The Impacts of the Brazilian NDC and their contribution to the Paris Agreement on Climate Change*

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Abstract

Brazil has announced ambitious reduction in emissions in the Paris Agreement. The goal of this paper is measure the impacts of the mitigation strategies of the Brazilian National Determined Contributions (NDC). These strategies include emissions reduction from deforestation, low carbon emission practices in agriculture, energy efficiency and expansion of renewables energy sources. We adopt and employ the computable general equilibrium MIT EPPA model to measure the impacts of such strategies. We also simulate alternative carbon pricing scenarios considering sectoral carbon taxes able to force the same percentage reduction in emissions in each sector, and a broad carbon market (cap-and-trade). These alternative scenarios are set to achieve the overall country emissions target announced in the Paris Agreement. The results show that the Brazilian NDC would partially achieve the proposed emission target due to limitation in the measurements of emissions reduction in agriculture. Further efforts to reduce emissions after 2030 would require changes in the climate policy strategy in the country, since all the potential emissions reduction from deforestation would be finished and the capacity to expand renewables will be constrained. The economic costs of the Brazilian NDC is only 0.7% of the GDP in 2030. These results show the potential of relatively cheap reduction in emissions from land use changes and agriculture in the short run in the country, but the need for a quick turn in the climate policy strategy to some carbon pricing system in order to avoid high costs and losses in the country competitiveness.

Key-words: Paris Agreement, climate policy, Brazil, general equilibrium.

1. INTRODUCTION

The Paris Agreement on climate change is the broadest and inclusive discussion to face climate change in the world. Both developed and developing countries have proposed measures to reduce greenhouse gas (GHG) emissions in the next decade.

Brazil has been an important player in the discussions about climate change. It has a unique pattern of emissions, since most of it comes from agriculture emissions (32%), land use changes and deforestation (28%), followed by fossil fuel energy use (27.7%) (BRASIL, 2016a). The country has also the broader market experience with biofuels in the world, which accounts for an important share of the total energy use in the transportation sector. At same time, it is heavily investing in deep oil exploration in the pre-salt layer, which can move the country to one of the world top positions in the production of this fossil fuel.

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The country has assumed a pioneering position among developing countries in terms of commitments to mitigate climate change during the 15th UNFCCC Conference of the Parties in Copenhagen in 2009. It announced volunteer goals to decrease emissions, which were confirmed by the Law 12.187, The National Plan on Climate Policy, passed in December 2009 (World Resources Institute, 2010). The policy determines emissions reductions of 36.1% or 38.9% by 2020 from a reference emissions scenario, depending of the growth rate of the economy. This target should be reached considering cuts in emissions from land use changes and deforestation (24.7%), agriculture (4.9% to 6.1%), energy (6.1% to 7.7%) and iron a steel production (0.3% to 0.4%) (Governo Federal, 2008).

More recently, Brazil toke a larger step in its commitments to fight climate change. It has announced at the Conference of the parties in Paris in 2015, the “Paris Agreement”, an ambitious plan to cut its emissions by 37% in 2025 and 43% in 2030, relative to 2005 emissions. The Brazilian proposed *Nationally Determined Contribution* (NDC) aims to reduce emissions from several sources, as land use changes, agriculture and energy (Brazil, 2016b).

To achieve such targets, the Brazilian NDC document has already defined intentions to develop mitigation efforts and actions to decrease deforestation, reforest degraded land areas, expand renewable energy, increase energy efficiency and intensify agricultural and livestock production. These commitments create a strong need for studies of the costs of these mitigation efforts as also as alternative policy options to reduce emissions in Brazil.

There are already several studies about GHG emissions control in Brazil. Some examples are Rocha (2003), Tourinho, Motta and Alves (2003), Ferreira Filho and Rocha (2008), Feijó and Porto Jr. (2009), Moraes (2010), Estudo das Mudanças Climáticas no Brasil - EMCB (2010), Gurgel and Paltsev (2014), Lucena et al. (2016), Magalhaes et al. (2016), among others. However, most of these papers use static economic models adapted to incorporate environmental aspects or focus in emissions reductions only in some specific sectors. At our knowledge, none of them has investigated the effects of the Paris Agreement goals considering all mitigation efforts Brazil has committed to take.

The goal of this paper is to estimate the economic impacts of the Brazilian NDC and compare these with the impacts from alternative climate policies, as carbon taxes and cap-and-trade. To achieve such goal, we adapt and employ a dynamic-recursive general equilibrium model of the world economy, the MIT Economic Projection and Policy Analysis (EPPA) model, in its fifth version (Chen et al., 2017; Paltsev et al., 2005). Next section describes the model. Section 3 presents the results and section 4 concludes the study.

2. METHODS

The policies to reduce GHG usually impact many sectors and economic agents in the economy. In order to evaluate the impacts of climate policies in Brazil we use an approach to represent several GHG emitting agents and sectors and their relationships. We use a computable general equilibrium (CGE) model, which captures the interdependencies among agents in the economy. The CGE models estimates directions and magnitudes of exogenous chocks on the economy, allowing the measurement of impacts and costs of alternative scenarios.

CGE models combine the abstract general equilibrium structure formalized by Arrow and Debreu with economic data to obtain supply, demand and price levels in equilibrium conditions in a set of specific markets. The CGE models are a standard tool of empirical analysis, widely used in welfare analyses and to estimate distributive impacts from policies. Kydland and Prescott (1996) and Shoven and Whalley (1984), discuss other aspects and details about the CGE models.

We use the MIT EPPA Model in its fifth version[1]. It is a dynamic recursive general equilibrium model of the world economy, built on the Global Trade Analysis Project (GTAP) database (Dimaranan and McDougall, 2002; Narayanan and Walmsley, 2008) and additional data about GHG and other pollutant emissions. The EPPA model considers a long run simulation horizon (2005 to 2100) and the treatment of the main GHG gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6). The model also allows the evaluation of economic impacts from mitigation policies, including welfare and equity measures.

The GTAP data in EPPA is aggregated in 16 regions and 21 sectors (Table 1). EPPA also disaggregates the GTAP data for transportation to include household transport (i.e. personal automobile), the electricity sector to represent existing supply technologies (e.g. hydro, nuclear, fossil), and includes several alternative energy supply technologies, as second generation biomass, not extensively used or available in the benchmark year of the model, i.e. 2004, but that could potentially be demanded at larger scale in the future depending on energy prices and/or climate policy conditions. To represent such technologies, the model takes into account detailed bottom-up engineering parameters. The parameterization of these sectors is described in detail in Chen *et al*. (2017) and Paltsev *et al.* (2005).

Table 1 – Regions, sectors and primary factors in the EPPA model

Regions	**Sector**	**Primary Factors**
United States (USA)	*Non Energy*	Capital
Canada (CAN)	Crop (CROP)	Labor
European Union (EUR)	Livestock (LIVE)	Cropland
Japan (JPN)	Forestry (FORS)	Pasture
East Europe (ROE)	Food (FOOD)	Harvested forest[1]
Australia and New Zealand (ANZ)	Services (SERV)	Natural grass
Brazil (BRA)	Energy intensive (EINT)	Natural forest
	Other industry (OTHR)	Oil
Russia (RUS)	Industrial transportation (TRAN)	Shale oil
India (IND)	Household transportation (HTRN)	Coal
Africa (AFR)	*Energy*	Natural Gas
China (CHN)	Coal (COAL)	Hydro
Middle East (MES)	Crude oil (OIL)	Nuclear
Rest of Asia (REA)	Refined oil (ROIL)	Solar and Wind
Mexico (MEX)	Natural Gas (GAS)	
Latin America (LAM)	Liquid fuel from biomass (BOIL)	
Fast growing Asia (ASI)	Oil from Shale (SOIL)	
	Eletric.: fossil (ELEC)	
	Eletric.: hydro (H-ELE)	
	Eletric.: nuclear (A-NUC)	
	Eletric.: wind (W-ELE)	
	Eletric.: Solar (S-ELE)	
	Eletric.: biomass (biELE)	
	Eletric.: NGCC	
	Eletric.: NGCC – CCS	
	Eletric.: IGCC – CCS	

[1] Includes managed forest areas for forestry production as also secondary forests from previous wood extraction and agricultural abandonment (natural vegetation re-growth).

[1] Paltsev *et al*. (2005) presents a detailed description of the EPPA model in its previous version.

In each period, production functions for each sector and regions describe how capital, labor, land, energy and other intermediate inputs are combined to obtain goods and services. The model represents a great number of primary factors to be able to better characterize the supply and demand of energy and alternative technologies to fossil fuels.

The EPPA model is formulated as a mixed complementarity problem (MCP) in the General Algebraic Modeling System - GAMS (Brooke et al., 1998) software and solved using the MPSGE modeling language (Rutherford, 1995).

Each region of the model there is a representative agent maximizing its utility by choosing how to allocate its income to consume goods and services. The economic sectors are represented by a representative firm which chooses primary factors and intermediate inputs to maximize its profits, given the technology. The model has a complete representation of markets, which must achieve the equilibrium simultaneously. We illustrate the general model structure in MCP here, presenting the three conditions that need to be fulfilled in this type of representation: zero profit, market clearance and income balance.

As stated before, EPPA uses CES function forms to specify production and utility functions, including Cobb-Douglas and Leontief functions. Nested structures are considered, in order to allow different levels of substitution among inputs and factors and a high flexibility in the use of elasticities of substitution among fuels, electricity and other process generating emissions. Figure 1 presents the technology assumed in the agricultural sectors (crop, livestock and forestry) as illustration. It shows several elasticities (σ) governing the ability to substitute inputs and primary factors. Table 2 lists the value of the elasticities in the model. The structure of the agriculture sector includes land explicitly, and represents the tradeoff between land and an energy materials bundle. This resource-intensive bundle enters at the top nest with the value-added bundle. Because the land input is critically unique in agriculture, the nest structure for agriculture provides flexibility in representing substitution between land and other inputs.[2]

Figure 2 presents the nested CES structure used to represent the household consumption. It considers the endogenous decision about consumption and savings at the top level. The model also includes an energy nest completely separated from the household transportation decision. It allows keeping separate the decision about fuel for transportation and other energy uses. The families can consume its own transportation services (composed by automobiles, fuel, maintenance parts and services and insurance) as also may buy transportation services from air, road and subway transportation companies. Table 3 presents the elasticities of substitution in the consumption.

[2] The nest structure for the other sectors in EPPA can be found in Paltsev et al. (2005).

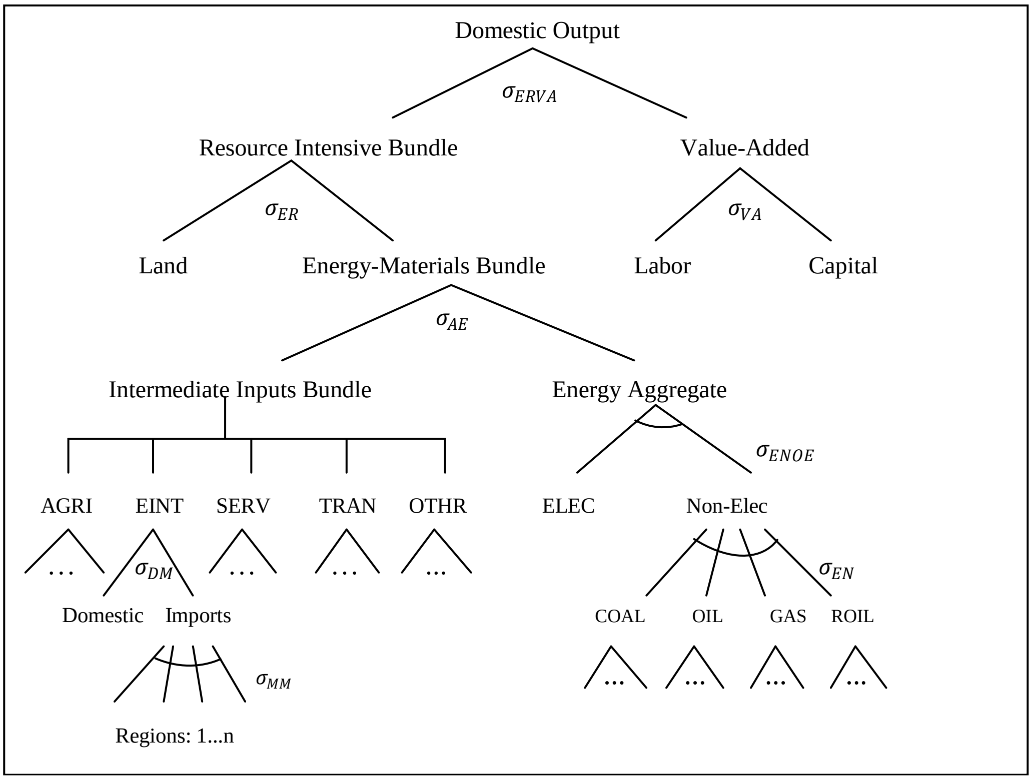

Figure 1. Structure of agricultural production sectors.
Source: Paltsev et al. (2005).

Table 2 – Elasticities of Substitution in the production sectors in the EPPA model

Symbol	Description	Value	Comments
σ_{EVA}	Energy - value added	0.4 - 0.5	Applies in most sectors, 0.5 in EINT, OTHR
σ_{ENOE}	Electricity-Fuels aggregate	0.5	All sectors
σ_{EN}	Among fuels	1.0	All sectors except ELEC
σ_{EVRA}	Energy/materials/land-value added	0.7	Applies only to AGRI[1]
σ_{ER}	Energy/materials-land	0.6	Applies only to AGRI
σ_{AE}	Energy – materials	0.3	Applies only to AGRI
σ_{CO}	Coal-oil	0.3	Applies only to ELEC
σ_{COG}	Coal/oil-gas	1.0	Applies only to ELEC
σ_{VA}	Labor-capital	1.0	All sectors
σ_{GR}	Resources – all other inputs	0.6	Applies to OIL, COAL,GAS
σ_{NGR}	Nuclear resource – value added	0.04 -0.4	Varies by region
σ_{DM}	Domestic – imported (Armington)	2.0 – 3.0	Varies by good
		0.3	Electricity
σ_{MM}	Among imports from different regions (Armington)	5.0	Non-energy goods
		4.0	Gas, Coal
		6.0	ROIL
		0.5	Electricity

1 AGRI sectors are: CROP, LIVE and FORS
Source: Paltsev et al. (2005).

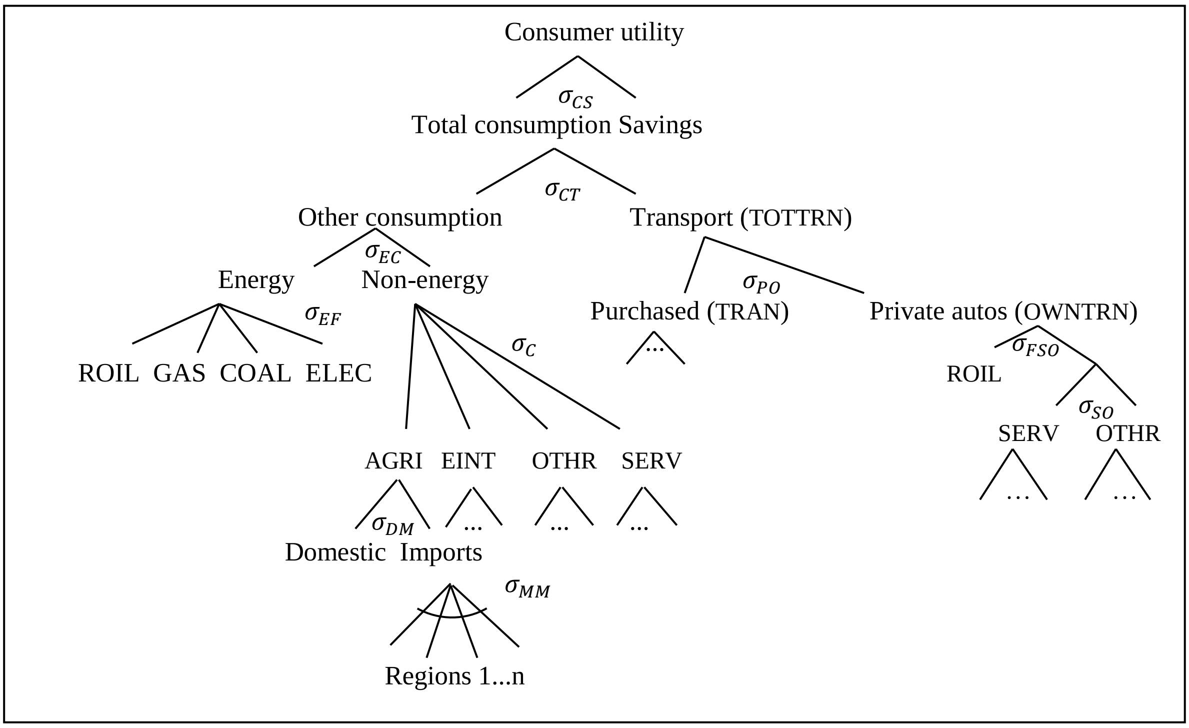

Figure 2. Structure of final demand in EPPA.
Source: Paltsev et al. (2005).

Table 3. Elasticities of substitution in the final demand in the EPPA model.

Symbol	Description	Value	Comments
σ_{EC}	Energy – other consumption	0.25	
σ_{EF}	Among fuels and electricity	0.4	
σ_{FSO}	ROIL - services/others	0.3	Increase over time
σ_{CS}	Consumption – savings	0.0	
σ_C	Among non-energy goods	0.25-0.65	Base year values that varies among countries, and increase whit per capita income
σ_{CT}	Transportation – other consumption	1.0	
σ_{PO}	Purchased - own transportation	0.2	
σ_{SO}	Services - others	0.5	

Source: Paltsev et al. (2005).

The model closure in each period considers a fixed endowment of primary factors in each region, which is free to move among sectors, excepting the non-malleable fraction of the capital.[3] Land is used only in the agricultural sectors and to grow natural vegetation. One land use type can be converted to another if the full conversion costs are paid. Fossil fuel resources, as also nuclear and hydro resources are specific to the energy sectors using them. The model does not consider unemployment and prices are flexible. From the demand side, the marginal propensity to save is constant and regionally specified, given the benchmark share of savings in the aggregate household expenditure.

[3] The non-malleable fraction of the capital is specific to the sector and used in fixed proportions to other inputs. It allows representing the short run rigidity in technology and fixed investments, what is particularly important in the case of energy suppliers, as electricity power facilities, which can make very few changes in its capacity and inputs mix once its operation starts.

The international capital flows that compensate the trade imbalances are exogenously specified to smoothly decline through time. It means that an implicit real exchange rate will adjust in each period to accommodate changes in export and import flows. The government expenditure reacts to changes in relative prices, and the tax revenue is subject to the level of the economic activity.

The model also considers the land competition for alternative uses. Each land type area can be converted to another type or removed from agricultural production to a non-use category (secondary vegetation). Land is also subject to exogenous productivity improvements, reflecting assessment of this potential (Reilly and Fuglie, 1998). Land use conversion is achieved by assuming that 1 hectare of land of one type is converted to 1 hectare of another type, assuring consistency between the physical land accounting and the economic accounting in the general equilibrium setting, and the marginal conversion cost of land from one type to another is equal to the difference in value of the types, with real inputs being added during the conversion process through a land transformation function, following Gurgel et al. (2007) and Melillo et al. (2009). Conversion of natural forest areas to agriculture produces timber and other forestry products.

We calibrate the land use transformation from natural vegetation to agricultural production in order to represent an observed land supply response. It assumes the response we see in land conversion in the last two decades is representative of the long-term response. The own-price land supply elasticity for each region is calculated using observed average annual percentage land price increase from 1990 through 2005 and the average annual natural forest area converted to managed land as a percentage of managed land over the same period.

The base year of the EPPA5 is 2004. The model simulates the economy recursively at 5-year intervals from 2005 to 2100. Economic development in 2005 and 2010 is calibrated to the actual GDP growth data.

Future scenarios are driven by economic growth that results from savings and investments and exogenously assumptions about the productivity improvement in labor, energy, and land. Growth in demand for goods produced from each sector including food and fuels occurs as GDP and income grow. The use of depletable resources decreases its stocks, driving production to higher cost grades. Sectors that use renewable resources such as land compete for the available flow of services from them, generating rents. These together with policies, such as constraints in the amount of greenhouse gases, change the relative economics of different technologies over time and across scenarios. The timing of entry of advanced technologies, such as cellulosic bio-oil, is endogenous when they become cost competitive with existing technologies.

The population growth is based on long run trends in the United Nations forecast (United Nations, 2009). The labor productivity improvement is specified to reproduce the observed and expected average GDP levels from the International Monetary Fund (IMF, 2011). Physical units are used to represent the energy data, based on the International Energy Agency (IEA, 2015). In the case of Brazil, we have compared this data with the main domestic statistics sources. The numbers about GHGs in EPPA come from Waught et al. (2011).

3. RESULTS

3.1 Climate Policy Scenarios and BAU

During the 21st Conference of the Parties in Paris in 2005, Brazil has announced the target of reducing GHG emissions by 37% compared to 2005 levels by 2025 and the intention to reduce 43% by 2030. Several mitigation strategies were envisioned and explicitly described in the Brazilian NDC to be achieved by 2030. These include (BRAZIL, 2006b): achieve zero illegal deforestation; restoring and reforesting 12 million hectares (ha) of forests; increasing the share of sustainable biofuels in the energy mix to 18%; achieving 45% of renewables energy sources in the energy mix; increasing the share of renewables in the power supply to 23%; achieving efficiency gains of 10% in the electricity sector; restoring 15 million ha of degraded pastures, and; expanding the area of integrated cropland-livestock-forestry systems (ICLFS) by 5 million ha.

We simulate several scenarios to investigate alternative ways to achieve the committed Brazilian targets. We implemented a *business as usual* (BAU) scenario and several policy scenarios considering alternative policies to reduce GHG emissions. We compare results from policy scenarios with those fom the BAU scenario to measure the policy impacts on emissions and economic indicators. The scenarios were designed to investigate not only the measures and mitigation efforts proposed by the Brazilian government at the Paris agreement, but also carbon pricing instruments.

We first consider those strategies described in the Brazilian NDC, with a mix of sectoral incentives (subsidies) to renewable energy, agricultural and livestock expansion, and penalties (taxes) to deforestation. We also implement alternative scenarios with carbon pricing instruments, as taxes and cap-and-trade. The carbon tax scenarios consider a specific tax for each sector of the economy, in order to impose the same emissions cut in relative terms to each sector. To assure that each sector will achieve the same relative emissions target, the sectoral tax is endogenously calculated by the model. Finally, we consider also cap-and-trade scenarios covering all sectors, besides emissions from deforestation, which are constrained by a specific tax on it. The tax and cap-and-trade scenarios are imposed first on all gases, and after, only on CO_2 emissions.

Table 4 briefly presents the scenarios. The climate mitigation measures are applied from 2020. We simulate the model from 2010 to 2050.

The climate policies in Brazil are implemented to achieve the reduction target announced in the Paris agreement, which are 37% below 2005 levels by 2025 and 43% by 2030. After 2030, we keep constraining emissions linearly to reach emissions around 50% below 2005 levels.

Figure 3 shows the Brazilian GHG emissions trajectory in the BAU scenario. The data from 2005 to 2012 are the official emissions from the early emissions estimates (MCTI, 2014). The emissions in 2014 were provided by the independente Sistema de Estimativa de Emissão de Gases de Efeito Estufa (SEEG)[4]. From 2015 the emissions are projected by EPPA. Figure 3 also presents the level of emissions expected by 2025 and 2030 when implementing the NDCs.[5]

[4] Available at: http://seeg.eco.br/

[5] The Third National Communication of Brazil to the United Nations Framework Convention on Climate Change (Brazil, 2016a) published in 2016 improved its methodology regarding land use change emissions compared to the previous official GHG inventories of the country. The most recent inventory shows total emissions in 2005 as 2.73 billions tons of de CO_2 equivalent. At the Second Communication, the total emissions reached 2.04 billion tons of CO_2 eq (MCTI, 2014). The Brazilian iNDCs were defined as cuts in

Table 4. Scenarios description

Scenario	Overall Description	Deforestation treatment in Brazil	Mitigation on other sectors in Brazil	Mitigation in other countries
BAU	No active climate policy	No rigid control	No control	No policies, besides those already in place
COP 2030	All countries apply mitigation measures on all GHG, Brazil applies its announced measures	Increasing control until reach zero deforestation by 2030	Specific mitigation measures in agriculture, livestock, reforestation, and renewable energy, after 2030 mitigation efforts are not intensified	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050
COP	All countries apply mitigation measures on all GHG, Brazil applies its announced measures	Increasing control until reach zero deforestation by 2030	Specific mitigation measures in agriculture, livestock, reforestation, and renewable energy, after 2030 mitigation efforts are intensified	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050
TAX	All countries apply mitigation measures on all GHG	Increasing control until reach zero deforestation by 2030	Sectoral GHG taxes to achieve the same relative cut in emissions in every sector	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050
TAX CO2	All countries apply mitigation measures on all GHG, Brazil applies only on CO_2	Increasing control until reach zero deforestation by 2030	Sectoral CO_2 taxes to achieve the same relative cut in emissions in every sector	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050
Cap-and-Trade	All countries apply mitigation measures on all GHG	Increasing control until reach zero deforestation by 2030	Cap-and trade system on all GHG taxes	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050
Cap-and-Trade CO2	All countries apply mitigation measures on all GHG, Brazil applies only on CO_2	Increasing control until reach zero deforestation by 2030	Cap-and trade system on all GHG taxes	Domestic cap-and-trade system on emissions to achieve the country NDC from 2020 to 2050

total emissions as declared in the Second Communication. As so, we understand that the absolute level of total emissions in 2025 and 2030 should be those related to the commitments in the Paris agreement.

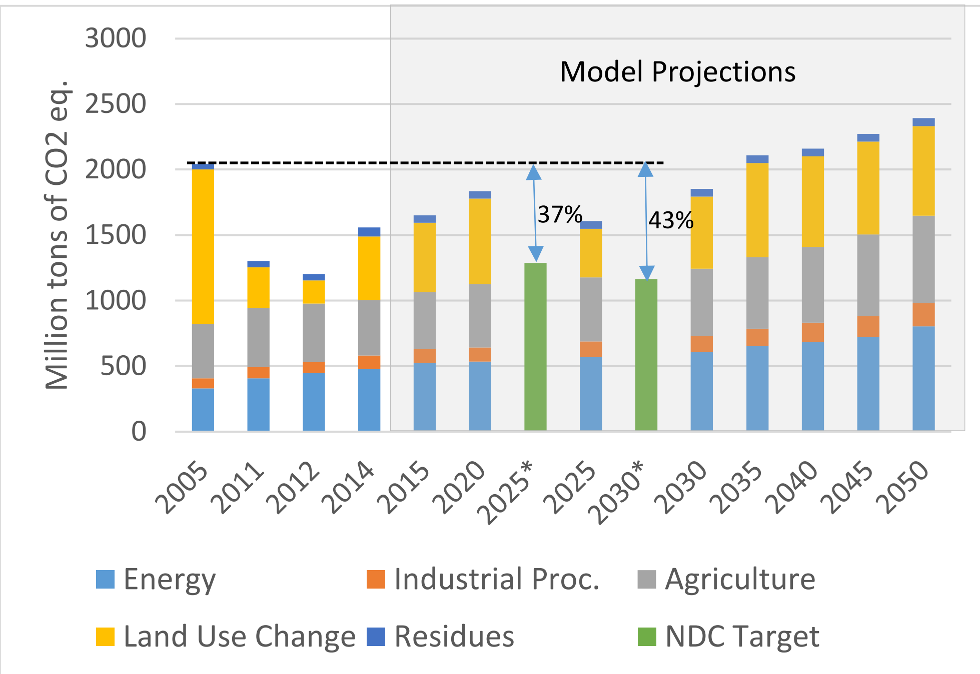

Figure 3. GHG emissions in Brazil
* Emissions targets set at Paris Agreement
Sources: MCTI (2014)[6], SEEG[7], and EPPA results.

The model produces an increasing trend in emissions, specially from the energy sector. Emissions from land use changes and agriculture keep large shares in total emissions during all the projection. Total emissions reflect the expected economic growth, the increasing use of fossil fuels in the energy mix and the expansion of the agricultural sector. The rate of economic growth is one of the most important drivers of emissions in the BAU scenario. Table 5 presents the yearly GDP growth rate in Brazil from the EPPA model, relative to 2015. These rates are in alignment with IMF projections, besides the rate between 2015 and 2020, which is slightly higher in EPPA.

Table 5 – Yearly GDP growth rate in Brazil projected by the model

Year	2020	2025	2030	2035	2040	2045	2050
%	2,48	2,72	2,78	2,80	2,77	2,75	2,74

Source: results from EPPA model

Land use changes are a relevant driver of emissions in the country also. Figure 4 shows the changes expected in the pattern of land use from the model in the BAU scenario, in cumulative terms compared to 2015 land use. These changes reflect the average of deforestation in the Amazon and Cerrado (Brazilian Savannah) biomes from 2000 to 2010. It means the BAU scenario considers a weak control of deforestation after 2015. It has been observed an increasing effort to reduce deforestation since 2015, mainly in the Amazon biome. So, as we assume in the BAU the absence of any strong policy to contain GHG emissions, we believe the weak deforestation control is a better representation of such scenario. The land use changes projected by the model also

[6] The GHG emissions data for 2005, 2011 and 2012 at Figure 3 are from the 2º Brazilian Emissions Inventory and were published in MCTI (2014).
[7] Available at: http://seeg.eco.br/

consider an increase of the cropland area from 51 million ha in 2015 to 95 million ha in 2050. The area of pasture would reduce from 182 million ha in 2015 to 175 million in 2050, following current trends.

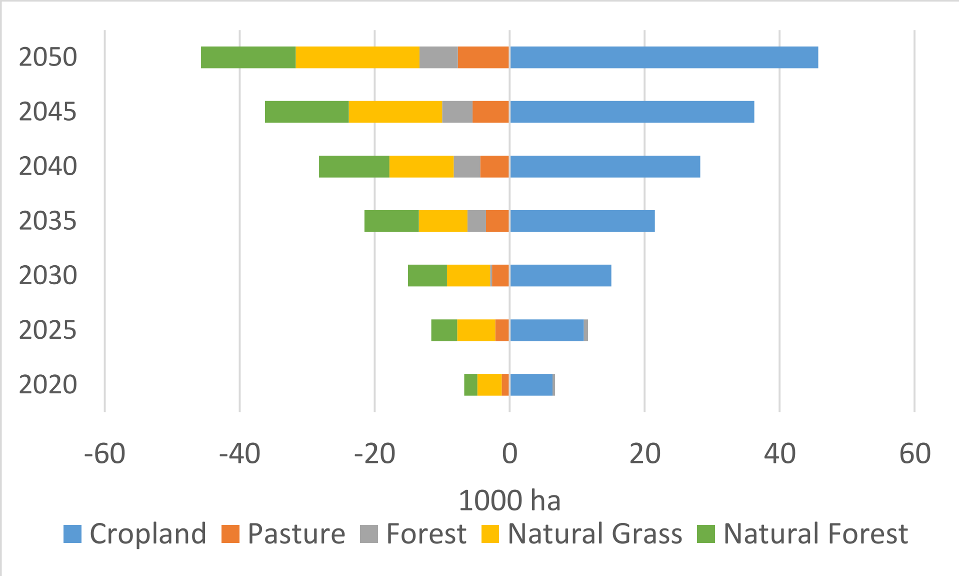

Figure 4. Cumulative land use changes in the BAU scenario compared to 2015.
Source: model results.

3.2 Results from Climate Policy Scenarios

3.2.1 Emissions Trajectories

The total GHG emissions in Brazil in the alternative scenarios is presented in Figure 5. We include a dashed black line representing the emissions target set at the Paris Agreement for 2025 and 2030. After 2030, the targets were defined in order to reach 50% reduction in emissions by 2050 relative to 2005 emissions.

The mitigation actions proposed by the country to reach the NDC are simulated in the COP-2030 scenario. Figure 5 shows that these actions would not guarantee the country would reach its targets, although it would get closer. A possible reason for this is related to the lack of current measures of GHG emissions and sequestration from pasture areas, as also those emissions reductions and sequestration from recovered pasture areas and crop-livestock-forest integrated systems. These are not present in the Brazilian GHG official inventories. As so, we do not have data to represent these emissions and sequestration in the model, although we implement the measures related to them, as pasture recovery and expansion of the integrated systems. A first lesson from this result is the urgent need to create methodologies and mechanisms to measure and register the emissions from these processes and include them in the Brazilian official GHG inventory. The lack of such measures may compromise the achievement of the targets set at the Paris Agreement.

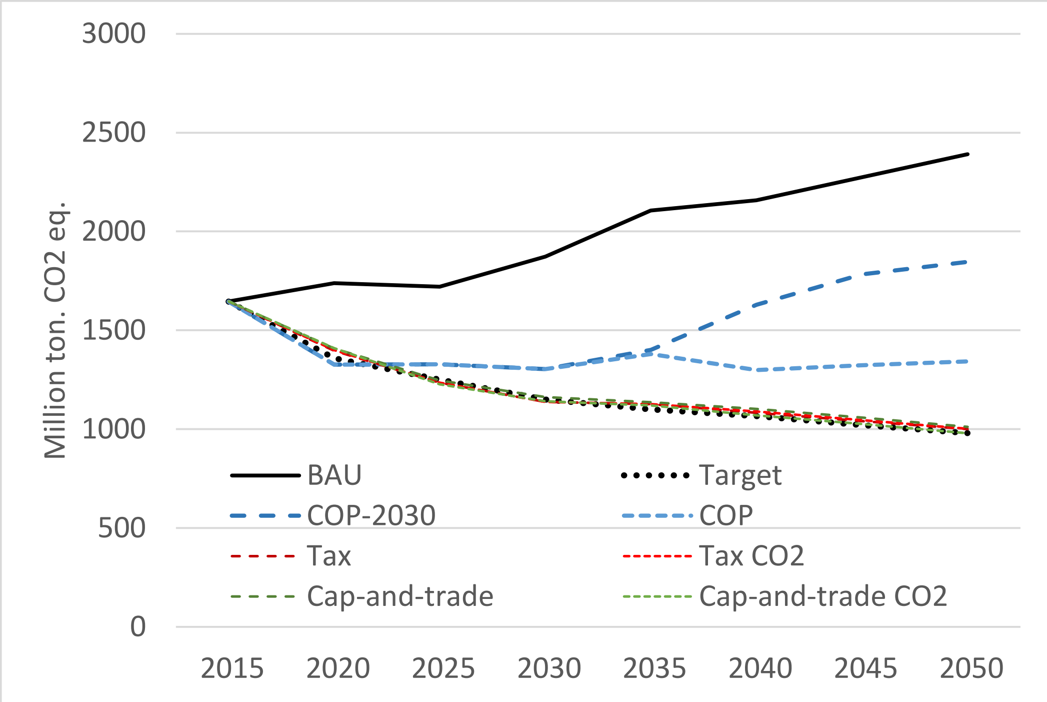

Figure 5. GHG emissions (Million ton. of CO_2 Eq.) in Brazil in the alternative scenarios
Source: model results

Figure 5 also shows the COP-2030 scenario does not avoid the increase in emissions after 2030, since there is no intensification of efforts to reduce emissions through sectoral mitigation actions, as incentives to renewable energy, forest recovery and intensification in agriculture and livestock production. As many other important sources of emissions are not directly covered by the NDC, as the fossil fuel emissions from energy, the emissions grow back after 2030.

In the COP scenario we assume increasing efforts to reduce emissions after 2030, using the same mitigation actions as in the COP-2030 scenarios. These efforts allow emissions stabilize at 1.3 billion tons of CO_2 eq. per year, but are not able to achieve the increasing reduction targets. It means the mitigation actions Brazil proposed at the COP of Paris are not enough to cut emissions below 43% of the 2005 levels after 2030. These actions are based on stopping deforestation, restoring forest areas, increasing renewable energy and intensifying agriculture and livestock production. As deforestation will be controlled until 2030 and the carbon sequestration from agriculture intensification are not accounted for, the model results just mean that the potential to expand renewables in the Brazilian energy system in order to curb emissions has some limits. This result also reflects the current energy mix in Brazil, which relies more in renewables than the world average. Given that the current policy proposals will have reach their potential to reduce emissions by 2030, the country needs to plan other mitigation strategies in the long run, maybe based on carbon pricing and covering a broader number of sectors and activities.

The carbon tax and cap-and-trade scenarios were tested here considering the long run limits in the current mitigation proposals. They all are designed to reach the proposed emission targets. In the carbon tax scenarios, we impose sectoral cuts in emissions by applying sectoral level carbon taxes. All sectors reduce emissions by the same share. In the cap-and-trade scenarios we set the quantitative emissions target to the whole economy and let the model generate the equivalent national carbon price to reach such target. As so, GHG emissions in these scenarios are equal to the dot black line given by the "Target" lavel in Figure 5. One important difference among the COP scenarios and the carbon pricing scenarios is that these last ones cover all the sectors in the economy, while the proposals Brazil presented at the Paris Agreement cover just a limited number of sectors and emission sources.

3.2.2 Economic Costs

The alternative climate policy scenarios induce changes in relative prices of energy inputs and activities intensive in emissions, changing consumers and producers choices. These changes determine the impacts on the aggregated economic activity, which is measured here by changes in the GDP. Figure 6 shows the impacts of the policies on the Brazilian GDP relative to the GDP at the BAU scenario. These impacts are relatively small until 2030, reaching at most a 0.8% lower GDP in the scenario "Tax", in comparison with the GDP at the BAU. The COP-2030 and COP scenarios lead to a 0.7% decrease in GDP compared to the BAU by 2030. Such result suggests that the Brazilian mitigation proposals at the Paris Agreement were well designed in terms of choosing to take action in those sectors with relatively low abatement costs. Such decrease in GDP seems modest to achieve the overall 43% reduction in emissions compared to 2005 levels.

After 2030, however, the low cost mitigation opportunities in the country become scarce, and costs increase fast. The COP-2030 scenario is the only which does not lead to higher costs, since the mitigation efforts after 2030 are not intensified. However, the COP scenario produces unreasonable GDP losses, since the cheap reduction in emissions through stopping deforestation and reforesting are all finished by 2030, and the only mitigation measure becomes the increase incentives to renewable energy. The 19% loss in GDP by 2030, compared to GDP at the BAU, suggest that such incentives bring too much distortions in the economy and reach the limit of expanding too fast the renewable sources in the country. Given that, the carbon pricing strategies are better options for a long run effort to curb GHG emissions.

The sectoral carbon tax scenarios impact GDP by -1.5% in 2035. This impact reaches -6.6% by 2050 in order to achieve 50% reduction in emissions compared to 2005 levels. These are expressive numbers, but much lower than those from the COP scenario. The reason for that is the broader coverage of the carbon tax, which allows the burden of reducing emissions to be divided among all sectors in the economy. However, as every sector needs to reduce emissions by the same relative amount, the sectoral tax does not allow the best allocation of resources, since those sectors facing higher mitigation costs need to reduce emissions by the same share as those sectors with lower costs.

The "Cap-and-trade" scenarios produce the lowest negative impact on GDP. The GDP loss by year 2035 is around 0.5% in these scenarios, and reaches only 3.3% by 2050. It is half of the losses in the "Tax" scenarios. This difference is just due to the possibility of those sectors with higher mitigation cost buying carbon allowances from those sectors with lower mitigation costs, which leads to an efficient outcome. Given the complexities to set up and implement a carbon cap-and-trade program, these results show the importance to plan ahead the institutions and instruments to guarantee future reduction in emissions at lower costs to the economic growth of the country.

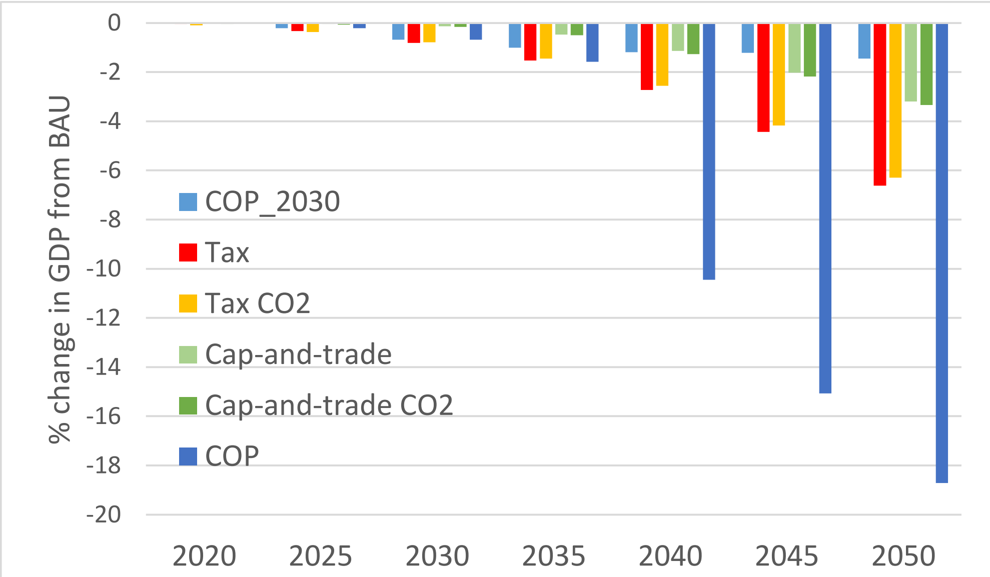

Figure 6. Changes in GDP (%) relative to BAU.
Source: model results.

3.2.3 Carbon taxes and prices

Figure 7 shows the carbon taxes applied to each sector in the "Tax" scenario and the carbon price negotiated in the overall economy in the "Cap-and-trade" scenario. The carbon tax is endogenously determined by the model in each sector in order to force the same relative cut in emissions in each of them. As sectors have different mitigation opportunities and capacities to substitute energy sources and technologies, those with higher mitigation costs but highly needed in the economy tends to face higher taxes. This is the case of the services sector, which pays the higher carbon taxes. Since this sector produces low level of emissions, but don´t have much alternative energy sources nor lower carbon technologies available, any level of reduction in emissions imposes big challenges to the sector. But, as the consumers and all other sectors in the economy need to buy services, the only way to induce the sector to achieve strong emissions reduction is imposing very high carbon taxes on it. The carbon tax in the service sector reaches US$370/ton of CO_2 eq. by 2050.

The carbon price at the "Cap-and-trade" scenario is very low compared to the carbon tax for most of the sectors. It reaches only US$ 3/ton of CO_2 eq. by 2030 and increases to US$ 103/ton of CO_2 eq. by 2050. These numbers show how cheap are the mitigation opportunities in the Brazilian economy until 2030, but how these opportunities are all taken by 2050. But, although the carbon price reaches the US$100/ton by 2050, it still much cheaper than the sectoral taxes from the "Tax" scenario in most of the sectors. It reinforces the conclusion that future mitigation strategies need to be designed considering the lowest impact in the economic efficiency in the Brazilian economy.

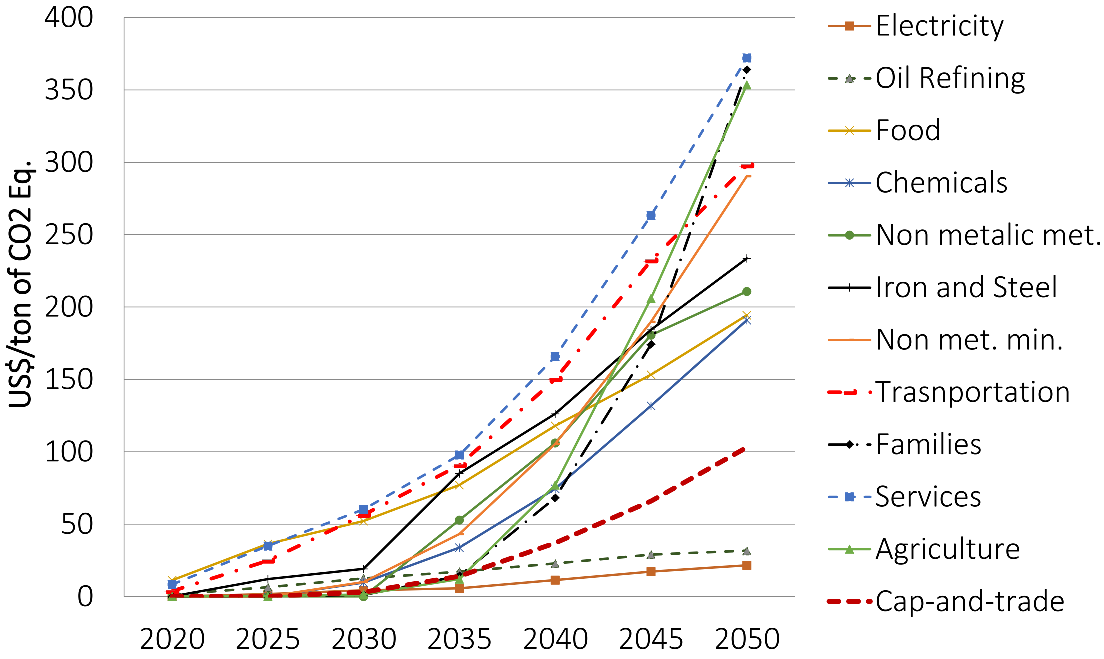

Figure 7. Sectoral carbon taxes at the “Tax” scenario and caron price at the “Cap-and-trade” scenario.
Source: model results.

4. CONCLUSION

The goal of this paper was to investigate the impacts of the Brazilian NDC to reduce GHG emissions. We simulate the country mitigation strategies announced at the Paris agreement, as also as other climate policy scenarios in for the country. The main scenario is the representation of the Brazilian NDC as it was announced in the Paris Agreement. It targets emissions reduction from deforestation, the adoption of low carbon emission practices in agriculture, the improvement in energy efficiency and the expansion of renewables sources as biomass, wind, solar and hydropower. We implement the most of these as incentives to increase the supply, as also as taxes on emissions from deforestation. We also implement other two groups of alternative scenarios: a) broad carbon markets (cap-and-trade); and b) sectorial carbon taxes forcing every sector to reduce emissions by the same percentage. Both alternative scenarios are set to achieve the overall country emissions target announced in the Paris Agreement. We also implement in all scenarios cap-and-trade climate policies in the other regions and countries of the model. These are assumed as carbon markets to achieve their announced NDCs. Finally, we extend the climate policies in all countries after 2030, including Brazil, to keep the world reducing emissions until 2050, since the efforts presented in Paris will be not enough to keep warming below 2^o Celsius until the end of the century.

The main results from our simulation show that the Brazilian NDC would partially achieve the proposed emission target due to caveats on measurements of emissions reduction in agriculture and limitation on renewable energy generation in the country. Further efforts to reduce emissions after 2030 would require changes in the climate policy strategy in the country, since all the potential emissions reduction from deforestation and renewables would be finished. The economic costs of the Brazilian NDC is relatively low until 2030, a 0.7% decrease in GDP relative to a business as usual scenario. However, the same emissions target may be achieved with less than 0.2% decrease in GDP if a cap-and-trade policy is adopted. The carbon price to be paid under a national cap-and-trade scheme will be as low as US$ 3 per ton of carbon equivalent in 2030, but can reach U$103 per ton in 2050 if further reduction in emissions is pursued. If sectoral carbon taxes are applied to make each economic sector to reduce emissions by the same ratio, carbon taxes may vary from US$ 0.5. to US$ 60 per ton by 2030, and from US$ 25 to US$ 370 per ton. These results show the potential of relatively cheap reduction in emissions from land use changes and agriculture in the short run in the country, but the need for a quick turn in the climate policy strategy to some carbon pricing system in order to avoid high costs and losses in the country competitiveness.

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