COSTS OF REDUCING GREENHOUSE GAS EMISSIONS IN BRAZIL*

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Abstract – The Brazilian government has announced volunteer targets to reduce greenhouse gas (GHG) emissions during the 2009 COP meeting in Copenhagen and reassured them in Cancun (2010) and Durban (2011). In this paper we estimate the economic impacts from alternative policies to achieve such targets, including actions to cut emissions from deforestation and agricultural production. We employ a dynamic-recursive general equilibrium model of the world economy. The main results show that deforestation emissions in Brazil can be reduced at very low costs, but the costs of cutting emissions from agricultural and energy use may reach 2.3% loss in GDP by 2020 if sector specific carbon taxes are applied. Those costs may be reduced to 1.5% under a carbon trading scheme. The negative impacts of carbon taxes on agricultural production indirectly reduce deforestation rates. However, directly cutting emissions from deforestation is the most cost-effective option, since it does not negatively affect agricultural production, which still expands on lower yield and underutilized pasture and secondary forest areas.

Key-words: Climate policies, Brazil, deforestation, general equilibrium.

1. INTRODUCTION

The debate about climate change has received a lot of attention from the international community in the last decades. The most recent report from the Intergovernmental Panel on Climate Change (IPPC) points to an increase in 70% of the global greenhouse gas (GHG) emissions between 1970 and 2004 as the main driver on recent and expected future climate anomalies (IPCC, 2007).

The consequences from changes in the climate are very diverse. They range from the loss of biodiversity and ecosystems resilience to decreases in the agricultural production and yields, increasing incidence of tropical diseases, extreme weather events, among others.

Considering the risks of these changes, there is an increasing debate about the need for adopting mitigation and adaptation strategies at local, regional and global levels. The meetings carried at the United Nations Conference on Human Development and Environment in Rio de Janeiro in 1992 and in Kyoto in 1997 are important marks of the global concern about reducing emissions and avoiding climate change.

In particular, Brazil is an important player in the discussions about climate change. It has a unique pattern of emissions, since most of it comes from land use changes and deforestation (58%), followed by agriculture emissions (22%) and those related to energy use (16%) (BRASIL, 2009). 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. Other characteristic of the country has to

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do with the large potential to export carbon credits from projects related to the clean development mechanism (CDM). The United Nations Framework Convention on Climate Change (UNFCCC) lists Brazil as the third larger country in terms of CDM projects, which accounts for 6% of the world total. Only China and India have larger shares, with 39% and 27% respectively (UNFCCC, 2011).

Brazil 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 the country has announced volunteer goals to decrease emissions. Those goals were confirmed by the Law 12.187, The National Plan on Climate Policy, passed in December 2009 (World Resources Institute, 2010). Total emissions must be reduced by 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).

Although the country has assumed such targets, there is not a very clear definition of the policies and actions to be implemented and the costs to achieve them, besides some explicit strategies to increase deforestation monitoring, expanding hydropower generation and ethanol production. It creates a need for studies of the costs of alternative policy options to reduce emissions in Brazil.

The literature about the economy of GHG emissions in Brazil is developing fast. Some examples are Rocha (2003), Lopes (2003), Tourinho, Motta e Alves (2003), Feijó e Porto Jr. (2009), Moraes (2009), Estudo das Mudanças Climáticas no Brasil - EMCB (2010), among others. However, few of these studies evaluate quantitatively the impacts of policies to reduce GHG emissions on the Brazilian economy. Also, most of the papers use static economic models adapted to incorporate environmental aspects, and none of them have investigated the effects of the Copenhagen goals, nor policies to reduce emissions from deforestation.

The goal of this paper is to estimate the economic impacts of climate policy scenarios for Brazil, considering the possibility of reducing emissions from land use changes and deforestation. To achieve this goal, we improve and implement a worldwide economic model, extensively developed and used to forecast emissions and estimate costs from climate policies. Our investigation takes in consideration many of the specificities of the Brazilian economy, as an energy grid intensive in renewable sources and the explicit representation of the main GHG source in Brazil, i.e. deforestation. It also considers a forecast about the economy for the next 20 years and the representation of other countries and regions of the world and the relationship among them through international markets.

2. METHODS

2.1 The Model

The policies to reduce GHG usually cover many sectors and economic agents. To evaluate the economic impacts of the adoption of climate policies in Brazil it is necessary to use an approach able 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.

The CGE models are intensively used in studies about climate policies. They have been used to estimate the impacts from the Kyoto Protocol on the European Economy (Virguier *et al*., 2003), on the Japanese economy (Paltsev *et al*., 2004), and on the developing countries (Babiker, Reilly and Jacoby, 2000); to assess the costs of a climate policy in the United States (Paltsev *et al*., 2009); to evaluate the role of Russia in the Kyoto Protocol (Bernard *et al*., 2003); to investigate alternatives to reduce climate change in a cost-benefit analysis (Nordhaus and Yang, 1996; Nordhaus, 2007); and many others applications.

In this study we use the MIT Emissions Prediction and Policy Analysis (EPPA) Model[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 Paltsev *et al.* (2005).

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. We adopt the EPPA5 version of the model, since in the EPPA4 the Brazilian economy couldn't be analyzed alone since it was aggregated to the Latin America region. Given some characteristics of the Brazilian economy, as the large availability of natural resources as forestland, the electricity generation intensive in hydropower and the large share of biofuels in the transportation sector, it is justifiable the development and use of the EPPA5 version.

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).

In 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. Each economic sector is represented by a representative firm which chooses primary factors and

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

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.

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).

The zero profit condition imposes that any activity should have normal economic profits (equal to zero) to be able to achieve any positive amount of output, or the value of inputs need to be less or equal the value of the output. If it does not occur, there is no economic activity, since profit is negative. This is in accordance with perfect competition assumptions and constant returns to scale in production. This condition can be written as:

$$profit \geq 0, output \geq 0, output^T(-profit) = 0 \quad (1)$$

The second condition, market clearance, requires that a positive price exists if the supplied quantity equals the demanded quantity. Any good in excess supply will have a price equal to zero. This condition needs to be respected for all goods and primary factors, and the associate variable will be the price. Using the MCP approach, we can write this condition as:

$$supply - demand \ \geq 0; price \geq 0; price^T(supply - demand) = 0 \quad (2)$$

The income balance condition requires that, for each agent, the value of the total expense is equal to the value of the income. The income of the representative agent is obtained from selling its endowments and collecting the tax revenue:

$$income = endowment \ + tax\ reveune \quad (3)$$

In each region (r) and sector (i), a representative firm chooses the level of output (y) to be produced from the combination of primary factors (k_f) and intermediate inputs from other sectors in order to maximize its profits (π). Denoting its cost function by C, the prices of goods by p and of factors by w, the profit maximization problem can be represented as:

$$\max_{y_{ri}, x_{rji}, k_{rfi}} \pi_{ri} = p_{ri}\, y_{ri} - C_{ri}(p_{ri}, w_{rf}, y_{ri}) \text{ such that } y_{ri} = \varphi_{ri}(x_{rji}, k_{rfi}) \qquad (4)$$

All production sectors in EPPA are specified by technologies with constant elasticity of substitution (CES) with constant returns to scale. Using the duality theory and the property of linear homogeneity of the cost function, together with the zero economic profits assumption, we can represent the optimizing behavior of the firm by:

$$p_{ri} = c_{ri}(p_{rj}, w_{rf}) \qquad (5)$$

where c is the unit cost function.

By the Shephard's Lemma, the intermediate demand of sector i by good j is:

$$x_{rji} = y_{ri} \frac{\partial c_{ri}}{\partial p_{rj}} \qquad (6)$$

and the demand by the factor f is:

$$k_{rfi} = y_{ri} \frac{\partial c_{ri}}{\partial w_{rf}} \qquad (7)$$

A representative agent in each region is endowed with primary factors, which are sold or rented to firms. The agent's income (M) is used to maximize its utility function through consumption (d) and savings (s):

$$\max_{d_{ri}, s_r} W_{ri}(d_{ri}, s_r) \text{ such that } M_r = \textstyle\sum_f w_{rf} K_{rf} = p_{rs} s_r + \sum_i p_{ri} d_{ri}, \qquad (8)$$

The preferences are represented by CES functions. Using the duality theory and the property of linear homogeneity, we can write a unit expenditure function and welfare price index for each region of the model, as:

$$p_{rw} = E_r(p_{ri}, p_{rs}) \qquad (9)$$

Considering the initial expenditure level in each region as $\overline{m}_r$, the compensated final demand by goods can be found by the Shephard's Lemma:

$$d_{ri} = \overline{m}_r \frac{\partial E_r}{\partial p_{ri}}, \qquad (10)$$

As also the compensated final demand by savings:

$$s_r = \overline{m}_r \frac{\partial E_r}{\partial p_{rs}}, \qquad (11)$$

The system of equations given by the described equations is closed, with a set of prices for goods and factors determined by market clearing conditions:

$$y_{ri} = \textstyle\sum_j y_{rj} \frac{\partial C_{rj}}{\partial p_{ri}} + \overline{m}_r \frac{\partial E_r}{\partial p_{ri}}, \qquad (12)$$

$$K_{rf} = \textstyle\sum_j y_{rj} \frac{\partial C_{rj}}{\partial w_{rf}} \qquad (13)$$

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 below 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]

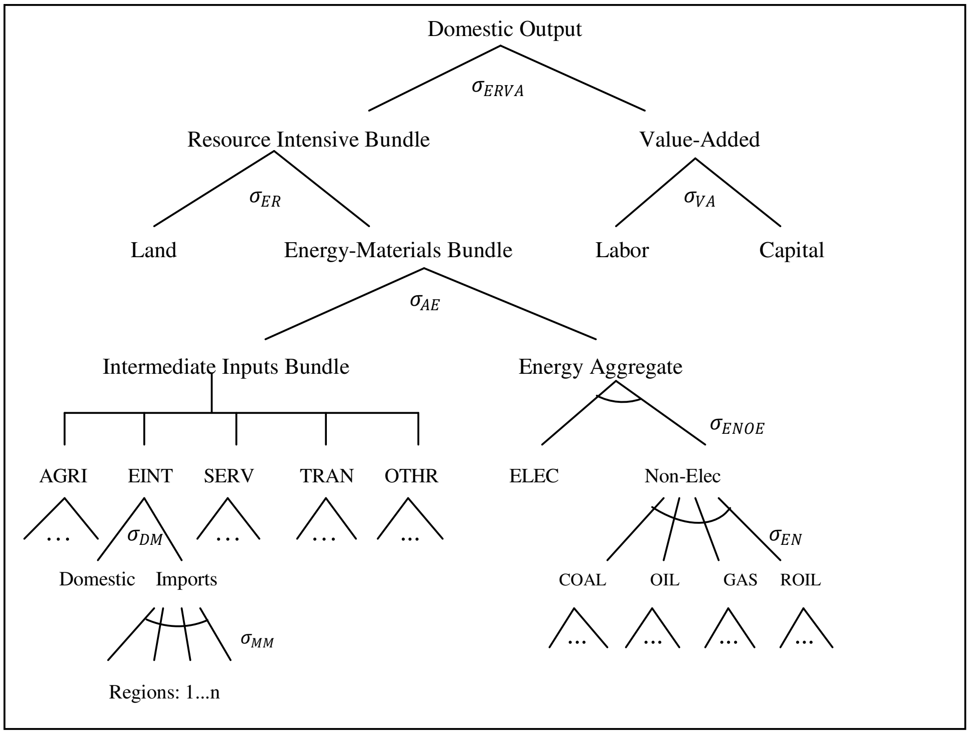

Figure 1. Structure of agricultural production sectors.
Source: Paltsev et al. (2005).

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 0.3	Varies by good Electricity
σ_{MM}	Among imports from different regions (Armington)	5.0 4.0 6.0 0.5	Non-energy goods Gas, Coal ROIL Electricity

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

Figure 2 presents the nested CES structure used to represent the household consumption. It considers the endogenous decision about consumption and savings at

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

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.

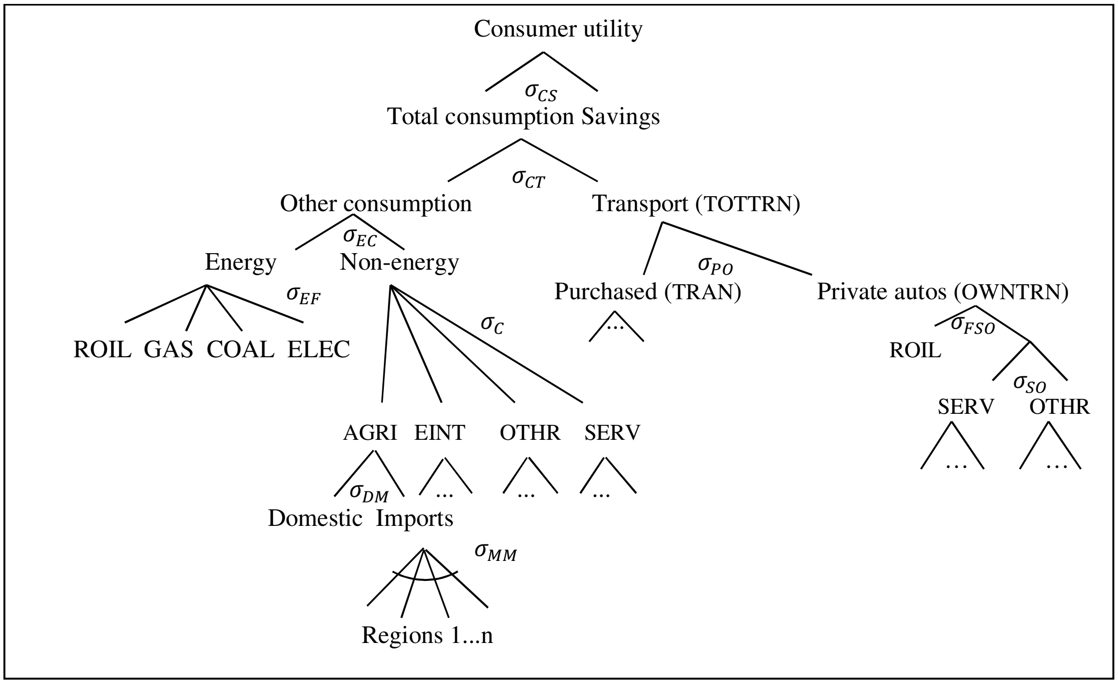

Figure 2. Structure of final demand in EPPA.
Source: Paltsev et al. (2005).

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

[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.

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. 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 giving the United Nations forecast (United Nations, 2000, 2001). The labor productivity improvement is specified to reproduce the observed and expected average GDP levels from the International Monetary Fund (IMF, 2000). Physical units are used to represent the energy data, based on the International Energy Agency (IEA, 2004, 2005). In the case of Brazil, we have compared this data with the main domestic statistics sources. The numbers about GHGs in EPPA come from the US Environmental Protection Agency (US EPA, 1999) and the global EDGAR database (Olivier and Berdowski, 2001). The Appendix A presents some of the Brazilian energy and emissions data in the benchmark as also in a reference (BAU) scenario simulated in the model. It also shows some benchmark economic data in the model.

3. RESULTS

3.1 Climate Policy Scenarios

Several climate policies are being discussed in the international debate about options to reduce GHG emissions, as taxes on carbon emissions, cap-and-trade policies, renewable fuel portfolios and standards, among others. Such measures are considered to be efficient in terms of reducing emissions and promoting innovation and development of less carbon intensive technologies.

During the 15th Conference of the Parties in Copenhagen in 2009, Brazil has announced a compromise to reduce its emissions. The national goal is to reduce GHG emissions between 36.1% and 38.9% by 2020 in comparison with the expected emissions for that year under no actions to mitigate climate change. This target is divided among four sources of emission. The cut in emissions from land use changes and deforestation should account for 24.7%. The agricultural sector needs to contribute between 4.9% and 6.1%, the energy use between 6.1% and 7.7%, and the iron and steel sector between 0.3% and 0.4%. It is important to notice that the sum of the cuts in the four sources needs to be equal to the national target. It means that, from the 38.9% cut in the 2020 emissions level from a hypothetical no-policy scenario, 63% must be reduction in deforestation emissions, 16% in agricultural emissions, 20% in energy use emissions and 1% in iron and steel industrial emissions.

Although the larger share of the expected reduction in emissions is related to land use changes, the emissions from energy use and other sectors is expect to grow in the next years since the economy has experienced strong growth rates recently. It means that the costs to cut emissions in the use of energy may increase as the economy grows.

We simulate several scenarios to investigate alternative ways to achieve the committed Brazilian targets. We first consider a carbon tax in each sector of the economy in order to reduce the emissions to the desired target level. As the government has specified different targets to agriculture, energy use and deforestation, we assume in this first scenario that there is no market for emissions abatement or trade in carbon allowances. To assure that each sector will achieve its emissions target, the tax is endogenously calculated by the model, and may differ among sectors.

The second scenario considers the carbon tax only on emissions from deforestation. In this way, there is no attempt to reduce emissions from energy use. In the third scenario we cut emissions only on energy and agriculture and do not consider reductions in the emissions from land use change. These two scenarios should allow understanding the role and costs of cutting emissions from different sources to achieve the total Brazilian target.

Finally, we also implement an emissions trading scheme among all sectors in the economy and all gases to capture the possible lower costs of implementing a carbon market instead of sectoral using emissions taxes. We exclude deforestation emissions from the trade scheme, but still implement the carbon tax on emissions from land use changes, since they are being treated separately in the global discussions about climate change mitigation.

As a summary, we identify the scenarios by the following:

BAU: reference or business as usual, no targets to reduce emissions;
Copenhagen: achieve the Brazilian target assumed in Copenhagen, reducing emissions by 39.1% in 2020, applying sectoral carbon taxes;
Copenhagen – LUC only: achieve the Brazilian target assumed in Copenhagen, reducing emissions by 24.7% in 2020 only from deforestation, applying a carbon tax;
Copenhagen – Ener & Agr: achieve the Brazilian target assumed in Copenhagen, reducing emissions from energy use and agriculture by 7.7% and 6.1% in 2020, respectively;
Copenhagen – C market: achieve the Brazilian target assumed in Copenhagen, reducing emissions by 39.1% in 2020, applying an overall market on GHG allowances on emissions from energy use and agriculture, and a carbon tax on emissions from deforestation to achieve 24.7% of reduction in emissions by 2020;

All policy scenarios cover all GHG gases and allow trading among them based on Global Warming Potential (GWP) numbers within a sector (in the case of specific carbon taxes by sector) or among all sectors (in the *Copenhagen – C Market* policy). We start all the policies in 2015, assuming that half of the 2020 target needs to be achieved at that year. We simulate the model horizon till 2030, and assume that the emissions constraints need to be 25% higher in 2025 and 45% higher in 2030 compared to the 2020 target. This assumes that Brazil will keep pursuing to reduce its emissions after 2020 with stronger commitments, although not yet discussed by the Brazilian government.

3.2 Results Discussion

The introduction of targets to reduce GHG emissions in Brazil through carbon taxes and carbon markets will change the trajectory of emissions in the country, as shown in Figures 3 and 4. The EPPA model projects a decrease in emissions from 2005 to 2015 in the *BAU* scenario, due to lower emissions from deforestation, but some increase in emissions from deforestation, energy use and agriculture after 2015. The deforestation rates reduce till 2015 as consequence of the calibration process, which captures the observed reduction in emissions from land use changes from 2005 to 2010. However, as the land supply elasticities were calibrated based on the expansion of the agricultural frontier from the past two decades, period with considerable deforestation rates in Brazil, the world economic growth expected after 2015 pushes the recovery in deforestation rates in Brazil in our BAU scenario.

Under the *Copenhagen* scenario, the country achieves 21% of reduction in GHG emissions by 2015, 39% by 2020, 50% by 2025 and 58% by 2030, compared to BAU emissions.[4] The higher cut in emissions come from land use changes (or deforestation), as determined by the target, while energy and agriculture emissions have a minor role. In the case of the *Copenhagen – LUC only* scenario, energy and agriculture emissions are not affected by reductions in deforestation emissions. It means that there are no side effects from stopping deforestation rates on energy use or agricultural emissions in the country. If the country decides to cut only emissions from deforestation, it alone could reduce Brazilian GHG emissions between 12% and 36% from 2015 to 2030. However, if there is no attempt to reduce emissions from land use change while reducing emissions from agriculture and energy use, deforestation is indirectly affected, and, as consequence, a higher total reduction in emissions is

[4] As the emissions in the scenario *Copenhagen – C market* are the same as in the scenario *Copenhagen*, we decide do not include them in the Figures 3 and 4.

obtained in comparison to just cutting deforestation emissions. This result suggests that deforestation rates could be considerably reduced only by curbing agricultural emissions.

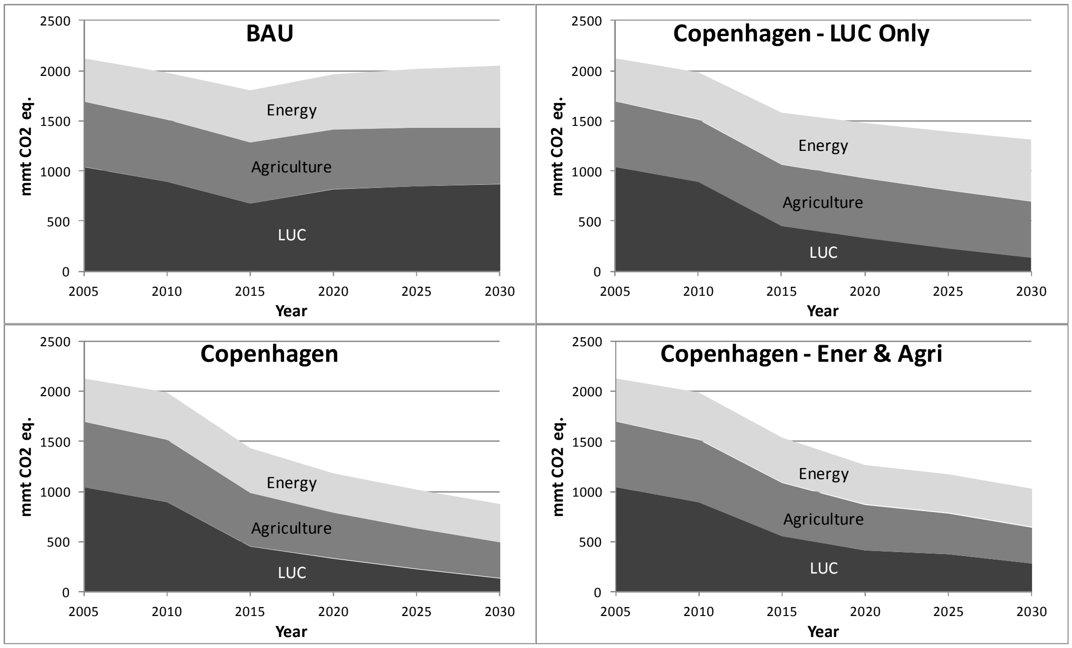

Figure 3. GHG emissions from alternative scenarios

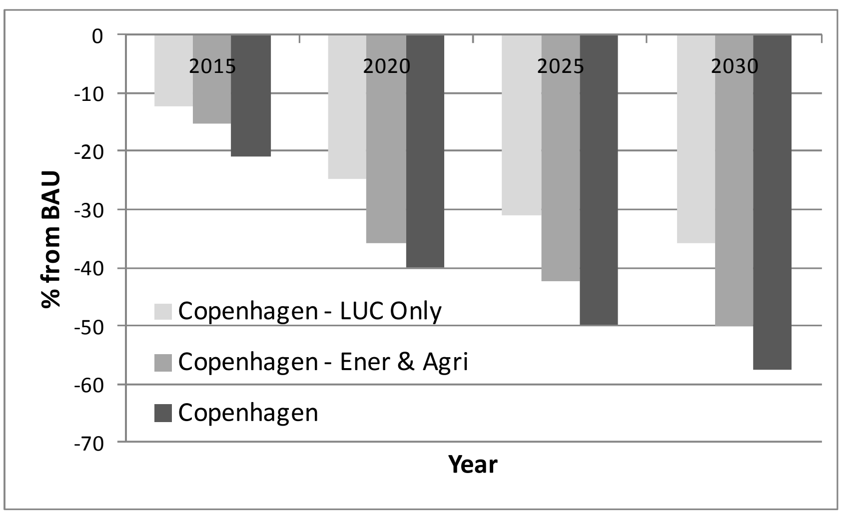

Figure 4. Total reduction in GHG emissions from BAU under alternative scenarios.

The strong impact on emissions from the *Copenhagen – Ener & Agri* scenario raises the question about how the alternative scenarios affect the land use in the country. Figure 5 shows the land use trajectory for the main four land use categories. The reference (*BAU*) trajectory in the EPPA model suggests that cropland and pasture areas will continuously advance after 2015, while forests (natural, secondary and for forestry production) will give space to them. Under the *Copenhagen – LUC only* case, the conversion of natural forest is prevented by the tax on its emissions, which strongly reduces the rate of deforestation. It also slightly decreases the advance of cropland and pastures that now advances on secondary forest and forestry production areas, which have much lower carbon than natural forests. In the *Copenhagen – Ener & Agri* scenario, the GHG taxes impact the agricultural production, preventing its expansion. As consequence, the pressure to reduce forest land area is gone, avoiding much of the deforestation observed in the *BAU* case. The *Copenhagen* case has the same impact, but the taxes on land use emissions prevent even more deforestation. In summary, if emissions from deforestation are directly targeted, it does not compromise the expansion of agricultural areas in Brazil till 2030, since agriculture still can expand on previously deforested (secondary forests) and managed forest areas. However, if agriculture emissions need to be reduced, it will increase the costs of crop and livestock production at the point that those activities will stop expanding in the country.[5]

It is important to notice that the cropland area is less affected than the pasture area by the taxes on land use changes in the *Copenhagen – LUC only* scenario, suggesting that the pasture expansion has a stronger influence on the deforestation of natural forests than the cropland expansion. It just reflects the fact that the EPPA model calibration of land use changes reproduces a pattern where, in net terms, the pasture is a first option to use the land after the conversion of the natural forest, and cropland is preferable settled on secondary or managed forest areas.

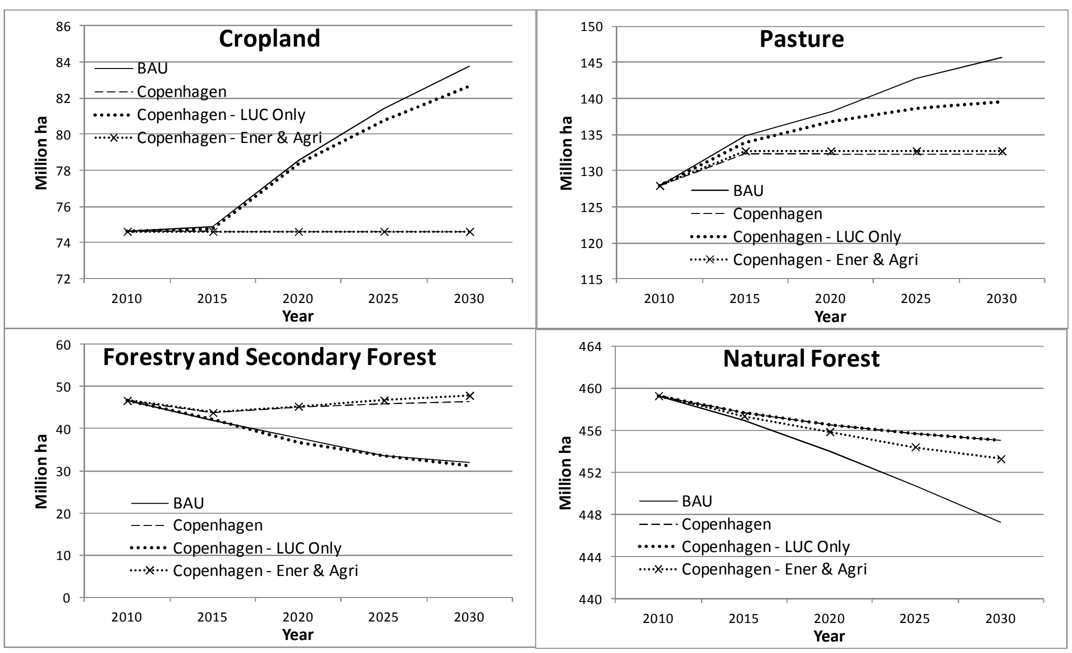

Figure 5. Land use in the alternative scenarios.

One important aspect of a climate policy to reduce GHG emissions is the magnitude of carbon tax or price to be paid by the economic agents. Figure 6 shows the carbon tax in each sector to achieve the emissions target set by the policies in the *Copenhagen* scenario. They range from U$ 28 per ton of CO_2 eq. in 2015 to US$ 290 in 2030. The tax is endogenously calculated by the model in order to achieve the quantitative constraint in emissions. It gives a signal about how costly it would be to achieve the sectoral emissions target assumed by the country in the Copenhagen meeting. The resulting carbon price, or endogenous tax, is the result of the equilibrium between the sectoral supply and demand by the carbon permits (or carbon allowances)

[5] This suggests very few mitigation opportunities in the Brazilian agriculture sectors in EPPA. We discuss this aspect latter in the paper, as also in the Appendix B by performing some sensitivity analysis.

issued to achieve the quantitative emissions target. As the reduction in emissions is specified by sector, its supply of carbon permits is given. Those sectors with more abatement possibilities (i.e. cheaper abatement technology options or higher capability to switch from high carbon fuels to alternative energy sources) tends to generate lower demand by carbon permits to keep the same BAU output level than other sectors without much abatement options, which tends to decrease the carbon tax. However, if a sector is a strong polluter and do not have cheap ways to reduce its emissions, a low carbon tax will increase its costs too much and may force a reduction in its activity level, reducing its demand of carbon permits and freeing some factors and inputs to be used in other sectors. In this situation, a sector with many abatement possibilities may attract the available resources to expand its activities, which will increase the demand of permits and the carbon price. At the end, the final carbon price is the result of forces changing the comparative advantage among sectors under the sectoral carbon constraints, the competition by factors among sectors and the sectoral emissions abatement possibilities.

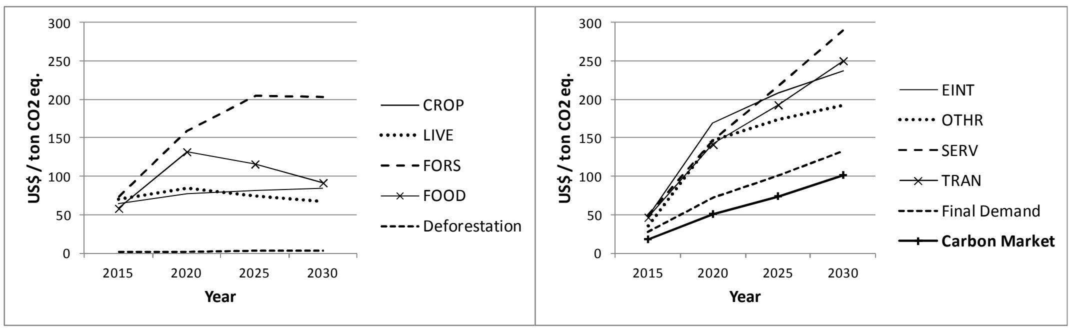

Figure 6. GHG sectoral carbon prices

The level of the carbon price for the crop and livestock sectors are relatively low, which in principle could be associated with the availability of several technology options to reduce GHG emissions, as lower emissions related to better methods of nitrogen application, no tillage practices, improving pasture yields and intensifying cattle production, burning methane emissions from manure, among others.[6] However, as the use of land by those sectors does not increase under the policy, we can conclude that the carbon costs reduce the comparative advantage of these sectors, limiting their growth, what will reduce the demand of permits[7]. The food sector would pay relatively lower carbon prices since its main input comes from agricultural production. The price on emissions from final demand is also relatively low, since households have the option of using sugarcane ethanol in household transportation, which generates much lower emissions than fossil fuels. Higher carbon prices are observed in the energy intensive industry (EINT), services (SERV) and industrial transportation (TRAN). It reflects the fact that those sectors do not have many options to change their energy sources, or to

[6] These technology options are indirectly represented in the EPPA model by elasticities of substitution between the emissions allowances and the sectoral output or inputs used in the sector. Such elasticities are documented in Paltsev et al. (2005) and reflect bottom-up estimates of abatement possibilities. In the case of Brazil, the default elasticities are 0.02 for CH_4 and N_2O emissions in the agricultural sectors, what is considerably low. Appendix B presents a simple sensitivity analysis of these elasticities in the Brazilian agricultural sector.

[7] We further confirm it when discuss later the results of reduced output for crop and livestock sectors.

control its composition[8], but their output level does not decrease as much as the carbon constraint.

Figure 6 also shows the carbon price that would arise under the *Copenhagen CO_2 Mkt* scenario, labeled "Carbon market". This price is substantially lower than an average sectoral carbon price, and shows how it would be much less costly in average to create a carbon market for all emissions from energy use and agricultural production than set specific carbon markets to each sector. This lower carbon price arises since the supply of carbon permits is now available to all sectors, and those with cheaper abatement opportunities could sell some carbon allowances to those sectors with less flexibility in reducing emissions.

Another important result from Figure 6 is the carbon prices on emissions from deforestation, which are incredible low, between U$ 1 and U$ 3 per ton of CO_2 eq. It means that a very low carbon tax on emissions from land use change could strongly reduce deforestation. Actually, it happens since the total amount to be paid per deforested area is considerably large, due to the high content of carbon lost during the deforestation process[9], much higher than the emissions coming from the industrial or agricultural processes. It should be noticed that the carbon tax on land use changes is an idealized cost-effective policy, since in practice it would be very hard to think how it could be implemented or enforced. Maybe a more realistic policy to be tested in a future work would be to tax the land conversion per area, instead of taxing it per emissions.

Table 4 presents the changes in the value of sectoral output in Brazil in the alternative scenarios, in comparison with the output value in the *BAU* case. The changes under the *Copenhagen* and *Copenhagen – Ener & Agri* cases are exactly the same, while there is very few output changes under the *Copenhagen – LUC only* scenario. It means that the agricultural output is barely affected when the deforestation rate decreases, since it still expands on secondary and managed forest areas. Also, crop and pasture production is intensified, achieving higher yields. It is in accordance with the observation of low cattle stocking rates in the Brazilian pastures and high potential to improve agricultural output by adopting better management practices.

When the emissions from energy use and agricultural production are taxed, many sectors suffer considerable reduction in output. Fossil fuel and agricultural sectors are the most negatively affected, since they are directly responsible for emissions sources. The output from the industrial transportation sector (TRAN) is also strongly impacted, since the model does not consider alternative fuels (as biofuels) as an option in this sector, only in the household transportation. There is some mobility of primary factors from those sectors reducing output to others, what explains the output gains in the forestry (FORS), other (OTHR) and service (SERV) sectors. It means that such sectors rely much less on energy than others, facing lower increases in production costs due to the carbon taxes. As consequence, the carbon taxes change the comparative advantage in the economy in favor to less energy-intensive sectors. The shifts in comparative advantage may also be observed by comparing the reductions in output to the level of reduction in emissions from the reference scenario. As discussed in the Introduction, emissions in agriculture must reduce by 16% and in energy use by 20% in

[8] Most of the electricity in Brazil comes from hydropower. The EPPA projections about the future expansion of the hydropower capacity in Brazil are lower than the expected economic growth, reflecting increasing barriers to build new plants in Brazil due to environmental and social issues.

[9] The EPPA model assumes the average amount of carbon in the Brazilian natural forest (in soil and vegetation) as 22,143 g per m^2 , based on the Terrestrial Ecosystem Model used in Melillo et al. (2009). This amount is reduced to 7,176 g per m^2 if the conversion generates a secondary or managed forest. Given the EPPA results about CO_2 taxes on deforestation, they would correspond to a land use tax per ha of U$ 792 in 2020.

2020 compared to the BAU emissions. Table 4 shows output reductions in crop, livestock and transportation sectors as large as the cut in emissions, while food, energy intensive and electricity sectors do not reduce their outputs that much.

Table 4. Change in the value of output (%) from the BAU scenario

	Copenhagen												
	CROP	LIVE	FORS	FOOD	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
2015	-3.1	-1.9	6.7	-1.3	-10.9	-4.6	-8.5	-14.9	-1.1	-3.2	0.7	0.1	-8.7
2020	-14.2	-12.3	13.3	-9.3	-20.9	-11.0	-15.8	-30.0	-2.8	-7.5	2.6	0.4	-19.2
2025	-21.1	-19.2	15.3	-15.0	-25.3	-12.0	-18.4	-37.2	-3.5	-8.2	3.1	0.4	-22.9
2030	-27.7	-25.9	17.9	-20.5	-29.2	-11.2	-20.0	-42.4	-3.9	-8.2	3.4	0.4	-25.9
	Copenhagen - LUC Only												
	CROP	LIVE	FORS	FOOD	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
2015	-0.1	-0.1	7.6	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2020	-0.1	-0.1	17.7	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	-0.3	-0.3	21.4	-0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2030	-0.4	-0.4	24.4	-0.3	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0
	Copenhagen - Energy Only												
	CROP	LIVE	FORS	FOOD	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
2015	-3.1	-1.9	3.1	-1.3	-10.9	-4.6	-8.5	-14.9	-1.1	-3.2	0.7	0.1	-8.7
2020	-14.2	-12.3	10.3	-9.3	-20.9	-11.0	-15.8	-30.0	-2.8	-7.5	2.6	0.4	-19.2
2025	-21.1	-19.2	10.2	-15.0	-25.3	-12.0	-18.4	-37.2	-3.5	-8.2	3.1	0.4	-22.9
2030	-27.7	-25.9	13.0	-20.5	-29.2	-11.2	-20.0	-42.4	-3.9	-8.2	3.4	0.4	-25.9
	Copenhagen - Carbon Mkt												
	CROP	LIVE	FORS	FOOD	COAL	OIL	ROIL	GAS	ELEC	EINT	OTHR	SERV	TRAN
2015	-0.7	-0.5	7.3	-0.3	-19.9	-2.3	-9.0	-14.2	-2.7	-2.4	0.3	0.0	-4.8
2020	-8.7	-6.3	15.4	-4.6	-38.4	-8.3	-18.8	-34.1	-7.1	-4.9	1.4	0.0	-10.1
2025	-14.9	-12.6	17.9	-9.7	-45.3	-9.8	-22.9	-43.8	-8.8	-5.6	2.2	0.1	-12.7
2030	-21.0	-19.2	20.4	-15.1	-50.2	-9.8	-26.2	-49.3	-8.4	-5.6	2.8	0.2	-15.0

Source: Research results.

Under a carbon market (*Copenhagen – Carbon Mkt* case), most of the decrease in output becomes smaller than under the sectoral carbon taxes (*Copenhagen* case). In general, sectors need to pay a carbon price lower than the sectoral carbon tax, what implies in lower carbon costs. The fossil fuel energy sectors face higher decreases in their output value, since the carbon price applies directly to their output, reducing the demand for fossil fuels and their profits.

The overall policy costs to the Brazilian economy can be assessed by the changes in welfare[10] and in GDP. Figure 7 shows that the higher welfare costs range from 0.23% loss in welfare in 2015 to 2.5% in 2030, and 0.7% loss in GDP in 2015 to 4.5% in 2030 compared to *BAU* welfare and GDP, in the *Copenhagen* scenario. Those costs are not negligible, although they are relatively low compared to the somewhat

[10] We measure welfare changes as the equivalent variation in consumption.

large reductions in emissions.[11] Under the *Copenhagen – LUC Only* case we do not observe any loss. Two aspects drive this result: cropland and pasture areas keep expanding on secondary and managed forest if emissions from land use changes are taxed, and some land intensification is occurring at lower costs due to better agricultural practices, avoiding the decrease of agricultural output. We do not show the costs in the *Copenhagen – Ener & Agri* case in Figure 7, since they are exactly the same as in the *Copenhagen* case, confirming that all the losses are due to the emissions constraints in energy use and agricultural production.

If the country implements a carbon market covering emissions from energy and agriculture, the welfare and GDP costs decrease by 30% to 45%, confirming this policy as a more cost-effective option. As discussed before, a unique carbon price would allow higher level of emissions abatement in those sectors with cheaper green technology options and more flexibility in energy choices, and avoid higher economic costs to achieve the overall emissions target.

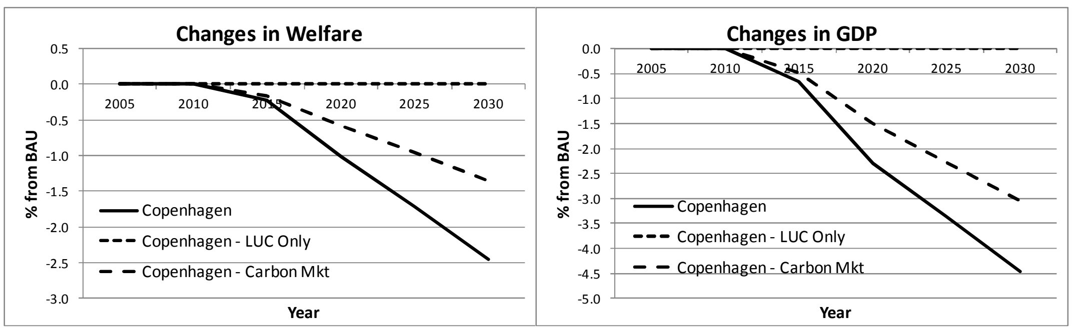

Figure 7. Changes in welfare and GDP.

4. CONCLUSION

Brazil is an important player in the discussions about climate change, due to its considerable contribution to emissions from land use changes. During the 2009 15th COP meeting in Copenhagen, the Brazilian government announced its volunteer target to reduce emissions between 36.1% and 38.9% by 2020, with most of it (24.7%) coming from lower deforestation rates. This paper used a global economic model to estimate the possible impacts of such challenging goal.

We implemented the Brazilian emissions target in alternative ways. First we assume differentiated sectoral taxes on emissions, since the agricultural target differs from the one on energy use. Second, we considered that the country only seeks to achieve the reduction in the emissions from land use change. Alternatively, we simulate the cut in emissions in energy use and agricultural production, without considering the cuts in deforestation. Finally, we simulated a carbon market among sectors using energy and agricultural sectors, with trade in emissions allowance among them, and keeping the target to reduce emissions from land use changes.

Our results suggest that a very small carbon tax on emissions from land use changes would be enough to reduce deforestation, practically without losses in welfare or in GDP. We recognize, however, the corresponding challenge of measuring

[11] It should be noticed that the EPPA model does not measure the benefits from avoiding climate change. In this way, we just look at the cost-effectiveness of the policy, and do not perform a cost-benefit analysis. It means that we cannot draw conclusions about how the policy could increase welfare or GDP by avoiding climate change impacts, but recognize that such gains are the reason to apply climate policies and may be higher than the economic losses from the carbon taxes and carbon markets.

andenforcing emissions reductions, which means that our results might be too optimistic since they neglect the possible costs associated with monitoring and enforcement. Given the small economic incentive necessary to reduce deforestation rates in our model, we conclude that the pressure to open new land to agriculture use in the country is much more related to the very low cost of converting new areas to agriculture, a sign of poorly defined and/or enforced property rights, than to the necessity of area to satisfy increasing demand by food, fiber and fuels.

As stopping deforestation does not generate aggregate welfare costs in our scenarios, we can conclude that Brazilian agricultural production, mostly cattle and beef, may be improved to achieve higher efficiency and be better distributed, developing underutilized land in the country, mostly occupied by low yield pasture.

Our results also point that the deforestation can be indirectly reduced by constraints in the emissions from agriculture production and energy use. But in such case, the agricultural sectors will reduce production and lose competitiveness, contributing to welfare and GDP losses. Although such losses are relatively low, given the strong cut in emissions, it would be a wiser choice to pursue the less costly policy option, which is to cut emissions from deforestation. When reducing emissions from energy use and agriculture, it is possible to achieve lower losses under the implementation of an emissions trading scheme, what means to abandon the original Brazilian proposal of applying different cuts in emissions in agricultural and energy use.

There is no certainty yet about how the Brazilian target about emissions from energy use and agriculture would be implemented. Sectoral carbon taxes would not be a cost-effective way to do it, as shown in this study. If the government chooses a single carbon tax to apply to all sectors, this should be equivalent to the price coming from a carbon market, but the uncertainty about this price makes it difficult to set the correct level of the tax. In this way, a carbon market would be the better option, although the implementation of such market is challenging, since there is the need to measure and control all emissions sources in the economy. Given such difficulties and the low cost of stopping emissions from land use changes, we believe the country should seek to reduce emissions from deforestation while improving methods to measure industrial and agricultural emissions and seeking technological advances to reduce emissions from them.

REFERENCES

Babiker, M., J. Reilly and H. Jacoby. The Kyoto Protocol and developing countries. *Energy Policy,* v. 28, p. 525-536, 2000.

Bernard, A., S. Paltsev, J. M. Reilly, M. Vielle, L. Viguier. *Russia's Role in the Kyoto Protocol.* Cambridge, MA: MIT, 2003. (MIT Joint Program on the Science and Policy of Global Change, Report 98).

BRASIL. Ministério de Ciência e Tecnologia. *Inventário Brasileiro das Emissões e Remoções Antrópicas de Gases de Efeito Estufa* – Informações Gerais e Valores Preliminares. 2009.

Brooke, A., D. Kendrick, A. Meeraus, R. Raman. GAMS: *a user's guide*. GAMS Development Corporation, p. 262, 1998.

Dimaranan, B., R. Mcdougall. *Global Trade, Assistance, and Production:* The GTAP5 data base. West Lafayette: Center for Global Trade Analysis, 2002.

EMCB. *Economia da Mudança do Clima no Brasil: Custos e Oportunidades* / editado por Sérgio Margulis e Carolina Burle Schmidt Dubeux, coordenação geral Jacques Marcovitch.– São Paulo: IBEP Gráfica, 2010. 82 p.

Feijó, F. T., S. S. Porto Jr. Protocolo de Quioto e o Bem Estar Econômico no Brasil Uma Análise Utilizando Equilíbrio Geral Computável. *Análise Econômica*, v. 51, p. 127-154, 2009.

GOVERNO FEDERAL. *Plano Nacional sobre Mudança do Clima (PNMC)*. Available in: <HTTP://www/mma/gov.br/estruturas/smcq_climaticas/_arquivos/plano_nacional_mudanca_clima.pdf>

Gurgel, A., J. M. Reilly, S. Paltsev. Potential land use implications of a global biofuels industry. *Journal of Agricultural & Food Industrial Organization* 5, article 2, 2007.

Intergovernmental Panel on Climate CHANGE (IPCC). *Climate Change 2007:* Mitigation of Climate Change. Cambridge: Cambridge University Press, 2007. 851 pp. Available in : < http://www.ipcc-wg3.de/publications/assessment-reports/ar4/working-group-iii-fourth-assessment-report>

International Energy Agency. *World Energy Outlook: 2004*. OECD/IEA: Paris, 2004.

International Energy Agency. *Energy Balances of Non-OECD Countries* (2005 edition) OECD/IEA: Paris, 2005.

International Monetary Fund, *World Economic Outlook (September)*, Washington DC: International Monetary Fund, 2000.

Kydland, F., E. C. Prescott. The Computional Experiment: An Econometric Tool. *Journal of Economic Perspectives*, v.10, n.1, p. 69-85, 1996.

Nordhaus, W. *The challenge of global warming*: economic models and environmental policy in the DICE-2007 Model. New Haven: Yale University, 2007. Available in: <http://nordhaus.econ.yale.edu/dice_mss_091107_public.pdf>

Nordhaus, W. D., Z. Yang. A Regional dynamic general-equilibrium model of alternative climate change strategies. *The American Economic Review*, Nashville, v. 86, n. 4, p.741-765, 1996.

Melillo, J. M., J. M. Reilly, D. W. Kicklighter, A. C. Gurgel, T. W. Cronin, S. Paltsev, B. S. Felzer, X. Wang, A. P. Sokolov, C. A. Schlosser. Indirect Emissions from Biofuels: How Important?. *Science*, v.326, p.1397 - 1399, 2009.

Moraes, G. I. *Efeitos econômicos de cenários de mudança climática na agricultura brasileira: um exercício a partir de um modelo de equilíbrio geral computável*. 2010. 103 f. Tese (Doutorado) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2010.

Lopes, R. L. *Efeitos de uma restrição na emissão de CO_2 na economia brasileira*. 2003. Tese (Doutorado) – Escola Superior de Agricultura “Luiz de Queiroz” - USP, Piracicaba.

Narayanan, B. G., T. G. Walmsley. *Global trade, assistance, and production: the GTAP 7 data base*. [West Lafayette]: Center for Global Trade Analysis, Purdue University, 2008.

Olivier, J. G. J., J. J. M. Berdowski. Global emissions sources and sinks. In: Berdowski, J., R. Guicherit, B. J. Heij (Ed.). *The climate system*. Lisse: Balkema Publishers/Swets & Zeitlinger Publishers, 2001. p. 33-78.

Paltsev, S., J. M. Reilly, H. D. Jacoby, K. H. Tay. *The Cost of Kyoto Protocol Targets:* the Case of Japan. Cambridge, MA: MIT, 2004. (MIT Joint Program on the Science and Policy of Global Change, Report 112).

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. Mcfarland, M. Sarofim, M. Asadoorian, M. Babiker. *The MIT Emissions Prediction and Policy Analysis (EPPA) Model:*

Version 4. Cambridge, MA: MIT, 2005. (MIT Joint Program on the Science and Policy of Global Change, Report 125) Available in: <http://web.mit.edu/globalchange/www/MITJPSPGC Rpt125.pdf>

Paltsev, S., J. M. Reilly, H. D. Jacoby, J. F. Morris. *The Cost of Climate Policy in the United States.* Cambridge, MA: MIT, 2009. (MIT Joint Program on the Science and Policy of Global Change, Report 173) Available in: <http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173.pdf>

Reilly, J., K. Fuglie. Future Yield Growth in Field Crops: What Evidence Exists? *Soil and Tillage Research* 47, 275-290, 1998.

Rocha, M. T. *Aquecimento global e o mercado de carbono:* uma aplicação do modelo CERT. 2003. 196 f. Tese (Doutorado) – Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba, jan. 2003.

Rutherford, T. F. Extensions of GAMS for Complementarity Problems Arising in Applied Economic Analysis, *Journal of Economic Dynamics and Control,* v. 19, n. 8, p. 1299-1324, 1995.

Shoven, J. B., J. L. Whalley. Applied General Equilibrium Models of Taxation and International Trade: An Introduction and Survey, *Journal of Economic Literature* v. 22, p. 1007-1051, 1984.

Tourinho, O. A. F., R. S. da Motta, Y. L. B. Alves. *Uma aplicação ambiental de um modelo de equílibrio geral.* Rio de Janeiro: IPEA, 2003. Texto para discussão n. 976. Available in: <http://www.ipea.gov.br/pub/td/2003/td_0976.pdfp>

United Nations Framework Convention On Climate Change (UNFCCC). *Clean Development Mechanism.* 2011. Available in: http://cdm.unfccc.int

United Nations (UN). *Long-Run World Population Projections:* Based on the 1998 Revision. New York, 2000.

_____. *World Population Prospects:* The 2000 Revision, Data in digital form. New York: Population Division, Department of Economic and Social Affairs, 2001.

US Environmental Protection Agency. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-1997*, Technical Report EPA 236-R-99-003, Office of Policy, Planning and Evaluation, Washington DC 1999.

Viguier, L., M. Babiker, J. Reilly. The costs of the Kyoto Protocol in the European Union. *Energy Policy*, v. 31, n. 5, p. 393-483, 2003.

World Resource Institute. *Brazil's Global Warming Agenda.* Washington, DC, 2010. Available at: <http://www.wri.org/stories/2010/03/brazils-global-warming-agenda>

Appendix A – Benchmark database and BAU projection

We present here some of the benchmark data in EPPA and the numbers generated by the model through its time horizon. Table A1 presents the GDP by EPPA region. Tables A2 to A6 present: Brazilian benchmark data and projections about land use, value of production by sector, GHG emissions by source, primary energy consumption and electricity supply by source. The historical data (2004 to 2010) was compared to official statistics and reflect the historical numbers in general. The future projections are in agreement with forecasts from international institutions, as the IMF, the World Bank, the U.S. Environmental Protection Agency and the International Energy Agency.

Table A1. Benchmark and Reference GDP projections in EPPA, (in US$ 10 billion of 2004)

	USA	CAN	MEX	JPN	ANZ	EUR	ROE	RUS	ASI	CHN	IND	BRA	AFR	MES	LAM	REA
2004	1167	97	69	462	76	1279	54	57	167	183	64	61	79	85	86	28
2005	1202	100	70	472	78	1304	57	59	177	191	68	69	84	90	90	31
2010	1259	106	75	488	84	1347	67	69	197	296	98	83	107	116	108	42
2015	1460	120	83	532	97	1474	77	80	231	429	137	100	123	136	123	50
2020	1647	136	91	577	111	1618	88	91	261	610	188	115	140	156	142	60
2025	1856	154	100	623	129	1768	101	102	296	859	258	133	165	181	164	73
2030	2116	177	113	675	150	1931	117	114	340	1194	333	154	196	210	190	90

Source: Model projections in the reference scenario.

Table A2. Land use in Brazil (in Million ha)

	Crop	Pasture	Forest	Nat.Grass	Nat.Forest	Bioelec	Ethanol	Other	Total
2005	72	121	51	93	462	0	3	51	853
2010	70	128	47	93	459	1	4	51	853
2015	70	135	42	93	457	1	4	51	853
2020	74	138	38	93	454	1	4	51	853
2025	77	143	34	93	451	1	4	51	853
2030	79	146	32	93	447	1	4	51	853

Source: Model projections in the reference scenario.

Table A3. Sectoral value of production in Brazil (in US$ 10 billion of 2004)

	Crop	Live	Fors	Food	Coal	Oil	Roil	Gas	Elec	Eint	Othr	Serv	Tran
2004	4.9	1.7	0.1	8.2	0.0	1.8	3.8	0.1	3.1	14.4	28.3	38.0	3.3
2005	4.6	1.7	0.1	9.2	0.0	1.9	3.8	0.1	3.2	15.4	31.7	41.2	3.6
2010	4.7	1.9	0.1	10.4	0.0	2.1	4.0	0.1	3.6	17.2	36.9	50.2	4.4
2015	5.3	2.2	0.1	11.9	0.0	2.4	4.5	0.2	4.0	20.7	43.7	61.5	5.4
2020	5.9	2.4	0.1	13.0	0.0	2.5	4.7	0.2	4.3	23.5	49.2	71.5	6.2
2025	6.5	2.6	0.1	14.4	0.0	2.7	5.0	0.2	4.6	27.1	55.9	83.9	7.2
2030	7.2	2.9	0.1	15.9	0.0	2.7	5.3	0.2	4.8	31.1	63.3	98.4	8.4

Source: Model projections in the reference scenario.

Table A4. Sectoral GHG emission in Brazil (in mmt CO_2 eq.)

	2004	2005	2010	2015	2020	2025	2030
Crop	372	367	345	340	339	333	323
Live	284	286	277	271	260	252	242
Fors	0	0	0	0	0	0	0
Food	4	4	5	5	5	5	5
Coal	1	1	1	1	1	1	1
Roil	75	75	84	96	103	113	122
Elec	23	26	24	27	30	28	26
Eint	92	97	104	118	126	136	145
Othr	8	9	10	11	12	13	14
Serv	5	5	5	5	6	6	6
Tran	92	99	112	125	132	142	151
Htran	51	37	34	33	31	30	29
FD	51	59	68	73	74	75	76
Cem	14	15	18	23	28	34	40
Deforest.	948	1,044	894	676	819	851	871
Total	2,020	2,123	1,982	1,806	1,965	2,018	2,050

Source: Model projections in the reference scenario.

Table A5. Primary Energy Consumption in Brazil (in EJ)

	Coal	Roil	Gas	Hydro	Biomass	Nuclear
2004	0.51	4.15	0.56	1.11	0.34	0.08
2005	0.53	4.10	0.59	1.16	0.37	0.08
2010	0.60	4.31	0.64	1.32	0.59	0.09
2015	0.68	4.73	0.74	1.46	0.61	0.09
2020	0.73	4.95	0.82	1.55	0.64	0.09
2025	0.79	5.22	0.88	1.68	0.71	0.10
2030	0.84	5.46	0.94	1.81	0.77	0.10

Source: Model projections in the reference scenario.

Table A6. Electricity by Source in Brazil (in EJ)

	Coal	Oil	Gas	Hydro	Nuclear	Bioelec
2004	0.03	0.06	0.07	1.11	0.04	
2005	0.04	0.07	0.08	1.16	0.04	
2010	0.04	0.06	0.08	1.32	0.04	0.04
2015	0.04	0.07	0.09	1.46	0.05	0.04
2020	0.05	0.07	0.10	1.55	0.05	0.04
2025	0.04	0.07	0.09	1.68	0.05	0.05
2030	0.04	0.06	0.09	1.81	0.05	0.05

Source: Model projections in the reference scenario.

Appendix B – Sensitivity Analysis

We performed some simple sensitivity analysis to understand the influence of some parameters in the results and verify the robustness. There are several possible sensitivity tests in EPPA, given the large number of behavioral parameters and assumptions. Here we have chosen three main groups of tests, regarding the GHG abatement possibilities in the agricultural sector, the elasticity of land supply which governs the deforestation rates, and the assumption about the overall growth rates in the model. We briefly discuss the conclusions from these tests below.

a) Abatement possibilities in agriculture

There are several alternatives to reduce emissions in the agricultural sectors, as the implementation of better methods of nitrogen application, no tillage practices, improving pasture yields and intensifying cattle production, burning methane emissions from manure, among others. Given the level of sectoral representation and coverage in EPPA, these options need to be represented in a simple way, but should allow to capture the important aspects about technology choices and trade-offs. In this way, the adoption of abatement technologies in the agricultural sector is governed by elasticities of substitution between the GHG allowances (for CH_4 and N_2O) and the inputs used by the agricultural sectors. These elasticities in the case of Brazil received the value of 0.02, the lowest value in the model. Our sensitivity analysis consists of increasing such values by factors of two and four, to assess if greater abatement possibilities in Brazil would affect our results and conclusions. Table B1 presents some results from implementing the Copenhagen scenario with higher abatement elasticities in Brazilian agriculture, for the year 2020[12]. In general, higher abatement possibilities have a small impact on land use changes. Pasture and cropland areas are slightly higher in the Copenhagen scenario under higher abatement elasticities, while harvested forest area is smaller. Such results are expected, since higher abatement possibilities mean that crop and livestock sectors can achieve the reduction in emissions without the need to give up too much production and area. The relative low impact on land is consequence of the very low initial abatement elasticities, which do not give much degree of substitution between inputs and emissions, even when the elasticities are multiplied by a factor of four. However, the abatement elasticities have a substantial impact in the CO_2 taxes necessary to force the sectors to achieve the reduction in emissions, as also in the changes in the value of output and GDP. Under higher abatement possibilities, the agricultural sectors reduce output much less than the overall cut in emissions (around 16%), what means that they do not lose competitiveness as before, and then demand more carbon permits, leading to higher carbon taxes to force the sectors to meet the same quantitative reduction in emissions as before. As the crop and livestock sector have more flexibility to adapt their technologies to the emissions constraint, they suffer less reductions in output, what have positive consequences to sectors buying agricultural goods and help the economy to suffer lower losses in GDP.

[12] We present results only for year 2020 to simplify the analysis. Our choice is due to the fact that the Brazilian government has announced its Copenhagen emissions targets to be achieved at that year.

b) Land supply elasticities

The deforestation rates observed in the simulations are governed by several aspects of the model, including the benchmark deforestation rates, the land supply elasticity related to the expansion of the agricultural frontier, the growth rates in the economy and the increasing demand for food in the world, among other elements. One important parameter governing the rate of transformation of natural vegetation to agricultural use in EPPA is the land supply elasticity estimated based on observed data in the last two decades. For Brazil, the benchmark value of such elasticity is 0.26. We perform several model simulations changing this value in the BAU and in the Copenhagen scenarios. We multiply this elasticity by two, three and by half. Table B1 shows the results for some variables in 2020. As expected, higher land supply elasticities generate higher deforestation and emissions in the BAU, as also larger areas of cropland and pastures, although the differences in area are in the order of 100 thousands of ha compared to the original simulation, or less than 1%. It means that the model results have a low sensitivity to the changes in the land supply elasticity. The impacts from the Copenhagen scenario on carbon taxes output changes, welfare and GDP almost don't change under alternative land supply elasticities. It allows us to conclude that the model results are robust to changes in the land supply elasticities and, as consequence, to alternative deforestation rates in the BAU. The CO_2 taxes necessary to achieve the reduction in emissions are also very similar under the alternative land supply elasticities. It means that all conclusions do not change with changes in the land supply elasticity for Brazil.

c) Growth rates

The EPPA model is initially calibrated to reproduce growth rates forecasted by the IMF. Improvements in the labor productivity are specified to match such forecasts. Here we vary such parameter to obtain alternative growth rates in the model. We first increase by 10% the improvements in the labor productivity in all regions of the model, to achieve greater GDP growth all over the world. Finally, we reduce by 10% the improvements in the labor productivity. As expected, the higher growth generates higher emissions from all sources, and the opposite is true for lower growth rates, considering the model results for 2020 (Table B1). Land use for crop and livestock production is also bigger for higher growth rates, while natural forest and harvested forest areas are smaller. The Copenhagen scenario requires larger CO_2 taxes in the agricultural sectors when growth rates are higher, in order to achieve the emissions target set in the Policy. However, the changes in output, welfare and GDP from the policy are almost the same, regardless the growth rate assumed. One reason for this is the way the policy is specified, as a fixed percent cut in emissions from the BAU emissions trajectory. It allows us to conclude that the model results are not sensitive to the economic growth rate, since it generates similar policy costs under alternative assumption about growth.

Table B1 – Sensitivity Analysis

		Central cases		Sensitivity to Agricult. abatement		Sensitivity to Land Supply Elasticity						Sensitivity to calibrated growth rates			
		BAU	Copenha-gen	Copenh. 2x abate-ment elastic. in agricult.	Copenh. 4x abate-ment elastic. in agricult.	BAU 2x land supply elastic.	Copenh. 2x land supply elastic.	BAU 3x land supply elastic.	Copenh. 3x land supply elastic.	BAU 1/2 x land supply elastic.	Copenh. 1/2 x land supply elastic.	BAU high growth rates	Copenh. High growth rates	BAU low growth rates	Copenh. low growth rates
Emissions (mmt CO2 eq.)	Deforestation	819	333	333	333	919	364	983	337	756	308	951	387	571	221
	Agriculture	599	454	454	454	599	454	599	454	599	453	626	475	570	431
	Energy	547	392	392	392	547	392	547	392	547	392	570	409	525	376
Land Area (million ha)	Crop	78.52	74.62	74.62	76.48	78.60	74.62	78.64	74.62	78.48	74.62	81.46	74.64	75.49	74.62
	Pasture	138.10	132.27	133.21	135.72	138.52	132.17	138.80	132.10	137.86	132.37	142.08	135.67	133.83	128.69
	Harv. Forest	37.90	45.11	44.17	39.81	37.53	45.12	37.29	44.97	38.17	45.11	32.20	42.38	42.57	46.73
	Nat. Forest	453.96	456.48	456.48	456.48	453.84	456.58	453.75	456.79	453.97	456.39	452.75	455.80	456.60	458.45
CO2 tax (US$/ton CO2 eq.)	Crop		77	202	259		77		77		77		83		75
	Livestock		85	209	266		84		84		85		88		81
	Forestry		158	192	144		155		152		160		204		163
Change in output from BAU (%)	Crop		-14.2	-6.0	-3.0		-14.2		-14.2		-14.2		-14.1		-14.5
	Live		-12.3	-4.8	-1.9		-12.3		-12.3		-12.3		-12.2		-12.4
	Fors		13.3	15.6	16.4		16.3		20.0		11.6		15.6		7.5
	Food		-9.3	-3.5	-1.4		-9.3		-9.3		-9.3		-9.2		-9.4
Welfare change from BAU (%)			-1.01	-0.98	-0.98		-1.01		-1.01		-1.02		-1.03		-1.01
GDP change from BAU (%)			-2.3	-1.9	-1.8		-2.3		-2.3		-2.3		-2.3		-2.3

Source: Model results.