Regional Impacts of Carbon Taxes

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Abstract

This paper presents the model GreenMod and an application regarding the impacts of the carbon taxes on the three Belgian regions (Brussels, Flanders and Wallonia).

GreenMod is a modelling platform for regional and sectoral analysis for energy and environmental issues. The current version is a recursively dynamic CGE model with imperfect competition, increasing returns to scale, and a detailed disaggregation level of the households, the firms, and the government.

We decide that carbon taxes alone are not sufficient in achieving the Kyoto targets at both regional and federal levels. Furthermore, our results indicate that carbon taxes have an adverse effect on income distribution.

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1. Introduction

Environmental regulations started to become an increasingly undeniable part of regular conduct of business and even daily life where their impact is clearly felt by firms, households and governments, local and federal alike. Especially governments which decided to sign binding agreements found themselves in urgent need of sound and reliable tools to assess and monitor the consequences of their policy choices and to generate outcomes of further possible scenarios. The necessity for well-designed and dependable quantitative analysis which will help policy makers to make more informed decisions became apparent.

The application of the GreenMod modelling platform presented in this paper helps to assess regional impacts of implementing a tax on CO_2 emissions in Belgium. GreenMod captures sectoral, macro and regional effects, as well as income distribution, private consumption, employment and welfare consequences of the tax, while assessing its effectiveness in curbing GHG emissions and Belgium's projected distance from the Kyoto goal by the year of 2012. The results emphasize the absence of a silver bullet and call for caution when endorsing policies which rely solely on carbon taxes.

Building on the United Nations Framework Convention on Climate change, adopted on 9 May 1992, the Kyoto Protocol was launched in 1997 and became operative on 16 February 2005, after its ratification by Russia on 18 November 2004. The Protocol aims at implementing legally-binding constraints on greenhouse gas (GHG) emissions and cutting the cost of curbing emissions with innovative mechanisms (UNFCCC, 2002).

On 25 April 2002, the Kyoto Protocol was approved on behalf of the European Community by Council Directive 2002/358/EC[1]. The enforcement of the Protocol commits the Member States to reduce the emissions of greenhouse gasses in Annex A (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6)[2] by 8 per cent during the period 2008-2012, compared to their 1990 levels. The target will be shared between the Member States. The burden-sharing agreement is set in Annex II of the Council Directive 2002/358/EC, and assigns emission cuts to each member state ranging from 4 to 28 per cent. In this context, Belgium has agreed to reduce its emissions of greenhouse gases for the period 2008-2012 by 7.5 per cent compared to its level in 1990.

In 1990, CO_2 emissions represented more than 80 per cent of the total greenhouse emissions in Belgium, while the N_2O was responsible for 8.2 per cent of the total emissions, and the CH_4 for 7.4 per cent. The other greenhouse gases, HFC, PFC and SF_6, accounted for less than 3 per

[1] Official Journal of the European Union, L 130, 15.05.2002, p.1-20.
[2] Annex A of Kyoto Protocol available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf.

cent of the total emissions. Since 1990, the total emissions of greenhouses gases have increased, but the shares of CH_4 and N_2O have slightly diminished by 2004. The explanation for this comes from a reduction of the emissions generated by the agricultural and the waste sectors (CH_4 and N_2O) that has been outweighed by a rise in the CO_2 emissions. The structure and evolution of the GHG emissions in Belgium between 1990 and 2004 is provided in table 1.

Table 1: The evolution of greenhouse gasses emissions (GHG) in Belgium

	CO2	CH4	N2O	HFCs, PFCs, SF6	Total
	CO2 equivalent (kt) and the share of each component in the total GHG				
1990	119,081	10,825	12,010	3,850	145,766
1990	81.7%	7.4%	8.2%	2.6%	100.0%
1997	122,272	10,254	12,979	2,358	147,863
1997	82.7%	6.9%	8.8%	1.6%	100.0%
2004	126,907	7,916	11,210	1,840	147,873
2004	85.8%	5.4%	7.6%	1.2%	100.0%

Source: Belgium's Greenhouse Gas Inventory (1990-2004) - National Inventory Report submitted under the United Nations Framework Convention on Climate Change, April 2006

Given the federal structure of the Belgian State, the emission reduction will be shared between the federal government and the three regions: Flanders, Wallonia and Brussels.

There are big differences in the economic structure of the three Belgian regions. The Brussels region, due to its limited size, is characterized by a high population density and very few industries. Most of its emissions stem from household and service sector heating and transportation.. The total emissions in the Brussels region represent only about 3 per cent of the total emissions of Belgium. Flanders and Wallonia have a much more developed industrial structure. Currently, Flanders is responsible for about 60 per cent of the total emissions of Belgium and Wallonia for the remaining 37 per cent.

On 8 March 2004, after more than 5 years of long and complex negotiations, the federal and regional governments came to an agreement to share the burden of the reduction in the emissions in the following way: the Walloon region will reduce its emissions by 7.5 per cent compared with its levels in 1990, the Flemish region by 5.2 per cent, and Brussels is allowed to increase its emissions by nearly 3.5 per cent (see table 2). Due to the fact that the total reduction would not meet the assigned amount given to Belgium, the rest of the reduction will be achieved by the federal government through the flexible mechanisms anticipated by the Kyoto Protocol.

Table 2: Burden sharing of the reduction in the GHG between the regions and the federal government[3]

Regions	Emissions 1990	Emissions allowances allocated for the period 2008-2012
	Million of tons CO2 equivalent	
Flanders	87.95	416.86
Wallonia	54.30	251.14
Brussels	3.99	20.64
Total emissions allocated to the regions:		688.64
Assigned amounts to Belgium:		676.36
Amount of emissions to be acquired by the federal government through flexible mechanisms		12.28

Source: Belgian National Allocation Plan, June 2004.

In spite of the importance of the challenges facing the three regions of Belgium and the permanent debate on the policies to follow and on the reforms to implement, quantitative analyses of environmental policies have been conducted using the Markal family of models, Gem-E3, Hermes and EPM. None of these models is able to provide analytical and quantitative support for decision-making at both regional and federal levels.

The *Markal* model, developed in a cooperative multinational project by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA), is a technical-economic dynamic optimisation model. Its Belgian version has been implemented jointly by the Centre for Economic Studies, KULeuven and the Flemish Institute for technological research VITO through financing by OSTC (Belgian Prime Minister's Office for Scientific, Technical and Cultural Affairs) under the Global Change Research Program (Proost, 2001). Energy carriers integrate the conversion and consumption of energy in Markal, as in most energy system models. The Markal model has the advantage of selecting through an optimisation routine the sources, energy carriers and transformation technologies to produce the least-costly solution subject to technical characteristics constraints, technology costs constraints, and energy service demands constraints. However, the macro (Markal-Macro) and the sectoral framework are greatly simplified.

Gem-E3 is a recursively dynamic multi-national and multi-sectoral general equilibrium model of the European Union specially developed for energy/environmental issues with co-financing from the European Commission (Capros *et al.*, 1997). The 'top-down' structure of the model allows for quantifying the macro and sectoral effects of various environmental policy measures but the

[3] As revisions of the 1990 emissions figures are allowed until the end of 2006 (2002/358/EC), the sum of the regional emissions are slightly higher in 2004 compared to the level of 1990 estimated in 2006.

model does not take into account the regional dimensions of the Belgian economy and its institutions. Furthermore, the sectoral disaggregation is fairly limited. The behaviour of only one representative household is modelled in Gem-E3, which does not allow any analysis of the distributional effects of environmental measures.

Hermes is a macro-econometric model developed by the Belgian Federal Planning Bureau (Bossier, Bracke, Gilis and Vanhorebeek, 2004). It has the advantage of providing short and medium term forecasts, while also being used for scenario analysis. However, as Gem-E3, the model does not account for the regional structure of the Belgian state and provides a rather limited sectoral disaggregation. The distributional effects due to the environmental measures cannot be quantified either.

As for the *EPM* (Energy/Emissions Projection Model) model, developed by Econotec, it offers a techno-economic 'bottom-up' approach, providing energy consumption expressed in physical units at a detailed installation level and containing a comprehensive representation of GHG emissions sources (Econotec, 2001). The model also accounts for the main determining factors in the evolution of energy demand and the various types of emissions. Nevertheless, it lacks any macro-economic framework to asses the economic effects of environmental measures. Furthermore, it only focuses on the Brussels and Walloon regions.

The continuous evolution of the Belgian State toward a federal structure and the prospect of even further transfer of power to the regional governments strongly indicate the necessity of a modern and powerful quantitative tool to help policy makers make better informed decisions.

In this paper, we present the only regional modelling platform available for Belgium, called GreenMod, and one of its applications: the implementation of a tax of 20€ per ton of CO_2 emissions generated by the consumption of coal, gasoline, gas oil and natural gas for household heating and transportation.

The next section provides an overview of the GreenMod modelling platform. We present and discuss the simulation results in section 3 and conclude in section 4.

2. Overview of the GreenMod modelling platform

GreenMod is a dynamic multi-sector multi-household inter-regional computable general equilibrium (CGE) model for the Belgian economy, which is intended to act as an analytical and quantitative support for decision-making in the energy and environment field (Bayar *et al.*, 2006). GreenMod fills in the gaps left by the other models currently used in Belgium, in particular by explicit bottom-up modelling of the three Belgian regions (Brussels, Flanders, Wallonia), by further disaggregating the production and consumption blocs (sixty sectors/sixty nine commodities), by distinguishing ten household income groups to study the distributional effects of environmental policies and by paying special attention to the representation of technical change and to the modelling of capital structure and its evolution over time.

The model incorporates the economic behaviour of four economic agents in each region: firms, households, government and the external sector. In addition to the agents described at the regional level, the federal government and the French Community are explicitly modelled to take into account the complex federal structure of the Belgian State. All economic agents are assumed to adopt an optimizing behaviour under relevant budget constraints. GreenMod is calibrated on a highly disaggregated inter-regional Social Accounting Matrix for Belgium.

2.1. Firms

Sixty-two types of branches of activity are distinguished, consisting of both public and private enterprises[4]. Each sector produces one type or several types of commodities. Also, different sectors can produce the same type of commodity. For example, the manufacture of coke and refined petroleum products produces nine different types of commodities: coke oven coke, petroleum coke, nuclear energy, gasoline, heavy oil, gas oil, coke oven gas, refinery gas and other combustibles, while non-nuclear and nuclear electricity sectors produce one homogenous good: electricity. In total, GreenMod accounts for sixty-nine types of commodities, out of which ten of them are energy inputs.

2.1.1. The nested production structure

Gross output for each sector and each region is determined from a nested production structure. The nesting of the production structure is differentiated between sectors according to the specific production technologies used by the sectors. Three main ways of nesting the production structure are distinguished in the model. The first one (AGR) regroups the agricultural, forestry and fishing sectors. The second one (EN) refers to other mining and quarrying sectors, the manufacture of coke and refined petroleum products, production and distribution of natural gas, production and distribution of nuclear electricity and collection, purification and distribution of water. The last one (OTH) includes all other industrial and services sectors in the model which are not included in the AGR and EN groups. The nested structure and the functional forms used by the sectors are provided in Fig.1 and Fig. 2.

[4] A presentation of the production sectors considered in the model is given in Appendix A.

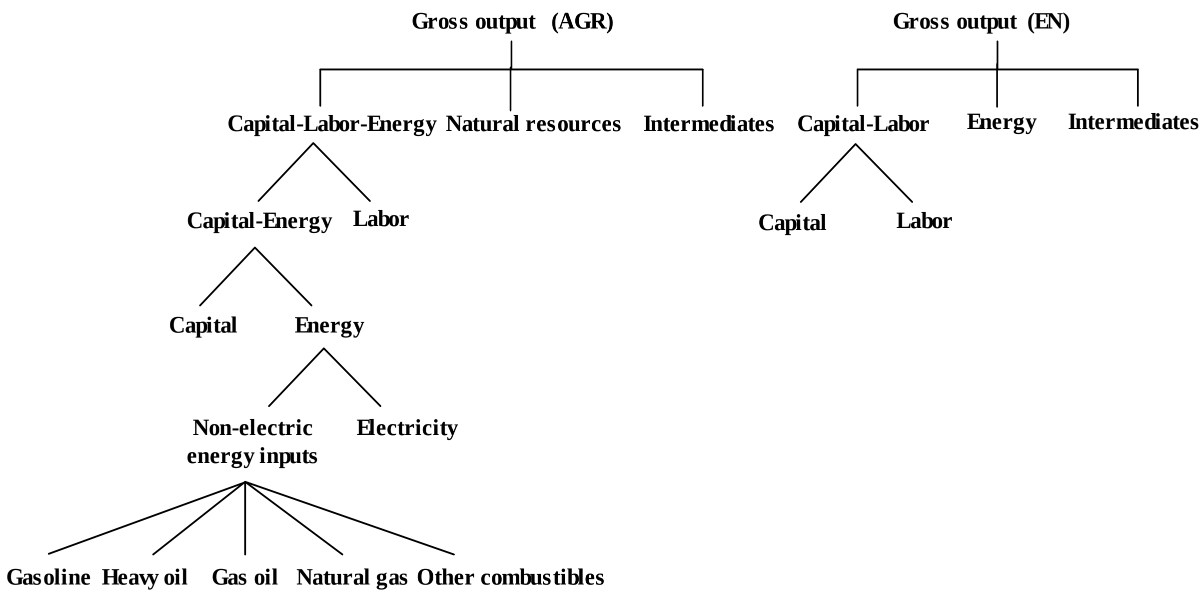

Fig. 1. A nested Leontief and CES production technology for the AGR and EN production sectors

The connection between the vertical and horizontal lines (see Fig. 1 and Fig. 2) represents the relationship between the output and the inputs in a Leontief production function, where the elasticity of substitution between inputs is assumed to be zero. For example, for the AGR nesting group producers are assumed to choose at the outer nest intermediate inputs of non-energy goods, natural resources (i.e. land) and a capital-labour-energy composite, according to a Leontief production function (Fig. 1). The connection between the slanted lines represents the relationship between the output and the inputs of a constant elasticity of substitution (CES) production function, where positive substitution possibilities are assumed between the inputs. For instance, producers corresponding to the AGR nesting group choose at the second stage the optimal level of labour input and capital-energy composite (Fig. 1). Production substitution possibilities are reflected in this case by a CES function.

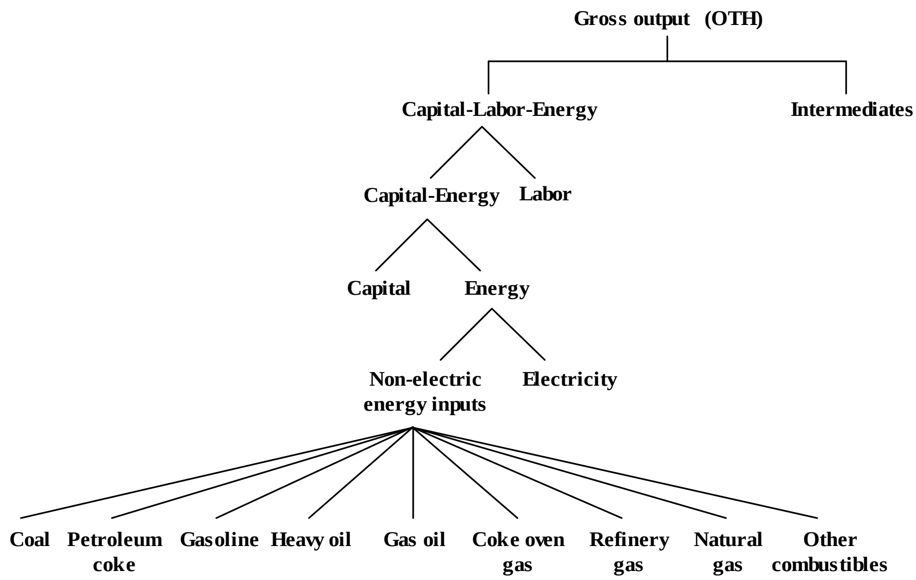

Fig. 2. A nested Leontief and CES production technology for the OTH production sectors

2.1.2. Imperfect competition

GreenMod explains the differences in the industry structure between the regions by variations in the economies of scale (Harris, 1984; Willenbockel, 1994). Strategic interactions between firms in an imperfectly competitive industry are represented using spatial Cournot oligopoly framework with free entry and exit. This framework has recently been used in general equilibrium literature to model firms' location and different industry structures for studying energy related issues (Babiker, 2005).

GreenMod incorporates the representation of a range of oligopolistic sectors. These sectors differ in their regional location, the number of operating firms and the degree of the economies of scale, which they enjoy. Each individual firm is a profit-maximiser. It chooses its output level based upon its marginal costs and the price elasticities of demand that it faces. The behaviour of individual firms defines the overall performance of the oligopolistic industry in terms of number of operating firms, output and price levels. Performance of an oligopolistic industry is represented using Cournot-Nash equilibrium.

All oligopolistic firms in GreenMod are country level oligopolists. They exercise their market power over all Belgian regions and cannot price differentiate between them. They take into account the weighted perceived elasticities of demands of all Belgian regional markets while choosing their outputs and prices.

2.1.3. Capital structure

The targets established by the Kyoto Protocol for the GHG emissions reduction entail an important change in the structure of consumption and production in the short-run. Given that the use of less carbon-intensive inputs in the production process calls for large replacement or retrofit rates for the capital stock, the representation of the capital structure and its evolution over time requires special attention in the model. Therefore, two types of capital are distinguished in each period in GreenMod: a "malleable" part and a "rigid" part (Jacoby *et al.*, 2004).

A share of gross output in each sector is assumed to be produced using "malleable" capital, whereas the rest is produced using old capital vintages ("rigid" capital). The technology is assumed to have a putty/semi-putty specification, which implies that possibilities of substitution among factors of production are assumed to be higher for the malleable than for the rigid capital (vintage capital). The older the capital vintage the lower are the substitution possibilities between capital and other factors of production, and thus the lower are the adjustments in factors' demand in response to changes in relative prices. Due to the coexistence of malleable and different generations of non-malleable capital within the same period, substitution effects are delayed over time and demand for production factors adjusts gradually in reaction to relative price changes (Van der Mensbrugghe, 1994).

2.1.4. Backstop technologies

Technical change has a strong influence on projections of greenhouse gas emissions and the costs of their control. Therefore, GreenMod incorporates three energy alternatives ("backstop" technologies[5]): a carbon-free electric power generation based on biomass, a carbon-free electric power generation based on wind power and a hydrocarbon-intensive technology for natural gas (coal gasification).

All these new technologies are available in the model at the regional level, but they are assumed to remain uneconomical in the first few years of the GreenMod simulation horizon. Following Babiker et al. (2001), the backstop technologies are endogenously switched on if they become economically competitive with the existing technologies. Depending on the policy simulation the three backstop technologies may become competitive energy sources in GreenMod at the same moment or at different moments in time. Backstop natural gas is assumed to be a perfect substitute for the conventional natural gas, while the backstop electricity based on biomass and

[5] According to Nordhaus (1979), the "backstop" technology represents an energy source which is not yet commercial, but is available in unlimited supply at constant marginal cost and is physically a perfect substitute for a conventional energy input.

the one based on wind power are assumed to be perfect substitutes for electricity. Both backstop natural gas and electricity are not traded either between the regions or internationally.

2.2. Households

Ten types of households are represented in each region, differentiated according to income level. Each decile of each region receives labour income originating from the region of residence and from the other two Belgian regions. Commuting activities between the Belgian regions lead to the labour income originating from regions different from the household's residence region. In addition to receiving labour income from the Belgian resident firms, the households also receive labour income from the non-resident firms. Moreover, each household group gets a fixed share of the capital income originating from the region of residence and transfers from the regional and federal governments, from the firms and from the external sector. The transfers from the federal government also include unemployment benefits.

Each decile of each region is endowed with a certain amount of time that is further allocated over labour supply and leisure. The optimal level of leisure required by the households is the result of an optimization process. Thus, labour supply by household income group and region is also endogenously determined. The regional labour supply is subsequently given by summing up the amount of labour supplied by each decile of each region.

On the expenditure side, households pay personal income taxes to both federal and regional governments. Personal income tax in Belgium is a co-joined tax. It is a federal tax in the sense that it is applied in a uniform manner on all the territory, but a share of the corresponding revenues is distributed to the regional governments. The regions are authorized to receive an additional percentage to the tax rate established at the federal level or to grant reductions, up to the total amount attributed to each region. Thus, a distinction has been made in the model between the tax rates paid at federal and regional levels.

A share of household net income is saved, whereas the difference between the net income and savings is allocated to the disposable budget for consumption of commodities. The extended disposable budget for consumption further takes into account the opportunity cost of leisure which is equal to before-tax region-wide average wage rate. A schematic representation of household decisions for each decile is given in Fig. 3.

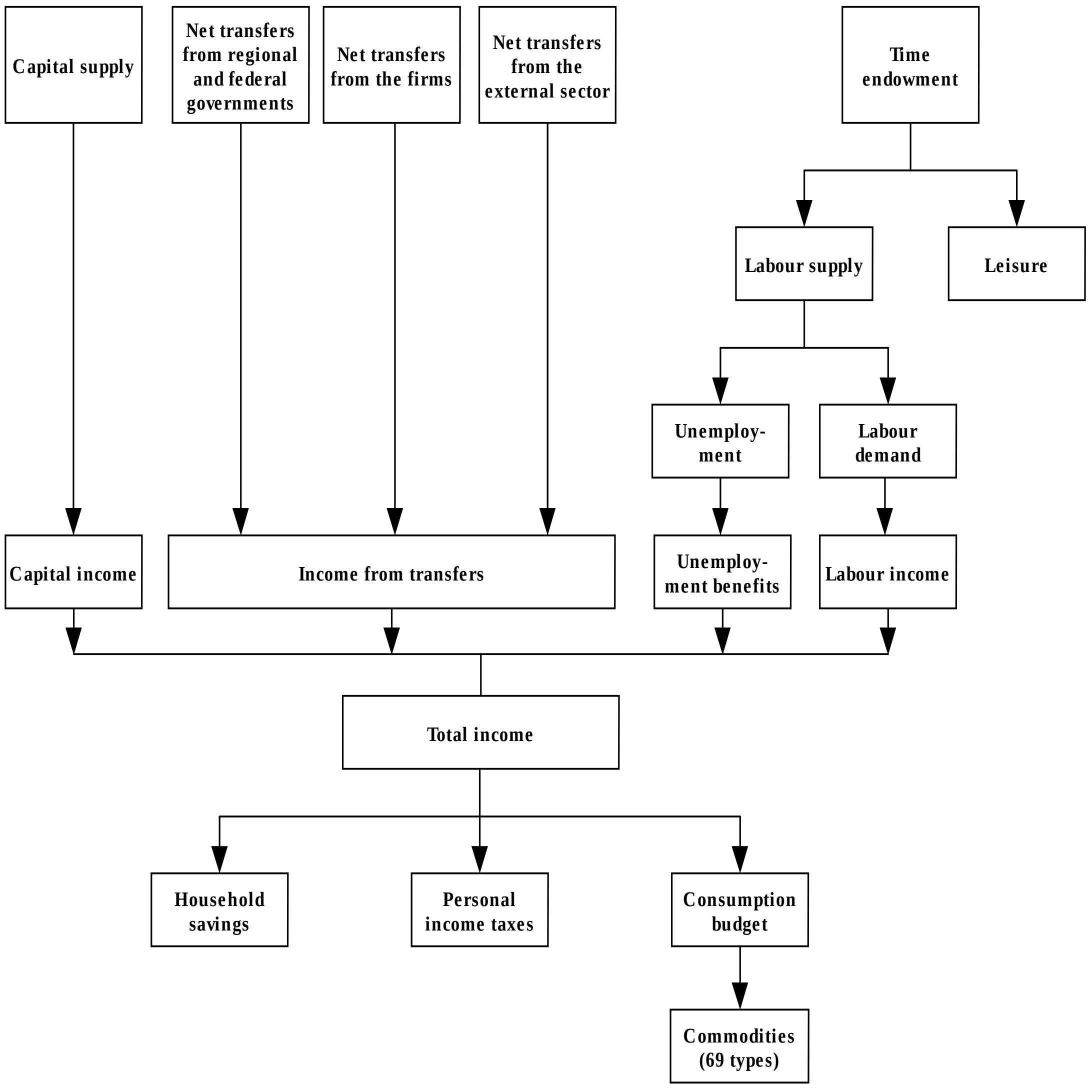

Fig. 3. Decision structure of the households, for each decile

Household demand for commodities and leisure is the result of a two-stage optimization procedure. In the first stage, the optimal allocation between a composite consumption commodity and leisure is given by maximizing a Stone-Geary utility function subject to the extended budget disposable for consumption. In the second stage, the optimal allocation of the composite commodity between consumption of sixty-nine types of commodities is given by maximizing another Stone-Geary utility function subject to the disposable budget for consumption of commodities. The two-stage optimization process generates the demand equations for consumption commodities and for leisure[6].

[6] The Linear Expenditure System (LES) was developed by Stone (1954) and represents a set of consumer demand equations linear in total expenditure.

Consumption is valued at market prices, including excise duties, value added taxes and other federal and regional taxes less subsidies on products. Excise duties are applied to commodities prices net of subsidies and are paid to the federal level. Value added taxes and other taxes on consumption are further applied to prices gross of excise duties.

Equivalent variation in income is used to evaluate the overall change in consumer welfare of each household group in each region (Varian, 1992). Equivalent variation measures the income needed to make the household as well off as she is in the new counter-factual equilibrium evaluated at benchmark prices. For welfare gains the equivalent variation is positive while for losses it is negative.

2.3. Government

Government behaviour is modelled at three different levels in GreenMod: federal, regional, and community. At the community level, only the behaviour of the French community is explicitly represented. The Flemish community and the Flemish region share a single government, which exercise the community and regional powers. Therefore, the Flemish community is accounted for together with the Flemish regional government in the model.

2.3.1. Federal government

The attributes regarding the tax collection in Belgium are shared between the federal and regional governments. Tax revenues of the federal government consist of custom duties levied on imports of goods, value added taxes, excise duties and other taxes on consumption of commodities, personal and corporate income taxes, social security contributions, taxes on production and taxes on investment goods. On the expenditure side, a part of the budget is allocated for current consumption of public services, education, health and social work services, a part is used to provide subsidies on consumption and direct subsidies to the firms in the three Belgian regions, another part is transferred to households, regional governments and the French community, and the rest is saved.

Public services, education and health and social work services are assumed to be produced by the corresponding production sectors in the model, using labour inputs, capital inputs, energy inputs and other non-energy inputs. Then, a part of these services is transferred to the federal government. The optimal allocation of consumption by the government among these services is given by the maximization of a Cobb-Douglas utility function subject to the constraint that the government budget disposable for current consumption should be equal to the difference between total tax revenues, government savings and total expenditures on subsidies and transfers. The optimization process yields the demand equations for public services, education, health and social work services by the federal government in each region.

Federal government transfers to each household group in each region include unemployment benefits and other transfers such as pensions. Unemployment benefits are determined by the number of unemployed in each region, to which the replacement rate out of the regional net wage is applied. Unemployment benefits are further distributed among the deciles taking into account the share of unemployment benefits received by each household group in each region.

2.3.2. Regional governments

Regional governments collect taxes on private consumption, taxes on capital use and taxes on production, and an additional percentage to the personal income tax rate established at federal level. Each of the governments also receives transfers from the federal government. Additionally, the Walloon government gets transfers from the French community.

On the expenditure side, all three regional governments allocate a part of their budget to public services and education services. They also subsidize consumption of the resident households and production of the resident firms in the corresponding region. Regional governments also make transfers to the resident households and to the external sector. The difference between total revenues and total expenditures is saved. Transfers to the rest of the world are provided in foreign currency, and converted into the domestic currency by multiplying them by the exchange rate. The optimal allocation of current consumption between public services and education services is again given by the maximization of a Cobb-Douglas utility function subject to the regional governments' budgets disposable for current consumption.

2.3.3. French community (Communauté Wallonie-Bruxelles)

French community gets all its revenues from the federal government as transfers. A part of its revenues is further transferred to the Walloon government, whereas the rest is allocated for consumption of public services and education services. Again, the optimal allocation of consumption between these services is given by the maximization of a Cobb-Douglas utility function, yielding the demand equations for the public and education services.

2.4. Inter-regional and foreign trade

The specification of foreign trade is based on the small-country assumption. This means that each region is a price taker in both its imports and exports markets. Thus, both import and export prices are fixed exogenously in foreign currency, but they are endogenously determined in domestic currency.

The assumption of imperfect substitution possibilities between domestically produced and imported goods, which goes back to Armington (1969), is now a standard feature of applied CGE models and is also adopted here. It indicates that domestic consumers use composite goods of imported and domestically produced goods, according to a CES function. Given the regional dimension of the model, the composite (Armington) demand consists of domestically produced goods, imports from the other Belgian regions and imports from the rest of the world (ROW). Because Belgium is a very open economy, substitution possibilities between imports from other Belgian regions, imports from ROW and domestically produced goods are assumed to be the same.

In GreenMod each production sector can produce several types of commodities, whereas several sectors can produce the same homogenous good. Therefore, imports from the Belgian regions and domestically produced goods account for the sector of origin and the type of commodity they produce. Imports from the rest of the world only take into account the type of product and their region of destination.

The derived Armington demands for domestically produced commodities are utilized by the oligopolistic firms in their profit-maximisation problems. The output produced by these firms is equal to the demand they face and this equilibrium determines their oligopolistic price levels.

Imperfect substitution is also assumed to exist between goods produced by the perfectly competitive sectors for the regional domestic market and for exports as captured by a constant elasticity of transformation (CET) function. Again, a distinction is made between exports to the other Belgian regions and exports to the rest of the world. For each type of commodity, regional exports take into account its sector, its region of origin and its region of destination. Exports to the rest of the world only account for the sector and region of origin.

The use of the CET transformation function for the imperfectly competitive sectors is redundant, since their output levels are equal to the Armington demands in accordance with the formulation of their profit-maximisation problems.

The regional characteristic of the model imposes an obvious restriction: the exports of a Belgian region to another Belgian region represent the imports of the later from the former. For example, the exports of Brussels to Wallonia are equal to the imports of Wallonia from Brussels. As there are no tariffs on imports between the regions, the same equality stands for prices.

The trade structure for the Brussels region, adopted in GreenMod, is provided in Fig. 4. The trade structure for Flanders and Wallonia are represented in a similar way.

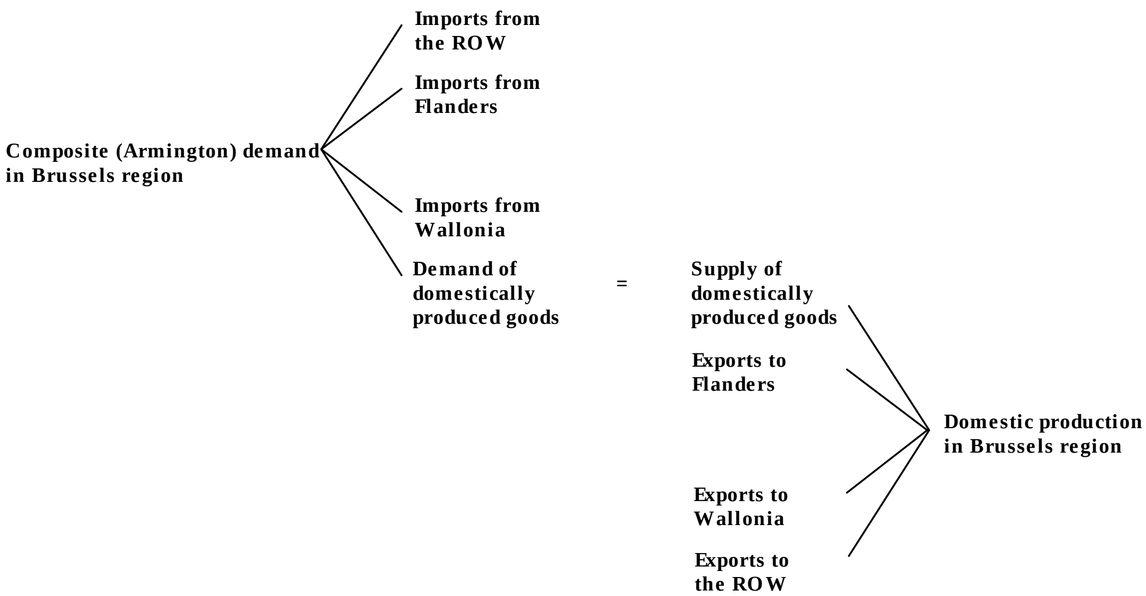

Fig. 4. The trade structure for the Brussels region in GreenMod

The balance of payments at the national level is further given by all international incoming and outgoing payments in foreign currency. The surplus or the deficit of the current account is thus defined by the difference between exports and imports, valued at world market prices, the transfers of the regional governments to the external sector, the foreign remittances received by each household group as well as the payments for labour supplied to the non-resident firms. The surplus/deficit of the balance of payments reflects the net lending/borrowing of the economy to/from the rest of the world.

2.5. Investment demand

Total savings are derived at a national level, because it is not possible to separate federal government and foreign savings at the regional level. The demand for investment commodities is differentiated instead by region and type of commodity.

National savings are given by the gross households' savings, firms' savings, federal and regional governments' savings and foreign savings. The allocation of savings between different types of investment goods demanded in each region is given by the maximization of a Cobb-Douglas utility function subject to the constraint that savings less changes in stocks should be equal to the total expenditures on investment goods. Expenditures on investment goods also include the value added taxes and other taxes on purchases of investment commodities, paid to the federal government. The optimization process yields the demand equations for investment goods by type of commodity and region.

No information is available on the composition of investments carried out in the sectors. Therefore, in the dynamic part of the model it has been assumed that a composite homogenous good is invested in each sector.

Changes in stocks are modelled as a fixed share of the composite supply of commodities, coming from imports and regional domestic supply.

2.6. Regional labour markets

Commuting activities are important between the regions, especially those from Flanders and Wallonia towards Brussels. In the model, the number of commuters is determined as a fixed share of the total labour demand in the region in which they are employed. As a consequence, each household group can earn its income in one region and spend it in a different one. Regional labour markets are closed by changes in unemployment.

The responsiveness of regional real wage rates to the regional labour markets conditions is captured by a wage curve. Janssens and Konings (1998) found evidence supporting a wage curve for Belgium. They estimated an unemployment elasticity of -0.04 for males and females taken together. Therefore, the regional unemployment elasticity in GreenMod is taken equal to this value for all three Belgian regions.

2.7. Greenhouse gas emissions

GreenMod accounts for the GHG emissions which make up the highest share of the total emissions in Belgium: the CO_2, CH_4, N_2O emissions. Both emissions on fuel combustion and process emissions are considered for each category of GHG emissions.

CO_2 emissions on fuel combustion, generated by the consumption of fuels by each sector of each region are derived by applying the emission factors corresponding to each fuel to the energy consumption by the sectors. Similarly, the CO_2 emissions generated by the consumption of fuels for heating and transport by the households are also derived by applying the emission factors to the consumption of energy by the households.

The CO_2 process emissions originate from the manufacture of chemicals and chemical products, manufacture of other non-metallic mineral products and manufacture of basic metals. They constitute less than 10 per cent of the total CO_2 emissions in Belgium. The CO_2 process emissions are linked to the level of production by the specific sector.

GreenMod allows for flexible aggregations with regard to CO_2 emissions: by sector at the national level, by sector and region, by fuel, sector and region, by region (including or excluding households' emissions). The CO_2 emissions are expressed in kilotons (kt).

The vast majority of methane emissions in Wallonia and Flanders originate from the agricultural and waste sector. Compared to the CO_2 emissions, only a small share of their total comes directly from fuel combustion. On the contrary, in Brussels 99.9 per cent of the total CH_4 emissions comes from fuel combustion. The CH_4 emissions generated by fuel combustion are derived by applying the emissions factors to the consumption of fuels by the sectors, whereas the CH_4 process emissions are linked to the level of production of the responsible sector.

The bulk of nitrous oxide emissions in Wallonia and Flanders come from the agricultural sector and from the industrial process of the chemical sector. The level of N_2O emissions in Brussels is very low relative to the other Belgian regions. They are mainly generated by the use of N_2O for anaesthesia, and by fuel combustion of different sectors. The N_2O emissions generated by fuel combustion and the N_2O process emissions are modelled similarly to the CH_4 emissions. Both CH_4 and N_2O emissions are expressed in kilotons (kt) of CO_2 equivalent.

2.8. Incorporating dynamics

GreenMod has a recursive dynamic structure composed of a sequence of several temporary equilibria. The first equilibrium in the sequence is given by the benchmark year, 2003. In each time period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period. The equilibria are connected to each other through capital accumulation. Thus, the endogenous determination of investment behaviour is essential for the dynamic part of the model. Investment and capital accumulation in year *t* depend on expected rates of return for year *t+1*, which are determined by actual returns on capital in year *t.*

The expected rate of return required to indefinitely maintain the current rate of capital growth in sector *s* of region *r* for the "malleable" part of the capital, is specified as an inverse logistic function of the proportionate growth in sector's *s* of region's *r* capital stock (Dixon and Rimmer, 2002).

The "malleable" capital stock in sector *s* of region *r* in the next period (year *t+1*) is given by:

$$KSKm_{s,r,t+1} = (1-d_{s,r})\cdot(1-\phi_{s,r})\cdot KSKm_{s,r,t} + INV_{s,r,t} \qquad (1)$$

where $KSKm_{s,r,t}$ is the current "malleable" capital stock (in year *t*), $INV_{s,r,t}$ are the investments carried out in sector *s* of region *r* in year *t*, $d_{s,r}$ is the depreciation rate, and $\phi_{s,r}$ is a "vintage" parameter which determines the share of “malleable” capital that becomes “rigid” each year (Jacoby *et al.*, 2004).

In period *t+1* the first vintage of non-malleable capital is given as a share $\phi_{s,r}$ of the malleable capital after depreciation:

$$KSKv_{s,v,r,t+1} = \phi_{s,r} \cdot (1 - d_{s,r}) \cdot KSKm_{s,r} \qquad \text{for v = 1} \qquad (2)$$

The other (older) vintages in each sector are updated in the dynamic part according to:

$$KSKv_{s,v+1,r,t+1} = (1 - d_{s,r}) \cdot KSKv_{s,v,r,t} \qquad \text{for v = 2,3,…} \qquad (3)$$

The model is solved dynamically with annual steps. The simulation horizon of the model has been set at 25 years, but it can easily be extended. In between periods, some other variables like transfers between firms, government and the rest of the world, and the foreign savings are updated exogenously.

2.9. Closure rules

The closure rule refers to the manner in which demand and supply of commodities, the macroeconomic identities and the factor markets are equilibrated ex-post. Due to the complexity of the model, a combination of closure rules is needed. The particular set of closure rules should also be consistent, to the largest extent possible, with the institutional structure of the economy and with the purpose of the model.

To balance the number of endogenous variables and the number of independent equations in the model for each year, additional assumptions are needed. Therefore, the transfers between the regional and federal government, households, firms and the rest of the world corresponding to each region are exogenously fixed in real terms. To achieve the regional labour market clearing, inter-sectoral mobility of labour is assumed. However, the presence of unemployment introduces rigidities in the labour market. Installed capital is sector specific, introducing rigidities in the capital market.

The most widely accepted macro closure rule for CGE models implies the assumption that investment and savings balance. In the model, the investment is assumed to adjust to the available domestic and foreign savings. This reflects an economy in which savings form a binding constraint. The interest rate is assumed to effectively balance the supply and demand for investments, even if the specific mechanism is not incorporated in the model. This macro closure rule is neoclassical in spirit. However, the model also allows for unemployment. As already mentioned, in models of this size it is not uncommon that a few closure rules are combined to get as close as possible to a realistic representation of the economy.

The government behaviour at the federal and regional level is modelled through an optimization process, which yields the optimal allocation of governments' consumption by type of commodity and region. The budget deficits/surpluses of federal and regional governments are exogenously fixed in real terms. With regard to the external sector, the surplus/deficit of the current account is fixed and the endogenous exchange rate brings the balance of payments into equilibrium.

3. A carbon tax policy scenario

The increasing awareness of the need of an efficient environmental policy at the European Community level during the 1990s resulted in broadening the types of policy instruments. Thus, the Fifth (1993-2000)[7] and the Sixth Environmental Action program (2002-2010)[8], drawn up by the European Commission, have promoted and encouraged the use of fiscal measures such as environmentally related taxes and incentives.

In this framework, a carbon tax scenario is evaluated using GreenMod to illustrate the model's ability in assessing the effects of environmental measures at very detailed regional, sectoral and households' group levels.

A tax of 20€ per ton of CO_2 emissions[9] generated by the consumption of coal, gasoline, gas oil and natural gas for heating and transportation by the households is imposed gradually starting with 2005. The tax target level of 20€ per ton is achieved in 2012. A recycling scheme is implemented to counterbalance the expected negative effects on private consumption, where the additional tax revenues are redistributed through a reduction in the personal income tax.

A reduced version of the model with perfect competition and thirty production sectors/thirty-seven commodities is used to present the results of the carbon tax policy scenario. The population is divided into two income groups, the second being the richest half. The aggregation of the production sectors and commodities in the carbon tax scenario is provided in table 3.

[7] Official Journal of the European Union C 138, 17.05.1993, p. 5-98.
[8] Official Journal of the European Union L 242, 10.09.2002, p. 1-15.
[9] A CO_2 tax can be translated into a carbon tax, since a tonne of CO_2 corresponds to 0.27 tonnes of carbon.

Table 3. Production sectors/commodities aggregation used to run the carbon tax scenario

Production sectors	**Commodities**
Agriculture, forestry, fishing	Agriculture, forestry, fishing products
Mining of coal and lignite; extraction of peat	Coal and lignite; peat
Extraction of natural gas	Natural gas
Extraction of crude petroleum	Crude petroleum
Mining of uranium and thorium ores; mining of metal ores; other mining and quarrying	Uranium and thorium ores; metal ores; other mining
Manufacture of food products and beverages	Food products and beverages
Manufacture of pulp, paper and paper products	Pulp, paper and paper products
Manufacture of coke, refined petroleum products and nuclear fuel	Coke oven coke Petroleum coke Nuclear energy Gasoline Heavy oil Gas oil Coke oven gas Refinery gas Other combustibles
Manufacture of chemicals and chemical products	Chemicals and chemical products
Manufacture of other non-metallic mineral products	Other non-metallic mineral products
Manufacture of basic metals	Basic metals
Manufacture of fabricated metal products	Fabricated metal products
Manufacture of machinery and equipment n.e.c.	Machinery and equipment n.e.c.
Manufacture of office machinery and computers	Office machinery and computers
Manufacture of electrical machinery and apparatus n.e.c.	Electrical machinery and apparatus n.e.c.
Manufacture of radio, television and communication equipment and apparatus	Radio, television and communication equipment and apparatus
Manufacture of medical, precision and optical instruments, watches and clocks	Medical, precision and optical instruments, watches and clocks
Manufacture of motor vehicles, trailers and semi-trailers	Motor vehicles, trailers and semi-trailers
Manufacture of other transport equipment	Other transport equipment
Other manufacturing	Other manufacturing
Electricity, gas, steam and hot water supply	Electricity, gas, steam and hot water supply
Production and distribution of natural gas	Distribution of natural gas
Production and distribution of nuclear electricity Production and distribution of non-nuclear electricity	Electricity
Land transport; water transport; transport via pipelines	Land transport services; water transport services; transport via pipelines
Air transport	Air transport services
Supporting and auxiliary transport activities; activities of travel agencies	Supporting and auxiliary transport activities; activities of travel agencies
Public administration and defence; compulsory social security	Public administration and defence; compulsory social security
Education	Education
Health and social work	Health and social work
Other services	Other services

Note: There is no domestic production of coal and lignite, natural gas, crude petroleum and uranium and metal ores in Belgium. However, these commodities are imported from the rest of the world and traded between the Belgian regions.

3.1 Sectoral Effects

The tax on CO_2 emissions generated by the consumption of coal, gasoline, gas oil and natural gas for heating and transportation by the households has two main effects: a 'direct effect' through price increases, and an 'indirect effect' through the recycling of the additional fiscal revenues. The 'direct effect' through prices stimulates conservation measures and further leads to modifications in the production structure, while the 'indirect effect' reinforces the previous effects by changing consumption patterns.

Due to the carbon tax, by 2012 consumer price for coal gross of taxes is expected to rise by about 40 per cent compared with the baseline, while the price of gasoline by about 1 per cent, the price of gas oil by 5 per cent and the price of natural gas by about 11 per cent in all three Belgian regions (see table 4). The differences between the consumer prices at the regional level are marginal. They arise due to the different composition of domestic fuel supply in terms of shares of imports and supply from the domestic producers. Subsequently, private consumption of coal, gasoline, gas oil and natural gas declines.

Table 4. Sectoral effects of the carbon tax in 2012

Sectoral effects	Regions		
	Wal	Vla	Bru
Coal			
Consumer prices gross of taxes	39.77	39.77	39.77
Consumer prices net of taxes	-0.17	-0.17	-0.17
Private consumption	-20.47	-20.06	-21.78
Domestic sales	-1.73	-1.10	-1.32
Imports	-1.73	-1.10	-1.32
Gasoline			
Consumer prices gross of taxes	0.96	0.98	0.96
Consumer prices net of taxes	-0.20	-0.19	-0.21
Private consumption	-0.51	-0.54	-0.59
Domestic sales	-0.21	-0.17	-0.20
Imports	-0.24	-0.19	-0.24
Gas oil			
Consumer prices gross of taxes	5.02	5.01	4.99
Consumer prices net of taxes	-0.21	-0.22	-0.25
Private consumption	-3.20	-3.23	-3.25
Domestic sales	-0.41	-0.40	-0.27
Imports	-0.45	-0.45	-0.34
Natural gas			
Consumer prices gross of taxes	11.32	11.07	10.86
Consumer prices net of taxes	-1.85	-2.07	-2.25
Private consumption	-6.08	-6.07	-6.05
Domestic sales	-1.41	-1.97	-1.23
Imports	-5.02	-6.03	-5.71

Note: All the variables are reported as a percentage change compared with the baseline. Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

The highest decline in the private consumption in all three regions is attributed to coal, about 20 per cent in 2012 compared with the baseline. However, coal consumption represents less than 0.2 per cent of the household consumption budget in all three regions, the 20 per cent fall in coal consumption thus being marginal (see table 4).

The relatively higher increase in the price of natural gas compared with the price of gas oil and gasoline leads to a stronger negative effect on the private consumption of natural gas. Thus, consumption of natural gas declines by about 6 per cent (see table 4). The different impact of the CO_2 tax on the natural gas price compared with the gas oil and gasoline prices arises mainly because the rise in the consumer price of natural gas in the absence of CO_2 taxes (in the baseline scenario) is slower compared with the gas oil and gasoline prices. As a consequence, the share of CO_2 taxation in the price of natural gas becomes relatively higher compared with the gas oil and gasoline, although the absolute level of the tax per unit of energy content is higher for the gas oil and gasoline.

3.2 Effects on Private Consumption of Energy Inputs

As expected, the carbon tax leads to a stronger negative effect on the consumption of gasoline by the poorest half of the population, while the decline in the consumption of coal, gas oil and natural gas is higher for the richest half (see table 5). Coal, gas oil and natural gas are used for heating, whereas gasoline is mainly used for transport purposes.

Table 5. Effects on private consumption of energy inputs subject to carbon taxes by income groups in 2012

Private consumption	All households' income groups by region			First household income group by region			Second household income group by region		
	Wal	Vla	Bru	Wal	Vla	Bru	Wal	Vla	Bru
Coal and lignite; peat	-20.47	-20.06	-21.78	-19.74	-19.30	-20.09	-21.48	-22.10	-21.99
Gasoline	-0.51	-0.54	-0.59	-0.56	-0.55	-0.60	-0.49	-0.53	-0.59
Gas oil	-3.20	-3.23	-3.25	-3.08	-2.98	-3.08	-3.28	-3.38	-3.35
Natural gas	-6.08	-6.07	-6.05	-5.78	-5.50	-5.69	-6.34	-6.44	-6.31

Note: All the variables are reported as a percentage change compared with the baseline. Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

The fall in the private consumption of fuels is restrained by the ‘indirect effect’ through the recycling of additional CO_2 tax revenues. The 0.86 per cent reduction in the personal income tax, achieved by 2012, leads to an improvement in the household disposable budget for consumption for both households’ income groups and diminishes the negative effect on the private consumption of fuels.

At the regional level, the patterns in the decline of energy inputs subject to the carbon tax are driven by the effects on the disposable budget for consumption and the shares of subsistence consumption of fuels in the total consumption of energy inputs by income group and region (see table 5).

3.3 Effects on Private Consumption of Non-Energy Inputs

The rise in household disposable budget for consumption in all three regions and the relative increase in consumer prices (including taxes) for fuels subject to a CO_2 tax compared with other commodities results in a rise of consumption demand for non-energy goods and electricity by both income groups, although its magnitude is higher for the richest half (see table 6).

Table 6. Effects on private consumption of non-energy goods and electricity by income groups in 2012

Private consumption	All households' income groups by region			First household income group by region			Second household income group by region		
	Wal	Vla	Bru	Wal	Vla	Bru	Wal	Vla	Bru
Agriculture, forestry, fishing	0.16	0.16	0.12	0.10	0.10	0.07	0.20	0.20	0.14
Uranium and thorium ores; metal ores; other mining and quarrying products	0.21	0.19	0.21	0.15	0.15	0.11	0.30	0.31	0.22
Food products and beverages	0.11	0.13	0.10	0.05	0.08	0.06	0.14	0.17	0.12
Pulp, paper and paper products	0.25	0.25	0.17	0.15	0.14	0.10	0.30	0.30	0.21
Chemicals and chemical products	0.22	0.24	0.18	0.12	0.14	0.11	0.27	0.29	0.22
Other non-metallic mineral products	0.26	0.27	0.20	0.15	0.15	0.13	0.30	0.31	0.24
Basic metals	0.25	0.25	0.18	0.15	0.15	0.11	0.30	0.31	0.21
Fabricated metal products	0.26	0.25	0.20	0.15	0.14	0.12	0.30	0.30	0.22
Machinery and equipment n.e.c.	0.29	0.26	0.21	0.19	0.16	0.13	0.34	0.31	0.24
Office machinery and computers	0.24	0.26	0.19	0.14	0.14	0.11	0.28	0.29	0.21
Electrical machinery and apparatus n.e.c.	0.25	0.24	0.16	0.14	0.14	0.10	0.28	0.28	0.20
Radio, television and communication equipment and apparatus	0.20	0.22	0.13	0.11	0.13	0.07	0.24	0.27	0.17
Medical, precision and optical instruments, watches and clocks	0.24	0.25	0.18	0.14	0.14	0.12	0.28	0.29	0.22
Motor vehicles, trailers and semi-trailers	0.21	0.24	0.19	0.11	0.14	0.12	0.25	0.29	0.22
Other transport equipment	0.26	0.25	0.19	0.14	0.14	0.10	0.28	0.28	0.20
Other manufacturing	0.21	0.23	0.17	0.10	0.12	0.10	0.24	0.27	0.20
Electricity	0.22	0.23	0.17	0.14	0.14	0.11	0.28	0.28	0.21
Land transport services; water transport services; transport via pipelines	0.22	0.22	0.13	0.11	0.12	0.07	0.26	0.27	0.17
Air transport services	0.34	0.29	0.19	0.18	0.18	0.12	0.36	0.36	0.25
Supporting and auxiliary transport activities; activities of travel agencies	0.24	0.27	0.20	0.12	0.15	0.11	0.28	0.31	0.22
Public administration and defence; compulsory social security	0.17	0.17	0.12	0.06	0.06	0.04	0.18	0.18	0.13
Education	0.15	0.16	0.08	0.04	0.05	0.01	0.16	0.17	0.10
Health and social work	0.14	0.14	0.09	0.06	0.06	0.03	0.19	0.19	0.12
Other services	0.23	0.23	0.18	0.13	0.13	0.11	0.27	0.28	0.21

Note: All the variables are reported as a percentage change compared with the baseline. Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

All coal supply originates from the external sector. Thus, the reduction in the domestic sales has a direct impact on imports (see table 4).

3.4 Effects on the manufacture of coke, refined petroleum products sector and production and distribution of natural gas

The drop in the domestic sales of gasoline and gas oil exerts downward pressure on the consumer prices net of taxes, the output price and the profitability of coke and refined petroleum products sector (see table 7). Consequently, the sectoral gross output diminishes in all three regions. The relatively larger decline, 0.31 per cent, in the production of coke and refined petroleum products in Wallonia compared with the other regions is due to the higher decline of the domestic sales of gasoline and gas oil in the region. The output fall leads to a decline in the employment by the regions. Investments in the sector decrease, fuelled by a drop in the sector's profitability (see table 7).

Table 7. Effects of the policy measure on the manufacture of coke, refined petroleum products sector and production and distribution of natural gas in 2012

Sectoral effects	**Regions**		
	Wal	**Vla**	**Bru**
Manufacture of coke, refined petroleum products			
Price of domestic production	-0.16	-0.20	-0.26
Domestic production	-0.31	-0.07	-0.06
Employment	-0.47	-0.14	-0.15
Investments	-0.60	-0.57	-0.58
Exports	-0.31	-0.04	0.03
Production and distribution of natural gas			
Price of domestic production	-2.12	-2.13	-1.75
Domestic production	-0.69	-0.69	-0.51
Employment	-1.69	-1.68	-1.27
Investments	-0.73	-0.71	-0.69
Exports	3.72	3.75	3.06

Note: All the variables are reported as a percentage change compared with the baseline. Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

Similar effects in terms of output, investment and employment can be observed for the production and distribution of natural gas (see table 7). Nevertheless, the negative effect on employment is more significant, compared with the one on coke, refined petroleum products and the nuclear fuel sector, due to the larger share of labour outlays in the production costs (about 15 per cent in Wallonia and Flanders and 13 per cent in Brussels for the production and distribution of natural gas).

3.5 Macro and Regional Effects

The policy measure generates additional tax revenues equivalent to 336 million euro in 2012, which could lead to a decrease in the personal income tax by 0.86 per cent. The negative effects in terms of real GDP are small during 2006-2012, while the unemployment rate rises up to 0.06 percentage points in 2012 compared with the baseline (see table 8).

The impact on the real GDP and unemployment at the regional level is also limited. The highest drop in the regional GDP is achieved in 2012 when the CO_2 tax reaches the targeted level of 20€ per ton. However, it only reflects a 0.11 per cent decline in Wallonia compared with the baseline, 0.10 per cent in Flanders and 0.09 per cent in Brussels (see table 8).

Table 8. Macro and regional effects of the policy measure

Macro and regional effects		**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Macroeconomic effects								
GDP (% change)	**Bel**	-0.02	-0.04	-0.05	-0.06	-0.08	-0.09	-0.10
National savings (% change)	**Bel**	-0.22	-0.32	-0.42	-0.52	-0.62	-0.72	-0.82
Labor supply (% change)	**Bel**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unemployment rate (%)	**Bel**	7.73	7.84	7.97	8.07	8.18	8.16	8.14
CO2 tax revenues (mil euro)	**Bel**	81	122	163	205	247	291	336
Income tax (% change)	**Bel**	-0.24	-0.35	-0.45	-0.56	-0.66	-0.76	-0.86
Regional effects								
Regional GDP (% change)	**Wal**	-0.03	-0.04	-0.06	-0.07	-0.09	-0.10	-0.11
Regional GDP (% change)	**Vla**	-0.02	-0.04	-0.05	-0.06	-0.07	-0.09	-0.10
Regional GDP (% change)	**Bru**	-0.02	-0.03	-0.05	-0.06	-0.07	-0.08	-0.09
Unemployment rate (%)	**Wal**	10.31	10.42	10.54	10.65	10.75	10.76	10.75
Unemployment rate (%)	**Vla**	5.06	5.19	5.33	5.45	5.56	5.54	5.51
Unemployment rate (%)	**Bru**	15.14	15.15	15.19	15.22	15.26	15.23	15.19

Note: If not indicated otherwise, all the variables are reported as a percentage change compared with the baseline. Bel stands for Belgium, Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

3.6 Welfare Effects

The carbon tax leads to welfare gains for the richest half of the population and welfare losses for the poorest half (see table 9). This is in line with the view that carbon taxes are regressive, illustrated by studies on Sweden (Brännlund and Nordström, 2004), on Australia (Cornwell and Creedy, 1997), on UK (Smith, 1992) and on US (Poterba, 1991), etc. The explanation lies in the fact that the budget share of energy inputs used for heating (coal, gas oil and natural gas) are higher for the households with relatively low total expenditures.

Table 9. Welfare effects of the environmental measure

Equivalent variation (mil euro)		2006	2007	2008	2009	2010	2011	2012
First households' income group	**Wal**	-0.04	-0.07	-0.10	-0.13	-0.17	-0.19	-0.22
First households' income group	**Vla**	-0.04	-0.07	-0.11	-0.15	-0.19	-0.23	-0.27
First households' income group	**Bru**	-0.02	-0.03	-0.05	-0.06	-0.07	-0.09	-0.10
Second households' income group	**Wal**	0.29	0.42	0.54	0.67	0.79	0.95	1.11
Second households' income group	**Vla**	0.51	0.74	0.96	1.19	1.41	1.66	1.92
Second households' income group	**Bru**	0.05	0.07	0.09	0.10	0.12	0.14	0.17

Note: Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

3.7 Effect on GHG Emissions

The CO_2 emissions at the national level decline by 1.26 per cent in 2012 compared with the baseline. The highest emission reduction at the regional level is achieved in Brussels, 2.44 per cent, due to the large share of emissions originating from the residential sector in this region, followed by Wallonia with 1.27 per cent and Flanders with 1.18 per cent (see table 10). Nevertheless, the highest emission abatement in volume is achieved in Flanders.

At the sectoral level, the strongest effect in CO_2 emissions reduction is attained by the manufacturing of coke and refined petroleum products and the production and distribution of natural gas. Yet, the CO_2 emissions by most sectors go up due to some substitution effects towards energy inputs not subject to the carbon tax.

The shrink in the fuels consumption by the households also leads to a decline in the CH_4 and N_2O emissions (see table 10). However, the magnitude of these effects is low due to the important share of the process emissions in the total CH_4 and N_2O emissions.

Table 10. Effects of the policy measure on the GHG emissions

GHG emissions		2006	2007	2008	2009	2010	2011	2012
CO2 emissions								
National CO2 emissions	**Bel**	-0.31	-0.47	-0.63	-0.79	-0.96	-1.11	-1.26
National CO2 emissions (kt)	**Bel**	125,879	126,834	127,748	128,618	127,934	128,106	128,295
Regional CO2 emissions	**Wal**	-0.32	-0.48	-0.63	-0.79	-0.97	-1.12	-1.27
Regional CO2 emissions	**Vla**	-0.29	-0.44	-0.59	-0.74	-0.89	-1.04	-1.18
Regional CO2 emissions	**Bru**	-0.62	-0.93	-1.24	-1.55	-1.86	-2.15	-2.44
Regional CO2 emissions (kt)	**Wal**	44,971	45,587	46,178	46,779	45,872	46,107	46,348
Regional CO2 emissions (kt)	**Vla**	76,733	76,942	77,135	77,277	77,368	77,237	77,116
Regional CO2 emissions (kt)	**Bru**	4,174	4,306	4,434	4,563	4,694	4,762	4,831
CH4 emissions								
National CH4 emissions	**Bel**	-0.01	-0.02	-0.02	-0.03	-0.03	-0.04	-0.05
National CH4 emissions (kt)	**Bel**	7,768	7,693	7,619	7,548	7,479	7,409	7,342
Regional CH4 emissions	**Wal**	-0.02	-0.03	-0.04	-0.06	-0.07	-0.08	-0.10
Regional CH4 emissions	**Vla**	0.00	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Regional CH4 emissions	**Bru**	-0.30	-0.45	-0.61	-0.77	-0.94	-1.09	-1.24
Regional CH4 emissions (kt)	**Wal**	2,367	2,343	2,320	2,298	2,277	2,255	2,233
Regional CH4 emissions (kt)	**Vla**	5,391	5,339	5,288	5,239	5,191	5,143	5,097
Regional CH4 emissions (kt)	**Bru**	10	10	11	11	11	12	12
N2O emissions								
National N2O emissions	**Bel**	-0.04	-0.06	-0.09	-0.11	-0.14	-0.17	-0.20
National N2O emissions (kt)	**Bel**	11,543	11,425	11,309	11,195	11,080	10,963	10,851
Regional N2O emissions	**Wal**	-0.01	-0.01	-0.02	-0.02	-0.03	-0.04	-0.04
Regional N2O emissions	**Vla**	-0.05	-0.08	-0.11	-0.14	-0.18	-0.21	-0.25
Regional N2O emissions	**Bru**	-0.25	-0.38	-0.52	-0.66	-0.80	-0.93	-1.06
Regional N2O emissions (kt)	**Wal**	3,714	3,657	3,600	3,545	3,491	3,435	3,381
Regional N2O emissions (kt)	**Vla**	7,716	7,652	7,588	7,526	7,461	7,398	7,338
Regional N2O emissions (kt)	**Bru**	113	117	121	125	129	131	133

Note: If not indicated otherwise, all the variables are reported as percentage change compared with the baseline. Bel stands for Belgium, Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

3.8 Distance from the Kyoto Target

The carbon tax could reduce the total GHG emissions by 1.12 per cent in 2012 compared with the baseline, which represents about 1,662 kt of CO_2 equivalent. Thus, the emissions reduction targets set by the Kyoto Protocol cannot be reached by implementing the examined measure alone. In relative terms, the highest efforts needed to attain the Kyoto targets would correspond to Brussels and Flanders, although in absolute terms Flanders would have to achieve the highest emission abatement (see table 11).

Table 11. Distance from the Kyoto target[10]

GHG emissions		1990	2006	2007	2008	2009	2010	2011	2012	Distance from Kyoto target
BAU scenario										
National GHG emissions (kt)	**Bel**	140,773	145,591	146,560	147,494	148,394	147,748	147,937	148,149	17,934
Regional GHG emissions (kt)	**Wal**	54,128	51,198	51,807	52,395	52,995	52,092	52,324	52,563	2,495
Regional GHG emissions (kt)	**Vla**	82,659	90,070	90,279	90,477	90,628	90,732	90,604	90,488	12,128
Regional GHG emissions (kt)	**Bru**	3,987	4,323	4,474	4,622	4,771	4,924	5,010	5,098	975
Carbon tax scenario										
National GHG emissions	**Bel**		-0.28	-0.41	-0.55	-0.70	-0.85	-0.99	-1.12	
National GHG emissions (kt)	**Bel**	140,773	145,189	145,952	146,676	147,362	146,493	146,478	146,487	16,272
Regional GHG emissions	**Wal**		-0.28	-0.42	-0.56	-0.70	-0.87	-1.01	-1.15	
Regional GHG emissions	**Vla**		-0.26	-0.38	-0.51	-0.65	-0.79	-0.91	-1.04	
Regional GHG emissions	**Bru**		-0.61	-0.91	-1.22	-1.52	-1.83	-2.11	-2.40	
Regional GHG emissions (kt)	**Wal**	54,128	51,053	51,587	52,099	52,622	51,640	51,796	51,961	1,893
Regional GHG emissions (kt)	**Vla**	82,659	89,840	89,932	90,011	90,041	90,020	89,778	89,551	11,190
Regional GHG emissions (kt)	**Bru**	3,987	4,297	4,433	4,566	4,698	4,834	4,904	4,975	853

Note: If not indicated otherwise, all the variables are reported as a percentage change compared with the baseline. Bel stands for Belgium, Wal stands for the Walloon region, Vla for the Flemish region and Bru for the Brussels region.

4. Conclusions

Following the approval of the Kyoto Protocol by the European Union and the Burden Sharing Agreement among the member states, the *regional* impacts of various burden sharing formulas have been a major political and economic concern for Belgium.

The only quantitative tool capable of producing results at the sectoral and regional level for Belgium is the dynamic regional and sectoral general equilibrium model GreenMod. The modelling platform for Belgium pays particular attention to the technical change and the structure of capital, which are known to have an important effect on the GHG emissions and their evolution over time. Furthermore, by distinguishing the behaviour of several households' income groups, GreenMod is able to evaluate the distributional effects of various environmental measures.

In this paper, we use the GreenMod model to evaluate the effects of implementing a carbon tax on the consumption of coal, gasoline, gas oil and natural gas for heating and transportation by the households. The scenario illustrates the usefulness of employing such a model in quantifying the GHG emission reduction at both federal and regional levels. It further shows, in detail at the regional

[10] The 1990 figures include all CO_2, CH_4 and N_2O emissions, except for the fugitive emissions from fuels (0.6% of the total GHG emissions). Also, the land-use change and forestry are not taken into account for Wallonia, which leads to an increase in the CO_2 emissions by 1,893 kt, compared to the official numbers. The fugitive emissions from fuels and the land-use change and forestry are not accounted for in GreenMod and therefore are not taken into account in the estimation of the distance from Kyoto target in the carbon tax scenario.

level, the effects on prices, consumption of energy and non-energy inputs, sectoral production, employment and trade to be expected by implementing the environmental measure. As the impact of a domestic carbon tax on income distribution is critical in determining its acceptability, GreenMod estimates the welfare effects related to different households' income groups (Zhang and Baranzini, 2004).

Two main conclusions can be drawn from the results of the carbon tax scenario. First, the tax alone is not sufficient in achieving the Kyoto targets at both regional and federal levels. Second, the measure has a regressive impact on the distribution of income. Therefore, special attention should be given to the design of the environmental measure in order to secure its public support.

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Appendix A. Classification of the production sectors and commodities in GreenMod

Table A.1: Classification of the production sectors and commodities in GreenMod

NACE code	Name of the production sector or commodity	Commodity code in GreenMod	Production sector code in GreenMod
1	Agriculture, hunting and related service activities	com01	sec01
2	Forestry, logging and related service activities	com02	sec02
5	Fishing, operation of fish hatcheries and fish farms	com03	sec03
10	Mining of coal and lignite; extraction of peat	com04	sec04
11	*Extraction of crude petroleum and natural gas; incidental service activities*		
	Extraction of natural gas	com05	sec05
	Extraction of crude petrolium	com06	sec06
12	Mining of uranium and thorium ores	com07	sec07
13	Mining of metal ores	com08	sec08
14	Other mining and quarrying	com09	sec09
15	Manufacture of food products and beverages	com10	sec10
16	Manufacture of tobacco products	com11	sec11
17	Manufacture of textiles	com12	sec12
18	Manufacture of wearing apparel; dressing and dyeing of fur	com13	sec13
19	Tanning and dressing of leather	com14	sec14
20	Manufacture of wood and of products of wood and cork	com15	sec15
21	Manufacture of pulp, paper and paper products	com16	sec16
22	Publishing, printing and reproduction of recorded media	com17	sec17
23	Manufacture of coke, refined petroleum products and nuclear fuel		sec18
	Coke oven coke	com18	
	Petroleum coke	com19	
	Nuclear energy	com20	
	Gasoline	com21	
	Heavy oil	com22	
	Gas oil	com23	
	Coke oven gas	com24	
	Refinery gas	com25	
	Other combustibles	com26	
24	Manufacture of chemicals and chemical products	com27	sec19
25	Manufacture of rubber and plastic products	com28	sec20
26	Manufacture of other non-metallic mineral products	com29	sec21
27	Manufacture of basic metals	com30	sec22
28	Manufacture of fabricated metal products	com31	sec23
29	Manufacture of machinery and equipment n.e.c.	com32	sec24
30	Manufacture of office machinery and computers	com33	sec25
31	Manufacture of electrical machinery and apparatus n.e.c.	com34	sec26
32	Manufacture of radio, television and communication equipment and apparatus	com35	sec27
33	Manufacture of medical, precision and optical instruments, watches and clocks	com36	sec28

Table A.1: Classification of the production sectors and commodities in GreenMod (continued)

NACE code	Name of the production sector or commodity	Commodity code in GreenMod	Production sector code in GreenMod
34	Manufacture of motor vehicles, trailers and semi-trailers	com37	sec29
35	Manufacture of other transport equipment	com38	sec30
36	Manufacture of furniture; manufacturing n.e.c.	com39	sec31
37	Recycling	com40	sec32
40	*Electricity, gas, steam and hot water supply*		
	Production and distribution of natural gas	com41	sec33
	Production and distribution of nuclear electricity	com42*	sec34
	Production and distribution of non-nuclear electricity		sec35
41	Collection, purification and distribution of water	com43	sec36
45	Construction	com44	sec37
50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel	com45	sec38
51	Wholesale trade and commission trade, except for motor vehicles and motorcycles	com46	sec39
52	Retail trade, except for motor vehicles and motorcycles	com47	sec40
55	Hotels and restaurants	com48	sec41
60	Land transport; transport via pipelines	com49	sec42
61	Water transport	com50	sec43
62	Air transport	com51	sec44
63	Supporting and auxiliary transport activities; activities of travel agencies	com52	sec45
64	Post and telecommunications	com53	sec46
65	Financial intermediation, except insurance and pension funding	com54	sec47
66	Insurance and pension funding	com55	sec48
67	Activities auxiliary to financial intermediation	com56	sec49
70	Real estate activities	com57	sec50
71	Renting of machinery and equipment without operator	com58	sec51
72	Computer and related activities	com59	sec52
73	Research and development	com60	sec53
74	Other business activities	com61	sec54
75	Public administration and defence; compulsory social security	com62	sec55
80	Education	com63	sec56
85	Health and social work	com64	sec57
90	Sewage and refuse disposal, sanitation and similar activities	com65	sec58
91	Activities of membership organization n.e.c.	com66	sec59
92	Recreational, cultural and sporting activities	com67	sec60
93	Other service activities	com68	sec61
95	Private households with employed persons	com69	sec62

**: Final user is consuming electricity regardless of its origin (nuclear or non nuclear)*