Working Paper

Brazilian Mitigation Scenarios Beyond 2020: Modelling and Methodologies

CDKN Linking Project

Energy Planning Program - COPPE/UFRJ

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1. Introduction

Brazil is becoming one of the most important economies in the world. Even so, there remain a number of barriers, both internal and external, to be overcome if the country is to follow the path of sustainable development. The best solutions will include a response to the challenges posed by global climate change.

In addition to its notable presence in the international economy, finance and trade, and its great influence on agricultural and food products at a global level, the country also has considerable natural capital in terms of land resources, forestry, hydrology and oceanography. There are, on the other hand, major social problems to be overcome, such as poverty and inequality.

Due to the high rate of deforestation the country is also one of the world's major GHG emitters. With its big offshore oil discoveries Brazil may also become a major world power in the market for the supply of fossil fuels, with a significant impact on emissions of the energy sector.

The understanding that the country is vulnerable in the face of the possibility of global climate change may be one explanation for its political and institutional stance. Brazil is already acting proactively in this context, and has played a prominent role in international negotiations over actions to reduce the negative effects of climate change.

Under the Copenhagen Agreement, Brazil voluntarily committed to reduce its emissions by between 36.1% and 38.9% in relation to the trend-based ("business as usual") scenario by 2020. Such voluntary commitments are to be achieved through the mitigation actions envisaged under the National Plan on Climate Change and Sectoral Mitigation Plans. The latter were drawn up in order to achieve the goals voluntary ratified into law (National Policy on Climate Change - Law N º 12.187 dated December 29, 2009). These plans include mitigation and adaptation measures for the period 2012-2020, covering GHG emissions from the sectors of Energy, Land Use and Agriculture, Industry, Transportation and Urban Mobility, Mining and Health

Estimates of annual greenhouse gas emissions in Brazil (La Rovere et al., 2012) show big changes in the profile of Brazilian CO_2 emissions. The Land-use, Land-use change and Forest - LULUCF sector share in domestic emissions passed from 57% in 2005 to 22% 2010. This change in profile reflects the internal efforts for voluntary emission reduction currently under way. The energy sector, which accounted for 16% of emissions in 2005, reached a level of 32% in 2010 and in this context, the participation of this sector in the total national emission will continue to rise.

It is therefore necessary to develop scenarios of future GHG emissions (timeframe 2005-2030) to assess the social and economic impacts on the country's development as well as necessary actions in terms of mitigation. To this end, appropriate tools will be required to facilitate the studies that need to be carried out. The aim of this work is to build such tools, so that policies that ensure the transformation of a traditional economy into a low carbon one can be formulated.

2. Methodological Aspects

The methods used to make a prospective analysis of the economy adopt approaches known as top-down, bottom-up or hybrid; their aim is to describe different paths (scenarios) and their respective costs, so as to allow the "mitigation potential" of the Brazilian economy in the short, medium and long term (depending on the time horizon of each study) to be estimated.

The concept of "mitigation potential" was developed to assess greenhouse gas reduction ranges that could be adopted, and is expressed in cost per unit of emissions of carbon dioxide equivalent avoided or reduced.

The mitigation potential is estimated based on the mathematical description of the economic interactions of all the country's productive activities that emit greenhouse gases. Studies can thus be based on assessment of mitigation options, emphasizing specific technologies and regulations, and are commonly called techno-economic models, or bottom-up. Alternatively, aggregated economic information on mitigation options can be used, identifying the macro-economic and market impacts. This approach is called a top-down model and evaluates the mitigation potential of the economy or of a sector as a whole. While advantages and disadvantages can be identified in either approach, several studies have shown that the integration of the two components (the hybrid model) provides the most consistent results.

The technical-economic models are typically sectoral studies which consider the macro-economy as a given. Based on such models, technologies and market constraints can be identified permitting assessment of the mitigation potential of an economy. Such models can be further classified into optimization models, simulation models, and accounting models, depending on how the data is processed.

The optimization models identify least-cost solutions for a range of potential mitigation measures, subject to several constraints, such as availability of technology, equality between supply and demand, environmental and investment restrictions, among others. Mathematical programming techniques are normally used for such solutions. A minimal cost solution also includes the marginal abatement cost (dual solution).

Simulation models, in turn, determine the behavior of consumers and producers in relation to a set of economic goods based on variation in prices, income and technological progress. Since they usually determine the market equilibrium from an iterative approach, these models are not limited by the optimal behavior of the agents. Relations between economic agents can, however, be controversial and difficult to parameterize. The projections are also quite sensitive to initial conditions and parameters.

Finally, the accounting models, also known as parametric models, are the simplest to be modeled since they only use the amounts of flows of goods and services specified in the description of the economy in question. The projections are usually based on specifications determined by the user. The main function of these models is to manage data and results, which makes them quite useful for solutions of the “what if” type. Despite being simpler and more flexible, they can generate inconsistent solutions.

The top-down models, as mentioned earlier, use more aggregated data of the economy as a whole, or of a sector, or of certain economic relationships. Such models can be classified as partial equilibrium models and general equilibrium models. The first are based on functions of demand and supply, which are usually built from econometric regressions, and allow the obtaining of a market equilibrium solution in a particular sector. Such models are easy to construct, but are usually heavily based on information from the past that may not well represent the future. Their use is therefore quite limited.

The general equilibrium models, on the other hand, are used to study a complete and homogeneous class of consumers and do not necessarily take into account its technological structure. Such models generate a consistent set of values for levels of economic activity and prices of capital, labor and primary materials. These features allow the carrying out of cost/benefit analyses of a set of mitigation measures through aggregate data on the economy, which also permits the evaluation of the implementation of macroeconomic policies. In addition, they allow verification of the inter-sectoral effects of certain one-off measures. The top-down models, however, show limitations when there is need for detailed evaluation of technologies.

As seen, it is possible to highlight several advantages and disadvantages of both types of approach (top-down and bottom-up); it is therefore possible to reconcile the consideration of important details in the top-down models, such as the endogenous determination of macroeconomic variables, and to incorporate the economic interactions of technical-economic models (such as energy, soil use and climate models, etc.) in a more consistent economic structure. Such models, called hybrid, make simultaneous projections of the input-output matrix (main input data of general equilibrium models) and of the technical-economic models. Communication between the top-down and bottom-up part of the model is typically done iteratively in terms of variations in prices and quantities. This way the equilibrium between production and consumption of goods and services throughout the economy can be obtained, unlike with bottom-up models that treat the economy partially.

3. The IMACLIM-Brazil Model

IMACLIM-Brazil is a hybrid model built especially to describe the Brazilian economy, coupling sectorial models in order to combine top-down and bottom-up modeling approaches. The macroeconomic and social implications scenarios can thus be evaluated in detail.

In general terms, IMACLIM-Brazil is a hybrid computable general equilibrium (CGE) model designed to analyze the medium and long-term macroeconomic effects of climate policies in a harmonized accounting structure where monetary and physical (with a special focus on the Energy Balance) value flows are in equilibrium.

Figure 1 schematically depicts a first version of the methodological approach to be used, specifying the main input and output variables in the interaction between sectoral models and the IMACLIM-Brazil macroeconomic model.

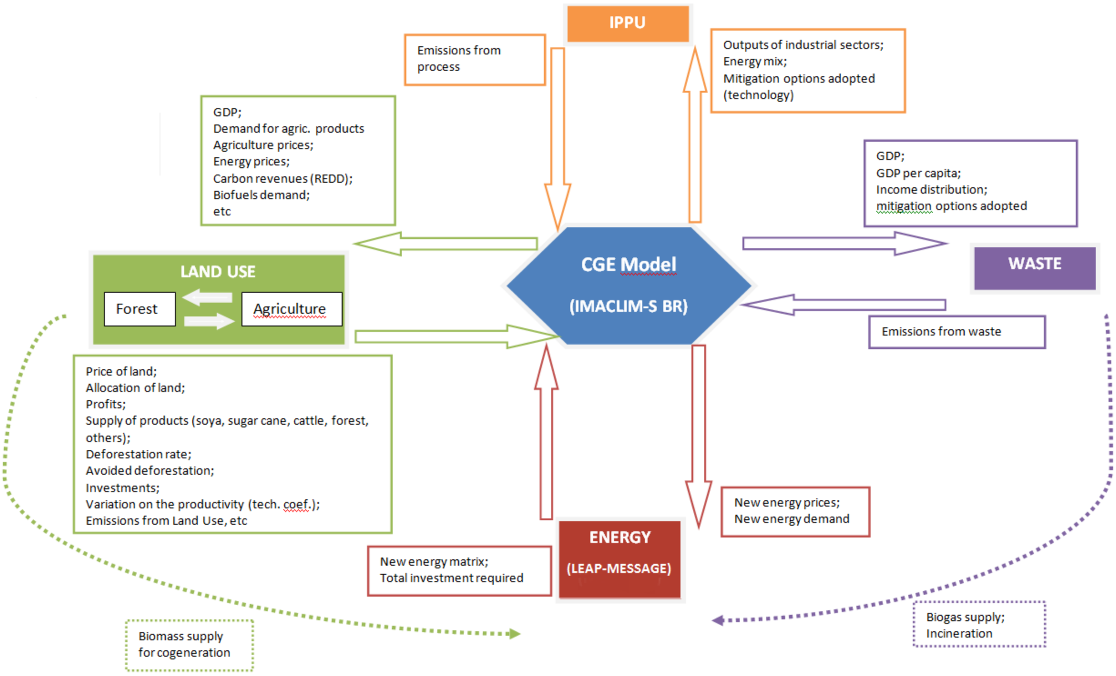


Figure 1. Methodological Approach: Modeling Scheme

IMACLIM-Brazil provides an open presentation of the Brazilian economy: 19 productive sectors (6 energy sectors, 6 heavy industry sectors, the rest of the industry, livestock, agriculture, construction, freight transport, passenger transport, and services). As regards final consumption of households, the model can simulate scenarios dividing this group into up to 10 income classes and 3 types of qualifying labor (skilled, unskilled and intermediate). There is a description of the interactions between 4 institutional sectors (Families, Businesses, Government and Rest of World). The model accounts for CO_2, N_2O and CH_4 emissions in the energy, land use, industrial processes and waste sectors.

IMACLIM-Brazil is similar to traditional neoclassical CGE models with regard to description of the choices of producers and consumers, but the structure of technical description of production systems was specifically designed to facilitate calibration with bottom-up information and models, with the intent of ensuring great technical realism even in simulations where there is a big deviation in relation to the reference scenario.

As regards final demand, the model has a demand function with price elasticity and income elasticity, promoting choices of consumption among the 19 sectors, with minimum requirements of basic needs. There is a more detailed description with respect to the demand for transport where, depending on income and relative prices, the consumer may choose between public and private transport, and between gasoline and ethanol, in the case of private transport.

The model provides a detailed description of the primary and secondary income distribution between the four institutional sectors, with a focus on the taxation system and on government transfers; this is critical to obtain a simulation of various forms of recycling of carbon revenues, thereby achieving different concomitant goals, such as abatement of emissions, economic growth and reduction of social inequality.

The model was developed to represent sub-optimal conditions of the Brazilian economy such as, for example, result from the rigidity of the labor market, which is represented by a wage curve. The evolution of foreign commerce is represented by elasticities in the terms of trade, and the issue of the competitiveness of the productive sectors of the Brazilian economy as a whole can be analyzed.

There is also the representation of the debt of the four institutional sectors cited, with a focus on the public debt. The closure of the model is done by calculating the interest rates paid by institutional sectors.

It was necessary to build a hybrid input-output model to calibrate the model to the base year 2005, and to build a social accounting model (SAM) to represent the Brazilian economy and tax system in great detail. This model is innovative due to the integration of sectoral or bottom-up information with the rest of the economy through the general top-down equilibrium framework. This methodology provides an interesting option for evaluation of the macroeconomic effects of climate policies, especially when compared to the traditional approach of computable general equilibrium models; these models use production functions with constant substitution elasticities whose use is questionable for simulation of high carbon taxation rates or of big deviations from a baseline scenario.

The development of an input-output hybrid model goes through a careful process of nomenclature adjustments and value manipulations in order to ensure full compatibility of the National Accounts with the Energy Balance. A double accounting system keeps these two matrixes (monetary flows and physical flows) permanently connected via a third one, the price matrix, which is variable and endogenous to the model. The double accounting system can be considered the bridge that allows communication and reconciliation between the two partial and complementary visions of the world: the bottom-up approach and the top-down approach.

The production choices in the time horizon under consideration are defined in principle as follows:

- Electrical and refining sectors: Defined through a hard-link with the MESSAGE energy optimization model (see first working paper - Wills et al., 2013);
- Energy Demand: Defined through a hard-link with the LEAP energy simulation model;

- Land use and agriculture: A connection will be established with the land use model (BLUM model) to be developed in collaboration with AgroICONE; and
- Final Demand: Demand function with price and income elasticity which represents the choices of consumption among the 19 sectors, with minimum requirements of basic needs.

IMACLIM-Brazil will additionally also be capable of analyzing the impacts on income distribution of mitigation measures such as carbon tax or carbon trading schemes. This part has already been implemented, analyzing the introduction of carbon taxes, initially using a SAM. The results obtained differ, as much in function of the tax level established as of how the revenue raised is reinserted into the economy. Two options were simulated: direct transfer to low income families and exemption from labor taxes. In a complementary analysis the impact on GDP, employment levels and GHG emissions was examined. The complete work is part of the second working paper by Grottera et al. (2013).

4. Reference Scenario

4.1. Macroeconomic Scenario

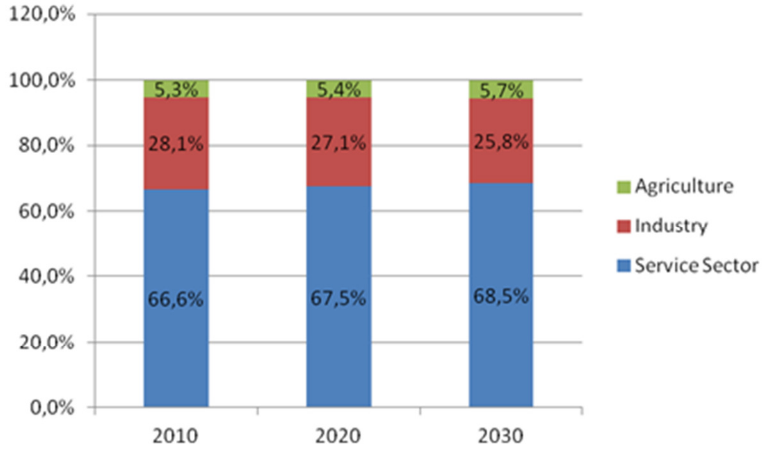
Various assumptions were considered on which the macroeconomic scenario for the global economy and the consequences for Brazil could be built. It was assumed for this purpose that international economic growth will be driven by the improved performance of emerging economies until 2020, while developed countries will still be recovering from the crisis. Subsequently, the growth rate of the world economy will begin a downward trend, due in particular to the slowdown in the growth rates of China in particular, and of developing countries in general as they reach higher levels of development.

There will consequently be increased investment in Brazil until 2020, especially in infrastructure, and also in connection with the exploration and production of oil, to which must be added the positive impact of domestic oil exports on the balance of payments. An improvement in the business environment will stimulate investment in the subsequent period. This framework would favor the maturation of investments made in previous years, thereby providing a partial solution for bottlenecks as Brazilian productivity advances. Table 1 shows the quantification of the above-mentioned assumptions.

Table 1 – Macroeconomic Scenario

	2013-2020	2021-2030
GDP World	3.8%	3.2%
GDP Brazil	3.7%	4.1%
GDP/cap Brazil	2.9%	3.6%

The gradual loss of contribution by industry was also considered; this is a process associated, in large part, with the movement of convergence which brings about the approximation of national industry to the sectoral composition observed in developed economies. This reduction is compensated by a gain in the participation of the services segment, which is the prevailing thesis of classical sectoral development. There is also growth in the agricultural sector, given its comparative advantages. Graph 1 below shows the evolution of the structure of the Brazilian economy.



4.2. Energy Demand

Four sectors were considered for the building of energy demand scenarios: industry, services, transport and residential. Additionally, we computed the final consumption of energy and non-energy sector. These figures, however, resulted from the supply model used, MESSAGE.

The tool used for energy demand simulations was LEAP, a bottom-up model, which can be classified as an accounting model. This feature allows the allocation of energy flows between different technological possibilities of energy supply, the calculation of resource usage, and environmental impacts, and detects the expansion needs of energy production processes, as well as the associated costs. It is thus possible possible to represent the energy system, clearly visualize its operation, and identify the implications of structural changes in the energy sector.

The main advantage of LEAP is its flexibility and convenience in use, facilitating the movement from implementation of policies to the analysis of their effects. It is not, on the other hand, possible to identify lower costs or find reliable price solutions. This problem can however be circumvented with the use of the MESSAGE and IMACLIM-Brazil models.

The building of the scenarios requires preparation of a detailed description of how energy is consumed, converted and produced. Additionally some exogenous variables, such as population, GDP, industrial growth, economic development and technological efficiency need to be considered.

With respect to demand, the composition by sector is described taking the end use of energy into account. Demand growth is determined by the competitive relations between fuels, energy intensities, equipment, and structural changes.

Given the flexibility of LEAP, it was decided to adopt the modeling of energy demand in accordance with SWISHER & Januzzi (1997). In the case of the residential sector, the calculation of the annual direct energy consumption per household of a device associated with a particular end use is made taking the following into account: the average time of possession of the equipment; the average usage time per day; the average number of days of usage per month; the average number of months of usage per year; and the average power of the equipment. The formulas for calculating the total annual direct final demand for energy in the residential sector (E_R) are presented in Equations 1 and 2:

$$E_R = \sum_{i=1}^{i=n} E_R^i \quad (1)$$

where,

$\boldsymbol{E_R^i}$= average specific consumption of end use i in the residential sector;

$\boldsymbol{i}$ = lighting, cooling; water heating; air conditioning; cooking; other uses.

With the average specific consumption of end use i in the residential sector (E_R^i) calculated as follows:

$$\boldsymbol{E_R^i = \sum_{j=1}^{j=n} N_i \,.\, P_i^j .\, M_i^j .\, I_i^j} \quad (2)$$

where,

$\boldsymbol{N_i}$= total number of houselholds with end use i

$\boldsymbol{P_i^j}$= average possession time of equipment j by household with end use i;

$\boldsymbol{M_i^j}$= average number of months that equipment j with end use i is used in the year for one household;

$\boldsymbol{I_i^j}$= average monthly energy intensity, or average monthly specific consumption of energy by equipment j with end use i per household;

In the case of the industrial sector it is in addition necessary to disaggregate by homogeneous industrial sectors and in accordance with the most important end uses, as shown in the equations below:

$$\mathbf{E_c = \sum_{i,j=1}^{n,m} E_C^{ij}} \quad (3)$$

where,

i = end use

j = industrial sector

$$\mathbf{Q_i^j = N_i^j * P_i^j * M_i^j} \quad (4)$$

where,

$Q_i^j =$ is the amount of energy services Q

$N_i^j =$ is the total number of industry j

$P_i^j =$ is the level of penetration by end use i

$M_i^j =$ is the number of tons of product j requiring the service of energy end use i

The Useful Energy Balance BEU - (MME, 2005) methodology was used to prepare the energy data for each industrial sector and the respective end uses. The BEU is the only source of data available in the country that allows segregation of the information for each industrial sector of the National Energy Balance (BEN) and the obtaining of estimates of the final energy consumption in seven different end uses:

Direct heating: energy used in ovens, furnaces, radiation, induction heating, conduction and microwave;

Process Heating: it occurs in the form of steam generated by the energy used in boilers and water heaters or the circulation of thermal fluids;

Engine Power: energy used in stationary engines or vehicles for individual or collective transport, cargo, tractors, etc.;

Cooling: energy used in refrigerators, freezers, refrigeration and air conditioning equipment, either compression or absorption cycle;

Electrochemistry: energy used in electrolytic cells, electroplating processes , electrophoresis and electroplating;

Lighting: energy used for interior or exterior lighting;

Other Uses: energy used in computers, telecommunications, office equipment, xerographic and electronic control equipment.

In the case of the transport sector, fleet size, average distance travelled and occupancy factor were considered for each vehicle type, as shown in the equations below:

$$\sum_{i=1}^{i=n} \boldsymbol{Qi\ x\ Ii} \quad (5)$$

where,

Q_i = quantity of energy service *i*

I_i = intensity of energy use for energy service *i*

In this case *i* represents the transportation sector.

It should be noted that *Qi* can be understood as:

$$Q = Fi \; x \; DMPi \; x \; FOi \quad (6)$$

where

F_i = Fleet

DMP_i = Average distance covered

FO_i = Occupancy factor

According to the National Energy Balance classification the service sector encompasses the energy consumption of the public and of the commercial sectors. It consequently has as main characteristic the heterogeneity displayed in the many establishments that consume energy and which present different types of end use.

The major establishments that comprise this sector include: restaurants, hotels, resorts, commercial buildings, schools, colleges, shopping malls, universities, buildings for public administration, financial institutions, and public lighting systems, among others.

It is a sector strongly interconnected with other sectors of the economy, such as industrial, residential, agricultural and transport. According to IBGE (2006) the service sector was responsible for the employment of 3.76% of the total Brazilian population in 2005, with an average annual income of R $ 7,478.

In terms of overall energy consumption for the year 2005, the services sector accounted for 8,903 thousand toe, or 4.6% of the total, just ahead of the agricultural sector (BEN, 2006).

The LEAP model was used to calculate the energy demand, using the bottom-up approach in which the Gross Leasable Area (GLA) was defined as a guiding parameter for the energy intensity of the sector, whose value was 7.5 million square meters for the year 2005 (ABRASCE, 2006).

Basically, to calculate the final use of energy in the service sector the following equation was used:

$$E = \sum_{i=1}^{i=n} Q_i I_i \quad (7)$$

In which, Q is the energy service and I is the energy intensity. Q, in its turn is obtained by:

$$Q_i^j = A_i^j P_i^j M_i^j \qquad (8)$$

With A representing the total área of the sector j, P is the share of surface that consumes the energy final use i and M, the frequence of energy final use i.

In spite of the heterogeneity of the various uses, it is possible to identify seven end uses in accordance with the classification of the Useful Energy Balance, namely:

1. Lighting;
2. Food Refrigeration;
3. Air Conditioning;
4. Engine Power;
5. Process Heating;
6. Direct Heating;
7. Electronic Equipment;

The table below relates the final energy use to the technology involved:

Table 2: Technology used for each service sector end use

End Use	Energy Technology
Lighting	• Incandescent Lamp • Compact Fluorescent Lamp • Tubular Fluorescent Lamp • LED Lamp • Other
Refrigeration	• Freezer • Refrigerator
Air Conditioning	• Ventilation • Aircondition – direct & indirect expansion
Engine Power	• Electric Motor • Diesel Engine • Fuel Oil Engine
Process Heating	• Electrical Heating • Natural Gas Heating • LPG Heating • Solar Heating
Direct Heating	• Electric Cooker • LPG Cookler • Wood-Burning Stove • Coal-Fire Stove

Calibration of the base year for subsequent analysis of the reference and energy efficiency scenario was based on data sought in the literature which could provide the average period of possession of the energy technology employed, and the corresponding energy intensity.

It should be noted that the Procel (2008) report on average possession of equipment provided this data only for some energy sources, while the others were estimated according to the final consumption of energy in BEN. Official data on average possession was thus only to be found for the technological sources applicable to lighting and air conditioning end uses.

Energy intensity data, on the other hand, was not found in any official literature and was therefore estimated.

The table below shows the figures found in LEAP for the 2005 base year for the uses noted in the service sector. It is noted that more than half (57%) of the energy is used for lighting, followed by air conditioning (~ 17%). Engine power appears in third place, due to characteristics of the equipment used, such as power generators and elevators, which require very high energy intensity.

Table 3: Service sector in 10^3 toe by end use, base year 2005

End Use	LEAP	Percentage of the total %
Lighting	5101	57
Refrigeration	376,6	4,23
Air Conditioning	1506,4	16,92
Engine Power	542	6
Process Heating	69,3	1
Direct Heating	1130,7	13
Electronic Equipment	177	2

Compared with BEN, base year 2005, it is noted that the figures were calculated satisfactorily, with an error of 2% in the total consumption.

Table 4: Energy consumption in 10^3 toe, base year 2005

Energy Source	LEAP	BEN - 2005
Electricity	7255	7415
Natural Gas	154	282
Diesel Oil	259	138
LPG	849	750
Fuel Oil	193	176
Wood	116	73
Coal	77	67
Total	8903	9041

The simulations resulted in the building of consolidated energy balances for each year in the time horizon of the study (2005-2030). These values are used as input data for the MESSAGE.

4.3. Energy Supply

MESSAGE (Model for Energy Supply System Alternatives and Their General Environmental impacts) was used for the building of the energy supply scenario. The model was originally developed at IIASA (International Institute for Applied System Analysis) for the optimization of an energy system (with its demands and supplies). The IAEA has acquired the latest version of the model and various upgrades have been made, in particular the introduction of a user-friendly interface in order to facilitate its application.

The mathematical principle of MESSAGE is the optimization of an objective function subject to a set of constraints that define the area of feasibility where the possible solutions of the problem are contained. The value of the objective function helps in choosing the best solution according to a specific criterion, usually cost minimization. Under a more general classification, MESSAGE is a mixed integer programming model (which allows some variables to be defined as whole), used for the optimization of a power system. The model was designed to formulate and evaluate alternative strategies for energy supply in line with restrictions such as investment limitations, availability and price of fuels, environmental regulations and market penetration rates for new technologies, among others. Environmental aspects can be evaluated by taking into account and, if necessary, limiting the emissions of pollutants by various technologies at various levels of the energy chain. This helps to assess the impact of environmental regulations on the development of the energy system.

The information in the model is organized as follows:

Variables: flows, production capacites and inventories; and

Constraints: flow swings (extraction, conversion, transmission, distribution, end usage), limits (absolute or relative) for dynamic (intertemporal) and accounting activities.

The representation of the energy system in MESSAGE uses the chain of energy production concept, which involves the representation of the energy production process starting from extraction, and passing through the process of energy conversion (power generation, transmission and distribution), as illustrated in Figure 2 below.

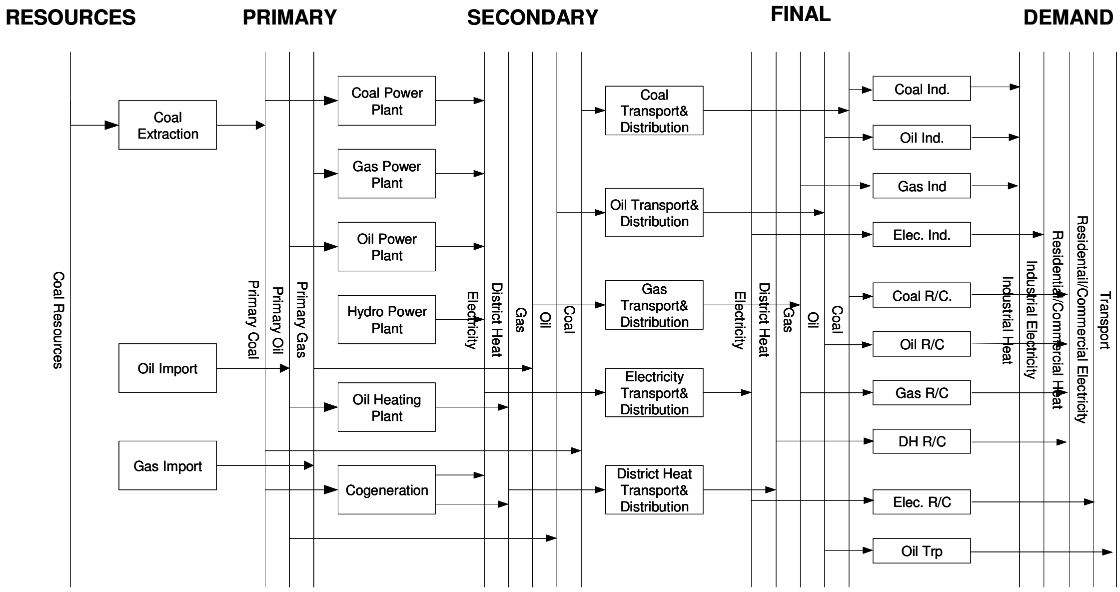


Figure 2– Representation of the Energy Production Chain in MESSAGE
Source: IAEA, 2003

As seen, MESSAGE can be used for the entire energy system. The focus, however, was kept on the electricity sector, emphasizing the representation of the extraction and processing of oil, natural gas and coal, and other uses of these fuels outside the electricity sector. Figure 3 below shows energy chains considered in this study.

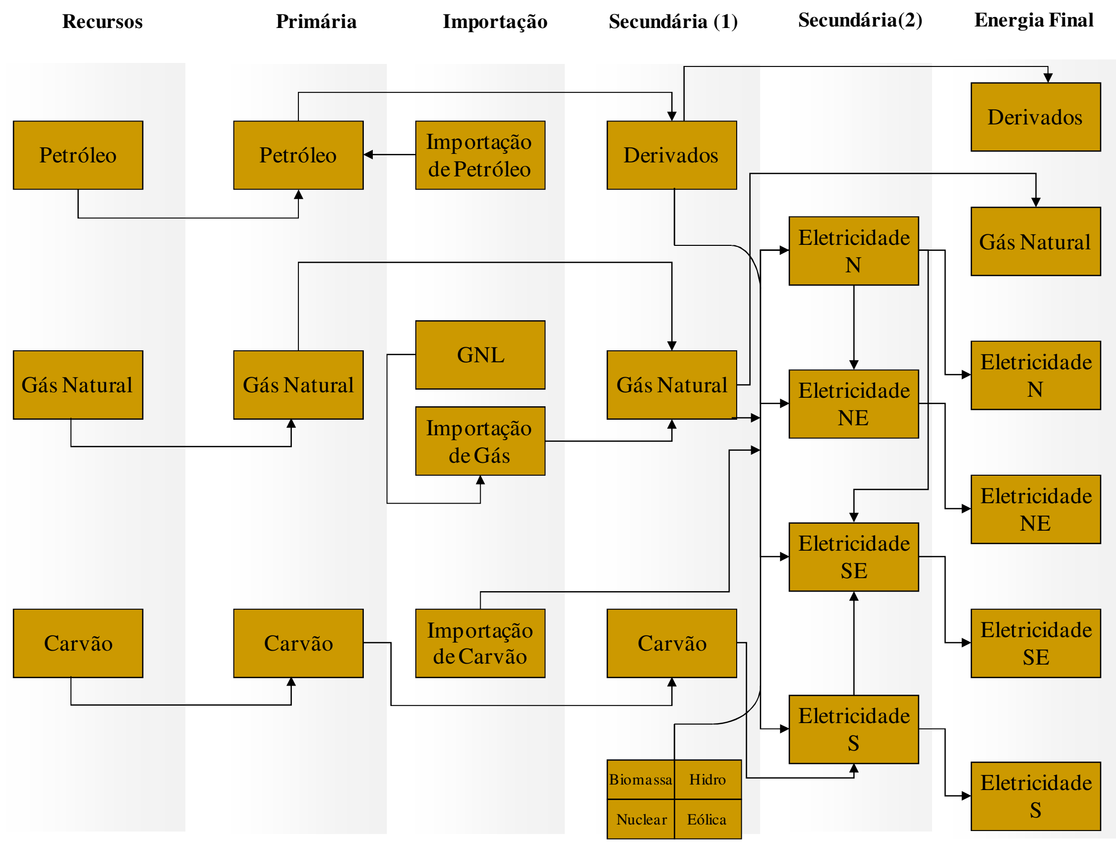
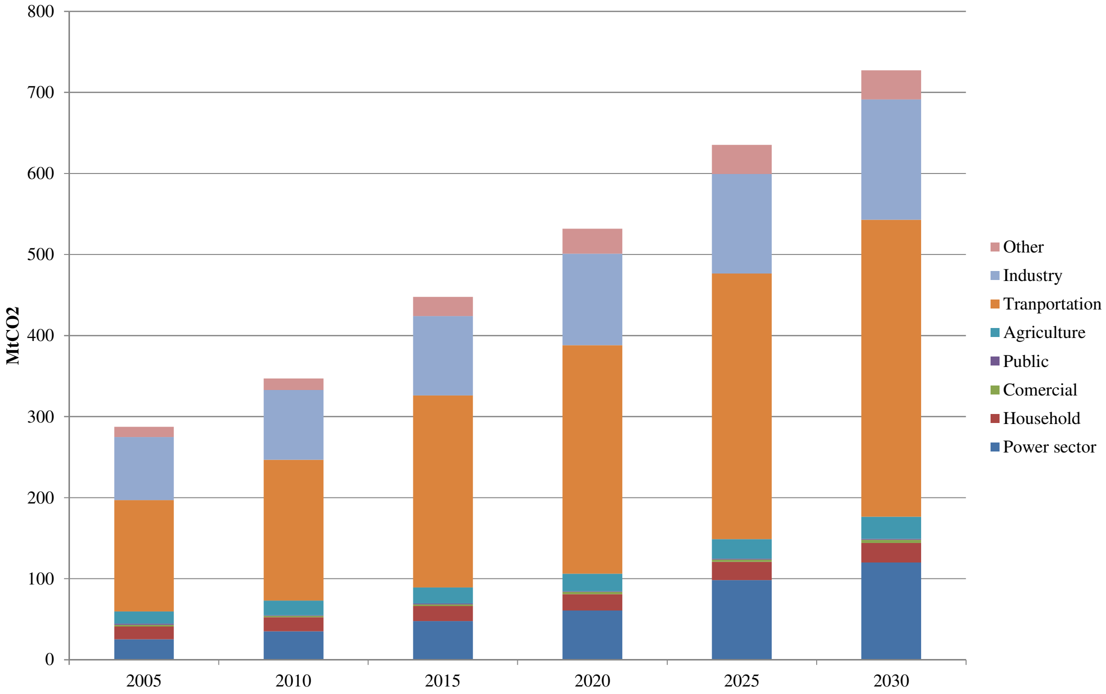


Figure 3 – Energy Chains Considered in the Study
Source: The Authors

The result of simulations with MESSAGE is used to supplement the consolidated energy balances. These in turn are used to build the hybrid input-output matrices, which are the input data for the IMACLIM-Brazil model.

Graph 1 below shows the CO2 emissions of the reference scenario relative to energy demand and supply.



Graph 1 – Energy Demand and Supply Emissions

4.4. Emissions from LULUCF

To estimate future demand for land and LULUCF emissions, the study developed two complementary models: i) Brazilian Land Use Model (BLUM) and (ii) Simulate Brazil (SIM Brazil). BLUM is an econometric model that estimates the allocation of land area and measures changes in land use resulting from supply-and-demand dynamics for major competing activities.[1] SIM Brazil, a geo-referenced spatialization model, estimates future land use over time under various scenarios. SIM Brazil does not alter BLUM data; it finds a place for land-use activities, taking into account such criteria as agricultural aptitude, distance to roads, urban attraction, cost of transport to ports, declivity, and distance to converted areas. SIM Brazil works at a definition level of 1 km^2, making it possible to generate detailed maps and tables.

Under the Reference Scenario, about 17 million ha of additional land are required to accommodate the expansion of all activities over the 2006–30 period. In Brazil as a whole, the total area allocated for productive uses, estimated at 257 million ha in 2008, is expected to grow 7 percent—to about 276 million ha—in 2030; 24 percent of that growth is expected to occur in the Amazon region. In 2030, as in 2008, pastures are expected to occupy most of this area (205 million ha in 2008 and 207 million in 2030). Growth of this total amount over time makes it necessary to convert native vegetation for productive use, which mainly occurs in frontier regions, the Amazon region, and in Maranhão, Piauí, Tocantins, and Bahia on a smaller scale.

[1] These include six key crops (soybean, corn, cotton, rice, bean, and sugar cane), pasture, and production forests; the model also projects the demand for various kinds of meat and corresponding needs for hay and corn.

To estimate the corresponding balance of annual emissions and carbon uptake over the next 20-year period, these and related models calculated land use and land-use change for each 1-km^2 plot at several levels.[2] Results showed that land-use change via deforestation accounts for the largest share of annual LULUCF emissions – up to 533 Mt CO2e by 2030. Direct annual emissions from land use only (agriculture and livestock) increase over the period at an average annual rate of 346 Mt CO2e. Carbon uptake offsets less than 1 percent of gross LULUCF emissions, sequestering 29 Mt CO2e in 2010, down to 20 Mt CO2e in 2030. Over the 20-year period, LULUCF gross emissions increase one-fourth, reaching 916 Mt CO2e by 2030. The net balance between land use, land-use change, and carbon uptake results in increased emissions, which reachs about 895 Mt CO2e annually by 2030.[3]

5. Policy Scenario

The carbon policy scenario can be implemented either via a “carbon price” or a "carbon constraint"[4] that increases aggregated energy prices for intermediary and/or final demand depending on the perimeter of the climate policy defined. This carbon policy induces a “shock” to the reference equilibrium so that impacted sectors react by trading-off between factors of production (supply side) or levels of final consumption (demand side) along innovation possibility curves built from sectoral analysis. In fact, it is inappropriate to think about those curves as ruling trades-off starting from the reference situation. However, for the supply side, each “point” of the curve is supposed to stand for one given structure of production or “technology” (defined by technical coefficients and production factors) resulting from a stabilized adaptation of the productive system to the carbon policy respective to a time horizon (here 2030) as if this carbon constraint had been implemented for some time in the past. Crossing the curves from the different sectors and players provide insights on the final result in 2030 of an endogenous technical adaptation to the carbon policy and its correlated impacts (cross-price evolutions) of the different sectors all together but without describing the exact path that led to the equilibrium in 2030. This is conforming to the principle of comparative statics.

This version of the model focuses on the regulatory aspects of a carbon policy specifically put on fossil fuel. Therefore the efforts were directed to represent accurate trades-off in industry and energy production. Classic production functions distinguish usually four factors of production: energy, material, labor and capital. It was assumed that the applied carbon policy only alters the energy and capital intensities of the industrial goods, keeping constant its labor and material intensities between the no-policy and policy cases. Next section explains in detail the way the innovation

[2] Micro-region, state and country.

[3] When calculating national car bon inventories, some countries consider the contribution of natural regrowth towards carbon uptake; therefore, although this study does not compute this contribution in the carbon balance of LULUCF activities, it would be fair to add that information for comparison purposes. If the carbon uptake from the natural regrowth of degraded forests were to be included, then the potential uptake would increase by 109 Mt CO2 per year, thus reducing net emissions.

[4] Share of GHG emission abatement in relation to the reference scenario.

possibility curves were built for heavy industry sectors according to expert-based studies on mitigation options. In short those curves embed both trades-off between overall energy consumption and capital and trades-off between energy sources: fossil fuel versus biomass, coal and oil versus natural gas. In this version of the model land-use change emissions are not included in the carbon policy.

5.1. Integration of expert-based information into IMACLIM-Brazil

5.1.1. MAC curves for Heavy Industry

Integration of expert-base information is possible due to the hybrid representation of economic flows. As previously mentioned it is possible to build for each sector an innovation possibility curve (alternative to classic CES for example) based on tangible technical content coherent with the notion of comparative statics explained above. Such curves were built for 6 industrial sectors (paper, cement, steel, aluminum – and others nonferrous –, chemical and mining) and for oil refining activities.

Expert-base data were taken from the analysis made for industry sector associated with a carbon price, calculated as the least average price (on the 20 years long period) that makes the relative mitigation option profitable compared to the reference scenario. In this calculation, an exogenous scenario of growth for the sector studied and an exogenous path of energy prices, the updated added capital costs (linked to the investment in new equipments for example) balance the hypothetic actualized carbon charge alleviation linked to energy consumption changes, whether it be energy efficiency gains or energy sources substitution from high to lower carbon content (fossil fuels to renewable biomass in particular). Such expert-based data are perfectly shaped to be used to calibrate an innovation possibility curve for each sector provided that two hypothesis are more or less valid: like energy consumption levels, added investments needed for technological change are proportional to the level of output. This enables to associate a carbon price to energy intensities variations and not absolute levels of consumption.

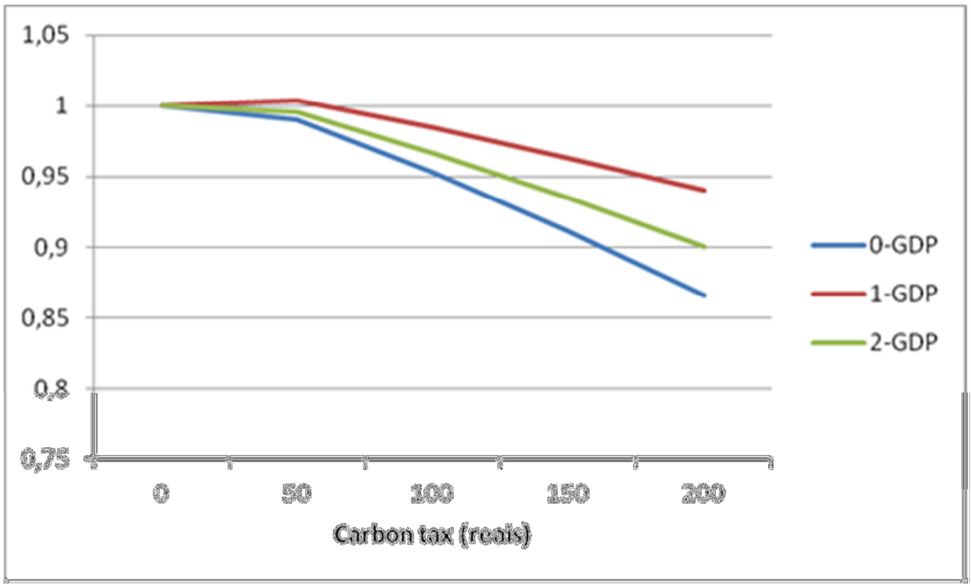
For each sector, the mitigation options considered are cumulative and independent. If such conditions are valid, for each sector studied and each energy source, it is possible to have a set of points linking one given level of carbon price (implemented from 2010 to 2030) to the final energy intensity adopted in 2030 (resulting from the adoption of all mitigation options with associated lower carbon prices). Then it only lacks to extrapolate those points with the right continuous function to embed the expert-base information with a compact format in a top-down framework with total consistency with the bottom-up expertise.

Almost every sector shows the same behavior along an increase of carbon price: (i) for small carbon prices, global energy efficiency gains are triggered and quickly reach an asymptote; (ii) for medium carbon prices there is a substitution between fossil fuel and renewable biomass.

With this framework, it was analyzed how to recycle the revenues from the carbon policy, whether it is a carbon tax or a Cap & Trade scheme, and the macroeconomic impacts. Three different types of carbon revenues recycling were considered:

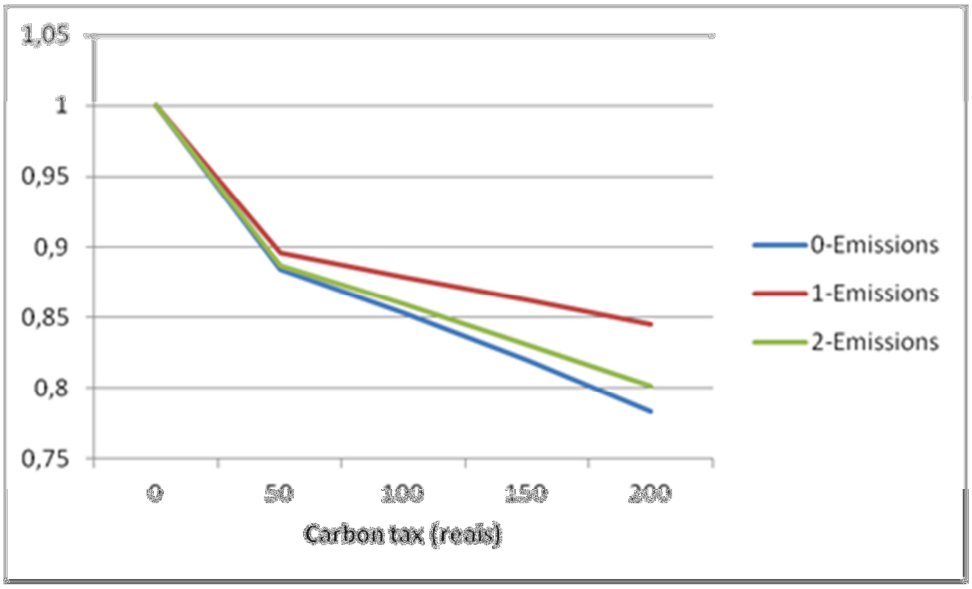
Option 0: carbon revenues are used to decrease public debt and are not recycled
Option 1: carbon revenues are used to decrease payroll taxes under the constraint of budget neutrality
Option 2: carbon revenues are divided between households.

It was considered a range of carbon tax varying from 0 and 200 R$/t$CO_2$, under the three different types of carbon revenues distribution. The next Graph presents the results in terms of GDP. Under option 1, GDP is always bigger than in option 2, which is always bigger than GDP in option 0 (if compared with the same level of carbon tax). The sensitivity analysis has showed that option 1 (reduce payroll taxes) is the one that has the smaller impacts over the economy because it stimulates the creation of new jobs, and thus, increases households' income and consumption, reducing the recessive impact of the carbon tax. It is also important to note that there is a special range of the carbon tax (approx between 0 - 50 R$/t$CO_2$) under option 1 that a double dividend is possible. There are reductions in GHG emissions and stronger economy at the same time.



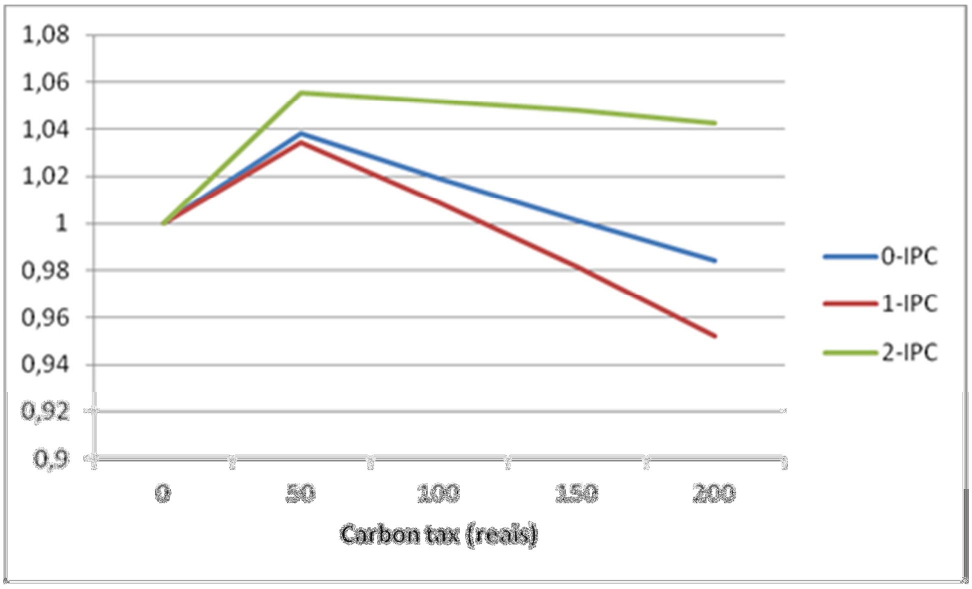
Graph 1 – Impacts on GDP

Next Graph shows how the emissions are affected by the carbon tax. It is important to clarify that: firstly, as for now all mitigation options costs below 50 R$/t$CO_2$, emissions reduce sharply with a carbon tax between 0 and 50 R$/t$CO_2$; after that, as there is no other mitigation option available and the economy cannot adjust more, the impact on the emissions is only linked to the recessive impact of the carbon tax. Here as option 0 (use carbon revenues to pay the debt of the government) implies in a bigger recessive effect over the economy, emissions are lower when this carbon revenues recycling option is chosen.



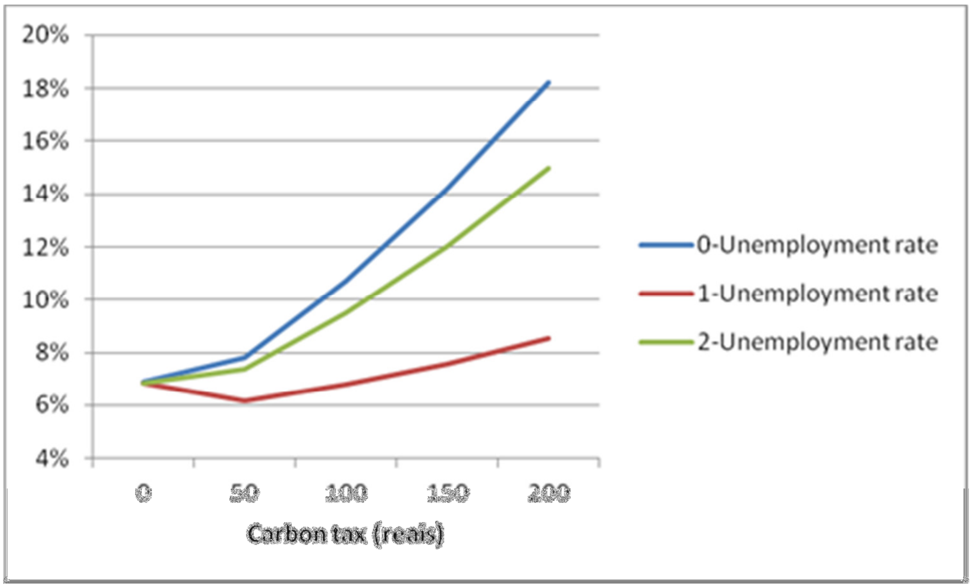
Graph 2 – Emission Reduction

This next Graph shows the impact of the carbon tax over the price index. Here option 2 (green check) causes the bigger rise of the prices because of the increased income of households. The fact is that this option favors households' consumption but not investments on the productive sector. On the other hand, option 1 reduces tax on labor, reducing costs for the productive sector and at the same time increases households' consumption by creating more jobs.



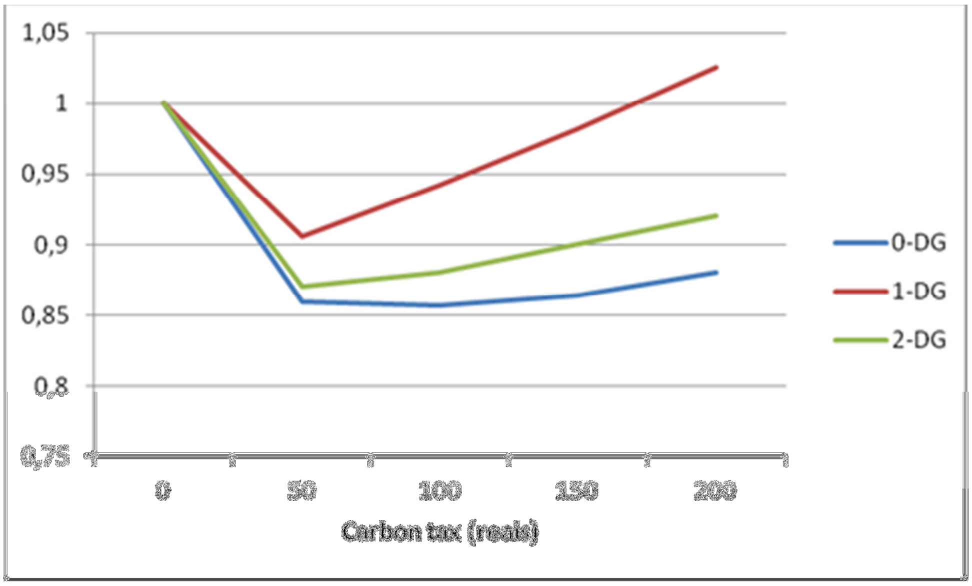
Graph 3 – Impacts on Prices

The next Graph presents the unemployment rate under the three different options. It is clear that option 0 produces a big recessive impact on the economy. With a 200 R$/t$CO_2$ carbon tax the unemployment rate goes up to 18%, much higher than the one got in the reference scenario (around 7%). Option 1, which employs carbon revenues to reduce tax on labor, presents a very promising scenario, keeping the unemployment rate below 9% even with a 200 R$/t CO_2 carbon tax.



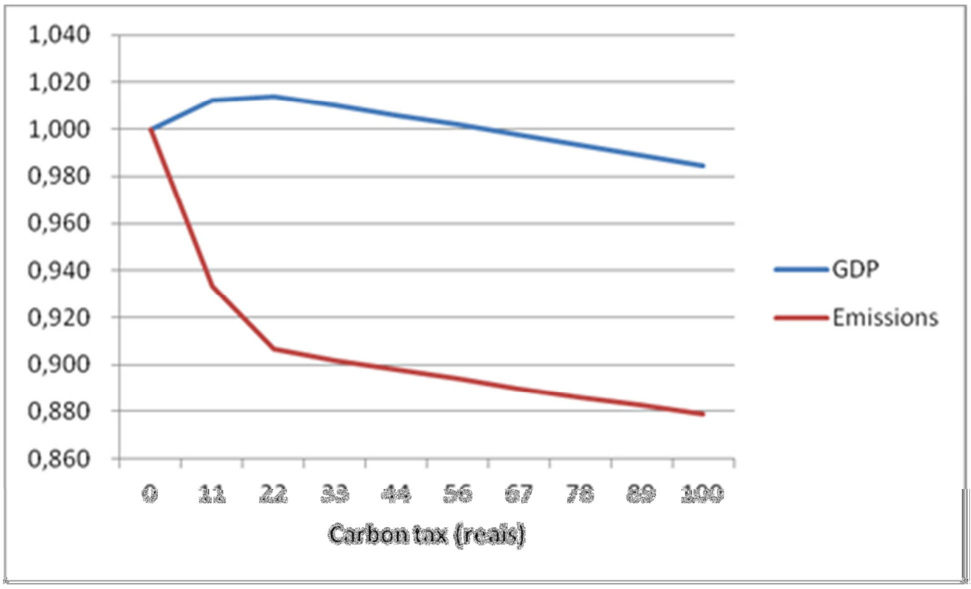
Graph 4 – Impacts on Job Creation

Next Graph shows the position of the government concerning the total debt. As option 0 uses all the carbon revenues to pay the debt of the government, the debt in this case is the lowest one.



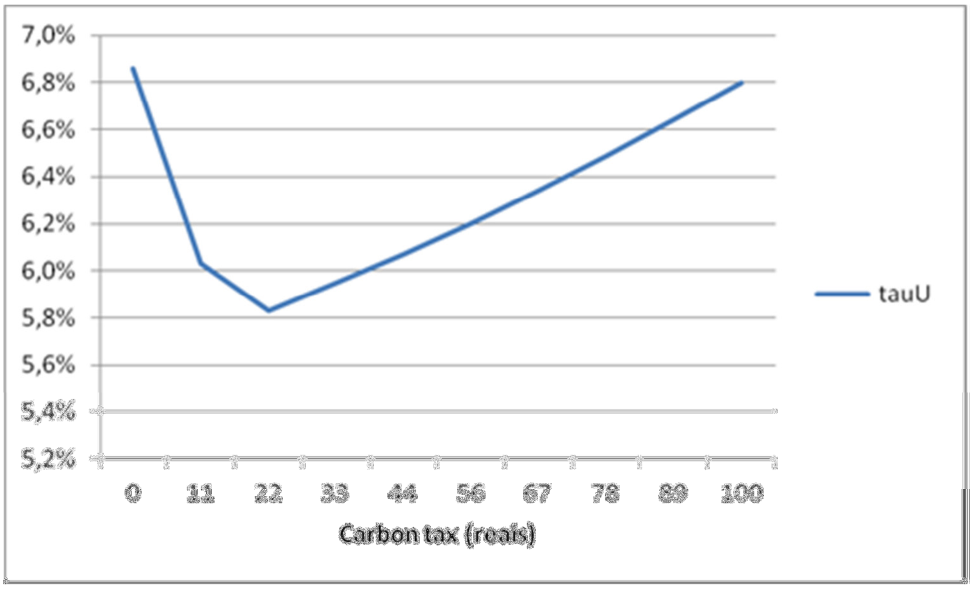
Graph 5 – Impact on Government Debt

It was studied in deep the carbon tax varying between 0 and 100 R$/t$CO_2$, under option 1 (reduce tax on labor). This range of the carbon tax showed to be very interesting because it produced double dividends. At the same time, it reduces emissions, have a higher GDP and a lower unemployment rate. A carbon tax under a 22 R$/t$CO_2$ produced a GDP almost 2% as higher as in the reference scenario, while achieving a GHG emissions reduction of almost 10% compared to the same scenario. After that point the recessive effect of the carbon tax starts to be stronger than the benefits provided by the reduction of the payroll taxes, so the GDP starts to decline in comparison to the reference scenario, as showed in Graph below.



Graph 6 – Double Dividend

Next Graph shows how the unemployment rate is affected under option 1. At the 22 R$/t$CO_2$ carbon tax level we reached a 5.8% unemployment rate, significantly lower than the 7% unemployment rate of the reference scenario.



Graph 7 – Unemployment Rate

It is important to mention that this "optimal" carbon tax is not fixed. It is very dependent on the mitigation options considered in the model. Rather than trying to find the "optimal" carbon tax, the focus here is just to show that there is a range of carbon taxes where it is possible to have a double dividend, and it depends strongly on the mitigation options modeled.

5.2. Hard Link MESSAGE – IMACLIM

The idea of this study was to establish a hard link between the bottom-up and top-down models. However, this was possible only for the power sector, which was modeled in MESSAGE. This exercise was important to get experience to integrate the other bottom-up models: LEAP and BLUM.

This link between IMACLIM-Brazil and MESSAGE was made in a simple fashion as described on the figure below:

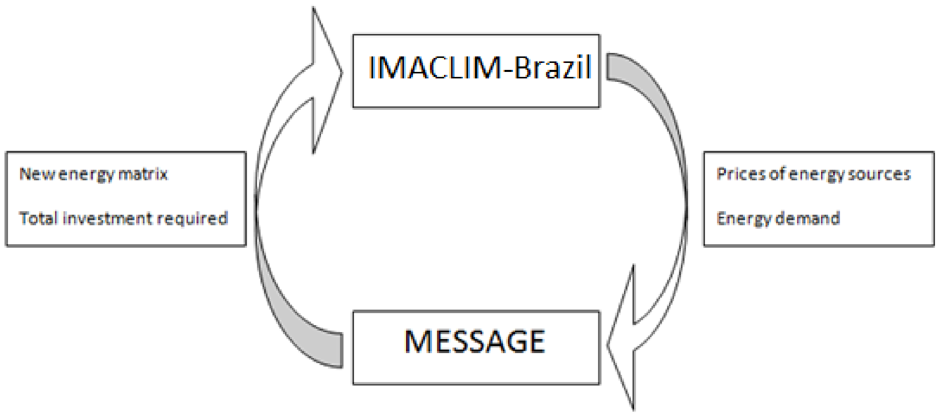


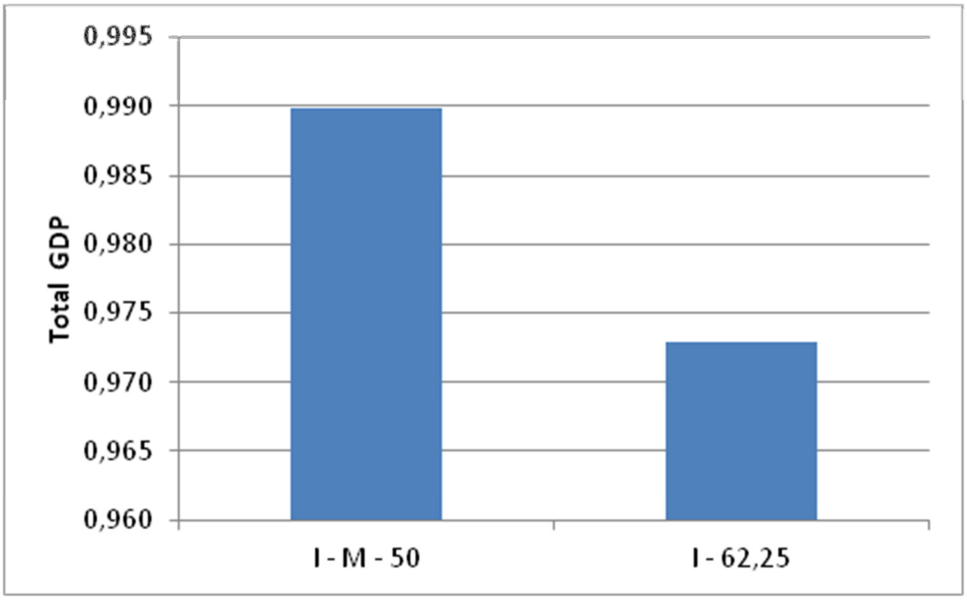
Figure 4 – Link IMACLIM-MESSAGE

At the start point IMACLIM imports the energy balance provided by the simulations from both LEAP (energy demand) and MESSAGE (energy supply). After building the reference scenario, IMACLIM runs the policy scenario, which is made by considering different carbon taxes. In the policy scenario new energy prices are calculated, the economy is impacted, and the energy demand varies from the reference scenario. This new energy demand and the new energy prices are imported by MESSAGE – so a new energy balance is calculated. With new relative energy prices and a new energy demand and supply, the new energy balance is optimized and the total investment needed is calculated. This information is imported by IMACLIM and new energy prices and a new energy demand is calculated. This iterative process continues until no further adjustment in the energy sector is needed. The higher the carbon price, and thus bigger the starting point from the reference scenario, the bigger is the number of iterations needed. Usually 5 iterations are enough to reach the convergence.

This methodology was chosen to test if this link was possible and the results would converge. The objective in the near future is to run any energy scenarios on MESSAGE, with different time horizons, and feed IMACLIM with the projected energy balance.

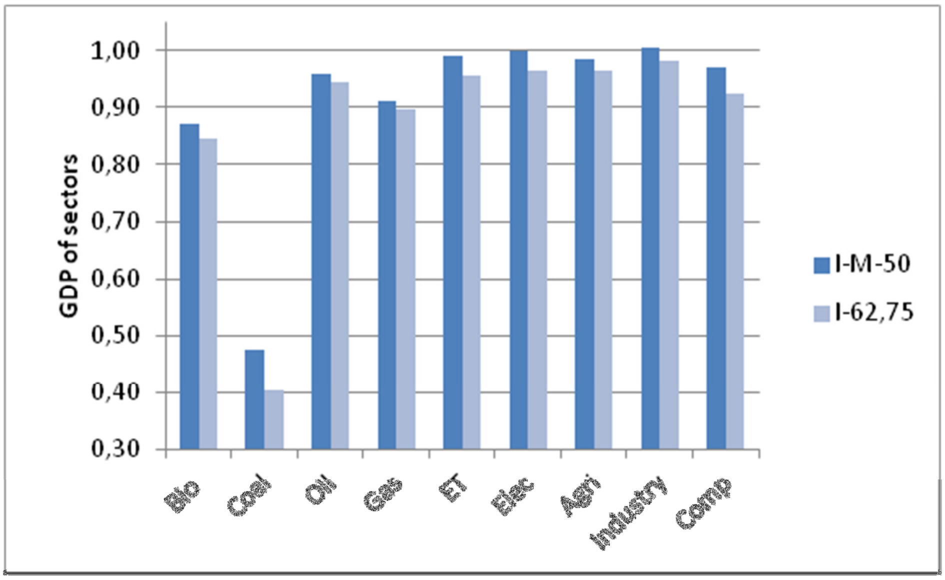
In order to analyze the benefits of the link with the two aforementioned models, two cases were simulated: I-M-50 (lMACLIM + MESSAGE) and I-62.75 (IMACLIM running alone). The abatement level was considered as given: 11% compared to the reference scenario.

When the two models are coupled, it is possible to adjust the energy sector. With higher fossil fuel prices MESSAGE recalculates the energy matrix in order to minimize the final price of electricity. The Graph below shows the impact of the carbon constrain on the economy. As expected, when the adjustment of the energy sector is possible, the economy suffers less. When IMACLIM runs alone, GPD is reduced by 2.75% in comparison to the reference scenario. When the two models are coupled, the impact on the GDP is reduced in only 1%. This simulation shows clearly the importance of having a precise description of the energy system linked to a GGE model. It is interesting to note the difference in the shadow price of CO_2 in the two different conditions. The shadow price of CO_2 is around 62.75 R$/t$CO_2$ when IMACLIM runs alone. When the link to MESSAGE is made, the shadow price of CO_2 reduces to 50 R$/t$CO_2$.



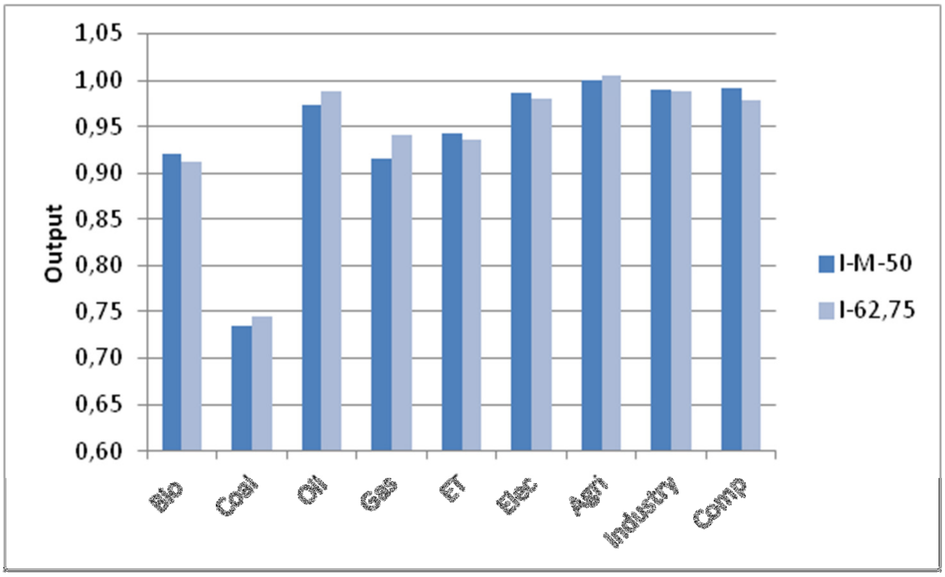
Graph 3 – Impacts on GDP

Next Graph presents how the sectors are affected by the carbon constraint. As expected, without the link to the energy system, and less possibilities of adaptation, all the sectors suffers more.



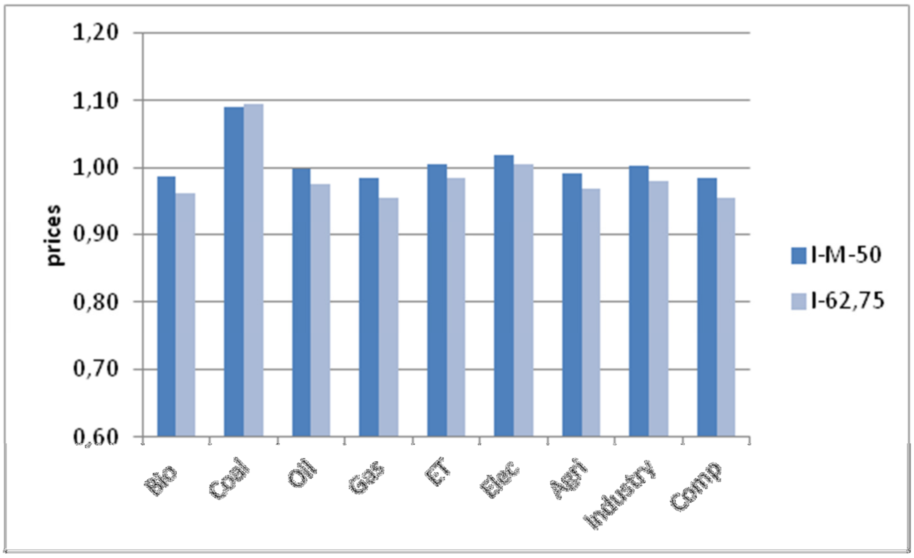
Graph 4 – Impacts on GDP of Different Sectors

Next Graph presents the output from the sectors. We can see that with the IMACLIM-MESSAGE link we have a bigger output for Biomass, electricity and the composite sector. In the other hand, sectors like coal, oil and gas have a smaller output since MESSSAGE chose other less carbon intensive sources to generate electricity.



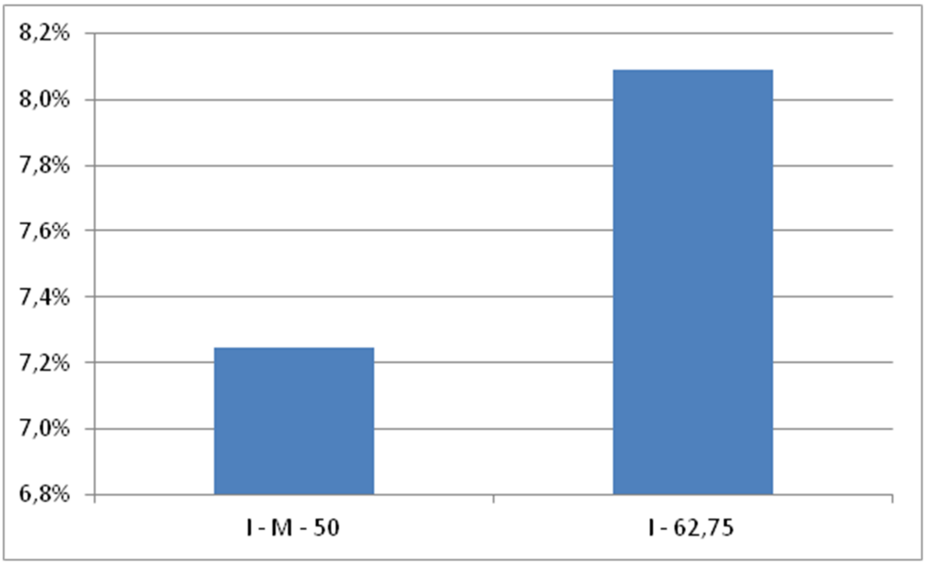
Graph 5 – Impacts on Output of Different Sectors

Next Graph presents the impact of the carbon constraint over the prices of the sectors. Due to a bigger recessive effect of the carbon constraint when IMACLIM runs alone, almost all the prices are smaller in this situation except for the price of coal. With the higher relative price of coal, MESSAGE finds another fuel to substitute it. The demand for coal is lower in this situation, configuring a recessive effect in this sector, keeping the prices at a lower level.



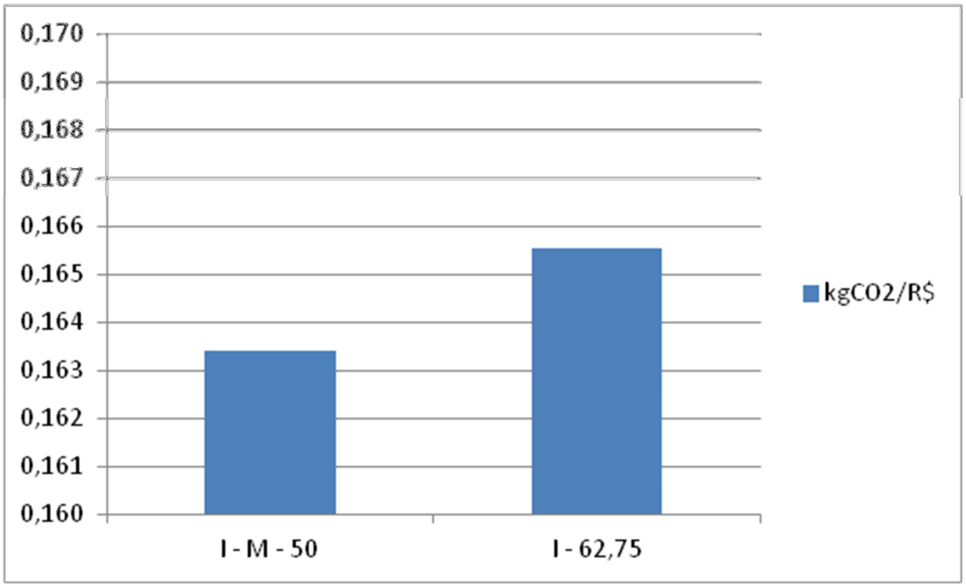
Graph 6 – Impacts on Price of Different Sectors

Another important effect is the impact of the carbon constraint over the unemployment rate. Linking IMACLIM to MESSAGE allows the economy to adjust more to the carbon constraint. The level of activity is higher and so the unemployment rate is significantly lower.



Graph 7 – Impacts on Unemployment Rate

Next Graph shows the carbon intensity of the economy. When the energy sector can adapt to the carbon constraint, the intensity of carbon of the economy is reduced.



Graph 8 – Impacts on Carbon Intensity

6. Final Comments

The aim of this study was to build capacity in the development of tools for the analysis of macroeconomic impacts of introducing measures to mitigate emissions of greenhouse gases such as Carbon Tax and Cap and Trade scheme. The idea was to make such a study based on the integration of bottom-up with top-down models. For this purpose, a reference scenario was built for energy demand with the LEAP model and power supply with the MESSAGE. Additionally, it was also done the same for LULUCF with BLUM model. In this scenario, these models (bottom-up) update the technical coefficients of the top-down IMACLIM .

For the policy scenario, it was analyzed the macroeconomic impacts of the introduction of a Carbon Tax scheme based on Marginal Abatement Cost Curves built for the industry sector. Also, it was analyzed the case of the power sector. This was done by taxing thermal power generation, considering a hard link between MESSAGE and IMACLIM, as a simulation, and compared with IMACLIM alone. The results showed that the adjustment made in the electricity sector by MESSAGE makes the environmental policies analysis more robust when it is made the integration (hard link) between bottom-up and top -down models .

Thus, for further research it will be done the hard link IMACLIM with LEAP and BLUM. Besides, this design will allow analyzing impacts on GDP, employment and income distribution. Such an assessment is the main distinction of the project under development, Which will add value by virtue of using a general equilibrium model built through a partnership of COPPE with UTC and CIRED .

Disclaimer

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