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Economic Implications of Reducing Carbon Emissions from Energy Use and Industrial Processes in Brazil

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Abstract

The overall impacts on the Brazilian economy of reducing CO_2 emissions from energy use and industrial processes can be assessed using a recursive dynamic general equilibrium model and a hypothetical carbon tax. The study projects that in 2040 under a business-as-usual scenario, CO_2 emissions from energy use and industrial processes would be almost three times as high as in 2010 and would account for more than half of total national CO_2 emissions. Current policy aims to reduce deforestation by 70 percent by 2017 and emissions intensity of the overall economy by 36–39 percent by 2020. If policy is implemented as planned and continued to 2040, CO_2 emissions from energy use and industrial processes would not have to be cut until 2035 as reductions of emissions through controlling deforestation would be enough to meet emission targets. The study also finds evidence that supports the double dividend hypothesis: using revenue from a hypothetical carbon tax to finance a cut in labor income tax significantly lowers the gross domestic product impacts of the carbon tax. Using carbon tax revenue to subsidize wind power can effectively increase the output of wind power in the country, although the impact of the tax on gross domestic product would be somewhat increased.

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Economic Implications of Reducing Carbon Emissions from Energy Use and Industrial Processes in Brazil

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I INTRODUCTION

Brazil has relatively low per capita greenhouse gas (GHG) emissions compared to other developing or developed countries due to its large hydropower resources and also to some extent ethanol for transportation. Currently hydropower accounts for around four-fifths of national electricity supply, and ethanol replaces around two-fifths of gasoline consumption (de Gouvello et al., 2010). The emissions patterns of Brazil have two characteristics. First, CO_2 emissions have been the most important GHG emissions in Brazil as they account for around 90% of total GHG emissions (Ministry of Science and Technology, 2010). Thus, reducing CO_2 emissions is the most crucial step toward lowering GHG emissions. Second, unlike most developed countries where the main sources of emissions come from burning fossil fuels, in Brazil, at this moment, around three-quarters of national CO_2 emissions are from land-use change, especially from converting forests to crop and pasture lands (Ministry of Science and Technology, 2010). Further, the future deforestation emissions rate may still remain at the current level.[1]

To contribute to global efforts in combating climate change, in December 2009, the Brazilian government passed the Law 12.187 which sets a voluntary national GHG reduction target of 36.1% to 38.9% of projected emissions by 2020 (World Resources Institute, 2010). Under the law, the National Plan on Climate Policy (PNMC) has become the national policy, which calls for a 70% reduction in the scale of deforestation by 2017 (Federal Government of Brazil, 2008). To carry out the target, the government is launching deforestation monitoring and control measures to protect its natural forest.[2] On the other hand, CO_2 emissions from energy related activities and industrial processes are becoming more and more significant since the promising economic growth of Brazil in recent years has increased the energy demand, including demand for fossil fuels, and this in turn raises CO_2 emissions a great deal. If the current growth trend continues, these non-deforestation emissions sources are expected to account for a much higher share of Brazilian national CO_2 emissions, and they would significantly offset the emissions cut achieved through reducing deforestation. Thus, whether the national emissions reduction target is feasible depends not only on the effectiveness of reducing deforestation but also on the effort of cutting the emissions from energy use and industrial processes. If deforestation can be greatly reduced, the burden of cutting CO_2 emissions from energy use and industrial processes would be

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[1] See p.21 in de Gouvello et al. (2010) for future deforestation emissions projection.

[2] See p.51 in de Gouvello et al. (2010) for Brazilian government's efforts in reducing deforestation.

minimal. Otherwise, CO_2 emissions from energy use and industrial processes would still need to cut a certain level of emissions to meet the national GHG emissions reduction target.

Achieving the low-carbon growth may have far-reaching and quite various impacts on different sectors. Relevant studies on Brazil, such as de Gouvello et al. (2010) and Machado-Filho (2009), however, are based on a partial equilibrium framework which focuses on a particular sector or issue.[3] To better address interactions among various agents and sectors of the economy, a general equilibrium analysis, which takes into account those interactions endogenously, would provide a more comprehensive analysis to explore the economy-wide effects of a given policy. Existing research for Brazil based on general equilibrium framework mostly focuses on issues such as trade, transportation, and regional development (Haddad et al., 2010; Haddad, 2006), change in tax structure (Tourinho et al., 2010), economic integration effects (Haddad et al., 2002), and policy effects for inflation stabilization (Simpson, 1994). None of the existing studies explores the impacts of climate change mitigation policies or measures on the Brazilian economy. An exception is Pattanayak et al. (2009), which analyzes Brazil's policy to expand national forests (FLONAS) based on a general equilibrium analysis. However, the potential impact of achieving the national emissions reduction target is beyond the scope of that study.

As a result, this study will investigate the potential effect of achieving Brazil's national emissions reduction target. More specifically, this study analyzes the economy-wide impact of reducing CO_2 emissions from energy-related activities and industrial processes on the Brazilian economy under different assumptions on the effectiveness of deforestation mitigation (and thus reducing the associated carbon source) by PNMC. While estimating and considering the cost of implementing PNMC are beyond the scope of this study, to represent the cost of cutting CO_2 emissions from energy use and industrial processes, this study considers a hypothetical carbon tax that covers all non-deforestation CO_2 emissions released from energy use and industrial processes. The hypothetical carbon tax requires individuals to internalize the cost of emissions impose on others and on future generations (Metcalf and Weisbach, 2009). In particular, the larger tax base which covers all non-deforestation CO_2 emissions sources ensures a less

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[3] In the research for transportation policies, Machado-Filho (2009) acknowledges the limitation of partial equilibrium framework and mentions that "for a more precise quantitative estimate, a computational model should be run (See p.501 and p.507)." Nevertheless, that is beyond the scope of that research.

distortionary impact on resource allocation and thus avoids overestimating the economic burden of cutting emissions.[4]

This study builds a recursive dynamic computable general equilibrium (CGE) model to assess the carbon mitigation impacts on the Brazilian economy. The model is characterized by the recursive dynamics with a portion of vintage capital generated from each period. In addition, when aggregating electricity outputs from distinct generation technologies by a constant elasticity of substitution (CES) function, the model applies an adjustment to the CES aggregator such that it could maintain the equivalence of input and output flows in terms of both value and physical units, respectively. A similar adjustment is also applied to the Constant Elasticity of Transformation (CET) function which models land allocation.

Compared to existing studies on evaluating the low-carbon growth of Brazil, the main contributions of this study are: 1) it presents a general equilibrium framework which allows the research to analyze the economy-wide policy effects based on a comprehensive and theoretically consistent approach. This is very different from other relevant research, which relies mostly on a simple cost-benefit analysis and fails to account for the complex interactions among distinct economic agents; and 2) it also considers alternative carbon tax revenue recycling options and analyzes their implications. This provides readers information regarding the potential effects of alternative carbon mitigation policy designs.

This study is organized as follows: section II, III, IV, and V present model descriptions, data, carbon mitigation impacts, and other revenue recycling options, respectively. Section VI provides the conclusions.

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[4] The hypothetical carbon tax is a policy tool commonly explored in studies of the economic impacts of greenhouse gas mitigation, but looking at the tax in this paper in no way implies an endorsement of carbon tax over cap and trade for Brazil. Technically, in the absence of uncertainty, as assumed with this study to focus on other issues, the carbon tax analysis is equivalent to a comprehensive economy-wide cap and trade system with auctioned allowances and rebated revenues. Given there are many other ways in which cap and trade could be implemented, and for that matter, a carbon tax would not have to apply to every unit of carbon content -- there could be "exempted quantities." like the zero bracket for an income tax, the model in this paper could be applied to explore some of the key impacts of different policy designs.

II MODEL SETTINGS

This section presents the main model settings. It begins with the static settings, follows by the model dynamics, and finally explores the new strategy of aggregating electricity generation from distinct technologies. The model is formulated in a series of mixed complementary problems (MCP) (Mathiesen 1985) using the MPSGE modeling language (Rutherford 1999).

II.1 Basic Settings

The household, producers, and government are main components of the model. The household owns labor (time endowment), capital, and land; supplies these factors to producers and receives net factor payments in return.[5] While labor and part of the capital are allowed to move freely across sectors within the same period, another portion of the capital is sector-specific, and land allocation is modeled by a CET function, as shown in **Figure 1**. The household allocates its disposable income on consumption savings, and leisure as follows:

$$
\begin{gathered}
\max_{c_i,l,s} w(c_i, s, l) \\
s.t. \ \sum_i pa_i \cdot c_i + pinv \cdot s + pl \cdot l \qquad (1) \\
= \sum_n pf_n \cdot f_n + pfx \cdot (ftrh - htrf) + pw \cdot (gtrh - dt)
\end{gathered}
$$

where w is represented by a nested CES function with the structure shown in Figure 1, pa_i is the price for the Armington goods i, which is the CES aggregation of domestic and imported goods, c_i is the amount of private consumption, pl is the price of leisure, l is the amount of leisure, $pinv$ is the price of investment, s represents household savings, pf_n is the rental price for primary factor n (including capital, labor, and land), f_n is the factor supply, and $gtrh$, $ftrh$, $htrf$, dt, pw, and pfx are government transfer to household, foreign transfer to household, household transfer to abroad, direct tax, price index for welfare, and price index for foreign exchange, respectively[6]. The first order condition for utility maximization can be written as:

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[5] Here the indirect tax has been subtracted from the gross factor payment.

[6] ftrh, htrf, and gtrh are exogenous and grow at the same rate GDP does.

$$e(pa_i, pinv, pl) \geq pw \,;\, w \geq 0 \,;\, [e(pa_i, pinv, pl) - pw\,] \cdot w = 0 \tag{2}$$

The final demand for consumption, savings, and leisure could be derived from Shephard's Lemma with h representing the household disposable income:[7]

$$c_i = h\frac{\partial e}{\partial pa_i} \;;\; s = h\frac{\partial e}{\partial pinv} \;;\; l = h\frac{\partial e}{\partial pl} \tag{3}$$

The producer's optimizing behavior, which determines the domestic output x_i, requires the following zero-profit condition:

$$c_i\big(pa_j, pf_n\big) \geq px_i \;;\; x_i \geq 0 \,;\, \big[c_i\big(pa_j, pf_n\big) - px_i\big] \cdot x_i = 0 \tag{5}$$

The output is sold domestically or exported abroad depending on market prices. Similar to the case of (3), the producer's optimization behavior determines the demand for intermediate goods (which are Armington goods) id_j and the demand for factor fd_n, which could be written as:

$$id_j = x_i\frac{\partial c_i}{\partial pa_j} \;;\; fd_n = x_i\frac{\partial c_i}{\partial pf_n} \tag{6}$$

Exports are determined by the zero-profit condition as follows:

$$px_i - pfx \cdot pxfex_i \geq 0 \;;\; e_i \geq 0 \,;\, (px_i - pfx \cdot pxfex_i) \cdot e_i = 0 \tag{7}$$

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[7] $h = \sum_n pf_n \cdot f_n + pfx \cdot (ftrh - htrf) + pw \cdot (gtrh - dt)$ as shown in condition (1).

where e_i and $pxfex_i$ are the export level and world price of commodity i, respectively, and pfx is the price index for foreign exchange as mentioned before. Similarly, the zero-profit condition that determines the import level of sector i, denoted by m_i, can be written as follows:

$$\begin{gathered} pfx \cdot pxfex_i \cdot (1 + tarfr_i) - pxf_i \cdot \geq 0\ ;\ m_i \geq 0\ ; \\ [pfx \cdot pxfex_i \cdot (1 + tarfr_i) - pxf_i \cdot] \cdot m_i = 0 \end{gathered} \tag{8}$$

The government, a passive entity in the model, collects taxes and receives transfer from abroad to finance its consumption, transfer to household or abroad, and savings. The total government expenditure can be expressed as:

$$govtexp = \sum_i pa_i \cdot g_i + pw \cdot gtrh + pfx \cdot gtrf + pinv \cdot sg \tag{9}$$

where g_i, $gtrh$, $gtrf$, and sg represent government consumption of Armington good i, government transfer to household, government transfer to abroad, and government savings. The total government revenue can be written as follows with idt, dt, and $ftrg$, representing the total indirect tax, direct tax, foreign transfer to the government, respectively. In addition, when there is a carbon mitigation policy with an emissions target $cquota$, the government will have an additional carbon tax revenue with an unit carbon price pc:

$$govtrev = pw \cdot idt + pw \cdot dt + pfx \cdot ftrg + pc \cdot cquota \tag{10}$$

The model is closed with a set of market clearing conditions and income balance conditions. With a_i and inv_i representing the Armington good supply and investment, respectively, the market clearing conditions for commodities could be written as the following problem:

$$a_i \geq id_i + c_i + g_i + inv_i\ ; pa_i \geq 0\ ; [a_i - (id_i + c_i + g_i + inv_i)] \cdot pa_i = 0 \tag{11}$$

Similarly, the market clearing conditions for factors could be expressed as:

$$f_n \geq fd_n \,; pf_n \geq 0 \,; (f_n - fd_n) \cdot pf_n = 0 \tag{12}$$

The market clearing condition for the foreign exchange can be written as follows where $resa$ is the reserve accumulation. This study assumes the economy is a price taker of foreign good so $pxfex_i$ is exogenous.

$$\sum\nolimits_i x_i - \left[\sum\nolimits_i pxfex_i \cdot m_i + (htrf - ftrh) + (gtrf - ftrg) + resa\right] \geq 0 \,;$$

$$pfx \geq 0 \,; \tag{13}$$

$$\left\{\sum\nolimits_i x_i - \left[\sum\nolimits_i pxfex_i \cdot m_i + (htrf - ftrh) + (gtrf - ftrg) + resa\right] \geq 0\right\} \cdot pfx = 0$$

The income balance conditions for the household and government are written as (14) and (15), respectively:

$$pw \cdot w = \sum\nolimits_n pf_n \cdot f_n + pw \cdot gtrh - pfx \cdot (htrf - ftrh) - pw \cdot dt \tag{14}$$

$$govtexp = govtrev \tag{15}$$

where in Equation (14), $htrf$ is the household transfer to abroad, and Equation (15) is just to equalize government expenditure and revenue presented in Equations (9) and (10), respectively.

Finally, this study chooses the price index for welfare, pw, to be the numeraire of the model such that all other prices are measured relative to pw.[8]

II.2 Dynamics Settings

The model built for this study is a recursive dynamic general equilibrium model, which means that investment is savings driven, the same setting as Rausch et al. (2010), Mensbrugghe (2010), and Paltsev et al. (2005). Since current period investment adds into the next period capital stock, it is the driving force of economic growth besides population and total factor productivity growth. Using t to denote period and expressing the aggregate investment $\sum_i inv_{i,t}$ as inv_t, the market clearing condition for the supply of and demand for savings can be written as the following MCP problem:

$$sh_t + sg_t - resa_t \geq inv_t \, ; pinv_t \geq 0 \, ; [sh_t + sg_t - resa_t - inv_t] \cdot pinv_t = 0 \qquad (16)$$

Capital includes malleable and non-malleable capital. Here, malleable capital refers to that which can freely move among sectors (to equalize capital rental rate) and nonmalleable capital is sector-specific. As a production factor, this nonmalleable capital could be, to some extent, replaced by malleable capital. The lower substitutability between these two kinds of capital captures the observed hysteresis of structural change or the capacity constraint within a given period. This setting is similar to the role of sector-specific “fixed factors” presented in Mensbrugghe (2010) and Paltsev et al. (2005). Let us denote the aggregated (national) capital stock of period t by nvk_t:

$$nvk_t = inv_{t-1} + (1 - \delta) \cdot nvk_{t-1} \qquad (17)$$

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[8] A general equilibrium model could be expressed as a system with n equations and n variables. According to Walras' Law, in a general equilibrium state, if $n - 1$ markets are in equilibrium, then the n^{th} market must be in equilibrium as well. This implies exactly one equation of the model is linearly dependent on others. As a result, there are only $n - 1$ linearly independent equations while there are n variables. Thus, the (price) numeraire, which has a value determined exogenously, is chosen such that all other prices are measured relative to this numeraire.

where δ is the depreciation rate. Suppose ϵ is the proportion of current period capital nvk_t which is nonmalleable (i.e., sector-specific).[9] Following this notation, $(1-\epsilon)\cdot nvk_t$ remains malleable in period t and can move freely among sectors to equalize the capital rental rate according to condition (12). The nonmalleable capital of each sector, $nvsk_{i,t}$, is assumed to grow proportionally with the total nonmalleable capital $\epsilon\cdot nvk_t$ as shown in Equation (18):

$$nvsk_{i,t}=\frac{\epsilon\cdot nvk_t}{\epsilon\cdot nvk_{t-1}}\cdot nvsk_{i,t-1}\,;\ \sum\nolimits_i nvsk_{i,t}=\epsilon\cdot nvk_t \tag{18}$$

Besides capital accumulation, this study also considers the labor force growth and labor productivity growth as motors that drive the economy. The labor force growth rate $lbgr_t$ in Equation (23) is from the World Bank (2010). Additionally, while in the baseline, the labor productivity growth rate is calibrated to match BAU projected GDP growth rate given exogenously, in policy scenarios, the baseline labor productivity growth rate becomes exogenous and the GDP growth rate becomes endogenous.[10]

$$enlb_{t+1}=enlb_t\cdot(1+lbgr_t) \tag{23}$$

II.3 Aggregating Electricity Generated by Distinct Technologies

Electricity sector is the main contributor to national GHG inventory in many countries. Although, this is not the case in Brazil at present because of pre-dominance of hydropower in the nation's electricity supply system, the role of fossil fuel based electricity generation technologies is increasing. It is therefore important to retain the characteristics of various types of electricity generation technologies in the model instead of representing them by a single technology. This

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[9] We assume that $\epsilon=0.1$ as in Markusen (2007).

[10] This treatment is the same as Rausch et al. (2010). Further, the BAU projected annual GDP growth rate of Brazil is assumed to be 4.1% up to 2030 according to the Empresa de Pesquisa Energética (EPE). After 2030, we assume a 3% annual GDP growth rate.

study uses CES functional forms to aggregate different types of electricity generation technologies following Timilsina and Shrestha (2007), and Timilsina (2009). The main purpose of using the CES function to aggregate distinct electricity generation technologies is to capture, for example, how hydro power plants can substitute for coal-fired power plants if the generation cost changes. To validate the aggregation for homogeneous goods, it must be the case that: 1) the value of inputs equals the value of output, and 2) the sum of physical quantities of inputs equals the physical quantity of output. While the CES aggregation meets the first requirement, the second is violated when the relative prices change due to the nature of this non-linear aggregation.[11] This means that in terms of physical quantity, a CES aggregation for electricity generated by distinct technologies will produce an output inconsistent with the sum of all inputs.

Few existing studies, however, have accounted for this issue. One exception is Welsh (1998), which used an endogenously determined scaling factor such that the CES aggregator for distinct electricity sources is continuously recalibrated. This study implement the idea proposed by Welsh so that the CES aggregator for electricity generated by distinct technologies could maintain the equivalence of input and output flows both in terms of value and physical units, respectively. Similar adjustment is also applied to the allocation of land-supply described by a CET function to ensure that: 1) the value of land input equals that of the sum of all land outputs, and 2) the sum of areas for different land-types remains the same.

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[11] Only two special types of CES function meet the two requirements simultaneously: the perfect substitution structure and the Leontief structure.

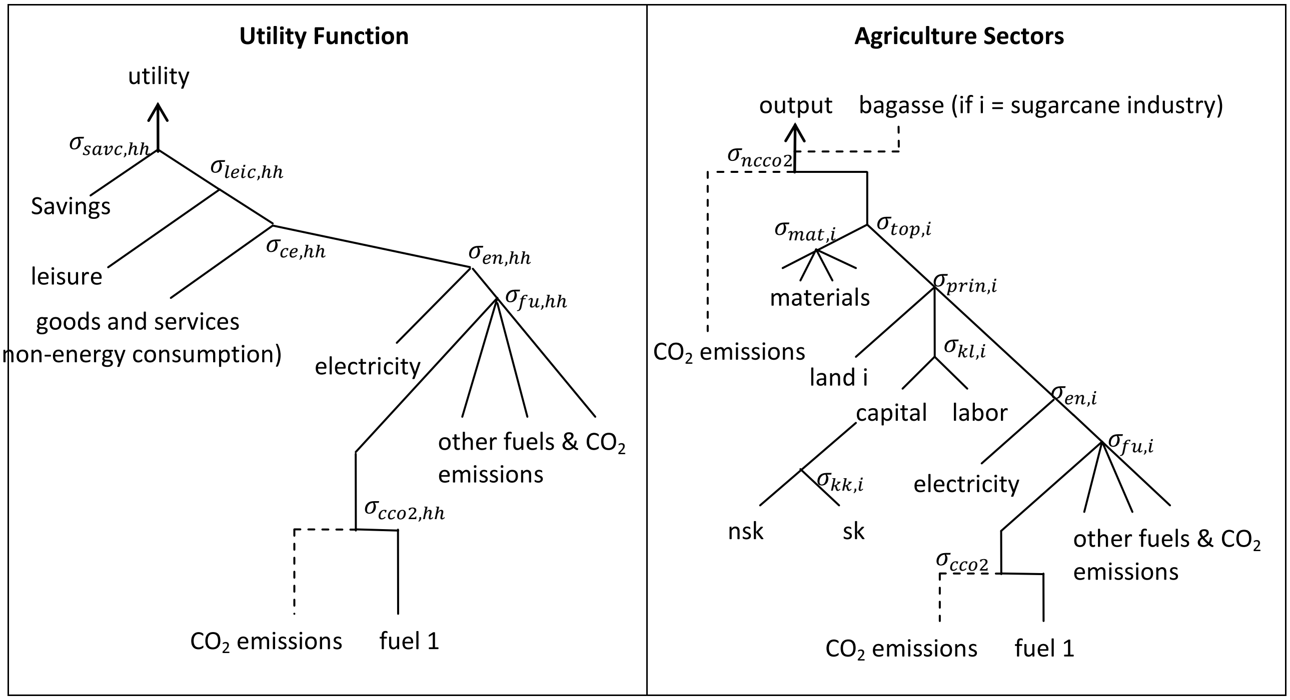
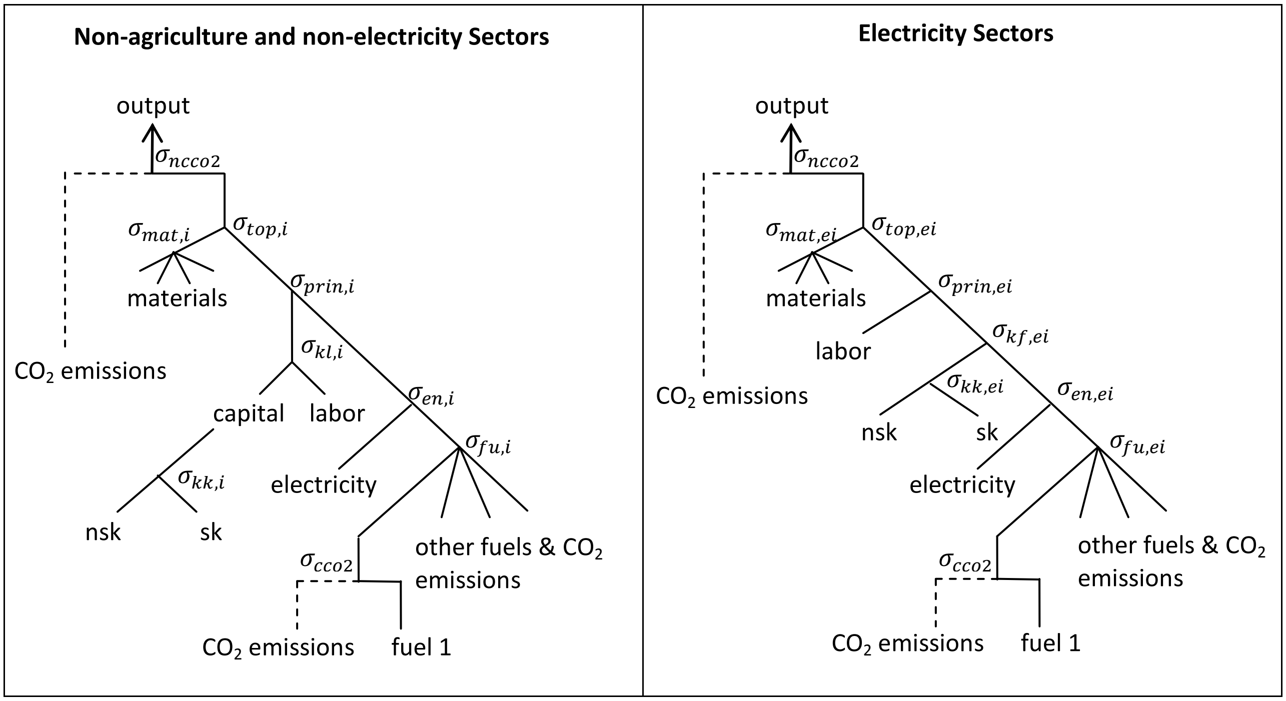


Figure 1. Utility and Production Functions



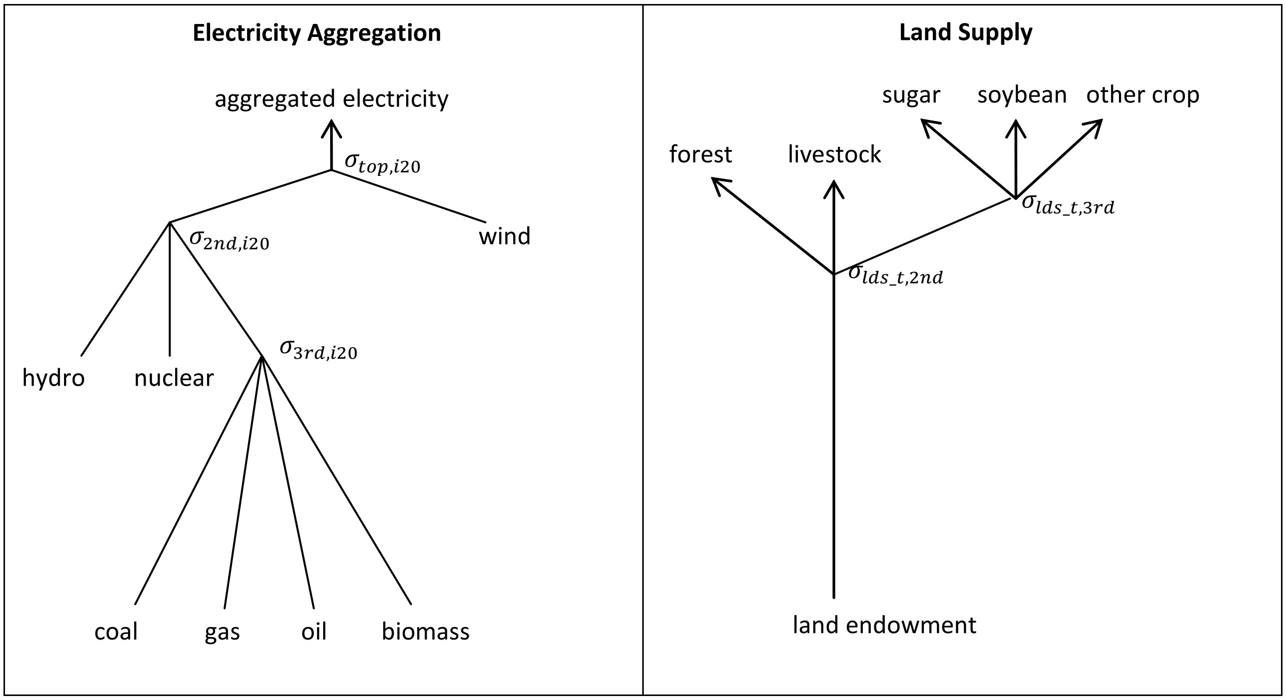


Figure 1 (Continued). Utility and Production Functions

III DATA

The data needed for the analysis can be classified into three types: 1) the Brazilian input-output and national accounting data to construct the Social Accounting Matrix (SAM); 2) the sectoral energy consumption and CO_2 emissions data for defining emission coefficients from fuel consumption; and 3) the elasticities of substitution that characterize how different inputs can be substituted by other inputs, and the elasticities of transformation that represent how different outputs can be converted to other outputs.

Based on Brazil's national accounting data for 2007 and the approach developed by Guilhoto and Sesso (2004), Pereira (2010) builds a 25-sector SAM for Brazil. An aggregated version of SAM is presented in **Table 1**, and the 25 industrial sectors are presented in **Table 2**. Further, following some existing studies such as Timilsina and Shrestha (2007), Pereira disaggregated the electricity sector into 7 subsectors including electricity generations from hydro, nuclear, coal, gas, oil, wind, and biomass. The biomass generation uses bagasse, the by-product from the sugarcane industry, as the feedstock and is assumed to be carbon neutral as hydro, nuclear, and wind generations. Thus, this study can better address the distinct impacts of achieving the goal of low-carbon growth on various generation technologies with different carbon footprints. The sectoral energy consumptions and emissions are drawn from Pereira et al. (2010), as summarized in **Figure 2**, where both combustion emissions from energy-related activities and non-combustion emissions from industrial-processes are presented. For each sector, the combustion emissions are linked to the use of energy inputs through emissions factors, and this study assumes that the non-combustion emissions are proportional to the output level.[12] The data of emissions from deforestation, on the other hand, are from de Gouvello et al. (2010) and the Ministry of Science and Technology (2010). In addition, the elasticity data come from existing studies including Paltsev et al. (2005) and Timilsina and Shrestha (2007). The details are presented in **Table A1** in the Appendix.

Finally, this study assumes that Brazil's domestic demand for and supply of tradable goods only have minimal impacts on the world price levels. This allows us to treat the world prices of tradable goods as exogenous to the model. While to consider the depletion of the global crude oil reserves, the model assumes that the world crude oil price, which is exogenous, will grow at the rate of 10% per period (i.e., every five years) based on the median projection for the future crude oil price presented by EIA (2010), other world real price levels are assumed to increase at the rate of 5% per period (every five years) to capture the indirect effects of rising oil prices and other scarcity rents.

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[12] Since this study uses a hypothetical carbon tax to represent the burden of cutting industrial and household emissions, the dashed lines in Figure 1 show that when there is an emissions reduction target, industry and household have to pay for their combustion and non-combustion emissions.

Table 1. The Base Year (2007) Aggregated SAM for the Brazilian Economy[13]

Unit: billion Brazilian Real (R$)

	x_i	e_i	m_i	a_i	inv	lds	w	hh	$govt$
px_i	4274	-333		-3941					
pxf_i			204	-204					
pf_{land}	-29					29			
pf_{labor}	-1100							1100	
$pf_{capital}$	-1127							1127	
$pldp$						3	-3		
pld						-32		32	
pa_i	-1968			4296	-405		-1385		-538
$tax\ or\ transfer$	-51		-6	-151				-318	526
pfx		333	-197					-11	-125
$pinv$					405		-541		136
pw							1929	-1929	

Table 2. Industrial Sectors in the Model

#	Industry	#	Industry
i01	Other agriculture	i17	Metal industry
i02	Sugarcane industry	i18	Machinery equipment
i03	Soy beans industry	i19	Other manufacturing
i04	Forest sector	i20	Electricity generation
i05	Livestock sector		ei01 electricity: hydro
i06	Food and beverage		ei02 electricity: nuclear
i07	Crude oil & natural gas		ei03 electricity: coal
i08	Metal & mineral mining		ei04 electricity: gas
i09	Coal mining		ei05 electricity: oil
i10	Textile & leather		ei06 electricity: wind
i11	Wood production		ei07 electricity: biomass
i12	Pulp paper & furniture	i21	Processed gas
i13	Petro refinery	i22	Construction sector
i14	Biofuels sector	i23	Commercial sector
i15	Chemical industry	i24	Transportation sector
i16	Non metallic industry	i25	Other service sector

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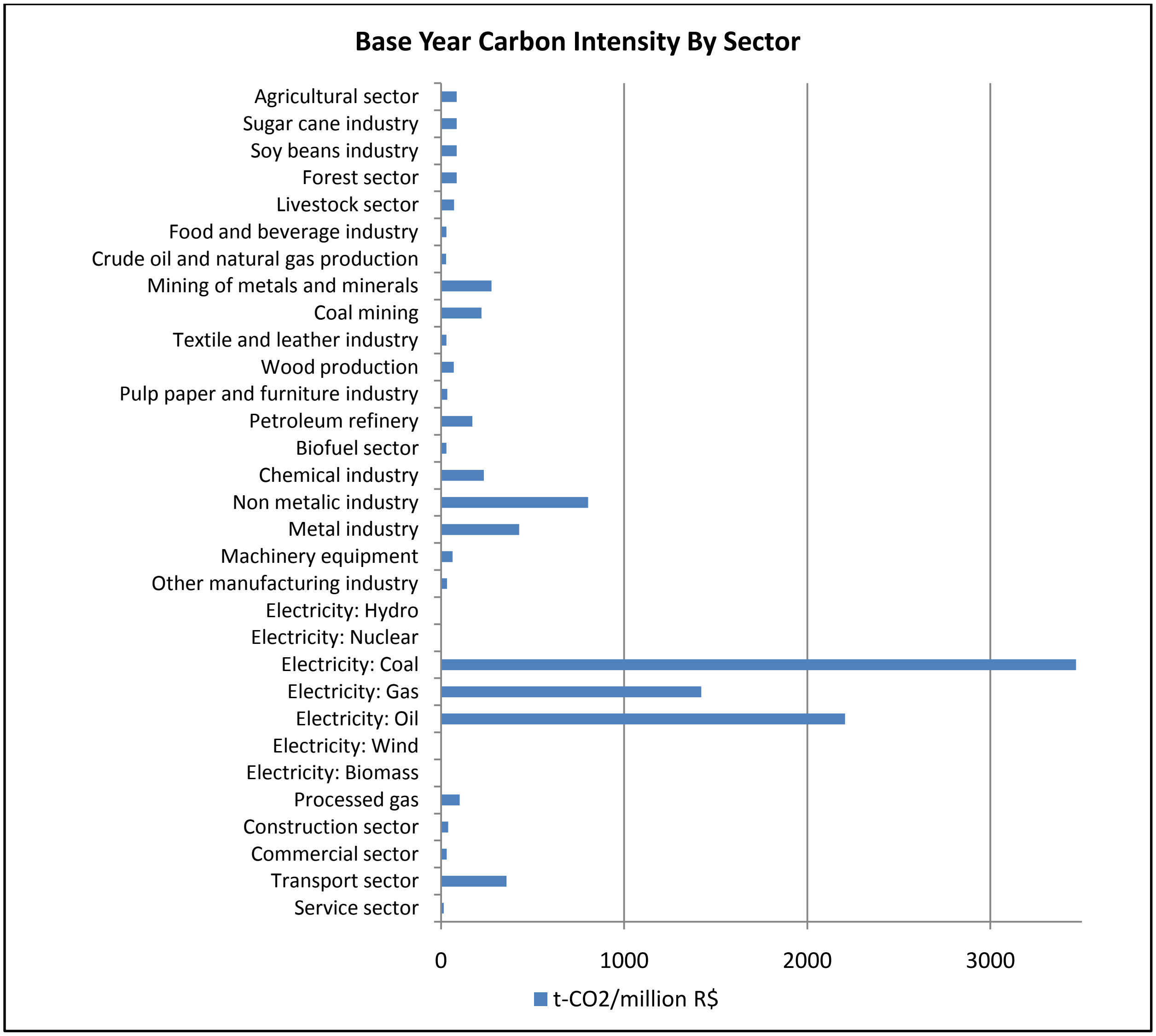
[13] This study presents the SAM in the form of a “Micro Consistent Matrix (MCM)” mentioned in Markusen (2006) and first presented in Rutherford (1999). Each row correspond to a market clearing condition with the positive and negative numbers representing supply and demand, respectively. The first 8 columns correspond to the zero-profit conditions for different production technologies with positive and negative numbers representing output and input, respectively. The last 2 columns are income balance conditions for household and government, respectively. Within an income balance condition, positive and negative numbers are income and expenditure, respectively.

Figure 2. Sectoral Carbon Intensities in the Base Year (2007)



Sources: Pereira et al. (2010) and Ministry of Science and Technology (2010). Note that CO_2 emissions from deforestation are not included in the calculation of forest sector carbon intensity.

IV CARBON MITIGATION IMPACT

This section explores the potential impacts of achieving the national reduction target on the Brazilian economy under various scenarios. In the simulations this study follows the country's voluntary target for GHG reduction and represents it by a 37.5% reduction of national CO_2 emissions relative to the projected BAU level in 2020. The model is solved every five years from 2010 to 2040. PNMC, which aims at reducing 70% deforestation relative to BAU by 2017, is assumed to be effective from 2010 onward. A linear interpolation is used to calculate the reduction targets of 2010 and 2015. This study considers three scenarios for carbon mitigation based on how effectively the PNMV is achieved: 1) PNMC is fully achieved, i.e., 70% reduction in deforestation (and associated CO_2 emissions) relative to BAU will be achieved from 2017 onward; 2) PNMC is achieved by 75%, i.e., 52.5% reduction in deforestation relative to BAU will be achieved from 2017 onward; and 3) PNMC is achieved 50%, i.e., only 35% reduction in deforestation relative to BAU could be achieved by 2017 and later. Under each scenario, this study considers a 30-year time horizon, from 2010 to 2040. Since the national emissions reduction target is set only for 2020, this study assumes that beyond 2020, there will be the same emissions reduction target for all years as in 2020, i.e., the emissions reduction rate is assumed to stay at 37.5% relative to the projected BAU level for later years. Similarly, after 2017, the effectiveness of PNMC in reducing deforestation relative to BAU is assumed to stay the same as that of 2017.

Following de Gouvello et al., this study assumes that the BAU annual deforestation level would remain the same as its 2007 level, which represents 1,259 million ton-CO_2 emissions per year (Ministry of Science and Technology, 2010). Based on this assumption, the BAU simulation suggests that while Brazil's national emissions may increase by around 50% in 2040 compared to the 2010 level (from 1,742 million ton-CO_2/year to 2,610 million ton-CO_2/year), CO_2 emissions from energy consumption and industrial processes may increase by almost three-fold in 2040 compared to the 2010 level (from 483 million ton-CO_2/year to 1,351 million-ton CO_2/year), as shown in **Figure 3**. Equivalently, the results show that in 2010, while CO_2 emissions from energy consumption and industrial processes only account for around a quarter of total CO_2 emissions, they could be responsible for more than half of the total CO_2 emissions in 2040 in the BAU scenario, which implies in the long run, cutting CO_2 emissions from energy consumption and industrial processes could also be crucial in mitigating CO_2 emissions.

Figure 3 provides an evidence that if the target of PNMC, a 70% reduction in deforestation by 2017, is fully achieved, the national CO_2 emissions, including emissions from energy use and industrial processes and those from deforestation, would be in line with and even somewhat lower than the national reduction target set by the Law 12.187. If the 70% reduction rate in deforestation (relative to the BAU level) is maintained up to 2040, there will be no need to reduce the emissions from energy use and industrial processes before 2035, and even from 2035 onward, the burden of reducing emissions from energy use and industrial processes is still quite small. However, if only 35% reduction in deforestation is achieved, the economy would have to bear much higher burden of cutting their emissions from energy use and industrial processes starting from 2015. The simple analyses based on Figure 3 have demonstrated that the effectiveness of PNMC plays a crucial role in how the national emissions reduction target could be achieved.

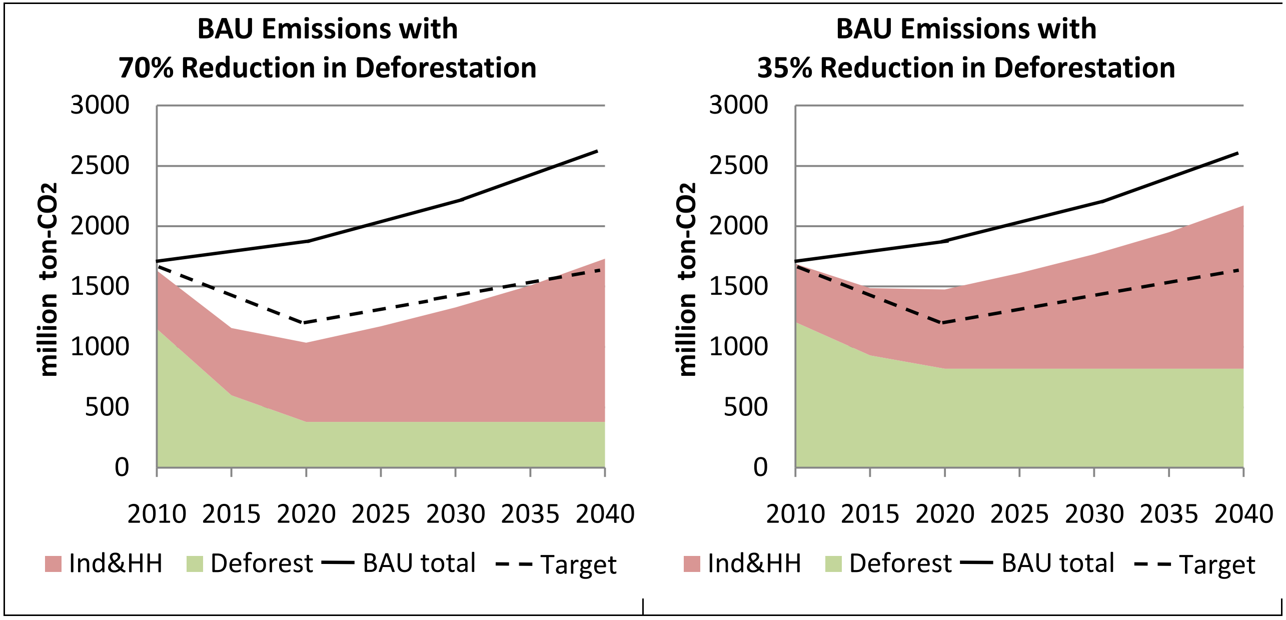


Figure 3. Emissions Structure under Distinct Deforestation Assumptions

In the discussion below, this study will present the impacts of meeting the national reduction target on the Brazilian economy. Note that since PNMC is achieved mostly by enforcing the existing legislation, there is no associated cost estimation available. The economic impact from imposing PNMC alone is beyond the scope of the research. This study will, instead, focus on the impact of cutting CO_2 emissions from energy-related activities and industrial processes based on different assumptions on the effectiveness of PNMC. Since the emissions reduction from deforestation has been taken care of by PNMC, the hypothetical carbon tax considered in this study will not cover the CO_2 emissions from deforestation. In addition, this study assumes that the additional tax revenue relative to BAU level goes to the household as a lump-sum transfer thereby ensuring that the government revenue remains constant. **Table 3** presents the impact on real GDP under different scenarios. In the table, DR denotes the deforestation reduction level from 2017 onward (DR = 70% means PNMC is fully achieved). The first scenario (DR = 70%) shows that if PNMC is fully achieved, there will be no need to cut emissions from energy use and industrial processes before 2035, and from 2035 onward, the negative impact on real GDP is quite small. This is also reflected by the shadow carbon prices, which are merely R$16/t-$CO_2$ in 2035 and R$37/t-$CO_2$ in 2040, respectively, as shown in **Table 4**. In the second scenario (DR = 52.5%), there would be no need to cut industrial and household CO_2 emissions until 2020. Under this scenario, the shadow carbon price in 2020 reveals that the GDP impact of cutting emissions is still quite small. The impact on real GDP is, however, more significant under the third scenario (DR = 35%). Under this scenario, a bigger amount of CO_2 emissions is deducted from energy use and industrial processes starting from 2015, which is also reflected in the corresponding shadow carbon prices presented in Table 4. These scenarios with different deforestation reduction assumptions confirm previous analyses based on Figure 3.

Finally, as expected, Table 3 shows that within the same period, the carbon price and the negative GDP impact both increase when a higher carbon reduction level is required. Note that, however, for a given scenario across different periods, this relationship does not hold.

Table 3. Real GDP Change (Scenario vs. BAU) under Different Scenarios

DR	70%	52.5%	35%
2010	0.00%	0.00%	0.00%
2015	0.00%	0.00%	-0.01%
2020	0.00%	-0.11%	-1.26%
2025	0.00%	-0.34%	-1.57%
2030	0.00%	-0.65%	-1.82%
2035	-0.02%	-0.77%	-1.70%
2040	-0.10%	-0.59%	-1.52%

DR: Deforestation reduction scenario (70% = reducing 70% deforestation from BAU in 2017 and later)

Table 4. Shadow Carbon Price under Different Scenarios (R$/t-$CO_2$)

DR	70%	52.5%	35%
2010	0	0	0
2015	0	0	7
2020	0	39	385
2025	0	87	379
2030	0	121	394
2035	16	106	372
2040	37	125	349

DR: Deforestation reduction scenario (70% = reducing 70% deforestation from BAU in 2017 and later)

To investigate the economic impact of meeting the national emissions reduction target on different sectors, **Table 5** presents the change in sectoral outputs relative to their BAU levels under different scenarios in 2020. As expected, in 2020, there will be no sectoral impacts when PNMC is fully achieved (DR = 70%) since no emissions reductions are needed from energy use and industrial processes. Under the second scenario (DR = 52.5%), although the overall GDP impact is small and the corresponding shadow carbon price is low, as presented in Table 3 and Table 4 before, the industrial structure begins to adjust in the direction that favors sectors with lower carbon footprints. This pattern is even more significant under the third scenario (DR = 35%). More clearly, sectors producing energy with higher levels of carbon content, such as coal mining and petroleum refinery, and sectors which intensively rely on energy inputs with significant carbon footprints (see Figure 2), such as nonmetallic industry, metal industry, machinery equipment, and thermal power plants (especially coal-fired power plants) would incur more negative impacts. On the other hand, the expansion of biofuels sector would stimulate the growth of sugarcane industry, and this in turn provides more bagasse as the feedstock for biomass generation. Table 5 also shows that with CO_2 emission cuts from the energy use and industrial processes, since more fossil fuels are substituted by biofuels, the negative impact of cutting emissions on transportation sector would be reduced compared to other sectors with comparable emissions intensities.

Table 5. Change in Sectoral Output (Scenario vs. BAU) in 2020

DR	70%	52.5%	35%
Other agriculture	0.00%	-0.03%	-0.89%
Sugar cane industry	0.00%	0.20%	6.79%
Soy beans industry	0.00%	0.01%	-0.52%
Forest sector	0.00%	-1.20%	-9.91%
Livestock sector	0.00%	-0.01%	-0.63%
Food and beverage	0.00%	0.01%	-0.52%
Crude oil & natural gas	0.00%	0.17%	-0.64%
Metal & mineral mining	0.00%	-37.50%	-69.40%
Coal mining	0.00%	-18.47%	-64.78%
Textile & leather	0.00%	0.03%	-4.46%
Wood production	0.00%	-4.57%	-49.80%
Pulp paper & furniture	0.00%	-0.15%	-1.00%
Petro refinery: gasoline	0.00%	-7.42%	-67.11%

Petro refinery: diesel	0.00%	-7.42%	-61.77%
Petro refinery: others	0.00%	-7.42%	-73.77%
Biofuels sector	0.00%	0.63%	17.33%
Chemical industry	0.00%	-2.88%	-22.88%
Non metallic industry	0.00%	-33.11%	-71.33%
Metal industry	0.00%	-14.38%	-54.99%
Machinery equipment	0.00%	-6.32%	-58.07%
Other manufacturing	0.00%	-5.03%	-57.60%
Electricity (aggregated)	0.00%	-1.51%	-5.79%
Electricity: Hydro	0.00%	-1.17%	-3.12%
Electricity: Nuclear	0.00%	-1.17%	-3.11%
Electricity: Coal	0.00%	-6.84%	-32.98%
Electricity: Gas	0.00%	-3.27%	-18.00%
Electricity: Oil	0.00%	-4.59%	-24.69%
Electricity: Wind	0.00%	-1.26%	-3.77%
Electricity: Biomass	0.00%	-0.03%	4.98%
Processed gas	0.00%	-2.27%	-3.84%
Construction sector	0.00%	-1.56%	-62.07%
Commercial sector	0.00%	1.49%	11.39%
Transportation sector	0.00%	-2.13%	-13.14%
Other service sector	0.00%	1.75%	12.83%

DR: Deforestation reduction scenario (70% = reducing 70% deforestation from BAU in 2017 and later)

V OTHER REVENUE RECYCLING OPTIONS

In addition to recycling the additional tax revenue by a lump-sum transfer to household, this section explores the effect of several alternative revenue recycling options. For simplicity, let us consider cases where PNMC is fully effective since the policy implications under different assumptions of PNMC effectiveness will be the same. Let us use TR to denote different tax recycling schemes. The scenario with TR = cutlb assumes that the additional tax revenue is used to lower the labor tax rate, an example of a distortionary tax. The corresponding change in real GDP relative to the BAU level is presented in **Table 6**. This study finds that if the additional tax revenue from implementing the carbon tax is recycled to finance the cut in labor tax, there will be a double dividend, i.e., CO_2 emissions are reduced and the real GDP increases (or at least most of the negative impact on real GDP is eliminated). This finding is in line with other research such as Goulder (1995), Böhringer and Rutherford (1997), Parry and Bento (2002), and Van Heerden et al. (2006). To further explore this phenomenon, **Table 7** presents the changes in real GDP (Cutting labor tax vs. Lump-sum transfer) under different scenarios. It shows that compared to a lump-sum transfer scheme, recycling the carbon tax revenue to finance the cut in labor tax rate can increase the real GDP level since cutting a more distortionary tax will improve the efficiency of resource allocation.

The sectoral adjustments under this low-carbon growth path, on the other hand, are quite similar to cases for the lump-sum transfer presented in Table 5 in a way that “dirtier” sectors suffer and “cleaner” sectors benefit, as shown in **Table 8** where only more aggregated sectoral results are presented for simplicity.

This study also considers the case where the additional tax revenue is used to subsidize the development of wind power generation (TR = subew). It considers the case where the subsidy rate is no greater than 50%, and the remaining carbon revenue is given back to the household as a lump-sum transfer. Under this scenario, while the negative impact on real GDP is close (but somewhat higher) to the case under the lump-sum transfer scheme, there will be a surge in the development of wind power plants, as shown in Table 8. Note that the effectiveness of this subsidy would depend on: 1) how wind power generation could replace other electricity generation options, and 2) how fast wind power generation can expand. Due to its intermittency nature, a wind power plant is usually complemented with other dispatchable sources of electricity generation (McFarland et al., 2008). This suggests that the elasticity of substitution between electricity generated by wind power plants and that comes from other generation technologies, denoted by $\sigma_{i20,top}$, may be lower. As presented in Section III, the potential of expanding wind power generation within a given period is modeled by $\sigma_{ei06,kk}$, the elasticity of substitution between the non-vintage nonmalleable capital (which account for the observed hysteresis of structural change or capacity constraint) and malleable capital. To explore how these two factors could affect the expansion of wind generation, **Table 9** provides a sensitivity analysis based on different values for $\sigma_{i20,top}$ and $\sigma_{ei06,kk}$. As expected, larger values for both elasticities would allow a higher penetration level of wind power generation when there is a subsidy on its development. At the extreme case with $\sigma_{i20,top}$ = 0.6 and $\sigma_{ei06,kk}$ = 0.5, relative to the base scenario (with $\sigma_{i20,top}$ = 0.3 and $\sigma_{ei06,kk}$ = 0.1), the electricity output from wind power generation would increase by around 14.69% in 2040, and at that level accounts for 0.20% of the total electricity supply compared to the 0.17% output share under the baseline scenario.

Table 6. Change in Real GDP (Scenario vs. BAU; DR = 70%)

Year / TR	Lump-sum transfer	cutlb	subew
2035	-0.02%	0.03%	-0.02%
2040	-0.10%	0.03%	-0.10%

TR: Tax revenue recycling scenario (cutlb = cutting labor tax; subew = subsidizing wind power generation)
Assuming PNMC is fully effective (DR = 70%). The subsidy rate cannot exceed 50%. The remaining carbon tax revenue is given back to the household.

Table 7. Change in Real GDP (Cutting labor tax vs. Lump-sum transfer)

Year / DR	70%	52.5%	35%
2007	0.00%	0.00%	0.00%
2010	0.00%	0.00%	0.00%
2015	0.00%	0.00%	0.02%
2020	0.00%	0.09%	0.24%
2025	0.00%	0.19%	0.26%
2030	0.00%	0.26%	0.28%
2035	0.05%	0.28%	0.32%
2040	0.14%	0.34%	0.35%

Table 8. Change in Sectoral Output (Scenario vs. BAU; DR = 70%)

TR	cutlb		subew	
Year	2035	2040	2035	2040
Other Agriculture	0.05%	0.00%	0.06%	0.03%
Sugarcane industry	-0.07%	0.10%	-0.10%	0.07%
Soy beans industry	0.14%	0.23%	0.08%	0.09%
Forest sector	-0.22%	-0.24%	-0.22%	-0.26%
Other industry	-4.44%	-0.78%	-4.38%	-0.99%
Electricity: Hydro	-0.60%	-1.30%	-0.64%	-1.36%
Electricity: Nuclear	-0.60%	-1.29%	-0.64%	-1.36%
Electricity: Coal	-3.28%	-7.84%	-3.22%	-7.68%
Electricity: Gas	-1.51%	-3.51%	-1.53%	-3.49%
Electricity: Oil	-2.11%	-4.95%	-2.10%	-4.89%
Electricity: Wind	-0.64%	-1.39%	10.19%	9.42%
Electricity: Biomass	-0.12%	-0.04%	-0.14%	-0.07%
Service sector	0.98%	2.43%	1.02%	2.61%

TR: Tax revenue recycling scenario (cutlb = cutting labor tax; subew = subsidizing wind power generation)
Assuming PNMC is fully effective (DR = 70%). The subsidy rate cannot exceed 50%. The remaining carbon tax revenue is given back to the household.

Table 9. Change in Wind Power Output: Various ($\sigma_{ei06,kk}, \sigma_{i20,top}$) vs. ($\sigma_{ei06,kk}, \sigma_{i20,top}$) = (0.1, 0.3)

Year = 2040 $\sigma_{i20,top}$ $\sigma_{ei06,kk}$	0.20	0.30	0.60
0.10	-3.63%	0.00%	8.07%
0.20	-3.45%	0.67%	11.98%
0.30	-3.38%	0.91%	13.62%
0.50	-3.33%	1.10%	14.92%

Scenario considered: subew under DR = 70%. Changes are relative to the case with $\sigma_{i20,top}$ = 0.3 and $\sigma_{ei06,kk}$ = 0.1. Assuming PNMC is fully effective under the scenario subew. The subsidy rate cannot exceed 50%. The remaining carbon tax revenue is given back to the household.

VI CONCLUSIONS

Brazil's voluntary national targets of reducing deforestation and GHG emissions have drawn much attention recently. Since CO_2 emissions account for around 90% of national GHG emissions in Brazil, cutting CO_2 emissions is the most crucial step toward reducing GHG emissions. Thus, this study focuses on carbon mitigations and assesses the potential economic implications of achieving the carbon mitigation targets under the full or partial achievement of deforestation target, using a recursive dynamic CGE model.

The study finds: 1) under the BAU scenario, in 2040, CO_2 emissions from energy use and industrial processes would increase to a level almost three times as high as that in 2010 and at that level account for more than a half of national emissions in that year; 2) if PNMC, the policy which aims at reducing deforestation by 70% by 2017, could be implemented effectively, the burden of reducing CO_2 emissions from energy use and industrial processes would be minimal. If this is not the case, Brazil would require a cut of its CO_2 emissions from energy use and industrial processes to meet its GHG mitigation target; 3) while reducing emissions from energy use and industrial processes would curb sectors producing energy with a higher carbon content and sectors that intensively rely on that energy as an input, it encourages the development of clean energy substitutes and guide the economy toward a low-carbon growth path; 4) if the additional tax revenue from implementing the carbon tax is recycled to finance the cut in labor tax, there could be a double dividend, i.e., CO_2 emissions are reduced and the real GDP increases; and 5) using the carbon tax revenue to subsidize wind power can effectively increase the output of wind power in the country, especially when wind power is less dependent on other dispatchable electricity generations.

A limitation of this study is that it does not consider the cost of enforcing PNMC since this policy is achieved mostly by enforcing the existing legislation, which makes cost estimation difficult due to lack of data. Since reducing deforestation is also costly, the economy-wide costs of meeting the voluntary GHG reduction target in Brazil would be much higher than those presented in this study.

APPENDIX

Table A1. Elasticities Used in the Model

#	Industry	$\sigma_{mat,i}$	$\sigma_{prin,i}$	$\sigma_{kl,i}$	$\sigma_{kf,ei}$	$\sigma_{kk,i}$	$\sigma_{en,i/hh}$	$\sigma_{fu.i/hh}$	$\sigma_{armt,i}$
i01	Other agriculture	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i02	Sugar cane industry	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i03	Soy beans industry	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i04	Forest sector	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i05	Livestock sector	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i06	Food and beverage	0.2	0.2	0.6		0.3	0.6	2.0	3.0
i07	Crude oil & natural gas	0.2	0.2	0.6		0.3	0.5	0.8	3.0
i08	Metal & mineral mining	0.2	0.2	0.6		0.3	0.6	0.8	3.0
i09	Coal mining	0.2	0.2	0.6		0.3	0.6	0.8	3.0
i10	Textile & leather	0.3	0.3	0.6		0.3	0.6	0.8	3.0
i11	Wood production	0.3	0.3	0.5		0.3	0.6	0.8	3.0
i12	Pulp paper & furniture	0.3	0.3	0.6		0.3	0.5	0.8	3.0
i13	Petroleum refinery	0.3	0.3	0.5		0.3	0.3	0.8	3.0
i14	Biofuels sector	0.3	0.3	0.5		0.3	0.6	0.8	3.0
i15	Chemical industry	0.3	0.3	0.6		0.3	0.3	0.8	3.0
i16	Non metallic industry	0.2	0.2	0.5		0.3	0.3	0.8	3.0
i17	Metal industry	0.3	0.3	0.5		0.3	0.3	0.8	3.0
i18	Machinery equipment	0.3	0.3	0.5		0.3	0.2	0.8	3.0
i19	Other manufacturing	0.3	0.3	0.5		0.3	0.6	0.8	3.0
i20	Electricity generation								1.0
ei01	electricity: hydro	0.0	0.0		0.5	0.1	0.0	0.0	
ei02	electricity: nuclear	0.0	0.0		0.5	0.1	0.0	0.0	
ei03	electricity: coal	0.0	0.0		0.5	0.1	0.0	0.0	
ei04	electricity: gas	0.0	0.0		0.5	0.1	0.0	0.0	
ei05	electricity: oil	0.0	0.0		0.5	0.1	0.0	0.0	
ei06	electricity: wind	0.0	0.0		0.5	0.1	0.0	0.0	
ei07	electricity: biomass	0.0	0.0		0.5	0.1	0.0	0.0	
i21	Processed gas	0.2	0.2	0.5		0.3	0.1	0.1	3.0
i22	Construction sector	0.3	0.3	0.5		0.3	0.3	0.8	3.0
i23	Commercial sector	0.3	0.3	0.6		0.3	0.6	2.0	3.0
i24	Transportation sector	0.3	0.3	0.6		0.3	0.3	0.8	3.0
i25	Other service sector	0.2	0.2	0.6		0.3	0.3	2.0	3.0
	Household						0.6	2.0	

For each sector *i*, the Armington elasticity for aggregating imported and domestic goods is denoted by $\sigma_{armt,i}$. For all other elasticity notations, please see Figure 1 for details.

Sources: Paltsev et al. (2005); Timilsina and Shrestha (2007).

Table A1 (Continued). Elasticities Used in the Model

#	Industry	$\sigma_{ncco2,i}$	$\sigma_{cco2,i/hh}$	$\sigma_{savc,hh}$	$\sigma_{leic,hh}$	$\sigma_{ce,hh}$	$\sigma_{top,i}$	$\sigma_{2nd,i}$	$\sigma_{3rd,i}$
i01	Other agriculture	0.0	0.0				0.1		
i02	Sugar cane industry	0.0	0.0				0.1		
i03	Soy beans industry	0.0	0.0				0.1		
i04	Forest sector	0.0	0.0				0.1		
i05	Livestock sector	0.0	0.0				0.1		
i06	Food and beverage	0.0	0.0				0.1		
i07	Crude oil & natural gas	0.0	0.0				0.1		
i08	Metal & mineral mining	0.0	0.0				0.1		
i09	Coal mining	0.0	0.0				0.1		
i10	Textile & leather	0.0	0.0				0.1		
i11	Wood production	0.0	0.0				0.1		
i12	Pulp paper & furniture	0.0	0.0				0.1		
i13	Petroleum refinery	0.0	0.0				0.1		
i14	Biofuels sector	0.0	0.0				0.1		
i15	Chemical industry	0.0	0.0				0.1		
i16	Non metallic industry	0.0	0.0				0.1		
i17	Metal industry	0.0	0.0				0.1		
i18	Machinery equipment	0.0	0.0				0.1		
i19	Other manufacturing	0.0	0.0				0.1		
i20	Electricity generation						0.3	0.4	0.6
ei01	electricity: hydro	0.0	0.0				0.1		
ei02	electricity: nuclear	0.0	0.0				0.1		
ei03	electricity: coal	0.0	0.0				0.1		
ei04	electricity: gas	0.0	0.0				0.1		
ei05	electricity: oil	0.0	0.0				0.1		
ei06	electricity: wind	0.0	0.0				0.1		
ei07	electricity: biomass	0.0	0.0				0.1		
i21	Processed gas	0.0	0.0				0.1		
i22	Construction sector	0.0	0.0				0.1		
i23	Commercial sector	0.0	0.0				0.1		
i24	Transportation sector	0.0	0.0				0.1		
i25	Other service sector	0.0	0.0				0.1		
	Household		0.0	0.8	0.6	0.25			

For each sector i, the Armington elasticity for aggregating imported and domestic goods is denoted by $\sigma_{armt,i}$. For all other elasticity notations, please see Figure 1 for details.

Sources: Paltsev et al. (2005); Timilsina and Shrestha (2007).

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