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Low carbon infrastructure priorities in the Brazilian context

Carolina Grottera

Emilio L. La Rovere

William Wills

Carolina B. S. Dubeux

Claudio Gesteira

Centro Clima / COPPE / UFRJ

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1. <u>Introduction</u>

Fostering investments in sustainable and resilient infrastructure is especially important in developing countries, where the bulk of the coming capital additions are to be made (New Climate Economy, 2016). They are particularly interesting because investing in low carbon infrastructure boosts economic development, creating positive externalities and spillover effects.

This paper seeks to summarize low carbon investment requirements in Brazilian infrastructure and to discuss their potential contribution to mitigation, barriers and opportunities in four strategic sectors, namely: (1) Biofuels; (2) Transport; (3) Power generation and (4) Waste.

The analysis derives from IES-Brasil - *Economic and Social Implications of GHG Mitigation Scenarios until 2030* (La Rovere et al, 2016), which has assessed different sets of GHG mitigation measures in Brazil up to 2030, with the aid of a Scenario Building Team made up of experts from government, academia, private sector and civil society.

Results presented and discussed here come from two scenarios with different levels of ambition and high economic growth rates including additional mitigation measures going beyond the extension of current governmental plans (Governmental Planning Scenario – GPS). A global carbon tax on burning fossil fuels is set, at USD 20 per tCO_2eq in Additional Mitigation Scenario 1 (AM1) and USD 100 per tCO_2eq in Additional Mitigation 2 (AM2).

By the end year 2030, emissions reach 1.3 Mt CO2eq in AM1 and 1.0 Mt CO2eq in AM2. After the presentation and discussion of these scenarios at the Brazilian Forum on Climate Change, the target set for the Brazilian Nationally Determined Contribution to the Paris Agreement was of 1.2 Mt CO2eq in 2030. In the GPS scenario with no additional mitigation measures implemented, GHG emissions would reach 1.7 Mt CO_2eq in 2030.

The analysis is complemented with insights from the Deep Decarbonization Pathways Project (La Rovere et al, 2015), which extends up to 2050 the most ambitious pathway designed in IES-Brasil (AM2) using a backcasting methodology to identify policies and measures to reach an emissions per capita close to 1.8 tCO_2eq in 2050 (consistent with a pathway towards stabilization of average global temperature of 2ºC above pre-industrial level).

This paper is organized as follows: Section 2 presents separately each of the sectors above mentioned, discussing their specificities and background, and showing their abatement potential for the low-carbon scenarios of IES-Brasil. Section 3 briefly summarizes investment requirements needed to put mitigation actions in place and compares them to GDP levels. Finally, section 4 discusses technological prospects and their policy implications and section 5 concludes.

2. Sectorial analyses

2.1 Biofuels

Due to Brazil's high reliance on road transportation, for both the freight and passenger sectors, liquid biofuels are important for decarbonization. The expansion of sugar cane ethanol in passenger transportation relies on favourable conditions such as the country´s vast land availability to yield sugar cane and the fact that nearly every light-duty vehicle is flex-fuel[1], that is, can run either on pure ethanol or gasohol (25% of ethanol blended in gasoline). If adequate public policies such as the setting of appropriate gasoline and diesel oil prices, avoiding subsidies and possibly including a carbon tax are put in place sugar cane ethanol can prevail in passenger transportation at low investment costs. The low carbon scenarios consider an increase of ethanol consumption in 2030 from 54 to 67 billion liters in AM1 and to 74 billion liters in AM2.

Heavy-duty vehicles used for freight transportation and passenger buses run mainly on diesel oil, for which a 7% blend of biodiesel is mandatory today (continuously increasing from 5% in 2010 and set to reach 8% in 2017).

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[1] In 2015, flex-fuel cars accounted for 95.95% of light-duty vehicles sales in Brazil.

Today, Brazilian biodiesel is mainly a byproduct of soybean production, but it can also be made of palm oil, sunflower and animal fat, among others. Nonetheless, apart from the high price of raw materials compared to fossil diesel or even ethanol, some other barriers can be pointed out, for example, the low number of producing units and their distance to final consumers.

The AM1 scenario considers a 10% blend of biodiesel in commercial diesel, while the AM2 scenario simulates a 15% blend in 2030. A blend including up to 25% of biodiesel in diesel is considered to be technically feasible by 2050.

Table 1

	Cumulative GHG avoided emissions from 2010 to 2030	
	AM1	**AM2**
Ethanol for passenger transportation	302.4	305.9
Biodiesel for freight transportation	121.3	265.2
Total	**423.7**	**571.1**

2.2 Modal Shift in Urban Mobility and Freight Transportation

Improving urban mobility reduces local and global pollutants while increasing worker productivity and time availability for leisure activities. Recently, investments in urban mobility infrastructure started shifting to a new model that includes Public-Private Partnerships and concession or leasing options. The Belo Horizonte subway system and the Santos tramway (and its integration with bus lines) are some successful examples, in which the public authority provides the required infrastructure while private agents are in charge of the rolling stock, logistics and operation for a given period. This ensures liability, greater commitment and shared risk between parties. Nonetheless, because fair ticket prices are technically and socially desirable to encourage mass transportation, investments cannot be financed only through tariff levels. Even with a greater involvement of private capital in urban mobility projects, public investment remains essential, and the debt capacity and financial health of governmental bodies are determinant factors.

Currently, around USD 22 billion have been allocated to urban mobility investments between 2014 and 2021 in 15 main metropolitan areas in Brazil, while the estimated demand is USD 234 billion. Investment needs include 381 km of subways, 365 km of tramway, 88 km of urban train and 799 km of Bus Rapid Transport systems (Santos et al, 2015).

Investments in wheeled transportation are generally less costly than rail options, hence they account for the totality of the urban mobility initiatives in the less ambitious scenario, in which 3.825 km of bicycle lanes and 1.149 km of BRT are built, at an abatement potential of 74 Mt CO2eq. In the AM2 scenario, together with investments in 150km of subways, 269 km of tramways and 8% of total bus fleet met by electrified buses in 2030, they add up to 475.7 Mt CO2eq of avoided emissions.

Freight transportation in Brazil depends mainly on roads, which require high maintenance costs. Investing in long-distance freight boosts economic growth and competitiveness, as it creates logistical and energy efficiency gains. This is especially relevant in Brazil, due to its continental dimensions and the need to link commodity-producing centres (such as soybean, iron ore, meat, among others) to distribution facilities and exporting ports. Between 2015 and 2016, USD 0.78 billion were spent to build and improve more than 2,400 km of railways through the PAC programme ('Growth Acceleration Programme'). In the AM2 scenario, investments in rail and water transportation include not only their expansion and conservation but also connecting them to capillary roads, enhanced interaction between operators and regulatory agents and optimized activity. They shift 13% of total freight from road transportation, reaching 36% and 20% of total sector activity in 2030, respectively, and avoid emitting 147.2 Mt CO2eq.

Table 2

	Cumulative GHG avoided emissions from 2010 to 2030 (Mt CO2eq)	
	AM1	**AM2**
Urban transportation on wheels		
BRT systems	43.9	43.9
Bicycle lanes	30.0	30.0
Electric buses	-	51.8
Urban transportation on rails		
Subways		138.9
Tramways	-	68.8
Freight transportation (railways and waterways)	-	142.2
Total	**74**	**475.7**

2.3 Power generation

Brazil's National Development Bank (BNDES) plays a major role in financing the electric sector, ranging from power plants, transmission lines, energy efficiency and cogeneration projects in the productive sector. BNDES generally requires a minimum mandatory national content share for specific industries. This is controversial approach, which has proved to be successful in the case of wind energy, for example, but national content requirements have just been considerably reduced for resuming investments in the oil & gas exploration sector.

In 2016, BNDES announced a new funding policy, ruling out investments in new coal and oil-fired plants for power generation, as well as large hydropower, while supplying more favourable conditions to solar energy projects.

Nonetheless, from all power plants currently under construction or foreseen[2], summing up to 24.8 GW, 27% are still coming from fossil primary sources,

[2] Power plants may be bestowed by the electricity regulation entity (in the Brazilian case, ANEEL) but this does not mean it will necessarily be built or operate. In some cases, the project may not be granted the construction license due to environmental constraints, for example.

mainly diesel oil and natural gas. Wind accounts for the highest share, 31%, overcoming traditional renewable sources such as large hydropower (11%) and small hydropower (8%). Solar photovoltaic reaches 12%, and nuclear 5%. Despite its huge generation potential and its synergy with the sugar and alcohol sector, bagasse-fired power plants only account for 2% of future planned installations (ANEEL, 2017).

Fading out fossil-fuel power supply is targeted for attaining long-term deep decarbonization goals. In the Brazilian case, with its huge hydropower, wind and solar potential, apart from its land availability for renewable biomass (e.g. sugar cane byproducts and wood products from forestry activities), a zero-emission electric sector can be achieved by the middle of the century (La Rovere et al, 2015).

In low carbon scenarios, the country hydropower potential that is considered economically feasible and environmentally sound is deployed up to 2030, reaching 155.5 GW of installed capacity in AM2, 10 GW more than in the GPS and AM1 scenarios. There are no solar power additions in the AM1 scenario, while in the AM2 2 GW of installed capacity are added, reaching 8.5 GW in 2030. For biomass, mainly sugar cane bagasse, both AM1 and AM2 add up to 10 GW in 2030, reaching 27.17 GW of total capacity. Finally, wind power reaches 31.325 and 29.325 GW of installed capacity in AM1 and AM2, respectively, while the GPS includes 24.325 GW.

Renewable sources already account for a high share of total electricity supply in 2010, 85%. In the GPS scenario, they decrease to 84%, as the country's hydropower potential depletes and fossil fuels such as natural gas and fuel oil have to be deployed in thermal generation in order to meet the energy demand. In the low carbon scenarios, the share of renewables increases to 87% and 89%. This small difference explains the limited mitigation potential in the residential, commercial and services sectors. In buildings, energy efficiency measures are generally associated to electricity consumption; hence one can only expect minor effects on total avoided emissions.

Table 3

Installed capacity evolution from 2010 and 2030 (MW)				
	2010	2030		
		GPS	AM1	AM2
Hydropower	93,457	145,493	145,493	155,493
Solar	0	6,500	6,500	8,500
Wind	1,981	24,325	31,325	29,325
Biomass	8,966	17,170	27,170	27,170
Others (fossil and nuclear)	19,094	37,557	31,527	26,361
Total	**123,498**	**231,045**	**242,015**	**246,849**
Share of renewables	85%	84%	87%	89%

Table 4

	Cumulative GHG avoided emissions from 2010 to 2030	
	AM1	**AM2**
Hydropower	-	142.9
Solar	-	10.3
Wind	84.4	66.2
Biomass	16.0	22.8
Total	**100.4**	**242.2**

2.4 Waste

Around half of the Brazilian population does not have access to adequate sewage and sanitation services. USD 91 billion are estimated to be necessary to universalize sanitation coverage in 20 years, from which 21 billion were already invested by federal government through the PAC programme ('Growth Acceleration Programme'). In addition, virtually all solid waste produced in Brazil is destined either to sanitary landfills or to garbage dumping sites and controlled landfills, as recycling rates are still very low.

The production of methane through anaerobic fermentation in landfills and dumpsites is the major source of emissions coming from the waste sector, and, with higher income and urbanization, they are expected to increase in the coming decades. The expansion of sewage systems will also produce more organic matter and contribute to increasing emissions.

Therefore, reducing sectorial emissions requires capturing and destroying the methane produced in landfills, dumpsites and sewage treatment stations. The biogas can be used to generate electricity, even though this option is only economically feasible at large scale landfills (around 300 ton of waste per day in the case of solid waste), due to high investment requirements.

Solid waste services generally have high costs, and expenditures are not recovered, not only but also because recycling is still incipient. Apart from the long maturation time concerning this type of investment, they often pose a heavy challenge on local governments, especially in small cities, as economies of scale are needed in order to afford those costs. Local consortiums among municipalities are frequently sought to reach those economies of scale, but as they gather a variety of governments and stakeholders, coordination issues may arise.

In the low carbon scenarios, these actions, whose coverage varies according to the size of the municipality[3], avoid 597 Mt CO2eq and 608.5 Mt CO2eq in AM1 and AM2, respectively.

Table 5

	Cumulative GHG avoided emissions from 2010 to 2030	
	AM1	**AM2**
Waste	**597.0**	**608.5**

[3] Systems for the destruction of methane in landfills – Coverage in 2030:
70% in small cities (below 100 thousand inhabitants)
100% in medium-size cities (between 100 and 500 thousand inhabitants)
100% in large cities (more than 500 thousand inhabitants)

Expansion of sewage treatment in stations with flares - Coverage in 2030:
60% in small cities (below 100 thousand inhabitants)
70% in medium-size cities (between 100 and 500 thousand inhabitants)
85% in large cities (more than 500 thousand inhabitants)

3. Total investment requirements

Sectorial bottom-up assessments have identified economy-wide total investment requirements in mitigation that sum up USD 49.3 billion in the AM1 and USD 185.9 billion in the AM2, for the whole period, using an 8% p.y. discount rate. They comprise not only the investments in infrastructure discussed above but also energy efficiency developments and mitigation in the Agriculture, Forestry and Land-Use sector. Despite the large volume of investments needed, they only represent a low share of GDP: 0.11% in AM1 and 0.4% in AM2. For comparison purposes, total investment in 2014 accounted for 19.9% of total Brazilian GDP.

4. Future technologies prospects, barriers to implementation and some policy recommendations

New technologies with steep learning curves must be taken into account in new scenarios of low-carbon development, especially for a longer-term horizon up to 2050. In Brazil, the most promising options are in energy production and use of renewable biomass, namely modern liquid biofuels, thanks to the specific national circumstances of large land, water and natural resources availability. In other technologies, Brazil will follow international trends.

Recently, a new variety of sugar cane was developed, the so-called 'energy sugarcane´. With higher fiber content than traditional sugar cane, yields are higher both in terms of ethanol and bagasse production.

New plants producing second-generation ethanol from cellulosic materials (e.g. sugarcane bagasse) have also been shown to be highly productive, up to 50% compared to current levels (Milanez et al, 2015), reinforcing the huge potential for increasing ethanol production. In 2014, the country had an installed capacity for producing 140 million liters of second-generation ethanol, which was low compared to volume of imported gasoline (2.2 billion liters). Incentives for expanding production include increasing the mandatory blend of ethanol on gasoline, including a share from cellulosic origin (at least in sugar cane producing states) and fiscal incentives in the biomass, enzyme and equipment production stages.

Biodiesel made out of sugarcane has revealed to have steep learning curves and thus is very promising to be deployed in the near future. Prices have recently decreased substantially, even though they remain above the price of fossil diesel oil. More productive varieties and the expansion of cellulosic ethanol can alleviate the land requirements for sugarcane crops, which may allow expansion of the production of biodiesel made from sugarcane, a key option for deep decarbonization of the transportation sector in the long run.

Biokerosene can reach up to 10% in the fuel blend used in air transportation. However, the Brazilian market has little influence on fostering the expansion of biokerosene deployment, as well as on its price variation, so international markets trends will determine its feasibility.

In spite of Brazil having one of the largest fleet of vehicles in the world, hybrid and electric cars are still a minor share of the country's market. In 2014, 855 vehicles were sold, which represents less than 0.03% of sales. With a clean electricity supply and increasing import needs of diesel oil and gasoline to meet demand, electrifying the country's fleet could bring various benefits.

Scarce supply infrastructure and low battery autonomy are a few of the many barriers electric vehicles still face worldwide and also in the Brazilian context. Fiscal incentives (coupled with existing emissions standards policies, for example), investments in Research and Development, including the integration of electric motors to those running on ethanol (e.g. fuel cells in hybrid cars could run on ethanol and not on fossil fuels) and rate equalization policies for city buses compared to internal combustion engines are some of the policy recommendations on the supply side.

On the demand side, some of the recommendations include expanding the charging infrastructure preferably with smart-grid technology, credit incentives, free and exclusive public parking, exclusive lanes, car-sharing, utilization in state-owned and taxi fleets, among others.

In the electricity supply sector, as the country eventually depletes its hydropower potential, reliance on offshore wind and batteries to store non-dispatchable energy from renewable sources, technologies that are still incipient, might become relevant. Another option is the development of power generation from solid biomass (pellets from wood or sugarcane, that can be easily stored) available to meet the demand during the dry season, when hydropower generation is lower. Upfront costs and institutional barriers related to low carbon infrastructure investments are not negligible. In addition, they often have long payback periods. Developing countries need to call upon international cooperation and other forms of institutional arrangements, such as public-private partnerships (PPP), in order to finance such initiatives (Trollip et al, 2014; La Rovere et al, 2017). Flows may come through public aid, multilateral development banks and special climate-related facilities (Tirpak and Adams, 2008; Bowen et al, 2015). International aid and targeted policies are needed to catalyse the private sector potential participation (Bowen, 2011; Bayer et al, 2013).

5. Concluding remarks

This paper sought to discuss the abatement potential and investment requirements of mitigation measures in a country-specific approach for the Brazilian economy up to 2030, complemented with qualitative insights for a mid-century landscape.

Two mitigation scenarios were presented, in which final emissions levels reach 1.3 Mt CO2eq and 1.0 Mt CO2eq, depending on the level of ambition. The Brazilian NDC sets a final target of 1.2 Mt CO2eq in 2030, that is, closer to the less ambitious additional mitigation scenario (AM1). In the coming negotiation rounds in which countries review their contributions to the Paris Agreement, Brazil can move towards a more ambitious target.

Building a low carbon sustainable infrastructure has a great mitigation potential, not to mention the various co-benefits that may arise, such as better air quality, shorter commuting journeys and improved logistics. Mitigation measures of other kinds can also make huge contributions to GHG emissions abatement, as shown in Table 5. In the Agriculture, Forest and Land-use sector (AFOLU), there are plenty of cost-effective mitigation actions. These generally do not implicate investing in infrastructure itself, but are essentially obtained through the adoption of appropriate policies and techniques (see the specific sectorial paper on AFOLU). Energy efficiency is also relevant in most sectors, the largest abatement contributions coming from the industrial and transportation sectors, which still rely heavily on oil products.

Table 6

Cumulative GHG avoided emissions from 2010 to 2030 (Mt CO2eq)		
	AM1	**AM2**
AFOLU	**657.4**	**1995.6**
Agriculture and cattle raising	260.3	259.2
Planted forests	29.6	427.3
Agroforestry systems	367.5	367.5
Atlantic Forest restauration	-	941.6
Energy Efficiency	**408.1**	**791.3**
Residential, Commercial and Services (includes solar water heating)	16.8	19.9
Industry (Cement and Steel) and oil refineries	38.7	382.7
Traffic optimization	30.5	30.5
Light duty vehicles	71.0	107.1
Heavy duty vehicles	251.1	251.1
Modal Shifts in Transportation	**74.0**	**475.7**
Urban transportation on wheels (BRTs, bicycle lanes and electric buses)	74.0	125.8
Urban transportation on rails (subways and tramways)	-	207.7
Freight transportation (railways and waterways)	-	142.2
Renewable Energy	**524.1**	**813.3**
Ethanol for passenger transportation	302.4	305.9
Biodiesel for freight transportation	121.3	265.2
Power generation	100.4	242.2
Waste	**597.0**	**608.5**
Total	**2,260.6**	**4,684.4**

The deep political and economic crisis hitting the country since 2015 will require an update of these scenarios, with lower economic growth rates. The attainment of output and welfare levels reached in these scenarios will be delayed. On one hand, lower growth rates will delay the necessity of resorting to technologies with uncertain economic and technical feasibility and buy more time for the development of new low carbon technologies. On the other hand, public budget constraints due to austerity policies may hamper investments in projects needing urgent public resources and political will in order to benefit from current low international interest rates to thrive PPPs.

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