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How to achieve the Kyoto Target in Belgium — modelling methodology and some results —

Stef Proost (KULeuven)
Denise Van Regemorter (KULeuven)

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contact:
Isabelle Benoit
KULeuven-CES
Naamsestraat 69, B-3000 Leuven (Belgium)
tel: +32 (0) 16 32.66.33
fax: +32 (0) 16 32.69.10
e-mail: Isabelle.Benoit@econ.kuleuven.ac.be

How to achieve the Kyoto Target in Belgium
- modelling methodology and some results -[1]

Draft

Stef Proost, Denise Van Regemorter

CES- KULeuven

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[1] This paper is based on two different studies: one study made in 1999 by the Energy Institute KULeuven, Institut Wallon and VITO for the Federal Department of the Environment and one study made in 2000 by CES-Kuleuven for the Ministry of Energy and Sustainable Development. We acknowledge the support of the Federal Science Ministry for the development of the Markal model under the 'Global Change' Research Program and the European Commission, DGRES, for their financial support in the development of the GEM-E3 model under the 'Joule' Research Program.

ENERGY, TRANSPORT AND ENVIRONMENT

CENTER FOR ECONOMIC STUDIES
Naamsestraat 69 B-3000 LEUVEN
BELGIUM

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1. INTRODUCTION

This paper discusses the methodology and some results to assess the means and costs of meeting the Kyoto target for Greenhouse gas emissions in Belgium. This target consists in reducing the emissions of Greenhouse gasses in 2008-2012 by 7.5% compared to the level of 1990. Here we assume that this target has to be met in Belgium and that no tradable permits or other flexible mechanisms can be used to achieve the required reduction in Belgium. This paper can therefore serve as an input into policy debates at the European level on flexible mechanisms and on coordination of Greenhouse policies.

The second chapter concentrates on the methodological aspects of this study. We explain how we represent carbon emissions in the economy, what models we use, how we construct scenarios and what cost concepts are chosen. In the third chapter we present the Reference with its macro-economic and energy price assumptions. It is a detailed scenario for the future GHG emissions in Belgium that takes into account the policy measures already decided. The fourth chapter is devoted to the ‘Kyoto’ scenario. In this scenario the GHG emissions are reduced in function of their costs in order to achieve the 'Kyoto' target. The last chapter presents a few sensitivity studies.

What greenhouse gasses are covered

The greenhouse gasses covered in this study are CO_2, CH_4 and N_2O emitted on the Belgian territory, with the exception of emissions from marine and aviation bunkers (used for international transport). For these gases, only energy related emissions are studied using appropriate models. Process emissions and emissions from the agricultural sector of CH_4 and N_2O are not considered in this study. Energy related emissions for CH_4 and N_2O account respectively for 8 % and 22 % of total emission levels for these gases. Together, the emissions considered represent 87% of the total emissions covered by the Kyoto protocol. All the results are derived for an average outside temperature[2].

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[2] The baseline for the Kyoto target are the observed emissions in 1990. Weather conditions in that year deviated from the average conditions. The scenario results we present are defined for average weather conditions.

2. THE METHODOLOGY

This section explains the methodology used in this study. We proceed in 4 steps. We first explain how we represent carbon emissions in an economy. What is the level of detail aimed at? How do we combine technological and behavioural information in models? The second step is to show how we use models to build a reference and to build alternative scenarios. The next step is to define the three cost concepts that we use in this study. The final step is to discuss the relationship between the choice of policy instruments and the type of cost concept to be used. It is important and helpful to make the distinction between measures and policy instruments. By 'measures' we understand technological measures or behavioural measures which can be taken by the economic agent to reduce his emissions, by 'instrument' we understand policy actions which the policy maker can implement to induce the economic agent to undertake a specific measure.

2.1. How do we represent the carbon emissions of an economy

In the energy sector, carbon emissions are equal to primary energy[3] consumption of a country multiplied by specific emission factors and corrected for sinks[4]. In order to build scenarios for future emissions and for reductions of emissions we need to know the driving forces of these emissions. The driving force of emissions is energy use, which is itself driven by economic activity, prices and technological possibilities.

In Table 1, first line, the different steps, from economic activity to primary energy use, are represented. The second and third lines explain how each driving force contributes to lower GHG emissions. The bottom lines of the table are used later to illustrate how these different driving forces are represented in models.

The aggregate level of economic activity is the driving force as it determines the level of economic production activities and the level of income available to consumers. A given level of economic activity (employment, value added) can be reached by different sectoral compositions. Some production sectors are more energy intensive than others because of the production processes they require. An economy that has a higher share of its production factors employed in iron and steel, chemical and or building materials will always be more energy intensive. National carbon emissions can be reduced by moving to a less energy intensive production structure. World-wide carbon emissions are not necessarily reduced if the energy intensive activities are located abroad.

Industry

Once the level of economic activity per sector has been determined, industry can through better management and changes in production processes decrease its final energy use. The final energy use is the energy sold by the energy sector to the non-energy industry and to the rest of the economy. We distinguish between choices on the level of energy services and choices on the energy efficiency level to produce the energy services. Energy services to industry correspond to physical levels of production: tons of steel, glass etc. produced. This concept is somewhat abstract for non-homogenous sectors. A given level of energy services can be reached by more or less efficient energy use and by using more or less carbon intensive fuels.

These definitions allow us to model three ways of carbon emission reductions. First, one can through better management and small product changes reduce the level of energy services needed per level of economic activity. Second, one can improve the efficiency of the energy use

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[3] Primary energy is the raw energy (coal, oil, gas, nuclear, renewables) that is imported or produced in a country before it is further transformed and transported to the final energy user.

[4] One knows that all primary fossil energy used in a country will ultimately lead to emissions, therefore CO2 emissions can be easily computed combining primary energy consumption data per type of energy and emission factors by type of fossil energy. Sinks refer to possibilities to capture CO2 emissions either via storage or via forests, etc.

process itself by switching to other processes, combined heat and power production, better insulation, better electric engines etc… Third one can work with less carbon intensive fuels (less coal and coke and more gas or renewables). These different reduction possibilities are given in the 2nd line of Table 1. This more detailed representation is necessary to include technological information.

Households

The action possibilities for households are represented in the third line of Table 1. They have in principle the same three possibilities to reduce carbon emissions. First they can reduce the level of energy services: lower indoor temperatures, limit ventilation losses, drive their car less and more carefully, etc. Second they can use more efficient appliances, better insulation, boilers, washing machines, etc. Third they can use less carbon intensive fuels: switch from coal or gasoil to gas.

The energy sector

All final energy demanded by end-users (households, non-energy industry, service sector) has to be supplied by the energy sector. This is represented in the second last column of Table 1. The energy sector transforms primary energy (imported coal, oil, gas, uranium) into final energy (coal products, oil products, gas, electricity). This sector can reduce carbon emissions by reducing its losses in transformation, transport and distribution operations and by using less carbon intensive fuels in electricity generation.

Available data and level of detail

We do not have statistics for all stages represented. The most important statistical sources are given in italic in the first line of Table 1. For the economic activity, the left side of the table, we dispose of macro-economic statistics that give value added per sector, prices of products, import and export shares, etc.. The second source of statistics are energy statistics that tell us how much primary energy is imported, how it is used by the energy sector and to what sectors final energy is delivered. This has important consequences for the way we examine future trends in emissions and reduction possibilities. The only “hard” measurements are final energy and levels of activity per sector. This implies that one has the option between two modelling strategies.

The first is to use an aggregate and statistical approach and use functions that link final energy use by sector to sectoral activity and prices on the basis of observations in the past. This will be the approach followed in the GEM-E3 model[5], used in this paper to represent the main equilibria in the economy. In Table 1, the second last line indicates the modelling domain of GEM-E3: the model focuses on the sectoral distribution of economic activity but can give us only aggregate information about the level of efficiency in energy use.

The second modelling strategy is to try to represent explicitly the energy use and production processes in Belgium. This will be done in the MARKAL-model[6] used in this paper (see last line Table 1). This model will be more useful to analyse energy policy options in detail. As there exist only aggregate statistics on the energy use process, the measurement and representation

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[5] The GEM-E3 model is a general equilibrium model for the 15 countries of the EU. It has been constructed by a European consortium of which CES-KULeuven was one of the main partners. It is described in Capros et al.(1997).

[6] MARKAL is a partial equilibrium model for the Belgian energy sector implemented by CES-KULeuven and VITO with support of the Federal Science Office, following the methodology developed within ETSAP, an IEA implemented agreement in which Belgium participates.

of energy services per sector and energy efficiency choices is more difficult and based on ad hoc measurements and many assumptions.

Table 1: Representation of carbon emissions and energy use of a national economy and their reduction possibilities

<table>
<tr><td colspan="8">Driving forces for emissions</td></tr>
<tr><td>Economic activity level
Macro-economic statistics</td><td>Economic activity per sector
Macro-economic statistics</td><td>Level of Energy services per user</td><td>Energy efficiency choices by user</td><td>Fuel choice by user</td><td>Final energy use
Energy statistics</td><td>Energy sector Transformation
Transport
Distribution
Energy statistics</td><td>Primary energy use
Energy statistics
Basis for tGHG budget per country</td></tr>
<tr><td colspan="8">Reduction possibilities for GHG emissions (excluding Carbon sinks)</td></tr>
<tr><td>Lower level of economic growth</td><td>Switch to less energy intensive production activities</td><td>Less energy intensive production in industry</td><td>More energy efficient processes</td><td>Substitute between coal oil, gas and renewables</td><td></td><td rowspan="2">Reduce losses
Use less carbon intensive fuels in electricity production</td><td rowspan="2"></td></tr>
<tr><td></td><td></td><td>Lower indoor temperature, less km driven</td><td>Better insulation, more efficient appliances</td><td>Substitute between coal oil, gas and renewables</td><td></td></tr>
<tr><td colspan="8">Modelling domain GEM-E3 model</td></tr>
<tr><td>Yes</td><td>18 sectors</td><td colspan="2">Implicit and joint</td><td>simple</td><td>simple</td><td>simple</td><td>simple</td></tr>
<tr><td colspan="8">Modelling domain MARKAL model</td></tr>
<tr><td>Constant</td><td>Implicit</td><td>39 categories</td><td colspan="5">detail</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

2.2. “Forecasting” energy use and carbon emissions with models

The future evolution of carbon emissions is the result of evolutions at all the stages that are represented in Table 1. Building scenarios at the horizon 2010-2030 is a hazardous but necessary exercise. Good scenario building satisfies three criteria:

1. Use all available information: this concerns technological information (present and expected future performance and costs of energy use and production, present stocks of equipment) as well as behavioural information (how did economic agents react to price and income changes in the past)
2. Internal consistency: there are certain physical and economic equilibria that have to be respected. The physical equilibria: all energy used must be delivered by the production or import sector. Different conditions need to be satisfied to guarantee the economic equilibria. There is the consistency between the production levels of different sectors: when the output level of one sector decreases, this implies also reductions for the intermediate deliveries by other sectors and by import. There is the consistency in the income account: when the activity in one energy intensive sector is reduced without increasing the value added generated in other sectors, the income level will decrease, etc.
3. Transparency: it should be clear on what assumptions the scenario is build.

In this study we have chosen to use two economic models: GEM-E3 and MARKAL. GEM-E3 is a general equilibrium model for the 15 EU countries and models the level of economic activity per sector. The main function of this model is to produce scenarios of sectoral activity that are economically consistent. It contains a simplified representation of the energy consumption and production activities but does not use explicitly technological information on energy use (cf.Table 1 modelling domain of GEM-E3). For the transport sector, GEM-E3 was complemented with the transport module of PRIMES[7] to compute disaggregated transport activity variables consistent with the economic activity derived from GEM-E3.

The main function of the MARKAL model is to integrate technological information on energy use and substitution possibilities both at the energy use and at the energy production level. It is called a partial equilibrium model because it takes the level of economic activity, the level of income of consumers and the level of non-energy prices as given (cf.Table 1 modelling domain of MARKAL). Process emissions (non-energy related) for CO_2 are not included in the MARKAL model.

Now we examine the different steps in the building of the reference and policy scenarios.

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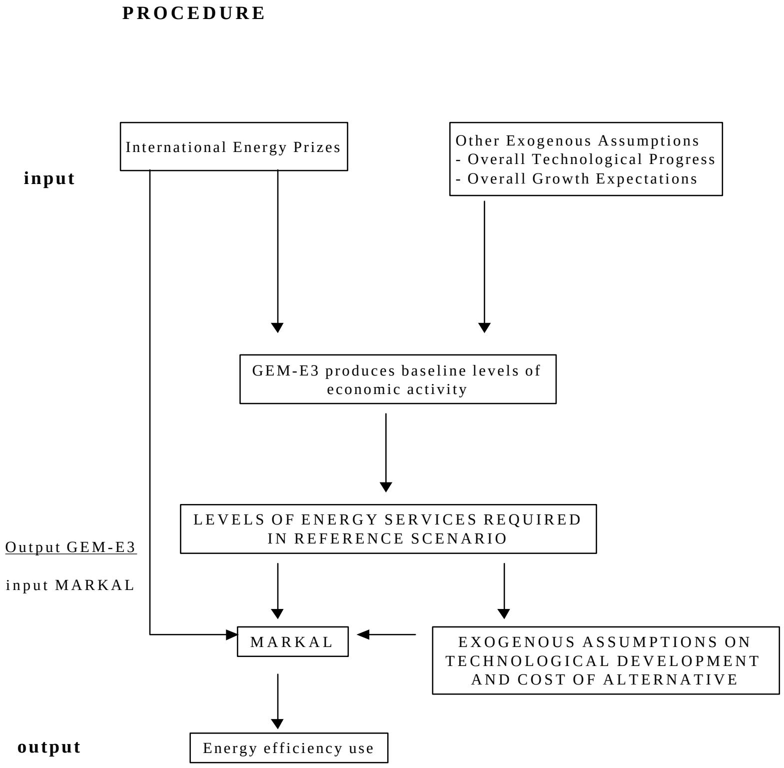
[7] PRIMES is a partial equilibrium model of the energy system constructed in the framework of the Joule Research Program of the EU, DGRES, by NTUA with a contribution of CES-KULeuven for the transport sector.

Figure 1: Procedure for scenario construction



2.2.1. *Computing the reference scenario*

The procedure followed in the construction of the reference scenario is illustrated in Figure 1 and has the following steps:

Step 1: Build a scenario for exogenous economic factors

The main exogenous factors are the international energy prices and the overall growth level of economic activity. International energy prices have been derived from simulations with the POLES model[8] that represents the world energy scene. The precise assumptions used are discussed in the next chapter.

Step 2: Build a scenario for EU and Belgium economic activity

Here the GEM-E3 model is used to construct a scenario that is consistent with the exogenous energy price and growth assumptions of step 1. The resulting medium term economic growth for Belgium is calibrated to make sure it is in line with the Belgian Planning Office forecasts. This gives a trend of economic activity by sector and a trend in disposable income that has a macro-economic consistency. These trends in economic activity and in income are then translated into trends for the demand for energy services (tons of steel, km driven, etc..), which determines the shift of the demand curves for these services in MARKAL over the horizon considered.

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[8] Poles is a model, developed for DGRES under the Joule research program, that represents the world energy demand and supply (IEPE,1996).

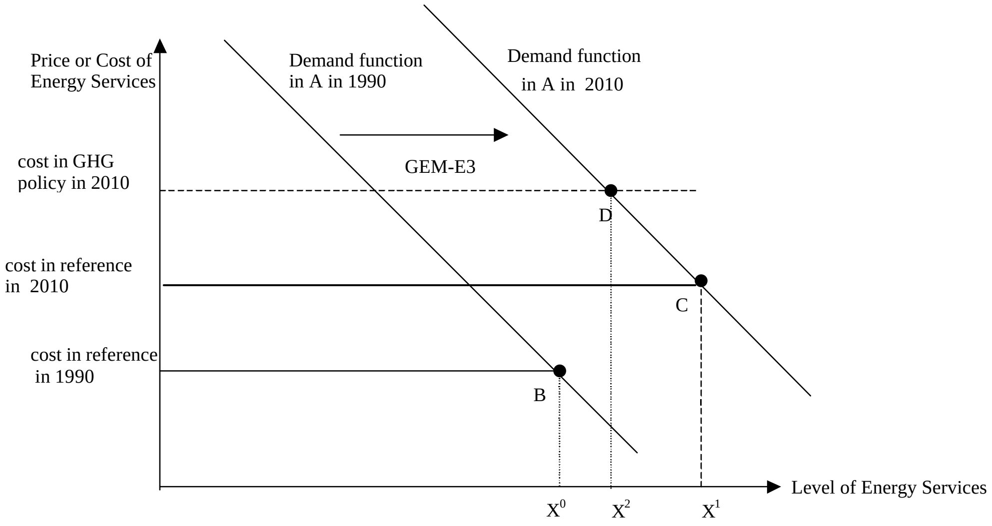
This is illustrated in Figure 2 where we represent the demand and supply of energy services for any sector A. The MARKAL model has been calibrated to represent the energy market equilibrium in 1990: the demand, supply and cost curves of energy services have to pass through point B and the corresponding level of demand of energy services is X°. In order to know the demand for energy services in the reference scenario, we need to know what is the level of activity in sector A in the future. GEM-E3 gives us this information and this is translated in the MARKAL model as a shift in the demand curve to the right (for an increase). In step 3 this information is combined with information about the change in the cost of energy services to obtain a reference level of energy services X^1 for 2010.

Step 3: Build a detailed scenario for energy use and energy production in Belgium

In this step, given the demand for energy services computed with the trends from step 2, the base year (1990) demand and the policy measures already taken, MARKAL simulates the choice of energy efficiency by energy users, their fuel choice, as well as the choice of energy production processes by the energy sector. The final result of this step is primary energy use and carbon emissions. In this step one uses information on the present and future availability of energy technologies, their costs and performance at the level of the energy user and at the level of the energy producer.

In terms of Figure 2, this step determines the cost of energy services in 2010 and the level of demand for energy services, the point X^1 and translates this into energy efficiency, fuel choice, energy sector activity, primary energy use and emissions. The demand functions for energy services play an important role in the construction of policy scenarios. Every policy scenario that affects the energy sector will alter the marginal cost of energy services and this will affect the level of demand for energy services. The demand function for energy services is a short cut to represent all substitution and behavioural reactions outside the energy use and production sector.

Figure 2: Demand and Supply of Energy Services



2.2.2. *Computing policy scenarios*

To construct the alternative policy scenarios where the major instrument is at the level of energy use or production, step 3 is replaced by step 4 where a least cost scenario is computed to reach the Kyoto target. Step 4 needs to be repeated for every alternative policy scenario.

Step 4: Simulate a least cost policy scenario to reach Kyoto

Here we take the economic growth, its sectoral allocation and the international energy prices as given. Also the shifts of the demand curve over time are those defined in the reference scenario. Next one requires the MARKAL model to compute additional measures such as to reach the Kyoto target at lowest cost. This will give rise to changes in energy efficiency at the user and producer's end. These changes will affect the cost of energy services to consumers and this will affect their level of demand for energy services via the demand function.

The alternative path comprises adjustments on the side of the producers as well as of the users of energy and also includes a lowering of the overall level of energy services. In terms of Figure 2, a policy scenario could increase the cost and the price of energy services (say via a tax). This means that we simulate the movement from point C to point D with MARKAL.

The least cost solution will depend on the cost concept used. Cost concepts are discussed in the next sections.

2.3. Computing the cost of a greenhouse policy

2.3.1. Some first principles

A first important principle is that the cost of a policy is always computed relative to a reference state. One works with the difference between costs rather than the absolute costs in the reference state and in the alternative.

A second important principle is that the definition of a cost depends on who the decision maker is. If the decision maker is a household or a firm, the private cost[9] is relevant. But we are interested in computing the cost for the Belgian society as a whole. We make the assumption that the policy maker is concerned about the general level of well being of the Belgian population. We measure this by the total income ("or equivalent income") the Belgian population would be willing to pay to avoid the transition from the reference state to the alternative. As we measure the cost of reaching a given reduction of GHG emissions, we do not take into account the reduced damage of climate change.

We make two implicit assumptions. First we suppose that the informed citizen knows best what is good for him (consumer sovereignty) and second that we do not need to weight the losses for the different income groups. The second assumption can be justified if the government has other, more performant instruments to redistribute income. Note also that by expressing all costs in monetary terms it is possible to take into account the value of changes in non market goods such as travel time and the damage of other air pollutants than GHG.

We use three alternative cost concepts in this study, we call them cost 1, cost 2 and cost 3 in order to avoid confusion with cost concepts used in other studies. Cost 2 and cost 3 are more complete concepts but more difficult to use. The following box summarises the definitions that are used.

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[9] A private cost is the cost effectively encountered by an economic agent and will include taxes, subsidies and market prices.

Cost = always difference with reference in a future year

Cost 1 = loss in consumer surplus on market of energy services + net loss in government revenue on energy market

Cost 2 = Cost 1 + secondary benefits for air pollution and saved congestion costs

Cost 3 = Cost 2 + labour market/other macroeconomic correction

The labour market correction is necessary if environmental tax revenues are used to reduce labour taxes

2.3.2. *Cost 1 = loss in consumer surplus on market of energy services + loss in government revenue on energy market*

In order to illustrate this concept, we use two graphical examples. Figure 3 represents the simplest case. In this figure the demand curve for energy services D is downward sloping and represents the willingness to pay for energy services of a consumer. At the price P° he consumes a quantity Q°. In this case we assume that emissions of GHG are proportional to the quantity of energy services consumed. Imagine now that we need to reduce the emission of GHG of this person by 50%. To reach this we use a tax t^2 on energy. The new price is $P^2 = P^\circ + t^2$ and the new quantity is Q^2. The total welfare cost of this decrease in energy use is the sum of two terms:

+ the loss in consumer surplus = DABE + ACB

+ the loss in government revenue = - DABE (the loss is negative and therefore a gain here)

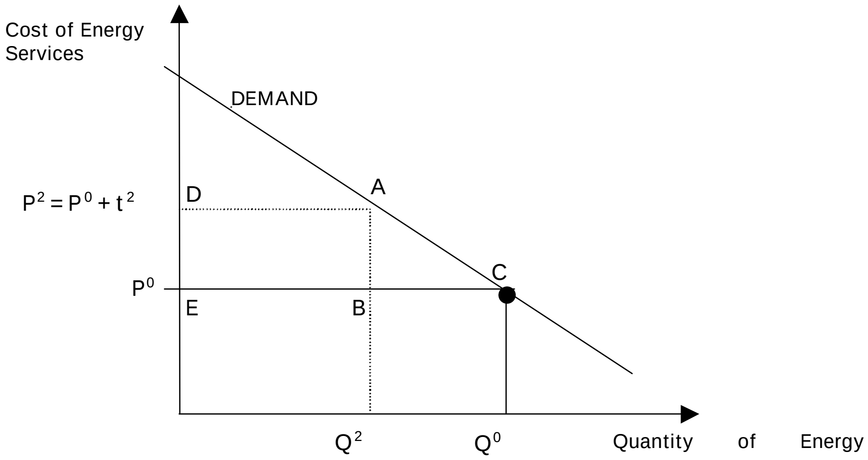

Figure 3 Cost 1 of a reduction of GHG-emissions

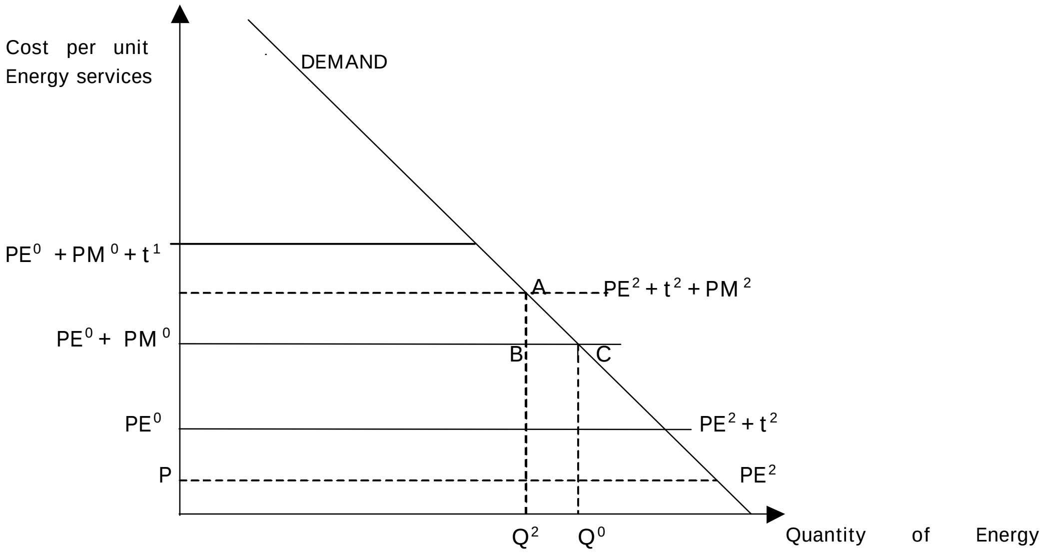

Figure 4 Cost 1 of a reduction of GHG-emissions

The net effect of this is the area ACB: this is a welfare loss for society because the consumers were ready to pay between P^2 and P° for the last units of energy consumed and in the reference situation they only had to pay P° for this. Now they are restricted to a quantity Q^2 and they forego this opportunity of surplus.

A tax is not considered as a cost to the society: it is a pure transfer. This procedure is correct under three assumptions: the administrative cost of raising revenue is negligible, the extra tax revenue is not wasted by the government and there are no important distortions on other markets (we return to this assumption in the discussion of the cost 3 concept).

In the second case, we consider a more typical case where the consumer of energy services combines equipment (heater, insulation etc.) and energy. In the reference situation, the consumer needs energy inputs that cost him PE° per unit of energy service (litres of gasoil per m^3 of his home that is heated) and other inputs (insulation etc.) that cost him PM° per unit of energy service. The total cost per unit of energy service is PE°

+ PM° and this means that our consumer chooses a level of energy use Q°. Emissions are proportional to the level of energy used.

Consider now the imposition of a tax of 100% (t^1 = PE°) on energy consumption to reduce the emission of GHG. The initial reaction will be an increase in the cost of energy services to PE° + t^1 + PM°. This is not an optimal reaction for the consumer: he can reduce his total costs by investing in energy saving equipment. The cost of the investment in energy saving equipment is PM^2 ($PM^2 > PM°$) and assume energy saving is 50%. Then the new price for energy services is only 50 % of the previous one (PE^2 = 0.5 PE°) and he also pays only 50% of the taxes he paid before the energy saving equipment ($t^2 = 0.5\ t^1$). The total cost of energy services now becomes $PE^2 + t^2 + PM^2$. The consumer pays more for his energy equipment (energy saving equipment) but less for energy and emission taxes. He chooses now a level of energy services equal to Q^2.

When we compute the net welfare cost of this operation we have the loss in consumer surplus (consumer surplus after the policy change – consumer surplus before the policy change) to which we have to add the change in tax revenues:

+ loss of consumer surplus = $(PE^2 + t^2 + PM^2)\ Q^2 - (PE° + PM°)\ Q°$

= $ABC + t^2Q^2 + \{(PE^2 + PM^2) - (PE° + PM°)\}Q^2$

+ loss in tax revenue = $-t^2Q^2$ (a negative loss is a gain)

The net welfare loss equals = $ABC + \{(PE^2 + PM^2) - (PE° + PM°)\}Q^2$

Both areas are shown in Figure 4. The first term (ABC on Figure 4) is the cost to the consumer of reducing his level of energy services (comfort reduction) due to the more costly energy. The second term is the increase in resource costs (net of taxes) measured at the new equilibrium level of energy services[10].

Until now we have used the consumer demand for energy services as example. The same framework applies to producers. The producers demand for energy services is also downward sloping. This demand curve represents substitution of energy services by other production factors and a substitution into other products. We will also use the term loss of consumer surplus for the producers : it is the producer as consumer of energy services.

In some simpler approaches, one restricts welfare costs of GHG abatement to the increase in private costs or resource costs measured at the initial level of energy services: one neglects the reaction of the demand for energy services. Those approaches overestimate the cost of GHG reduction, because one puts extra restrictions on the reaction possibilities of the economic agents[11].

2.3.3. Cost 2 = cost 1 + secondary benefits

In this approach we take into account that the reduction of energy use also leads to a reduction of other air pollutants or other external effects. The reduction of these external effects can be considered as a secondary benefit of the GHG emission abatement. This is illustrated in Figure 5 that is identical to Figure 3, except that we have added other marginal external costs (OMEC). The net cost of the greenhouse gas abatement equals now: ABC – DFCB or the loss in consumer surplus minus the savings in other external

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[10] It is not obvious from Figure 4 why the unit resource costs with energy saving equipment is higher than the unit resource cost without energy saving equipment: the basic intuition is that a rational consumer will always choose the best option for him. If the unit resource cost with energy saving equipment would have been lower, he would have chosen this option already before energy taxes are introduced.

[11] This is the case in the Dutch study on options to achieve Kyoto (Beeldman et al.(1998))

costs. Again we can add, as in Figure 4, the possibilities to substitute energy by energy saving equipment but this does not add any new insights.

This second cost definition is certainly more complete but there are two difficulties to use it. First, it is not so easy to estimate these other external effects: they can range from conventional air pollutants to noise and traffic congestion. This requires difficult valuation exercises. In this study we will rely on other studies for this. The second difficulty with secondary benefits is that they are the result of a lack of specific policies to address these other externalities. Conventional air pollution reduction is a secondary benefit of GHG reduction via energy saving because these externalities were not internalised in the reference situation. Imagine the contrary. If there exists, in the reference situation, a tax on energy use equal to the conventional air pollution damage, the level of energy use is already optimised for this type of damage. Any further reduction of energy use will reduce conventional air pollutants but also externality tax revenues and these two will normally be equal so that there is no secondary benefit. When policies for other external effects are not optimal, there is the risk that GHG reduction policies are geared too much towards abating also these other pollutants and this may not be the optimal policy mix. In general it is better to implement complementary policies to abate these other externalities.

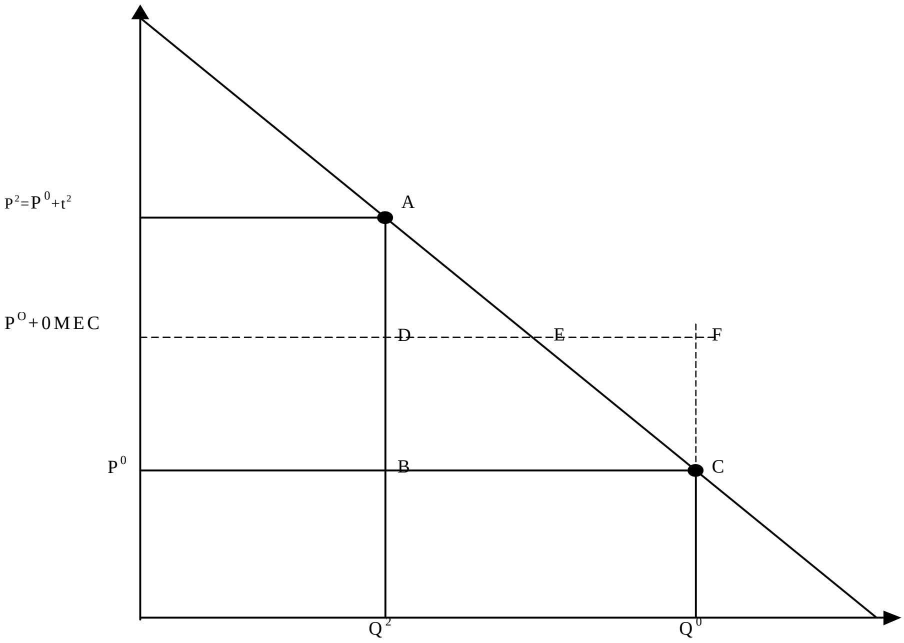

Figure 5 Cost 2 of a reduction of GHG-emissions

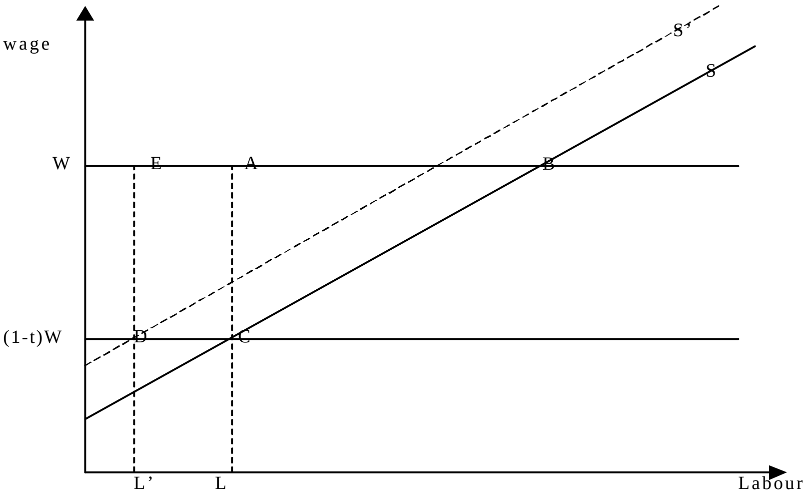

Figure 6 Labour market effect of an environmental tax

2.3.4. Cost 3 = cost 1 + secondary benefits + labour tax/macroeconomic correction

The first two cost concepts concentrate on the market of energy services and neglected the derived effects on other markets. This is justified as long as there are no economic distortions on the other markets. Economic distortions are present when there are important taxes or external effects that drive a wedge between the producer price and the consumer price on a market. The most important economic distortion is probably on the labour market where the social security contributions and the income tax drive a wedge between the producer's cost of labour and the net return of labour to the household. Moreover there can be unemployment in the sense that at the present minimum wages, the supply of jobs is smaller than the demand for jobs. Disequilibria are more frequent for low skilled labour.

In order to study the interaction between environmental policy and the labour market we will assume that the labour market is in equilibrium. This assumption is more justified for the long run and simplifies the exposition. Consider Figure 6 where the labour supply of a household is represented by the curve S. The horizontal axis measures the labour supplied (say in hours per year). The vertical axis shows the wage per hour. Start with a reference situation where there exist no pollution taxes. The wage before tax (marginal product of labour) equals W and the net wage after tax equals (1-t)W, this gives an equilibrium quantity of labour of L*. The economic distortion on this market can be measured by the triangle ABC, also called dead-weight loss. ABC represents a loss because, at the level of labour use L*, the real product of labour equals W, while the disutility of labour equals only (1-t)W. The difference is a foregone opportunity to create economic surplus for society as a whole. If the household would receive his full product of labour (W) he would work L** hours. The welfare cost of raising one EURO of tax revenue is therefore higher than one EURO: estimates vary between 20 and 40%.

Introduce now an environmental tax on the pollution associated to the production or consumption of a given dirty good Y. This will raise the consumer price of this good Y with two elements: an abatement cost incurred by this industry and an environmental tax on the remaining pollution per unit. This price increase will reduce the real purchasing power of an hour of labour, making the supply of labour less interesting. This will increase the distortion on the labour market. On Figure 6, this comes down to a shift to the left of the labour supply curve. This shift to the curve S' decreases the supply of labour and the tax revenue from labour taxes. The net tax revenue loss can be approximated by the rectangle EACD. It is clear that the magnitude of the tax revenue loss depends on the tax rate on labour and on the slope and the shift in the labour supply curve.

When the tax rate on labour is zero, there is no distortion on the labour market and we can work with cost concepts 1 and 2. When the labour tax rate is positive, the welfare effect of an environmental tax becomes more difficult and will be the result of three effects (we disregard here the environmental benefit of a pollution tax):

- *abatement cost*: environmental policies imply a reduction on emissions and this raises the marginal cost and the price of the product – this is the cost 1 concept
- *tax interaction effect*: abatement costs and environmental taxes on residual pollution reduce the purchasing power of labour and decrease the labour supply and the labour tax revenues – this is an extra cost element
- *tax recycling effect*: the revenues from the environmental tax can be used to reduce existing labour taxes – this is a benefit

It can be shown that the tax interaction effect is in general larger than the tax recycling effect. Therefore there is an extra welfare cost of environmental taxes when there are labour taxes. This has two consequences: first the total cost of an environmental policy increases and this could lead to a less strict environmental policy. Second it becomes important to recycle the revenue of the environmental tax as a reduction in the labour tax to limit the efficiency losses on the labour market. This has clearly implications for the choice of environmental instruments that will be discussed in the next section.

In more complex models, in which the interactions between the economic agents within the country and with the Rest of the World are more fully represented, a fourth type of effect can be present:

- *tax shifting effect*: the burden of an environmental tax can be shifted to the non-labour suppliers (owners of land and fixed capital) or to foreign customers; this allows to have a tax recycling effect that is larger than the tax interaction effect and there could be net efficiency gains associated to the introduction an environmental tax - this will benefit the suppliers of labour but will be paid by non-labour income and or by the rest of the world

This tax shifting effect is of the same nature as a secondary benefit: also non-environmental policies can be used to obtain this welfare gain.

The relative importance of the different effects will depend crucially on the level of parameters such as the price elasticity of labour supply and of export demand, on the capital income distribution parameters.

As this study is a cost-efficiency study where GHG reductions have to be met at the lowest cost, the cost 3 estimates are highly relevant for the choice of environmental policy instruments. This will be shown in the next section.

2.4. The cost of using different environmental policy instruments

Households and firms will never volunteer to implement sufficient reduction measures for GHG abatement. The government needs instruments to force the polluters to take abatement measures. This can be done by using different policy instruments ranging from emission taxes over tradable permits to mandatory use of more efficient technologies. In the following table[12] we illustrate the effects and relative costs that can be expected from the use of certain policy instruments.

In the left part of the table we concentrate on the cost 1 concept: the welfare loss measured on the market of energy services. In the first two columns we compare different policy instruments in function of the effects they have on input substitution and output substitution. Input substitution means the reduction of emissions per unit of energy service consumed: via the use of less carbon intensive fuels or via less energy intensive technologies. Output substitution means the reduction of total emissions of GHG via the substitution to less energy intensive outputs and consumption (reduction in the level of energy services used). The more leverage points a policy has, the lower will be its welfare cost because one adds extra flexibility.

In the third column we assess the relative cost 1 effects of a given GHG reduction. The first instrument is an emission tax on GHG emissions. This will induce input substitution (fuel switch, energy saving equipment) and output substitution (GHG intensive goods will be used less in the economy). The cost 1 of using this tax instrument is taken as benchmark and is put equal to 1.

Grandfathered emission rights (distributed to the polluters in function of the pollution in the past) will be as efficient as emission taxes for cost 1 concept.

Other instruments will imply higher costs (concept cost 1). The reason is that those instruments give the economic agents less flexibility in their GHG abatement decisions. When the government imposes the use of performance standards (maximum ratio for emissions over output) or technological standards, the welfare costs (cost 1) of meeting the emission standards are higher. This can range from a 3% increase to a 50% increase or more compared to an emission tax. Finally, an energy tax is a more costly instrument than an emission tax because it does not stimulate interesting fuel switches.

The results obtained in the left part of the table are well known in the economic literature[13]. Polluters will in general prefer standards (technology standards or other) and grandfathered permits to taxes because they consider the pollution taxes they pay as a cost for them while they are no cost for society. They are not a cost because they allow to reduce existing taxes.

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[12] Based on Goulder et al., 1999

[13] Consult any environmental economics textbook, Baumol & Oates, 1988 or Kolstad, 1999

In the right part of Table 2 we introduce distortions in the rest of the economy. The most important distortion is the existence of labour taxes (taking the form of income taxes, social security contributions and indirect taxes on consumption). This distortion will affect strongly the ranking of environmental policy instruments. This insight is new but important because labour taxes do exist and are important. When labour taxes exist and the revenue of the emission tax is returned under the form of a reduced labour tax, the first line in the table tells us that the relative cost per unit of emission reduction equals 1.3 (rather than 1 when there are no labour taxes)[14]. Environmental policy becomes relatively more costly because abatement efforts amplify slightly the labour tax distortions. This does not take into account any possible tax shifting effect, which can reduce the cost to 1 in specific cases.

More important is the relative cost 3 of other policy instruments. All instruments that do not raise revenues that are recycled via lower labour taxes, cost some 50% more. Grandfathered tradable permits therefore loose most of their attraction and so do the performance standards.

Analysing the full economic effects of environmental policies is difficult because it depends on many parameters. This means that the relative cost estimates mentioned in Table 2 give us only orders of magnitude. Nevertheless the second best effects are too important to be neglected.

2.5. Conclusions on cost concepts

In the rest of the text we will refer mostly to rankings in terms of cost 1. These are easiest to understand and probably best known. We will occasionally also refer to cost 2 rankings mostly for the transport sector where policies to address these other externalities could influence the ranking of GHG reduction policies. As long as we stick to one type of environmental policy instrument the ranking of measures in terms of the cost 3 concept will be identical to the cost 1 concept. The cost 3 concept will be used to select a least cost instrument: this will be emission taxes as this instrument has the lowest cost 3.

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[14] This is to be considered as an order of magnitude, one can consult Goulder et al. (1999) who made many sensitivity analyses.

Table 2: Relative costs of reaching GHG reductions with different instruments with and without labour market distortions

Instruments / effects	Market of energy services			Extra labour market effects			
	Input subst. Effect	Output subst.effect	TOTAL Cost 1	Impact on output price	Tax interaction effect	Revenue recycling effect	TOTAL Cost 3
Emission tax recycled via lower labour tax	Full	Full	1 = Benchmark	Large	Large	Large	1.3
Emission tax not recycled via lower labour tax Grandfathered tradeable emission rights	Full	Full	1	Large	Large	0	2 or more
Performance standard[1]	Full	Partial	1.03	Moderate	Moderate	0	1.35
Technology standard[2]	Partial	Partial	1.5 or higher	Moderate	Moderate	0	1.95 or more
Energy tax	Partial	Partial	1.04	Large	Large	Large	1.07

[1] performance standard: imposition of a general efficiency standard, without specifying a technology

[2] technology standard : imposition of an efficiency standard on specific technologies

3. THE REFERENCE SCENARIO

The main objective of this scenario is to estimate the trend in the GHG emissions in Belgium until 2010. This scenario takes as given the policy measures already taken in the period 1990-1998 to reduce the GHG emissions. This scenario will serve as benchmark for the other scenarios. The methodology used is illustrated in the previous sections and more particularly in Figure 1. We discuss first assumptions on the international economic activity and international energy prices. These are used as input to construct assumptions for the Belgian macro-economic activities and for the level of energy demand. The next step is to introduce the policy measures that have already been taken. The last step is to compute in a detailed way the expected developments in the energy production and energy use as this is the basis for the emission scenario.

3.1. Assumptions on economic activity and energy prices in the world.

The economic growth assumptions are based on those used in the European Commission (DG RES) long-term reference scenario with the POLES model (P.Criqui & N.Kouvaritakis, 1999): 2.5% as an average GDP growth rate until 2005 and 2.1% for 2005-2020, followed by a slowdown to 1.6% for after 2020 the OECD countries.

For the short to medium term they correspond to those used in the economic forecasts of the Federal Planning Bureau of April 1999 for 1999-2004. Though the Asiatic crisis and the problems in the former Soviet Union have induced a slowdown of the growth in Europe after the revival of the economic activity observed till 1997/1998, the growth in the US has continued, justifying the figures above. The assumption is that the EU will pursue an equilibrated policy mix allowing a stable non-inflationary growth and a soft-landing for the countries in crisis. The sectoral allocation of the economic growth reflects the trend towards a service economy coupled with a decrease in the share of the energy intensive sectors such as the iron and steel industry and the building materials industry. This shift is however slowed down after 2010.

These assumptions are comparable to those used by the OECD in their World Energy Outlook 1998 and close to the average growth rate in the past.

The oil price assumption is based on the same European Commission (DG XII) reference scenario computed with the POLES World energy model. In this scenario, given the assumption of a rapid economic recovery from the 1997-1998 crisis and relatively moderate oil and gas resources, the oil price in real terms continues to increase rather sharply until 2010 with a slowdown thereafter. Oil and gas prices evolve in parallel.

For the medium term, other studies, like IEA World Energy Outlook, 1998 and IIASA WEC98, and the Belgian Federal Planbureau assume that the oil price will remain constant in real terms. For the long term, the results are more in line with the POLES work: the oil prices in 2030 are relatively close in the different studies. A full comparison is available[15]. We used the POLES reference scenario because it is derived with a model in which energy demand and supply are modelled in a fully consistent and integrated way and because it takes into account the latest development on the oil market.

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[15] See the final report of the European research consortium “Energy Technology Dynamics and Advanced Energy System Modelling” (Chapter 5 and 12).

Table 3 summarises the growth and energy price assumptions used in this study.

Table 3: Growth and Energy Prices Assumptions (annual average growth rate)

	2000/2005	2005/2010	2010/2020	2020/2030
OECD GDP	2.5%	2.4%	2.0%	1.6%
Oil ($90/bl)	4.5%	4.5%	2.5%	1.8%
Gas ($90/boe)	4.2%	4.2%	3.6%	1.8%
Coal	0%	0.3%	0.2%	0.2%

3.2. Belgian macroeconomic and sectoral background under the Reference Scenario (REF)

3.2.1. *Country Specific Assumptions*

The European macroeconomic and sectoral evolution under the 'Reference' scenario is computed with the GEM-E3 model, a linked general equilibrium for 14 EU countries. The general assumptions described above were complemented with country specific policy assumptions regarding the evolution of tax policies and public consumption and investment and general assumptions regarding exogenous technical progress.

Table 4: Country specific background assumptions (annual average growth rate)

	1999/2005	2005/2010	2010/2030
Public Investment	1.4	2.0	2.0
Public Consumption	1.3	1.0	1.0
Tax Policy	Stable over the entire horizon		
Technical Progress			
Labour	0.8	0.8	0.8
Materials	1.0	1.0	1.0

3.2.2. *The macroeconomic and sectoral evolutions for Belgium,*

The evolutions, derived with the GEM-E3 model, are summarised in the box below.

Table 5: Macroeconomic background and sectoral evolution for Belgium (average annual growth rate)

	1999/2005	2005/2010	2010/2030
Macroeconomic background			
GDP growth	2.2	2.1	1.8
Private consumption	2.3	2.2	2.2
Housing stock	0.6	0.5	0.3
Sectoral production			
Agriculture	1.8	1.9	1.7
Iron & Steel	0.5	0.7	0.4
Chemical sector	0.9	1.0	0.7
Building materials	0.7	0.7	0.4
Non energy intensive sectors	1.6	1.7	1.4
Service sector	1.5	1.9	1.8

The sectoral activity levels and the growth in housing stock and private income (reflected in private consumption evolution) are the main determinants for the evolution in the demand for energy services in our reference scenario.

3.3. Technological options and modelling of the electricity sector

An important modelling assumption for the electricity production in the reference scenario and in other scenarios is that the demand for electricity in Belgium has to be met by production on the Belgian territory. This means that the effects of the European electricity market have not been taken into account. We discuss this problem later.

All technological and cost data for this sector are based on the results of the Ampere commission to be published in Dec 2000.

3.4. GHG policy measures already taken in the period 1990-1998

The main policy decisions concerning GHG emissions taken since 1990 and introduced in the model are reproduced in the table below.

Table 6: Measures and policy instruments since 1990

MEASURES	**POLICY INSTRUMENTS OTHER THAN TAXES**		
Residential and Service sector			
1. Improvement of the insulation level in new buildings	1.1. K55 insulation level for new buildings in the residential sector		
	1.2. Insulation standard for the service sector		
2. Penetration of highly efficient electric appliances and saving-bulbs	2.1 Subsidies for highly-efficient bulbs through agreement with the electricity producing and distributing companies.		
Industrial sector			
1. Penetration of renewables	1.1 Subsidy of 2 BEF/KWh for electricity based on renewables		
2. Investment plan in the electricity sector	2.1 New STAG power plants are built in 1995 and 2000		
	2.2 No new nuclear power stations and maximum lifetime for existing nuclear power stations of 40 years		
	FISCAL POLICY INSTRUMENTS (in 90BF/GJ)		
	1990	1995	1997
Industrial sector			
Heavy Fuel (high sulphur)		16.0	15.5
Heavy Fuel (low sulphur)		5.3	5.2
Gasoil		13.2	12.8
Residential and Service sector			
Gasoil		16.0	15.6
Natural Gas		15.9	15.5
Electricity		16.0	15.6
Transport sector			
Gasoline	467.1	531.5	626.9
Gasoil	283.3	336.7	327.8

3.5. Evolution of the demand curves for energy services

The demand of energy services differs from the final energy demand: the demand of energy services corresponds to the demand for heat in houses or industrial processes or the demand of vehicle-km in case of transport, whereas the final energy demand corresponds to the delivery of energy products to the consumers (cfr.Table 1). Final energy is one of the inputs into the production of energy services, other inputs are e.g. heating equipment or house insulation.

As explained in the methodological section, we use the macro-economic activity evolution to determine the shift in the demand (curves) of energy services.

In the industrial and service sectors, the demand function shifts at the same rate as the production or the value added of these sectors, taking into account the evolution of the relative energy service price and technical progress. For the households, the demand function shifts as a function of the evolution of income and relative energy prices, with an income elasticity of 0.3 for heating demand, 0.5 for hot water and cooking demand and 1 for specific electricity demand and a price elasticity of –0.3 for all categories of demand. For the transport sector, passenger transport is a function of income whereas freight transport is a function of the general activity level, with a price elasticity of –0.3[16].

The derived evolution of the demand for energy services in the REF scenario is summarised in the table below.

Table 7: Growth of demand curves for energy services (average annual growth rate)

	2000/2005	2005/2010	2010/2030
Industrial Sector Demand			
Iron & Steel	0.2	0.3	0.1
Chemical Sector	0.8	0.5	0.6
Building Materials	0.7	0.5	0.4
Other Sectors	1.7	0.9	0.9
Agriculture/Service Sectors			
Heat Demand	1.0	0.9	0.9
Other Uses	1.0	0.9	0.9
Specific Electricity Use	1.3	1.2	1.2
Residential Sector			
Heat Demand	0.7	0.6	0.6
Other Uses	1.0	0.9	1.0
Specific Electricity Use	2.0	1.8	1.9
Transport Sector			
Passenger Transport	2.3	2.3	2.1
Freight Transport	1.7	1.5	1.2

The demand for energy services serves then as input into the MARKAL model for the reference scenario.

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[16] These elasticities have been derived from studies at CES and from literature review.

3.6. The GHG emissions in the Reference scenario

3.6.1. CO2 emissions

In the Reference scenario, CO_2 emissions in 2010 are 10.2% higher than in 1990. Between 1990 and 2010, emissions decrease by 23% in the energy sector, mainly because of the increasing share of gas for electricity production. After 2010, the CO_2 emissions of the electricity sector rise rapidly as nuclear plants are replaced by coal power plants.

Between 1990 and 2010, CO_2 emissions rise by 14% in the industry and 17% in the residential and service sector. In these two sectors, the main increase occurs in the nineties, while after 2000 (and up to 2030), emissions remain more or less stable, as energy efficiency is progressively improved and the growth in the number of household decreases. In the transport sector, emissions increase steadily (+40% between 1990 and 2010, and +27% between 2010 and 2030), because of the demand increase (at about 2% per year), while the improvement in fuel efficiency of the road vehicles remains limited (0.4% per year).

3.6.2. Electricity generation

In the reference scenario, as well as in all other scenarios, nuclear power remains the main primary energy source used for electricity generation until 2010, because of the existing nuclear capacity. Until 2010 the increase in electricity demand is mainly satisfied by STAG's and cogeneration. After 2010, however coal power plants are installed because new, more efficient coal power plants (advanced and ultra super critical) become available and coal becomes relatively cheaper than natural gas. Indeed, the oil and gas prices are assumed to increase steadily in the long term, while coal prices remain more or less stable. This contributes to a significant increase of the CO_2 emissions, after 2010.

In this scenario, wind turbines (except inland ones) become cost effective, thanks to the subsidy to wind energy (2 BEF/kWh). Nearly the full potential of wind energy is used as soon as the subsidy is in place (2005). Only the inland wind turbines, which operate in poorer windspeed conditions, appear slightly later (2010). In reality, it could take some more time to install the full potential of wind turbines in Belgium, especially the 1GW potential of offshore wind farms.

Table 8: GHG emissions in the Reference scenario (millions tons)

	1990	**2000**	**2005**	**2010**	**2020**	**2030**	**2010/1990**
Energy sector - CO2	29.7	25.3	21.3	22.8	45.5	69.1	-23.3%
Industry - CO2	29.7	33.6	32.8	34.0	35.8	34.7	14.5%
Residential & services - CO2	29.9	33.8	34.2	35.0	36.3	39.2	17.3%
Transport - CO2	21.6	25.6	28.1	30.2	34.9	38.4	39.5%
Other GHG (CO2 eq.)	3.6	4.3	4.0	4.2	4.7	5.8	17.0%
Total GHG (CO2 eq.)	114.5	122.5	120.3	126.2	157.1	187.3	10.2%
Shares per sector (CO2 only)							
Energy sector - CO2	27%	21%	18%	19%	30%	38%	
Industry - CO2	27%	28%	28%	28%	23%	19%	
Residential & services – CO2	27%	29%	29%	29%	24%	22%	
Transport - CO2	20%	22%	24%	25%	23%	21%	
Total	100%	100%	100%	100%	100%	100%	

Table 9: Primary energy demand in the Reference scenario

	1990	2000	2005	2010	2020	2030
Total primary energy demand (PJ)	2,068	2,292	2,324	2,417	2,624	2,741

Table 10: Electricity generation in the Reference scenario (TWh)

Centralised	1990	2000	2005	2010	2020	2030
Pulverised coal (existing)	14.9	13.7	8.1	0.0	0.0	0.0
Pulverised coal (SC/ASC/USC)	0.0	0.0	0.0	7.4	47.7	81.9
IGCC	0.0	0.0	0.0	0.0	0.0	0.0
PWR nuclear reactors	37.7	42.5	42.5	42.5	29.5	3.5
Gasturbines	0.0	0.0	0.1	0.0	0.0	0.0
STAG	0.0	8.4	10.1	11.8	0.3	0.0
Waste incinerators	0.5	0.5	0.3	0.3	0.3	0.3
Renewables	0.7	0.9	5.3	5.4	5.4	5.4
Other centralised production	6.7	0.5	0.0	0.6	0.0	0.0
Total centralised	60.5	66.6	66.3	68.0	83.2	91.1
Decentralised						
Cogeneration in industry	4.2	8.7	13.3	13.7	14.5	15.4
Cogeneration in resid. & services	0.0	0.9	2.5	4.1	5.1	5.4
Other decentralised	3.5	2.1	0.0	0.9	0.3	0.3
Total decentralised	7.8	11.7	15.8	18.7	19.9	21.1
Total power generation	**68.3**	**78.3**	**82.2**	**86.7**	**103.0**	**112.2**

4. KYOTO SCENARIO

4.1. Major assumptions

In this scenario, we have imposed that emissions in 2010 must be 7.5% lower than in 1990, and we let the optimisation model Markal chose the technologies to satisfy the energy needs in the most efficient way. As a by-product, Markal provides the level of CO_2 tax that would lead to the same result. The tax has to be imposed on all sectors (energy, industrial, residential and service and transport sector).

For after 2010, we have assumed that emissions must continue to decrease: in 2030, they must be 15% below their 1990 level.

4.2. Results for a GHG tax scenario

Table 11 shows the CO_2 emission levels per sector and Table 12 shows where the strongest reduction takes place relative to the Reference scenario. By 2010, the strongest reductions are in the industry (31%) and in the electricity generation sector (26%). Emission reductions are much smaller in the residential and transport sectors (6% and 3%).

In the longer term (2030), emission reductions become stronger in all sectors. New house insulation measures, more rational use of energy in residential and services and more efficient cars lead to more savings in residential, service and transport sectors.

Table 11: GHG emissions in the Kyoto scenario (millions tons)

	1990	2000	2005	2010	2020	2030	2010/1990
Energy sector - CO2	29.7	25.0	19.9	16.9	19.5	29.8	-43.0%
Industry – CO2	29.8	33.3	31.8	22.8	19.0	17.2	-23.3%
Residential & services – CO2	29.8	33.5	34.1	33.0	26.3	15.9	10.6%
Transport – CO2	21.6	25.6	27.8	29.4	33.2	31.1	36.0%
Other GHG (CO2 eq.)	3.6	4.2	3.9	3.8	3.9	4.1	4.7%
Total GHG (CO2 eq.)	114.5	121.6	117.5	105.9	101.9	98.0	-7.5%
Shares per sector (CO2 only) – Kyoto							
Energy sector - CO2	27%	21%	18%	17%	20%	32%	
Industry – CO2	27%	28%	28%	22%	19%	18%	
Residential & services – CO2	27%	29%	30%	32%	27%	17%	
Transport – CO2	20%	22%	24%	29%	34%	33%	
Total	100%	100%	100%	100%	100%	100%	

Table 12: GHG emissions changes in the Kyoto versus the Reference scenario

	1990	2000	2005	2010	2020	2030
Energy sector - CO2	0%	-1%	-6%	-26%	-57%	-57%
Industry – CO2	0%	-1%	-3%	-33%	-47%	-51%
Residential & services - CO2	0%	-1%	0%	-6%	-27%	-60%
Transport – CO2	0%	0%	-1%	-3%	-5%	-19%
Other GHG (CO2 eq.)	0%	0%	-1%	-11%	-17%	-30%
Total GHG (CO2 eq.)	0%	-1%	-2%	-16%	-35%	-48%

The marginal cost of GHG abatement is 820 BEF90/ton GHG in 2010. In Table 13, this tax is translated into an excise tax in current prices, i.e. BEF2000 per unit of fuel.

Table 13: Additional excise tax per fuel - Kyoto scenario (in BEF current prices, without VAT)

	Unit	2005	2010	2015	2020	2025	2030
Gasoline	litre	0.6	2.7	7.9	9.1	21.6	22.2
Diesel	litre	0.6	2.5	7.2	8.3	19.7	20.3
LFO	ton	719.8	3198.4	9159.5	10633.0	25154.0	25876.1
HFO	ton	691.3	3071.7	8796.7	10211.8	24157.5	24851.0
Gas	GJ (GHV)	11.6	51.5	147.6	171.4	405.4	417.0
Coal	ton	626.0	2781.5	7965.5	9246.9	21875.0	22503.0

Table 14: Welfare cost and primary energy demand in the Kyoto scenario

	1990	**2000**	**2005**	**2010**	**2020**	**2030**
Welfare cost (% of GDP2000) vs Reference	0.0%	0.0%	0.0%	0.1%	0.4%	1.6%
CO_2 & non CO_2 Tax income (difference in % vs Ref)	0.0%	-0.3%	12.8%	49.9%	153.9%	244.7%
Total primary energy demand (PJ)	2,069	2,284	2,294	2,207	2,102	1,926
Primary Energy, change vs Ref	0.0%	-0.3%	-1.3%	-8.7%	-19.9%	-29.7%

To reduce CO_2 emissions in the electricity generation sector, the coal power plants used in the Ref scenario are replaced by STAGs. As natural gas has a much lower CO_2 content per unit of energy unit, this allows substantial savings in CO_2. There are no other significant changes in the electricity generation sector, because the full potential available to cogeneration (about 3.5 GW) and renewable energy (1.5 GW of wind turbines) is already used.

Table 15: Electricity generation in the Kyoto scenario (TWh)

Centralised	**1990**	**2000**	**2005**	**2010**	**2020**	**2030**
Pulverised coal (existing)	14.9	13.5	6.5	0.0	0.0	0.0
Pulverised coal (SC/ASC/USC)	0.0	0.0	0.0	1.5	0.0	0.0
IGCC	0.0	0.0	0.0	0.0	0.0	0.0
PWR nuclear reactors	37.7	42.5	42.5	42.5	29.5	3.5
Gasturbines	0.0	0.0	0.0	0.0	0.0	0.0
STAG	0.0	8.4	10.4	14.6	27.2	63.3
Waste incinerators	0.5	0.5	0.3	0.3	0.3	0.3
Renewables	0.7	1.3	5.3	5.4	5.4	5.4
Other centralised production	6.7	0.5	0.0	0.0	0.0	0.0
Total centralised	60.6	66.8	64.9	64.3	62.4	72.4
Decentralised						
Cogeneration in industry	4.2	8.1	13.3	13.4	14.5	13.7
Cogeneration in residential & services	0.0	0.9	2.5	4.1	4.9	3.7
Other decentralised	3.5	2.1	0.0	0.0	0.0	0.0
Total decentralised	7.8	11.0	15.8	17.6	19.4	17.4
Total power generation	**68.3**	**77.9**	**80.7**	**81.9**	**81.8**	**89.9**

As the temperature in 1990 was rather high compared to average figures, it is likely that a higher reduction effort will have to be made in 2010, compared to the figures in Markal (which are for average figures both in 1990 and 2010). One can estimate that the correction for temperature will impose a further increase of 3.5% of total emissions; this implies a reduction of

11% in 2010 compared to 1990. The tax increases needed to arrive at this reduction level are given in the table below.

Table 16: Additional excise tax per fuel - Kyoto scenario corrected for high temperature in 1990 (in BEF current prices, without VAT)

	Unit	2005	2010	2015	2020	2025	2030
Gasoline	Litre	0.7	3.9	10.7	13.0	21.6	22.2
Diesel	Litre	0.7	3.5	9.8	11.8	19.7	20.3
LFO	Ton	854.1	4507.3	12476.9	15088.2	25154.0	25876.1
HFO	Ton	820.2	4328.7	11982.6	14490.4	24157.5	24851.0
Gas	GJ (GHV)	13.8	72.6	201.1	243.2	405.4	417.0
Coal	Ton	742.7	3919.7	10850.4	13121.3	21875.0	22503.0

5. SENSITIVITY STUDIES AND OTHER CONSIDERATIONS

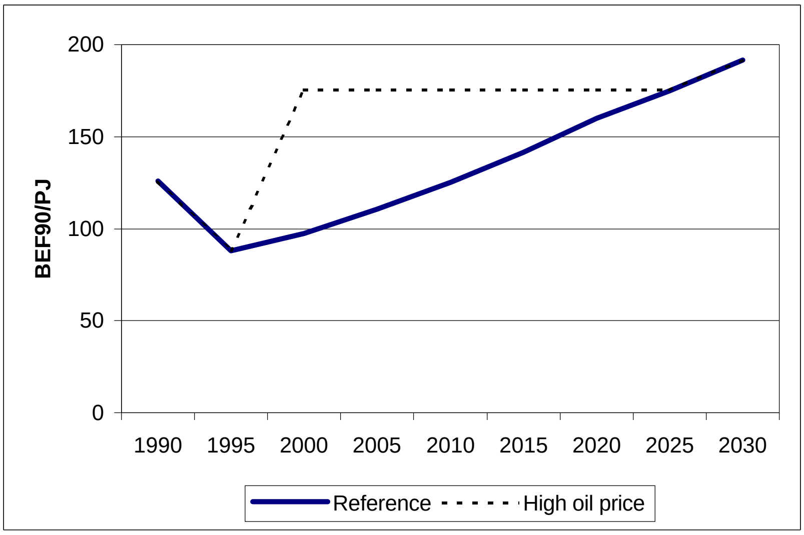
In this section we look at sensitivity studies on the level of the international oil prices, on the acceptance of new nuclear power stations. We also discuss some other issues as the cost of using standards rather than taxes, the macro-economic effects of a CO_2 tax and the role of the transport sector in the reduction of GHG.

5.1. High oil price

5.1.1. *Major assumptions*

In this scenario, we assume that the high price of oil observed in the summer of 2000 will be maintained (in real terms)[17] until the oil price in the reference scenario reaches this level. Then, the price resumes its growth according to the reference scenario. The price of other petroleum products and natural gas follows the same pattern. The price of coal is unaffected.

Figure 3: Price of crude oil in the reference and "high oil price"scenarios



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[17] An 80% increase in 2000 compared to the reference level has been assumed.

5.1.2. Results

The result of this scenario is a slowing down of the increase of CO_2 emissions in industry, transport and residential. Overall, CO_2 emissions are 5.9% higher in 2010 than in 1990, an improvement compared to the 9.7% of the Ref scenario.

Table 17: GHG emissions in the high oil price scenario (million tons)

	1990	2000	2005	2010	2020	2030	2010/1990
Energy sector - CO2	29.6	24.2	20.6	23.3	45.6	69.0	-21.5%
Industry - CO2	29.8	30.3	31.0	32.2	35.7	34.6	8.1%
Residential & services - CO2	29.9	30.9	31.4	32.4	35.1	39.0	8.3%
Transport - CO2	21.6	24.8	27.3	29.4	34.6	38.4	36.0%
Other GHG (CO2 eq.)	3.6	3.8	3.9	4.0	4.6	5.8	12.8%
Total GHG (CO2 eq.)	114.5	114.0	114.2	121.3	155.5	186.8	5.9%
Shares per sector (CO2 only)							
Energy sector - CO2	27%	22%	19%	20%	30%	38%	
Industry - CO2	27%	28%	28%	27%	24%	19%	
Residential & services - CO2	27%	28%	28%	28%	23%	22%	
Transport - CO2	20%	23%	25%	25%	23%	21%	
Total	100%	100%	100%	100%	100%	100%	

Table 18: GHG emissions changes in the high oil price scenario versus Reference

	1990	2000	2005	2010	2020	2030
Energy sector - CO2	0%	-5%	-3%	2%	0%	0%
Industry - CO2	0%	-10%	-6%	-5%	0%	0%
Residential & services - CO2	0%	-9%	-8%	-8%	-3%	-1%
Transport - CO2	0%	-3%	-3%	-3%	-1%	0%
Other GHG (CO2 eq.)	0%	-10%	-2%	-4%	-2%	-1%
Total GHG (CO2 eq.)	0%	-7%	-5%	-4%	-1%	0%

The decrease in emission occurs mainly outside the energy sector and the reduction goes nearly to 0 after 2020. In 2010, the quantity of CO_2 released by the electricity sector is even 2% higher than in the Reference scenario. However, this increase of emissions in the electricity sector disappears in the long run. When compared to Ref, the electricity production in 2010 relies more on coal (it was 7.4 TWh in Ref, against 10.8 TWh here), and less on STAGs (12.1 TWh in Ref against 8.9 TWh here).

The reason why coal is used in this scenario (instead of STAG) is that oil and gas prices are much higher than in the Ref scenario. It is thus cheaper to use coal power plants, which emit more CO_2 than gas power plants. However, after 2020, the oil price in the two scenarios becomes similar again, and the difference disappears.

The increase in oil price has a high welfare cost without significant decrease of the CO2 emissions. The higher oil price has to be paid and though favouring energy saving measures it does not induce any shift towards less CO_2 intensive technologies or fuels.

Table 19: Welfare cost and primary energy demand in the high oil price scenario

	1990	2000	2005	2010	2020	2030
Welfare cost (% of GDP2000) vs Ref	0.0%	1.7%	1.3%	1.0%	0.3%	0.0%
Non CO2 Tax income (difference in % vs Ref)	0.0%	-11.5%	-3.1%	-3.0%	-1.5%	0.0%
Total primary energy demand (PJ)	2,068	2,148	2,218	2,329	2,595	2,736
Primary Energy, change vs Ref	0.0%	-6.3%	-4.6%	-3.7%	-1.1%	-0.2%

Table 20: Electricity generation in the high oil price scenario (TWh)

Centralised	1990	2000	2005	2010	2020	2030
Pulverised coal (existing)	14.9	14.1	8.1	0.0	0.0	0.0
Pulverised coal (SC/ASC/USC)	0.0	0.0	0.0	10.8	48.3	82.1
IGCC	0.0	0.0	0.0	0.0	0.0	0.0
PWR nuclear reactors	37.7	42.5	42.5	42.5	29.5	3.5
Gasturbines	0.0	0.0	0.0	0.0	0.0	0.0
STAG	0.0	8.7	8.5	8.9	0.0	0.0
Waste incinerators	0.5	0.5	0.3	0.3	0.3	0.3
Renewables	0.7	1.3	5.4	5.4	5.4	5.4
Other centralised production	6.4	0.1	0.0	0.0	0.0	0.0
Total centralised	60.3	67.3	64.9	67.9	83.5	91.2
Decentralised						
Cogeneration in industry	4.4	7.6	13.3	13.7	14.5	15.4
Cogeneration in resid. & services	0.0	0.8	2.5	4.1	5.1	5.4
Other decentralised	3.5	1.2	0.3	0.6	0.2	0.1
Total decentralised	7.9	9.7	16.1	18.4	19.8	20.9
Total power generation	**68.2**	**77.0**	**81.0**	**86.3**	**103.3**	**112.2**

5.2. Can new nuclear power stations help to achieve the Kyoto target?

In the scenarios analysed above it was assumed as central hypothesis that no new nuclear power plants could be installed. Because of the uncertainty around this assumption and the role nuclear energy could play in the reduction of GHG emissions, we simulated a scenario where this option is available. The impact is rather limited until 2010 but becomes significant from 2025 onwards when the existing power plants are scrapped, as can be seen in the next table. This table summarises results obtained with a slightly different reference scenario (one without subsidies for renewables and a minimum of generation with coal) and where the cost function includes benefits for the reduction of other externalities than GHG gasses. For this reason cost figures can only be compared across scenarios in this table. The table compares total electricity demand, generation by type of power plant and total discounted welfare cost for scenarios with and without the Kyoto constraint and for scenarios with and without new nuclear power stations.

Table 21: Electricity demand and production by technologies (in TWh) and total cost of the scenarios compared to the reference (in % of GDP 2000)

	In 2010	In 2020	In 2030
No Kyoto constraint New nuclear	Demand ELEC: 84 TWh Nuclear 43 TWh Coal: 4 TWh Gas: 19 TWh Cogeneration: 17 TWh Renewables: 1 TWh Cost: -0.1% of GDP 2000	Demand ELEC: 99 TWh Nuclear 60 TWh Coal: 9 TWh Gas: 10 TWh Cogeneration: 19 TWh Renewables: 1 TWh Cost: -0.7% of GDP 2000	Demand ELEC: 113 TWh Nuclear 60 TWh Coal: 33 TWh Gas: 1 TWh Cogeneration: 19 TWh Renewables: 1 TWh Cost: -0.5% of GDP 2000
No Kyoto constraint No new nuclear	Demand ELEC: 84 TWh Nuclear 43 TWh Coal: 4 TWh Gas: 20 TWh Cogeneration: 17 TWh Renewables: 1 TWh Cost: -0.1% of GDP 2000	Demand ELEC: 88 TWh Nuclear 30 TWh Coal: 16 TWh Gas: 23 TWh Cogeneration: 19 TWh Renewables: 1 TWh Cost: -0.8% of GDP 2000	Demand ELEC: 106 TWh Nuclear 4 TWh Coal: 74 TWh Gas: 9 TWh Cogeneration: 19 TWh Renewables: 1 TWh Cost: -0.7% of GDP 2000
Kyoto constraint No new nuclear	Demand ELEC: 81 TWh Nuclear 43 TWh Coal: 4 TWh Gas: 17 TWh Cogeneration: 17 TWh Renewables: 1 TWh Cost: -0.2% of GDP 2000	Demand ELEC: 86 TWh Nuclear 30 TWh Coal: 4 TWh Gas: 27 TWh Cogeneration: 20 TWh Renewables: 5 TWh Cost: 0.1% of GDP 2000	Demand ELEC: 98 TWh Nuclear 4 TWh Coal: 4 TWh Gas: 62 TWh Cogeneration: 22 TWh Renewables: 5 TWh Cost: 2.7% of GDP 2000
Kyoto constraint New nuclear	Demand ELEC: 82 TWh Nuclear 43 TWh Coal: 4 TWh Gas: 17 TWh Cogeneration: 17 TWh Renewables: 1 TWh Cost: -0.2% of GDP 2000	Demand ELEC: 95 TWh Nuclear 60 TWh Coal: 4 TWh Gas: 12 TWh Cogeneration: 18 TWh Renewables: 1 TWh Cost: -0.3% of GDP 2000	Demand ELEC: 100 TWh Nuclear 60 TWh Coal: 4 TWh Gas: 11 TWh Cogeneration: 21 TWh Renewables: 5 TWh Cost: 0.6% of GDP 2000

The following conclusions can be drawn from the results:

- Until 2010 the production capacities in the electricity sector are relatively fixed; imposing the Kyoto constraint implies an effort to reduce electricity demand by around 3 TWh and the cost of meeting the Kyoto target remains limited (comparing the scenarios with and without Kyoto gives cost differences of 0.1% of GDP or less)
- After 2010, the results are different depending on the policy constraints considered:
    - the GHG-emission constraint imposes the largest reduction in electricity demand, 86TWh in 2020 and 98TWh in 2030 compared to respectively 99TWh and 113TWh when no constraints are imposed.
    - the cost of the GHG emission constraint increases sharply after 2010, reaching in 2030 some 3.4% (= 2.7% - (-0.7%)) of the GDP of 2000 when the nuclear option is not allowed and 1.1% (=0.6% -(0.5%)) when it is allowed.
    - When no GHG-emission constraint is imposed, the welfare cost of the ban on new nuclear is small and consists mainly in higher (non GHG) external costs that are associated to the more intensive use of fossil fuels (mainly coal)

- with the GHG constraint and without the nuclear option, mainly gas power plants are installed; without the Kyoto constraint either nuclear power plants are installed, and when this is not available, a sequence of gas power plants followed by coal power plants is used
- the contribution of cogeneration and renewables to reach the Kyoto target remains very limited. Renewables are only interesting in the long run and when a GHG constraint is imposed

5.3. The ‘Kyoto’ scenario under alternative policy cases

5.3.1. A ‘standard’ policy scenario

The previous results are derived under the assumption that an emission tax is used as policy instrument. Standards are an alternative instrument to reach the ‘Kyoto’ target, which will however be more costly. Even if the standards are differentiated over the different uses of energy to make sure one mimicks the cost-effective solution where the marginal cost of emission reduction is equal over all options, the remaining greenhouse gas emissions remain untaxed and this means that the reduction in the level of energy services will be smaller. This reduction in energy services was an important part of the optimal set of measures. In order to reach the total emission reduction required through standards, one has to implement efficiency improvements that are stronger than the ones implicit in the emission tax scenario. Moreover as shown in Table 2, when labour taxes exist, the use of standards tends to aggravate the existing distortions and the overall welfare cost of compliance will be much higher[18].

A good indicator of the cost increase due to the use of standards instead of an emission tax is the marginal cost of GHG reduction. In the table below, the marginal cost (cost 1 concept) for both scenarios is reproduced under the assumption that the policy maker has very good information on technologies and costs. When this assumption does not hold the cost disadvantage of standards becomes larger.

Table 22: Relative marginal cost 1 of GHG emission reduction for reaching ‘Kyoto’ target (Index 100 for GHG tax)

	2005	2010	2020	2030
with standard	102	169	303	130
with tax	100	100	100	100

5.3.2. An ‘energy tax’ scenario

Imposing an energy tax instead of a CO2/GHG tax will increase the cost of reaching the Kyoto target, as it does not give an incentive towards fuel switching, therefore leaving out one option for reducing the GHG emissions. Comparing with a GHG tax (the least cost scenario described above), the loss in welfare (discounted change in consumer/producer surplus) is increased with 4.2% over the entire horizon 1990-2030.

5.3.3. Tradable permits

Tradable permits, in as far as they are auctioned, will in first approximation, produce the same results as a GHG emission tax equal. The same caveats apply as for emission taxes. Tradable permits are often preferred because they can be grandfathered and this means a transfer of income (or rents) to the polluters.

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[18] One could also add that standards are static and stimulate less technical progress. Endogenous technical progress is not represented in the models used in this study.

When there are no pre-existing taxes on labour and there is a closed economy, grandfathering or auctioning the permits does not make a difference: the marginal cost for any polluter will still be equal to the price of a permit and it is this marginal cost that will steer the choices on the level of energy services, on the type of technology and on the fuel.

When there are pre-existing labour taxes, the decisions made within the energy sector are still efficient but the overall welfare cost of achieving the Kyoto goal will be much higher (+50 to +100%) compared to a GHG emission tax. The reason is that the environmental cost aggravates the existing labour tax distortions. The net real wage of labour has been decreased (by the increased price of the carbon intensive consumer products) and there are no carbon tax revenues to compensate (being partially) the reduction of the net wage. When there is an open economy, grandfathered tradable permits may have smaller effects on the activity levels.

5.3.4. Voluntary agreements

Voluntary agreements are established between the regulatory agency and the polluters (usually government and industry, respectively), where environmental goals as well as measures for no compliance are defined. The use of this type of instrument is still limited and is usually applied in other areas than those analysed in the present study (packaging, recycling, etc), though their application in the industry sector is growing. Their impact will be closer to the one obtained with standards than with taxes. The main interest of voluntary agreements is their flexibility. They are a weak instrument to implement costly abatement measures implied by the Kyoto constraint.

5.4. The macroeconomic impact of the 'Kyoto' scenario

The GEM-E3 model was used to evaluate the macroeconomic and sectoral impact of a GHG emission tax allowing to reach the Kyoto target in 2010. The revenue of the GHG is recycled through a reduction of the employers' social security contribution, while maintaining the public budget constant in terms of GDP. It is also assumed that the other EU countries are following the same type of policy to reach their own Kyoto target.

Table 23: Impact on the Macroeconomic Aggregates of the ‘Kyoto’ scenario compared to the ‘Ref’ scenario (%change unless otherwise indicated)

	2000	2005	2010
Gross Domestic Product	0.05%	0.18%	0.50%
Employment	0.07%	0.28%	1.21%
Employment (diff. in thousand)	2	10	44
Private Investment	-0.01%	-0.03%	-0.19%
Private Consumption	0.09%	0.26%	0.45%
Domestic Demand	-0.16%	-0.51%	-1.95%
Exports in volume	-0.34%	-1.11%	-3.82%
Imports in volume	-0.32%	-1.04%	-3.89%
Energy consumption in volume	-1.06%	-3.65%	-13.26%
Real wage rate	0.20%	0.68%	2.01%
Tax revenues as % of GDP*	0.19%	0.69%	2.62%
Avg. reduction in social security rate*	0.43%	1.53%	5.71%
Current account as % of GDP*	0.02%	0.09%	0.43%
Terms of Trade	0.07%	0.26%	0.78%
Total atmospheric emissions			
CO2	-1.86%	-6.42%	-19.96%
NOX	-1.89%	-6.59%	-21.49%
SO2	-2.76%	-9.49%	-28.78%
VOC	-1.05%	-3.72%	-13.39%
PM	-2.98%	-10.52%	-31.63%
* in absolute difference			

Table 24: Sectoral production evolution in the ‘Kyoto’ scenario (% change compared to ‘REF’ scenario)

	2000	2005	2010
Agriculture	-0.04%	-0.13%	-0.51%
Coal	-3.96%	-13.13%	-37.18%
Crude oil and oil products	-1.23%	-4.05%	-15.68%
Natural gas	0.02%	-0.05%	-0.75%
Electricity	-0.26%	-0.98%	-3.90%
Ferrous, non-ferrous ore and metals	-1.01%	-3.64%	-13.12%
Chemical products	-0.09%	-0.30%	-0.97%
Other energy intensive industries	-0.07%	-0.24%	-0.62%
Electrical goods	-0.08%	-0.20%	-0.62%
Transport equipment	-0.02%	-0.08%	-0.65%
Other equipment goods industries	-0.10%	-0.24%	-0.51%
Consumer goods industries	-0.03%	-0.06%	-0.08%
Building and construction	-0.01%	-0.03%	-0.18%
Telecommunication services	0.08%	0.29%	1.05%
Transports	-0.08%	-0.30%	-1.06%
Credit and insurance	0.06%	0.20%	0.51%
Other market services	0.03%	0.10%	0.22%
Non market services	0.01%	0.03%	0.09%

6. SAVING CO_2 EMISSIONS IN THE TRANSPORT SECTOR?

The transport sector represents in the EU some 25% of all CO_2 emissions. In this figure the international traffic in and out of the EU is not included. The majority of the emissions (85%) come from the use of fossil fuels for road transport (cars and trucks). These carbon emissions have been growing at a higher speed than GDP. The European Commission has proposed in its communication on Transport and CO_2, a wide set of measures to curb the growth of CO_2 emissions. Almost all measures proposed are also partly justified by transport considerations.

For passenger transport, one counts mainly on two measures: one affecting the volume of car use and a second affecting the fuel use (and CO_2 emissions) per vehicle-kilometre. According to the EU policy paper, the volume of car use could be reduced by 11% when car use is correctly priced. This will require a modal shift. The second principal measure is more fuel-efficient cars. This measure has been accepted by the European federation of car manufacturers (ACEA). The agreement between the Commission and ACEA foresees that the average emission of new cars would decrease from the market average of 186 g/Vehicle km in 1995 to 140 g/vehicle km in 2008. The European Commission is considering complementing this measure with fuel efficiency information to consumers and an increase in fuel taxation and another vehicle tax related incentive. Other local measures (promotion of cycling, speed limits, etc.) can each add a few percentages of emission reduction to these measures.

According to the Commission document, improved road freight logistics could reduce the empty truck kilometres. Other important factors are improved land use planning and the development of efficient rail-freight, inland waterways and coastal shipping to reduce the energy intensive road freight volume.

For air transport and CO_2, a communication has been announced. This mode of transport has the highest growth rate. Measures could include a tax on kerosene and fuel efficiency standards.

From an economic efficiency view, the EU agreement on more fuel-efficient cars is not the most cost-effective way to reduce CO2 emissions. In the scenarios above, the use of this new car has not been imposed, but when a CO2 constraint is imposed (the Kyoto scenario) this car starts to penetrate only from 2020 onwards. The reason is simple. At present the use of fossil fuel in the transport sector is already taxed at a rate of 200 or 300% compared to tax rates of 20% or less in the other energy uses. The efforts to save fuel have therefore been pushed much further in the transport sector than in the other sectors. For the consumer, automotive fuel is very expensive and from his point of view energy saving looks interesting. From a society point of view however, energy saving in the transport sector is not interesting because it consists for 75% in tax savings that are no real savings of resource costs.

This does not imply that there are no opportunities for CO2 saving in the transport sector. It is possible that measures that aim to correct other inefficiencies in the transport sector produce interesting side benefits in terms of CO2 reduction (S.Proost, K.Van Dender, (2000), S.Proost, (2000), S.Proost, D.Van Regemorter, F.Lantz, V.Saint-Antonin,(2000), S. Proost, D. Van Regemorter (1999). In the next table we show the possible effects on CO2 emissions of some transport policy measures for Brussels.

In the table we compare different alternatives for the transport sector, using the reference scenario (unchanged policy) as benchmark. The first column gives the welfare gain as compared to the perfect optimum that can be reached with perfect pricing and regulation instruments. The ideal policy is full external cost pricing and this generates a saving of CO2 emissions of the order of 22%. This policy addresses all externality problems in the transport sector in a perfect way. Perfect pricing of external costs leads to lower air pollution damage mainly as side effect of lower volume of car use. The lower value of car use is the result of different effects that are mainly targeted at reducing congestion: more car pooling, switch to other modes and a smaller number of trips. This table illustrates that the welfare maximising policies for the transport sector are those policies that address as directly as possible the problem of congestion and unpaid parking. Congestion problems can be tackled by time differentiated cordon charging (toll levied on commuters at entrance of city that is differentiated between peak and off peak). The unpaid parking distortion can be solved by making everybody pay for his parking resource cost (at destination). Both policy instruments generate important welfare improvements. The extent of the welfare improvement is correlated to the increase in speed they can generate in the peak period. The effects on CO2 emissions of the less perfect measures is rather limited. The effect of both measures can not be added.

Decreasing public transport prices or increasing public transport quality is often advanced as an efficient CO2 saving policy. The effect of this policy is in general very limited because of several reasons. First prices are already very low for Public Transport. Second, occupancy rates are in general not very high.

Table 25: Welfare efficiency of alternative transport and environment policy instruments for Brussels in 2005 (source: TRENEN II computations)

	Change in welfare (Mio ECU/day)	Change in CO2 (in % compared to reference)	Total volume of passenger car units	speed of cars in peak (km/h)
reference	0		100	23
perfect pricing	100%	- 17%	78	40
cordon pricing	+52%	-7 %	89	33
parking charges	+32%	-5%	95	26

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