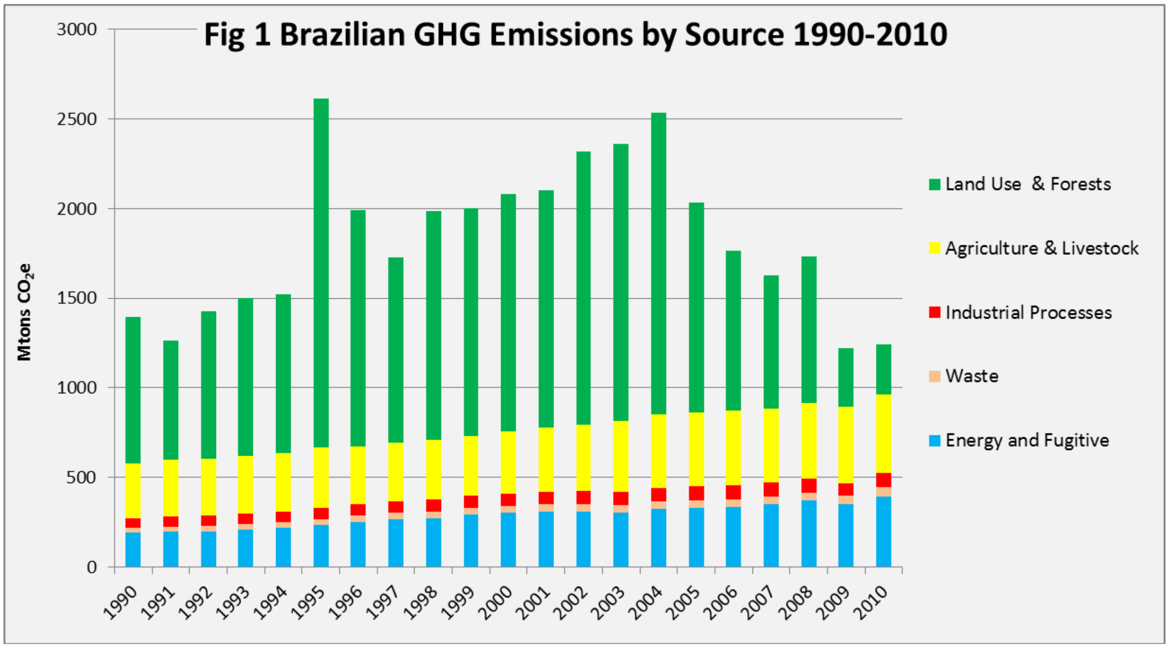
5 La Rovere, E.L., C.B.S. Dubeux, A.O. Pereira Jr; W.Wills, 2013; Brazil beyond 2020: from deforestation to the energy challenge, Climate Policy, volume 13, supplement 01, p.71-86.

6 EPE (2013), 'Balanço Energético Nacional' ; Available at: http://www.mme.gov.br/mme/galerias/arquivos/publicacoes/BEN/2_-_BEN_-_Ano_Base/1_-_BEN_Portugues_-_Ingles_-_Completo.pdf

## The Evolution of GHG Emissions in Brazil

Brazil's population increased from 145 million people in 1990 to 191 million in 2010. Population growth rates have declined to 0.9 percent per year, down from rates above 3 percent during the 1970s and 1980s. GHG emissions increased from 1.4 billion metric tons CO2 equivalent (GtCO2e) in 1990 to 2.5 GtCO2e in 2004, before falling sharply to 1.25 GtCO2e in 2010, thanks to the sharp fall of deforestation (see Figure 1 below).




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

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 growth in GHG emissions has been notably driven by methane emissions from the enteric fermentation of the large Brazilian cattle herd (numbering 213 million heads in 2012), and the share of fossil fuel combustion in total GHG emissions has been steadily increasing in recent years, from 16 percent to 32 percent over the period 2005-2010, ranking 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). Population and economic growth have been consistent drivers of increased energy-related $CO_2$ emissions, whereas the energy-related $CO_2$ intensity per unit of GDP increased from 1990 to 2000 but decreased from 2000 to 2010 (see Figure 3a). Transportation is the largest energy-related emissions source, followed by industry, electricity generation, and buildings (see Figure 3b).

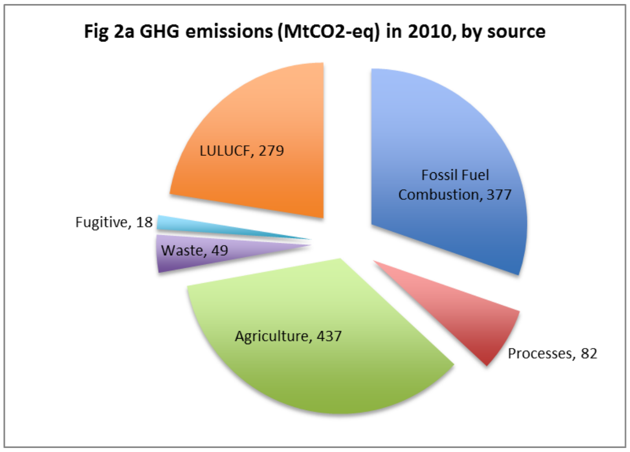


Fig 2a GHG emissions (MtCO2-eq) in 2010, by source

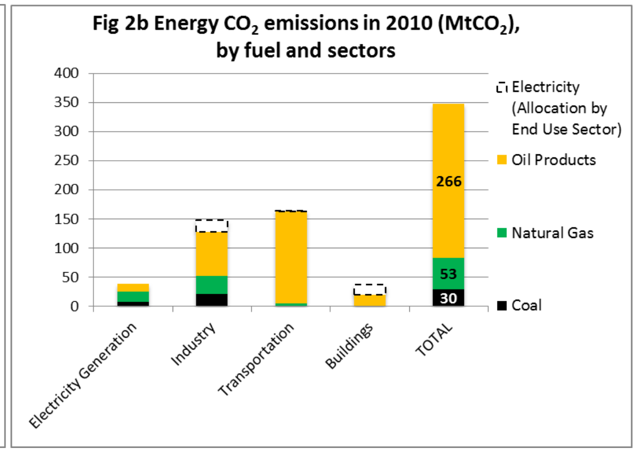


Fig 2b Energy $CO_2$ emissions in 2010 ($MtCO_2$), by fuel and sectors

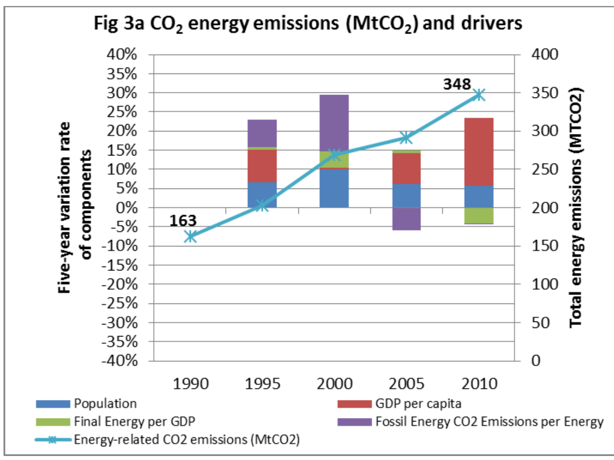


Fig 3a $CO_2$ energy emissions ($MtCO_2$) and drivers

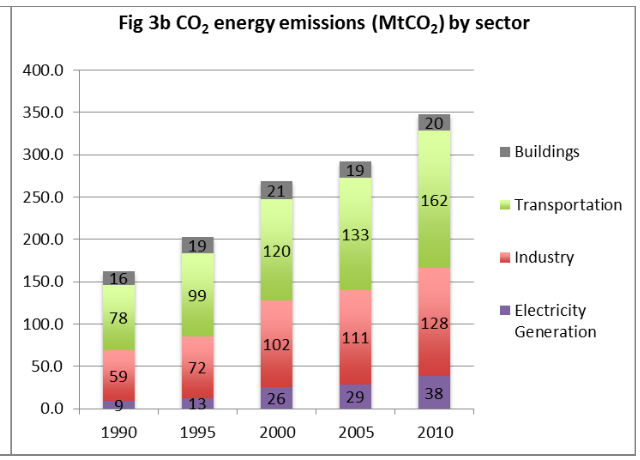


Fig 3b $CO_2$ energy emissions ($MtCO_2$) by sector

## An Illustrative Low Carbon Pathway

Through 2030 the projected illustrative Brazilian low carbon 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 that set in motion the major infrastructure changes that would allow for energy-related emissions to be significantly reduced after 2030. Thus, Brazil's energy-related emissions are expected to grow in the immediate future, to peak around 2030, and then decline through 2050. Since Brazil has sizable biological $CO_2$ sinks, which are assumed to increase until 2050, the illustrative pathway will be strongly complemented with initiatives promoting decarbonization outside the energy sector.

The large share of renewable resources in the Brazilian energy matrix will form a strong starting point for a process of deep decarbonization, which will focus on an expansion of existing systems. Deep decarbonization will be further supported by efficiency measures and structural changes that can reinforce the mitigation gains while at the same time improving living conditions and fueling economic growth. In fact, economic growth is assumed to be very strong through 2050, with GDP per capita tripling. Total population will stabilize at around 220 million people between 2040 and 2050, as shown in Table 1.

**Table 1. Population and Economic Growth, 2010 - 2050**

| | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Population [Millions] | 190,756 | 206,933 | 217,715 | 222,619 | 220,857 |
| GDP per capita [$/capita] | 11.236,54 | 14.928,24 | 20.014,95 | 26.305,84 | 35.634,84 |

## Sectorial Projections

All sectors experience growth in absolute terms, but the structure of the Brazilian economy features a partial evolution towards the commercial sector, see Table 2. The commercial sector increases as a of share in GDP by 1 percentage point per decade to reach 70.3 percent in 2050, whereas the share of heavy industry decreases (as a consequence of the uncertain growth prospects in a globalized and mobile industrial landscape), and the share of agriculture and livestock would remain constant (capturing increasing global demand for food), see Table 3.

**Table 2. Sectorial GDP (Billion 2010 US$)**

| | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Total GDP | 2,143 | 3,089 | 4,358 | 5,856 | 7,870 |
| Agriculture and Livestock | 122 | 176 | 248 | 334 | 449 |
| Heavy Industry | 600 | 834 | 1,133 | 1,464 | 1,889 |
| Commercial | 1,421 | 2,079 | 2,976 | 4,058 | 5,533 |

**Table 3. Sectorial GDP Shares (%)**

| | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Agriculture and Livestock | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 |
| Heavy Industry | 28.0 | 27.0 | 26.0 | 25.0 | 24.0 |
| Commercial | 66.3 | 67.3 | 68.3 | 69.3 | 70.3 |

**Non-energy related GHG emissions**

Insofar as agriculture and livestock is currently Brazil's most significant source of GHG emissions, the decarbonization pathway assumes the extension of the policies and measures in the Plan for Consolidation of a Low Carbon Emission Economy in Agriculture,[7] launched to meet the voluntary goals set for 2020. It thus assumes mitigation actions such as the recovery of degraded pasture land. Moreover, there will be an increase in land covered by agroforestry schemes, and more intensive cattle raising activities (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 decarbonization pathway assumes the extension of the policies and measures of the Action Plan for Prevention and Control of Deforestation in the Amazon[8] and of the Action Plan for Prevention and Control of Deforestation and Fires in the Savannahs,[9] launched to meet the voluntary goals set for 2020. These action plans include a number of initiatives that combine both market and command-and-control policy tools that 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 and charcoal use in the production of pig iron and steel. In fact, there is a huge availability of degraded land in the country where these afforestation programs would be developed with both environmental and economic benefits. It is assumed that such initiatives will continue and expand in the coming decades, so that as early as the mid 2020s, land-use change and forestry will become a substantial net carbon sink, and, by 2050, it would be capable of offsetting a substantial share of the emissions from the energy sector.

The robustness of such a pathway was demonstrated by a recent study using various models and climatic datasets: an estimate of the carrying capacity of Brazil's 115 million hectares of cultivated pasturelands has shown that its improved use would free enough land for expansion of meat, crops, wood, and biofuel, respecting biophysical constraints and including climate change impacts.[10]

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 to curtail emissions. With the capture of methane, a renewable fuel source is created, and biogas would be used to replace some fossil natural gas.

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

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

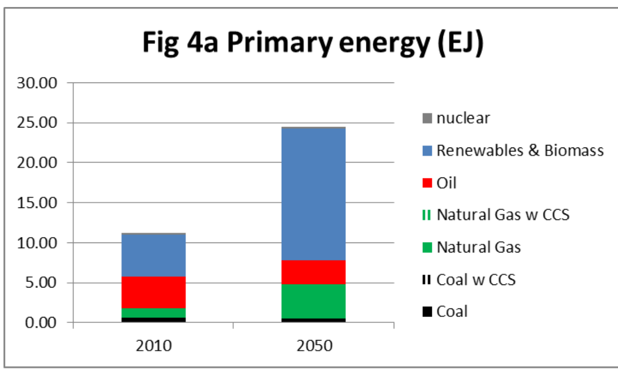
9 Available at: http://www.mma.gov.br/florestas/controle-e-prevenção-do-desmatamento/plano-de-ação-para-cerrado-ppcerrado

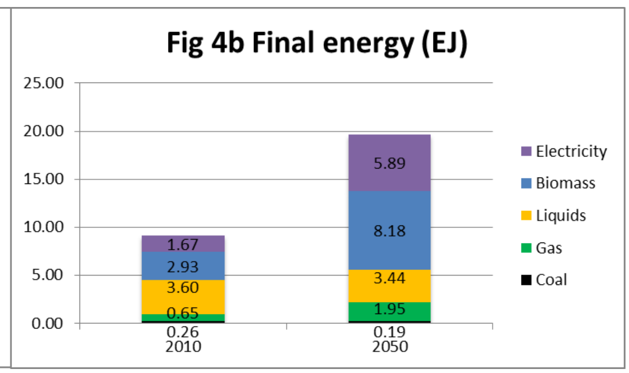
10 B.B.N. Strassburg, B.B.N.; Latawiec, A.E.; Barioni, L.G.; Nobre, C.A.; da Silva, V.P.; Valentim, J.F.; Vianna, M. Assad, E.D.; "When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil", Global Environmental Change 28 (2014) 84-97

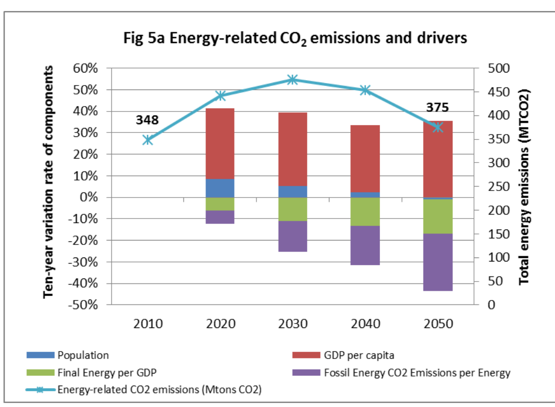
## Energy-related GHG emissions

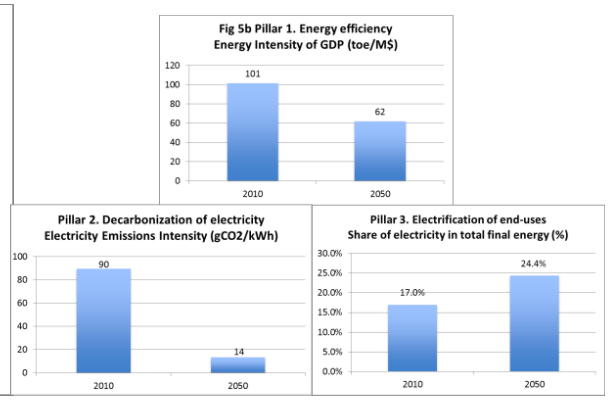
In 2050, renewables and biomass become the dominant source of primary energy and are used to meet a majority of final energy needs, notably through direct use of biomass and low-carbon electricity generation. Energy efficiency has a strong potential in Brazil, and several energy saving initiatives have been set in motion in recent times and will be extended across the board (see Figure 5).

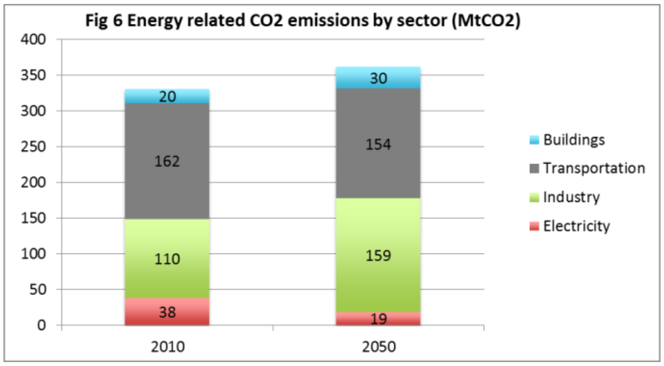
Energy-related CO2 emissions stabilize by 2030 and decline thereafter as a result of opposing drivers that result in a 2050 emission level that is only slightly higher than in 2010 (see Figure 6). Emissions will be pushed upwards by the strong growth of GDP per capita, but this effect is offset by a decreasing demographic pressure (where population stabilizes by 2040) and, even more importantly, by a substantial fuel shift towards renewable energy supply and a decrease in final energy intensity per unit of GDP. The transportation and industrial sectors will be responsible for the bulk of emissions, with transportation emissions dominating across most of the period, but surpassed by emissions from industry in 2050 (see Figure 6).





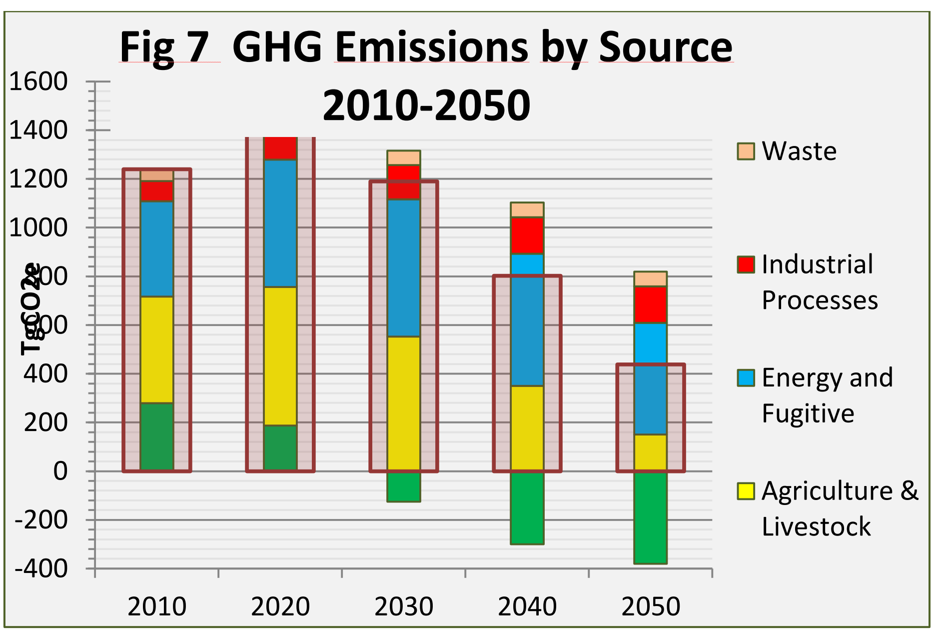

## Summary of Results and Discussion of Key Findings

Figure 7 below shows the sectorial projections, presenting the results achieved in the low carbon pathway for the Brazilian GHG emissions in 2050, by main source, in billion tons of $CO_2e$ (Tg $CO_2e$). The gross GHG emissions are represented above the zero line, while carbon sequestration is represented as negative GHG emissions, below the zero line. The net GHG emissions resulting from the difference between them are represented by the wider rectangles.

Substantial GHG emission reductions would be observed in agriculture and cattle raising activities, requiring a strong expansion of a number of best practices already being implemented in the Low Carbon Agriculture Program launched by Brazilian government. They include many "win-win" opportunities of adopting cost-effective mitigation measures.

The contribution of carbon sequestration would be key, allowing for compensating nearly half of gross GHG emissions in 2050. This would be achieved through revegetation of degraded land, both by restoration of native ecosystems and by forest plantations (forestation schemes using fast growing species as eucalyptus and pine).

A huge effort would also be required to limit energy-related GHG emissions, in order to curb their growth and keep them in 2050 nearly equal to their 2010 level.



## Main Assumptions

The illustrative pathway designed for a deep decarbonization of the energy system would be achieved through efficiency gains and fuel switching, mostly relying upon existing technologies, such as hydropower and bioenergy. The production of ethanol from sugarcane is acknowledged as an advanced first generation biofuel and production levels can be considerably extended without competing with food production or generating deforestation, as demonstrated by recent trends, since the doubling of sugarcane areas between 2004 to 2011 (from 5 to 10 million hectares) has happened in parallel with a notable fall of deforestation rate in the Amazon (from nearly 3 to less than 1 million hectares per year). Currently, sugarcane production areas are far from forests, as most production occurs more than two thousand kilometers away from the Amazon.[11]

While some second generation biofuels from sugarcane, such as biokerosene and farnesene ("diesel oil"), have already demonstrated technical feasibility, they see limited growth in the transportation sector due to the current high costs. Biodiesel production from palm oil would increase given the potential to grow the feedstock on the huge surfaces of degraded land available in the country.[12]

Clean power generation would be provided by hydropower, complemented by bioelectricity (to ensure reliability) along with emerging onshore wind and 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.

## Alternative pathways

Alternative deep decarbonization pathways in Brazil might be designed with a larger deployment of electric vehicles coupled with a substantial increase in clean power generation. Electric cars are not an immediate priority in Brazil for GHG reductions purposes because "flex-fuel" light-duty vehicles can run on ethanol with near-zero net emissions and lower transition costs. However, electric cars have other benefits (less urban air pollution and noise, etc.) and may be an alternative option. Electrified buses could also reduce GHG emissions and local pollution. Other pathways would be made possible by technological breakthroughs and cost reductions in technologies such as second generation biofuels, carbon capture and sequestration (CCS), off-shore wind, and concentrated solar power.

Brazil has a huge renewable energy potential from a number of different sources (hydropower, biomass, wind, and solar energy) and the relative shares of these technologies in the future energy mix will depend mostly on the outcome of the technological race towards economic feasibility.

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[11] 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.

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

**Potential for Additional Measures**

The availability of new technologies could eventually help Brazil follow a deeper decarbonization pathway than the illustrative pathway discussed above. Among the promising technologies, the diffusion of second generation biofuel technologies, when proven cost-effective, may contribute to further expand the already large Brazilian biofuel production. In the case of substantial cost reductions brought up by major technological breakthroughs, ethanol production from lignocellulosic materials (wood, bagasse, and other biomass wastes) would allow for a much higher ethanol use, as well as of biokerosene and "diesel oil" from sugarcane in Brazil. A deeper pathway would be made feasible by the combination of high-efficiency biomass production and use, electric vehicles, and green electricity generation, and more substantial modal shifts towards railways and waterways in the transportation sector.

The infrastructure of urban mass transportation, relying mostly on a large privately owned bus fleet, could be further decarbonized with the expansion of urban and suburban trains. Long distance freight transportation, currently carried out almost entirely on roads, may become low-carbon if financial resources are made available for substantial investment in railways and waterways.

In order to make possible a substantial shift to low-carbon electric vehicles, a number of additional sources of clean power generation may become increasingly available in Brazil. Offshore wind farms may become a relevant option, given the abundance of offshore sites, thanks to the potential synergy with the huge effort on offshore oil and gas drilling that would help reduce its costs. In addition, other clean power generation facilities may be built, such as concentrated solar power units with thermal storage, producing dispatchable energy.

Advanced batteries could overcome the non-dispatchability of intermittent renewable power sources, such as solar and wind, making it possible to replace natural gas for assuring the base load supply, further reducing GHG emissions from power generation.

Carbon capture and sequestration in Brazil is not important for the purpose of reducing GHG emissions from coal, since the use of coal is very limited; however, CCS coupled with the use of natural gas could support deeper decarbonization. CCS could also be helpful to lower GHG fugitive emissions from oil and gas production due to its continuous deployment and expansion, given its high future availability from the pre-salt country's resources. CCS is already being developed by Petrobras through the injection of $CO_2$ for offshore enhanced oil recovery, but the feasibility of large-scale deployment of CCS remains unclear.

**Challenges and Enabling Conditions**

Given that decarbonization of the economy represents such a formidable society-wide transformation, there will certainly be winners and losers. As such, the necessary political resolve to implement these changes cannot be obtained without some preconditions. The first is a strong public awareness of the potential dangers of climate change and the pitfalls of inaction. Brazil would clearly benefit from a decarbonized world, given the abundance of non-fossil natural resources in the country.

The main risk here is the temptation to channel the recently discovered huge offshore oil and gas resources to expand its domestic use through a low pricing policy that would help to curb inflation down. So far, the announced governmental policy, confirmed by Congress, goes in the opposite direction, aiming to export the bulk of the oil resources and channel the oil revenue to finance government investments in education and health. It is imperative for the feasibility of a low carbon future in Brazil to stick to this policy, avoiding the use of the newfound oil resources in such a way as to weaken the efforts to foster energy efficiency and renewable energy use.

The main technological challenges here are the design and construction of a new generation of hydropower plants in the Amazon that would avoid the disruption of ecosystems, as well as increasing the utilization of dispatchable bioelectricity to replace fossil fuel generation.

Many of the strategies would require structural changes and higher 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 flows and upgraded institutional arrangements (e.g. public/private partnerships) to provide funding in appropriate terms. The financial flow will need to largely come from outside of Brazil 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 case for the perils of inaction, would be required to mobilize the resources needed for initiatives. These include: accelerated research on the development of safe and energy-dense renewable fuels; research on industrial processes and materials to bring down the investment costs of renewable power sources; and the establishment of technology transfer mechanisms. The worldwide adoption of carbon valuing schemes and cut of fossil fuel subsidies would also be crucial.

**Near-Term Priorities**

For Brazil to get engaged in a deep decarbonization process, there are a number of immediate policy and planning measures that can be recommended. Reinforcing the initiatives aimed at curbing deforestation to maintain a trajectory toward eliminating illegal deforestation within a decade. A similar priority should be granted to substantially expand the forest plantations on degraded land, providing the appropriate financial schemes to meet the upfront costs. Another effort required is to pass legislation to shift the net effect taxes and subsidies on energy markets in favor of widespread adoption of renewable energy and energy efficiency options. To this end, in the near-term it is essential to cut subsidies to gasoline and diesel, and redress the financial health of the electricity generation sector.

Extending the existing incentives for investments in renewable energy resources to other types of equipment such as PV and solar heaters, and prompting electricity providers to adopt smart grid technologies would also produce short-term returns. Drafting a detailed and feasible plan for restructuring long-distance transport in Brazil, prioritizing an infrastructure that allows for the most energy and emissions-efficient modes of transportation, such as railways and waterways, is another initiative that would both cut down emissions and respond to the concerns of the business community. A similar initiative should also be undertaken, in collaboration with local authorities, concerning urban mobility, an aspect of Brazilian infrastructure that needs improvement and is currently high on the political agenda.

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