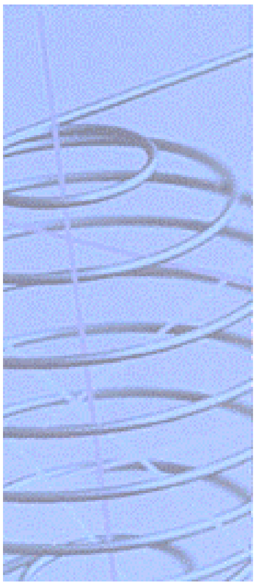
Markal, a model to support greenhouse gas reduction policies

Final report

CES-KULeuven - VITO



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Global change and sustainable development

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Final Report

MARKAL, A MODEL TO SUPPORT GREENHOUSE GAS REDUCTION POLICIES

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I. INTRODUCTION

A. *Objective*

In view of the Kyoto protocol signed by the EU, climate change and its policy implications both at national and international level will remain a priority for the policymakers. A correct evaluation of the potential for emission reduction in Belgium, their allocation between economic sectors and their cost is therefore essential. It is the main goal of this project to support the policy in Belgium regarding climate change with the MARKAL model. More concrete, it can contribute to the following objectives:

- evaluation of the CO2-emission targets, which Belgium can achieve in the long term
- determine which sectors or technologies have to be considered in priority

B. *Research Strategy*

To achieve the goal of this project, the objective is to make the MARKAL model available in Belgium to contribute to the definition of policies regarding climate change, at national and international level.

MARKAL is a generic model that represents all energy demand and supply activities and technologies for a country with a horizon of up to 40 years. It is a technico-economic model which assembles in a simple but economically consistent way technological information (conversion-efficiency, investment- and variable costs, etc.). As the model is formulated as a dynamic optimisation model, it can produce alternative developments for energy supply and demand that achieve CO2 emission reduction goals at least cost. Simultaneously, the model makes prospective energy and emission balances, tests the potential of new energy technologies and contributes to R&D policy formulation. Finally the model is well suited to approach the burden sharing issue between sectors of the same country in a transparent and scientific way. Compared to ad-hoc models which are more specific to a country or a sector and which use another modelling technique, it presents three important advantages:

- due to its transparency it promotes the communication between experts with different sectoral or technological background (it is the place where engineers and economists understand each other),
- it is easily verifiable : its results can be related to assumptions regarding technological data and economic parameters,
- it is comparable at an international level : as many countries use the same model, its results can be immediately compared with results from other countries.

The first Belgian version has been developed by CES-KULeuven and VITO in the first GLOBAL CHANGE program of the DWTC-SSTC and has already been used intensively for policy support.

At present the model is used in 30 countries for policy analysis purposes. It is a collaborative effort coordinated by the ETSAP (IEA) network. The ETSAP-network (Energy Technology Systems Analysis Programme) is an agreement within the International Energy Agency which concentrates its work on “Energy Options for sustainable Development”. The ETSAP-network is in charge of the maintenance of most of MARKAL model software (database-management system and model specification) and organises two workshops per year where the experience with case-studies of some 20 countries are compared. Results from common case-studies are presented in international forums, organised ea. by IEA and can contribute to the negotiations within the United Nations Framework Convention on Climate Change (FCCC). This international network contributes particularly to a continuous development of the model in many directions.

II. METHODOLOGY

This research project is centred on the development of the Belgian Markal model and its use for policy analysis. Markal is a partial equilibrium model, which is complementary to other models. The complementarity is mainly related to the following three types of models:

- detailed sectoral models : a model for one sector can be more detailed for the technologies or the type of behaviour of the economic agents (e.g. microsimulation models which represent the behaviour of a representative sample of approximately a hundred households); this type of model allows to evaluate more correctly other instruments with a more short term impact (information, specific norms, ...); these results can be used as an input to energy models as MARKAL.
- national general equilibrium models : these are economic models which allow to evaluate the macroeconomic impact of a CO2 policy (e.g. GEM-E3 model of the EU). These models can study such questions as the use of the revenue from a CO2 tax, the double-dividend discussion, the total impact on employment, etc. and deliver a basic forecast for the demand for energy services (an input for MARKAL).
- international energy-economy models : these models evaluate the world impact of CO2 emission reduction options in terms of burden sharing, climate damage, exhaustion of resources, etc. (e.g. DICE model of Nordhaus, MERGE model of Manne & Richels and GEM-E3 for the EU) - Markal can deliver inputs to such models and can make use of some of their results (e.g. feedback on the price of resources).

The model can contribute to the following problems:

- propose minimum cost solutions for CO2 reductions and in this way contribute to the burden-sharing within a country,
- compute prospective energy and emission balances,
- evaluate the role of new technologies for CO2 reductions and contribute to the setting of R & D priorities,
- evaluate the impact on the costs and on emissions of different types of regulations, standards and taxes,

Besides the basic version of Markal, three other versions have been developed within the ETSAP community:

- MARKAL-MACRO: through the integration of a simple macroeconomic sub-model the level of economic activity and the demand for energy services have become endogenous in the long run
- MARKAL-MICRO/ED: the demand for energy services become endogenous through demand functions for energy services (the first version has been developed by CES-KULeuven and is currently used in all studies with Markal for Belgium)
- MARKAL-STOCHASTIC: this version takes explicitly the uncertainty regarding technologies (carbon-free technology) or future emission reduction requirements (in 2010 -20% or -40%) into account in the formulation of the problem and searches for an optimal hedging strategy.

and the network is currently involved in the development of a new Markal, called TIMES.

Regarding policy analysis, one of the main goals is to help in the formulation of a national Kyoto strategy. MARKAL can contribute with sectoral or intersectoral cost-efficiency studies. It can contribute to the evaluation of the cost of emission reduction targets for the years 2005-2010. Markal can also be used to investigate the effects of economic instruments, of technological standards and fuel standards. The participation in an international reference group such as ETSAP allows to integrate the national studies into international studies in a harmonised way.

III. ACTIVITIES AND RESULTS

The activities can be grouped into three categories: the maintenance and improvement of the database, new model developments and policy-studies. A further activity which is important for the dynamics of the development of the Markal model is the participation in the ETSAP network.

A. Maintenance, extension and quality control of the technology database

A basic version of Markal should be directly available for policy analysis and therefore needs to be maintained. This maintenance necessitates a regular update of the technology databases and of the economic background figures. A common evaluation of the national database and an internal and external peer-review of the models is foreseen within the objective of ETSAP. This increases the reliability and representativeness of the model and allows for comparative international studies and analysis.

The technology database is the basic element of MARKAL. In the Belgian database approximately two hundred technologies are described. This includes existing technologies and technologies still under development and covers both technological and economical data. The maintenance and quality control of the technology database has been an important activity in the overall project, to take into account in the long term studies the potential development of technologies. VITO was mainly in charge of this activity.

1. The electricity sector

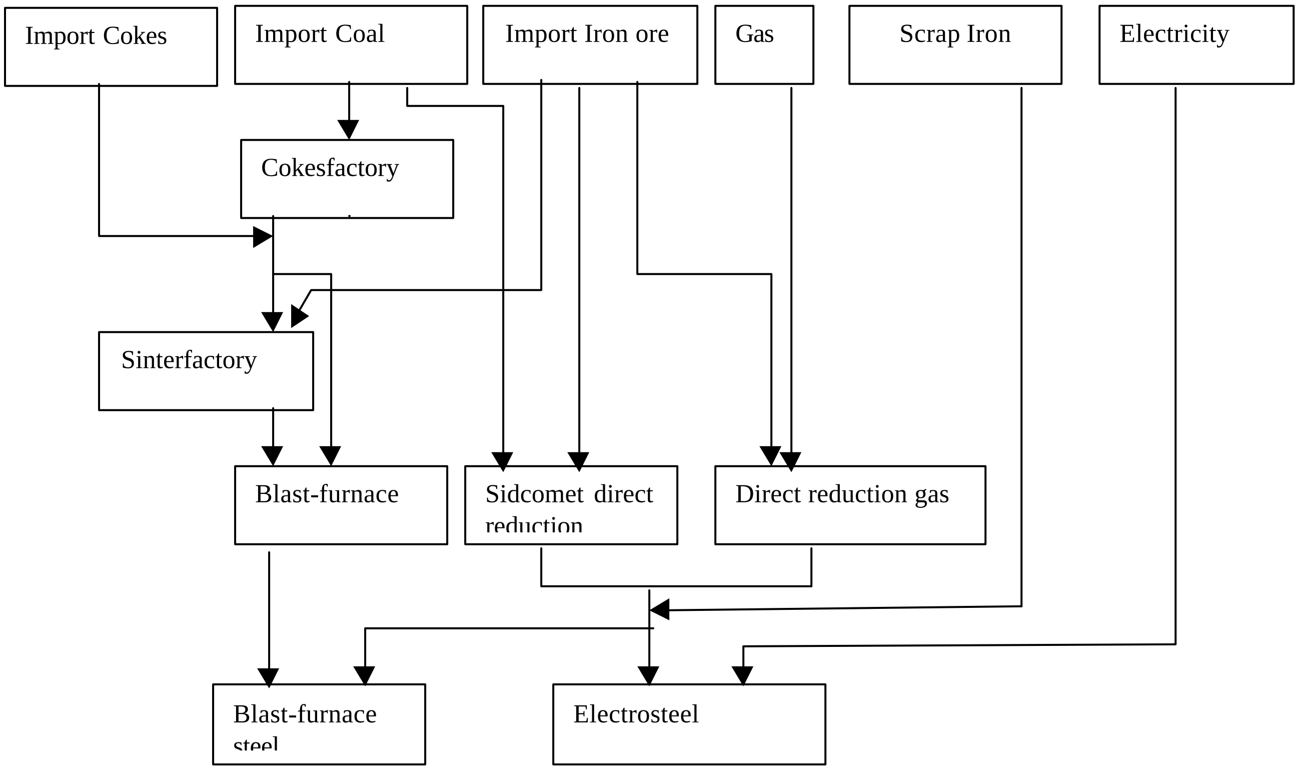
The data concerning the electricity sector were updated based on data collected within the Ampere Commission. A complete database with the cost and technical data on potential electricity generation technologies in Belgium until 2030 was established with the help of the Ampere reports on each technology, and through consultations with experts from the sector and members from the Commission. The engineering department of KULeuven also contributed. Significant changes were made in the fields of nuclear energy, fuel cells, wind turbines, STAGs, coal power plants and cogeneration.

2. The industrial sector

Industry is an important user of energy and an important emitter of CO2. Until now it was only modelled in a very simplified way. A further decomposition of the industrial sectors into subsectors necessitates the introduction of new technologies. This decomposition is done for the most energy intensive sectors with a complete revision of the technological and economic data associated with these sectors. Also the data for existing subsectors are revised with a special attention for the evaluation of the potential and the associated investment- and variable cost of energy saving technologies.

A short description for the steel industry is given below as an illustration of the work done. Steel production represents more than 40% of the industrial CO2 emissions in Belgium. The flowchart gives a first impression of the database structure for this sector.

The model has three reduction processes. Blast furnace reduction is the common used technology. Main inputs are sintered iron (and pellets can be used as well) and cokes. High quality steel requires high quality cokes, which is produced locally or is imported (not on the flowchart). A second technology is direct reduction on gas. This technology is actually not used in Belgium (it exists in Germany) but should be looked at as a theoretical solution. The third technology, Sidcomet is a direct reduction technology based on coal, which will be implemented in Belgian steel production. Steel production in the Belgian Markal database



Another alternative for steel production is the use of scrap iron. Depending on quality requirements it can be mixed with blast furnace steel or it can be used in electro-steel

Some secondary flows have not been indicated on the flowchart. At the blast furnace reduction process, blast furnace gas is produced. This low-caloric waste gas is used in electricity production. In the cokes factory, high caloric cokes-oven gas is produced as by-product. This gas can have different applications in steel industry (heating cowpers) as well as in electricity production. Also a small amount of coal is directly injected in blast furnace. Not all energy requirements are indicated on the flowchart. For instance small amounts of electricity are used is almost all processes. In the database also these flows are considered.

3. The residential sector

The data for the evaluation of the useful energy demand in the residential sector have been completely reviewed and updated on the basis of a specific study on heat demand per type of building by Prof. Hens of the Laboratory of Construction Physics of the KULeuven and of the population survey of 1991. This has led to a completely revised procedure to compute the total heat demand: it is based on assumptions regarding the evolution of the housing stock, the population and the size of households, starting from the heat demand per type of building and the allocation of the housing stock over the types in the base-year. The types of insulation measures in buildings and their cost were also revised.

4. The transport sector

Road transport has been modelled in detail, as it is in Belgium the primary energy consuming transport mode. Classical fuels (petrol-, diesel and LPG cars) as well as more advanced technologies (electrical cars, hybrid cars, natural gas, ethanol and methanol and fuel cell technologies) are introduced in the database. For classical cars, the European emission standards for different pollutants are explicit in the database through the introduction of distinctive car technologies according to their emission standards (Euro 0 cars, Euro 1, Euro 2, Euro 3 and Euro 4). The fuel-efficient cars, as specified in the voluntary agreement of the car-manufactures with the European Commission, were also introduced. For busses and trucks, a wide variety of technologies, using different types of energy and with the different European emission standards have been implemented.

Summary statistics of the transport sector in Markal

Demand category	Unit of measure	Number of demand technologies
Cars for short distance (14400km/year)	Billion km	17
Cars for long distance (22400 km/year)	Billion km	19
Busses	Billion km	13
Trucks	Billion km	11
Passenger train	Million km	2
Goods train	Million km	2
Inland transport by boat	Million km	1

A full description of the database is given in annex.

B. *Model development*

The model development are concentrated on two domain:

- the implementation and the use of the MARKAL-STOCHASTIC version, as there are no other models in Belgium that take the uncertainty element into account.
- the reformulation of the model to take better into account the secondary benefits of CO2 emission reduction, by secondary benefits one understands the saving of other external costs e.g. the decrease in emissions of other pollutants or the macroeconomic impact (e.g. the employment effect).

1. *Development of MARKAL-STOCHASTIC*

This version can compute optimal hedging strategies when the information on the necessity of CO2 emission reductions or the availability of cheap carbon free technologies becomes only available in later periods. Deterministic scenario analysis and sensibility analysis, the approach followed until now in the Belgian studies with MARKAL, can give some insights, but their results are not always useful for policymakers when the outcomes are very diverging and only one set of actions can be taken.

Within the ETSAP network, an experimental version of MARKAL-STOCHASTIC was developed in the Netherlands and Canada, based on “multi-stage stochastic programming”. This approach allows taking explicitly into account uncertainty and its evolution over time. This version has been adapted to the Belgian case.

a) Theoretical approach for MARKAL-STOCHASTIC

(1) Basic approach for modelling of decision making under uncertainty

In the economic theory, the main approach for decision making under risk is maximising the expected utility. However it is rather difficult to find a specific utility function and distribution function which yields a tractable form for the expected utility, when the situation considered becomes more complex. Therefore in practice when considering investment decision under uncertainty, the mean-variance model is applied.

The mean-variance model maximises the objective function :

$$\mu - \lambda * \sigma 2,$$

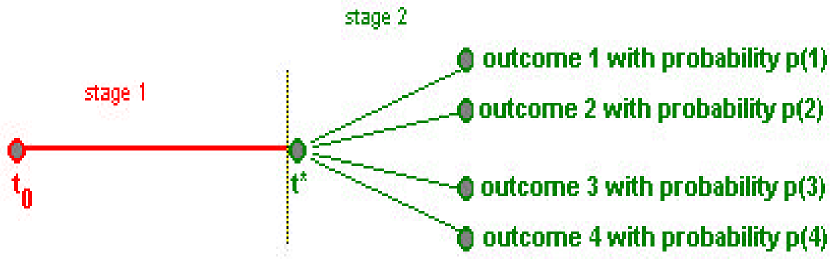
where μ is the expected return and σ^2 is the variance of the disposable income. The variance is used as an indicator of the risk of the return and λ is a parameter reflecting the degree of risk aversion of the decision-maker.

This model corresponds only exactly to the expected utility approach under very stringent conditions on the utility function or on the probability distribution function. But as Varian mentions "Even for non-normal distributions, which cannot be completely characterised by their mean and variance, the Mean-Variance model may well serve as a reasonable approximation to the expected utility model".

When λ is assumed to be zero, the decision-maker is assumed to be risk-neutral. Besides the assumption regarding the attitude towards risk of the decision maker, this assumption has also a practical advantage: the objective function becomes linear and linear optimisation programs are much more powerful than non linear ones.

(2) Uncertainty and learning

When considering uncertainty it is important to take into account of the possibility of learning, because this can change the nature of the problem. Learning is a continuous process, but modelling it as such leads to complicated model. The easiest way of modelling learning is to consider two stages in the model. In the first stage there is uncertainty about the state of nature that will be realised in the second stage. At the start of the second stage (t*) the uncertainty is resolved and the true state of nature becomes known.



To better approximate the continuous process of learning, more stages can be introduced, however this complicates the model[1].

b) Stochastic Markal

(1) Specification

The objective function of stochastic Markal is based on the Mean-Variance model. It tries both to minimise the expected cost and the risk. The weight that is given to the risk is determined by the parameter λ. For a risk neutral decision maker λ equals 0, so that the only objective is to minimise the expected cost.

Stochastic Markal considers 2 stages:

1. in the first stage, $t = 1 \rightarrow t2$, there is uncertainty,
2. the second stage, $t = t2 + 1 \rightarrow T$, starts when this uncertainty is resolved and when the future becomes known; T is the last period in the model.

At this stage, considering the size of the Belgian Markal model, λ has been set to 0 in the applications for this study, i.e. risk neutrality is assumed.

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[1] If one thinks that the characteristic of learning being a continuous process is important for the problem, one can model this by introducing successive shorter periods in which uncertainty disappears gradually.

(2) Influence of parameter values and model characteristics on the solution generated by the model

Certain characteristics of the model and assumptions that are made in the model can influence the generated solution and it is important to have them in mind to get a better understanding of the model and also to get a better interpretation of the results. The points specific for *stochastic* Markal are

1. the year that uncertainty is resolved
2. the probabilities attached to the different possible outcomes and the degree of risk aversion
3. modelling of technologies in the model

(a) The year that uncertainty is resolved

The date at which uncertainty is assumed to be resolved influences the solution. If uncertainty is resolved late, the stochastic will be closer to the deterministic strategy with the worst possible outcome. This is so because one of the assumptions of the model is that in the end it must be possible to satisfy the constraints for all possible outcomes. In the limiting case that the uncertainty is solved only at the end of the horizon, the stochastic path matches the deterministic path for the worst outcome.

(b) The probabilities attached to the different possible outcomes and the degree of risk aversion

It is obvious that changing these parameters will result in changes of the solution. Therefore it might be important to make sensitivity studies around these parameters, as there is great uncertainty attached to them.

(c) *Modelling of technologies in the model*

In the Belgian Markal model the fuel switch possibilities in the industry are mainly represented through technologies which can consume different types of fuels. Though the total cost is correct, the fuel switching possibilities and speed are overestimated. This can be important for the results, when using stochastic Markal model, because fuel switching technologies are very convenient in the uncertain stage. Ideally mono-fuel and bi- or tri-fuel technologies should be modelled explicitly and this has been partly improved with the update of the industrial database.

c) Application of Stochastic Markal for Belgium: a comparison of stochastic strategy with deterministic strategies for a Kyoto scenario

(1) Description of the Kyoto scenario

The focus in this study lies on the comparison of a stochastic strategy with the deterministic strategies. The stochastic strategy has the advantage, to define “one” strategy which takes into account the possible constraints that can be imposed after a certain period, it allows to keep a certain flexibility before the uncertainty is resolved.

We consider therefore two types of strategies for the Kyoto scenario:

1. deterministic strategies, one for each State of the World
2. a stochastic strategy combining the different States of the World

The model assumptions are:

1. in all the strategies, the CO2-emissions[2] for 1990 and 1995 are fixed to the observed levels[3].
2. in all strategies the CO2 emissions from 2008 to 2012 must be on average 7,5% below the CO2-emissions in 1990, this to satisfy the agreements under the Kyoto Protocol.
3. four possible states of the nature are considered for the cumulative CO2 constraints to be imposed

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[2] In order to make the scenario congruent with reality we should not only put fixed bounds on CO2-emissions but also on the technologies that were used in the past period. This is not yet the case in this implementation.

[3] The figures for 1990 and 1995 are drawn from a Markal run under the scenario business as usual.

4. under the stochastic strategy, it is assumed that after 2012 it will become clear which one of 4 possible cumulative emission levels will have to be reached between 1990 and 2030. Therefore the first decision moment on which there is certainty concerning the state of nature is 2013. Thus, one path is followed until 2012 and starting from 2013, four different paths are possible, one for each alternative emission constraint.
5. risk neutrality is assumed in the stochastic strategy.

The four possible states of nature, the attached cumulative emission levels (to be reached in 2030), and their attached probabilities are presented in the table below. The same cumulative emission constraints are used in the deterministic strategies, Det..., Det 0%, Det –8%, Det –25%.

State of nature Cumulative emission level, to be reached in 2030		**Maximum on Cum. CO2-emissions between 1988 and 2032 (Million tons)**	**Probability State of Nature**
without cumulative constraint	Stoch. ...		0.25
Stabilisation at 1990 level	Stoch. 0%	4541	0.25
-8% compared with stabilisation	Stoch. –8%	4178	0.25
-25%compared with stabilisation	Stoch. –25%	3406	0.25

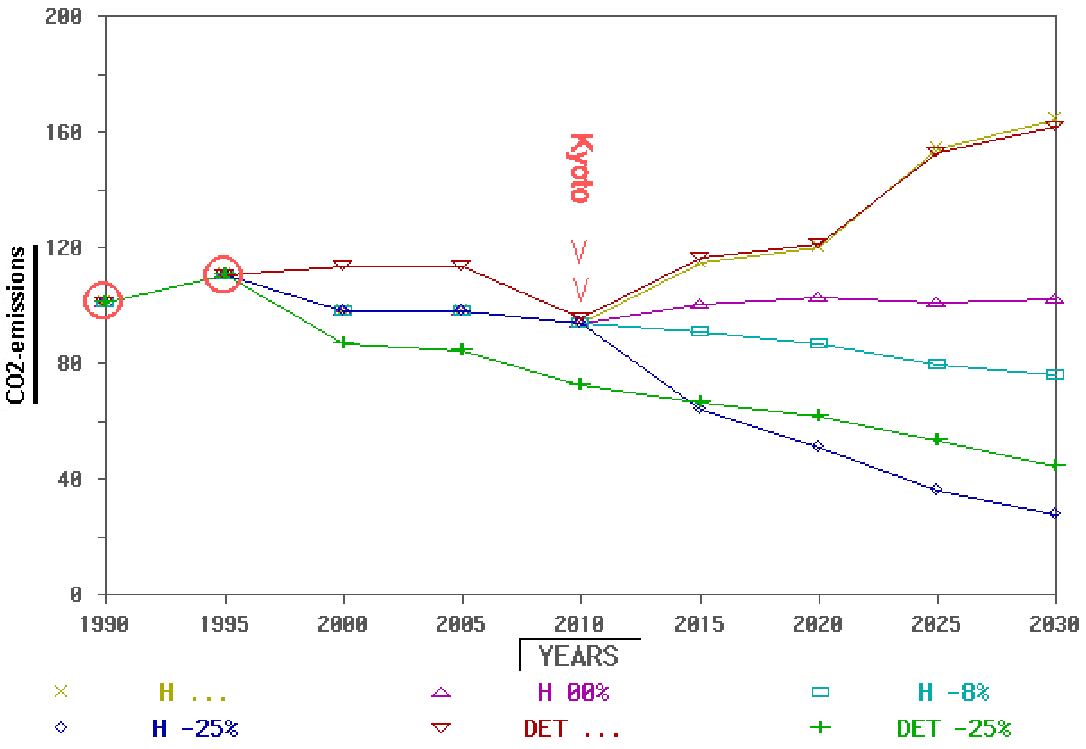
(2) CO_2 emissions and costs

(a) CO2 emission paths for the different scenarios

In the figure below, the CO2-emission paths of the stochastic strategy (Stoch..) and of two deterministic strategies (Det) are presented. As we mentioned already, the CO2-emissions for 1990 and 1995 were fixed. The stochastic strategy results in one path until the year 2012 (period 2010) and in four paths from the year 2013 (period 2015). The Kyoto constraints must be satisfied for all cases.

For strategy "Det -25%", the CO2-emissions in 2010 are already lower than should be according to the Kyoto-constraint. Therefore the Kyoto constraint is not binding under this strategy and does not result in extra costs.

Figure 1: CO2 emission paths for different strategies.



(b) Comparison of the costs for the different scenarios

Table 1 compares the total cost for the different scenarios, with the total discounted cost under "Det...", the "deterministic strategy without cumulative constraint", taken as a reference. *EV* stands for the Expected Value of the four stochastic cases.

Table 1: Total discounted costs and CO2 emissions under different strategies(/scenarios)

	Cost (MBF)	Relativ cost 'Det ...' =100	Diff. in Cost with 'Det ...' (MBF)	CO2 emission (Mton)	relativ CO2 em. 'Det ...' =100
Stoch. ...	20745559	100,3	66362	5265	97,3
Stoch. -0%	20813974	100,7	134777	4541	83,9
Stoch. -8%	20985476	101,5	306279	4178	77,2
Stoch. -25%	22016738	106,5	1337541	3406	62,9
EV	*21140437*	*102*	*461240*	*4348*	80,3
Det ...	20679197	100	0	5411	100
Det –0%	20793734	100,6	114537	4541	83,9
Det –8%	20981696	101,5	302499	4178	77,2
Det –25%	21762620	105,2	1083423	3406	62,9

In order to shed more light on the advantages of the stochastic strategy we put together the costs that are incurred for the stochastic and deterministic strategy for the 4 possible outcomes after 2012 in Table 2. To explain Table 2 below, we remark that the first 4 cells of the header row give the 4 possible cumulative constraints, of which will be known from 2013 on which is the true one. So, for instance, for the row indicated by "Det..." the total discounted costs are represented for the deterministic case where one assumes until period 2010 that it is certain that there will be no limit on the cumulative CO2 emissions. If then indeed it will be revealed after period 2010 that there will be no limit on the emissions, the cost will be "100". However, if the limit on yearly CO2 emissions will be on average 0%, 8% or 25% lower than the 1990 level, the cost will be respectively 100.8, 102.0 and 108.7. In the last cell of this row the expected cost of the "Det..."- strategy is calculated as the sum of 0.25 times the cost under each of the four possible outcomes.

Table 2: Relative total discounted costs under different possible outcomes after 2012, for all strategies.

		POSSIBLE OUTCOMES				
		...	0	-8%	-25%	E.V.
Strategies	Det...	**100.0**	100,8	102	108,7	102,88
	Det 0	100,2	**100,6**	101,6	107,3	102,42
	Det -8%	100,3	100,7	**101,5**	106,8	102,34
	Det -25%	102,3	102,4	102,6	**105,3**	103,17
	Stochastic	100,4	100,7	101,6	106,6	102,33

For the stochastic scenario, the difference between the costs under the ‘most extreme’ outcomes remains limited. The cost of “Stoch. -25%” is 6% (or 1279 * 10^9 BF) higher than the cost of “Stoch...”. In both cases we have the same (stochastic) strategy until 2012, but after 2012 in the first case a very strong cumulative constraint (-25%) has to be satisfied, whereas in the second case there is no cumulative constraint at all.

For each of the four possible cumulative CO2 restrictions that may be imposed after 2012, the total discounted system cost for the stochastic strategy never exceeds the cost of the “clairvoyant deterministic strategy with the correctly assumed outcome” with more than 1%.

If one looks at Table 2 one remarks that the total discounted system costs under the stochastic strategy are very close (+0.1%) to the best possible solutions for the “non- extreme” outcomes (“0%” and “-8%” as cumulative restriction). For the extreme outcomes they are further away from the best possible solution, 0.4% for outcome ‘...’ and 1.3 % for outcome “-25%’.

If the solution of the stochastic strategy is compared with “Det 0%” and “Det -8%” for the four possible outcomes, the differences seem to be very small. Therefore it may seem that the stochastic strategy has little advantage over intermediate deterministic strategies and that it may not be worth the effort to use a stochastic strategy. This is not the case. First, since we deal with huge costs, a difference of 0.1% of the total discounted system cost remains a very large amount (i.e. 20.6 * 10^9 BF). Secondly it is not always the case that the intermediate deterministic strategies are close to the stochastic strategy.

In terms of the expected value, the stochastic strategy performs better than the deterministic strategies. This should be so, because the stochastic strategy is chosen in a way to generate the smallest possible expected total discounted cost.

For a certain outcome no solution can be less costly than the deterministic strategy which assumed from the start that this outcome was certain to take place. In Table 2 above these costs are presented in bold characters. In Table 3, we calculated the regret that can be incurred for each strategy and each outcome as a percentage of the total discounted system cost of “Det...” if the real outcome is “...”.

Table 3: Regret for each strategy and each outcome as % of the total discounted system cost of “Det...” if the real outcome is “...”.

		POSSIBLE OUTCOMES					
		...	0	-8%	-25%	E.V.	diff in E.V.
St	Det ...	**0**	0.2	0.5	3.4	102.88	0.55
ra	Det 0	0.2	**0**	0.1	2.0	102.42	0.09
te	Det -8%	0.3	0.1	**0**	1.5	102.34	0.01
gi	Det -25%	2.3	1.8	1.1	**0**	103.17	0.84
es	Stochastic	0.4	0.1	0.1	1.3	**102.33**	**0**

From the five strategies presented in the table above, the stochastic strategy has the smallest maximum regret that can be incurred. The maximum regret that can be incurred under the stochastic strategy appears if outcome “-25%” is the true one. The regret is then 1,3% of the total discounted system cost of “Det...” if “...” is the true outcome or this is 269 * 10^9 BF. The minimax regret strategy itself was not calculated, but we can deduce that under the minimax regret strategy more effort would be taken to reduce CO2-emissions in the uncertain time-span than under the stochastic strategy. The maximum regret that can be incurred under “Det...”, “Det 0” and “Det -8%” is respectively 3.4%, 2.0%, and 1.5%, and this always if outcome “-25%” appears to be the true one, so that it is a “future” regret. The maximum regret that can occur for strategy “Det -25%” is 2.3% and this if outcome “...” would be the true outcome, it is a “present” regret. From the strategies above, it is strategy “Det -25%” that has the smallest maximum cost that can be incurred.

Further details on this study can be found in the report in annex. It clearly shows the interest of this approach for evaluation of policies and technologies with a great uncertainty component, however it appeared to be difficult to use for policy design.

2. *Representation of secondary benefits*

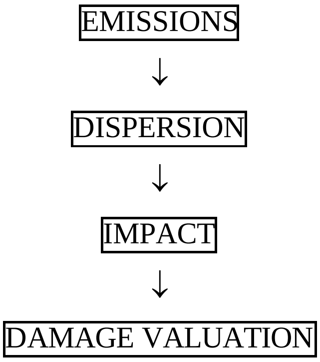
The second model development has been its reformulation to be able to take explicitly into account in the analysis of GHG policy options the secondary benefits/costs coming from other pollutants, as a reduction in greenhouse-gas emissions has not only an impact at global level but can also bring benefits locally by reducing other air pollutants linked to energy consumption. By secondary benefits one understands the saving of other external costs e.g. by the decrease in emissions of other pollutants or the macroeconomic impact (e.g. the employment effect). With the MARKAL model it is possible to evaluate the external cost and benefits of pollutants which are linked to energy consumption, such as NOx, SO2, VOC and PM. The benefits of the reduction of local air pollutants will accrue to the current generation contrary to the reduction of climate change and also mostly to the population undertaking the mitigation actions, though the transportation of pollutants can be rather extensive. Therefore it seems important to take these benefits into account to get a more correct evaluation of the cost of GHG reduction policies. It might be also useful to induce a policy design, which fully exploit these benefits, while obtaining the same impact on global warming.

a) Database extension and model adaptation

The local environmental problems considered are: (i) problems related to the deposition of acidifying emissions and (ii) ambient air quality linked to acidifying emissions and ozone concentration. We consider the energy-related emissions of NO_x, SO_2, VOC and particulates, which are the main source of air pollution. NO_x is almost exclusively generated by combustion process, whereas VOC’s are only partly generated by energy using activities (refineries, combustion of motor fuels); other important sources of VOC’s are the use of solvents in the metal industry and in different chemical products.

The approach followed for the evaluation of the benefits from the reduction of local pollutants is based on the bottom up damage function approach as developed by the ExternE project.

This approach can be illustrated by the following figure (EC, 1995).



(1) The database extension

The Markal database has been extended into three directions:

a) emission coefficients for pollutants such as NOx, SO2, VOC and PM,
b) immission coefficients for those pollutants, i.e. coefficient for the translation of emissions into concentration, inclusive the transportation mechanism
c) impact of emissions and immissions and their monetary valuation.

(a) Emission coefficients

Emission coefficients of NOx, SO2, VOC and PM associated with the energy using technologies have been added to the Belgian Markal database. This is a rather extensive work because, contrary to CO2 emissions coefficients, these coefficients are technology linked.

(b) Coefficients for the transformation and transport of emissions

This step establishes the link between a change in emissions and the resulting change in concentration levels of primary and secondary pollutants. The transboundary nature of pollutants leads to the necessity to account for the transport of SO_2, NO_x, VOC and particulates emissions between countries. In the case of tropospheric ozone (a secondary pollutant), besides the transboundary aspect, the relation between VOC and NO_x emissions, the two ozone precursors, and the level of ozone concentration has also to be considered.

Theoretically, the concentration/deposition of a pollutant in a country is a function of the total antropogenic emissions before time t, some background concentration[4] in every country, and other parameters such as meteorological conditions, as derived in models of atmospheric dispersion and of chemical reactions of pollutants. In the model a static and linear relation is used which reflect the effect the emitted pollutants in the different countries have on the deposition/concentration of a pollutant in a specific country, such as to measure the incremental deposition/concentration, compared to a reference situation.

It would be useful to include the distinction in the source of emission, for instance between emissions from mobile sources and/or low height stationary sources as opposed to high stack sources as it is expected that the deposition of pollutants per unit emitted will be different in each case. However, there is no information available at this moment that allows making such distinction.

(c) Damage parameters and their monetary valuation

The damage parameters and their monetary valuation are taken from the ExternE project of the European Commission, in which CES and VITO are responsible for its Belgian application. Therefore the approach followed here is entirely based on the framework derived in the project, though at a much more aggregated level. The damage occurs when primary (e.g. SO_2) or secondary (e.g. SO_4^{--}) pollutants are deposited on a receptor (e.g. in the lungs, on a building) and ideally, one should relate this deposition per receptor to a physical damage per receptor. In practice, dose/exposure-response functions are related to (i) ambient concentration to which a receptor is submitted, (ii) wet or dry deposition on a receptor or (iii) 'after deposition' parameters (e.g. the PH of lake due to acid rain). Following the 'damage or dose-response function approach', the incremental physical damage DAM per country is given as a function of the change in deposition/concentration (acidifying components or ozone concentration in the model).

The damages categories considered in the model are

1. damage to public health (acute morbidity and mortality, chronic morbidity, but no occupational health effect)
2. damage to the territorial ecosystem (agriculture and forests) and to materials, this last category being treated in a very aggregated way at this stage.

The impact on biodiversity, noise or water is not considered, either because there are no data available that could be applied in this study or because air pollution is only a minor source of damage for that category.

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[4] Resulting from natural emissions and emissions from geographic parts that are not included in the country set.

(i) Damage to public health

The assessment of health impacts by ExternE is based on a selection of exposure-response functions from epidemiological studies on the health effects of ambient air pollution (both for Europe and the US). The economic valuation of the damage is based on the willingness-to-pay or willingness to accept concept. The valuation figures used in ExternE are summarised in Table 4[5].

Table 4 : Valuation of mortality and morbidity impacts from ExternE (ECU 1990)

Mortality	
Statistical life	2600000
Lost life year	81000
Acute Morbidity	
Hospital admission for respiratory or cardiovascular symptoms	6500
Emergency room visit or hospital visit for childhood croup	185
Restricted activity days (RAD)	62
Symptoms of chronic bronchitis or cough	6
Asthma attacks or minor symptoms	31
Chronic Morbidity	
Chronic bronchitis/asthma in adults	87000
Non fatal cancer/malginant neoplasm	372000
Changes in prevalence of cough/bronchitis in children	186

Putting the impact and valuation data together, an estimation of the health damage figure per incremental pollution can be computed for PM10 en PM2.5 (direct and indirect), for SO_2 (direct) and ozone (cf. Table 3).

Table 5: Damage from an increase in air pollution ***(10^6 ECU95 per 1000 persons)***

From an increase of one µg/m^3 of PM10 and nitrite concentration	0.010058
From an increase of one µg/m^3 of sulphite concentration	0.016352
From an increase of one µg/m^3 of PM 2.5 concentration and Diesel particulates	0.017237
From an increase of one µg/m^3 of SO_2 concentration	0.000540
From increase of one ppb of ozone concentration	0.001593

(ii) Impacts on territorial ecosystems and materials

Because of the great uncertainty around dose response functions and the valuation of the damages on the ecosystem and materials, it was impossible to derive a damage impact coefficient with a valuation term associated to it for each category of damage. Moreover first results from ExternE showed that they were relatively less important than public health impact: in the first ExternE evaluation they represented approximately 25% of total damage from particulates (direct and indirect). Therefore Mike Holland (ExternE, ETSU) computed an average damage cost per person from the ExternE detailed computations to be used as an indicative value which has been implemented.

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[5] The latest ExternE figures (1997) are expressed in ECU 1995. They were transformed in ECU 1990 assuming a price increase of 20.8% between 1990 and 1995.

Table 6: Damage from an increase in air pollution ***(10^6 ECU per 1000 persons)***

From an increase of one µg/m³ of sulphite concentration	0.0028
From an increase of one µg/m³ of nitrite concentration	0.0018

(d) Damage from emissions in Belgium

Combining the figures for the transportation and transformation of pollutants and the figures for the damages, one can compute a figure representing the damage per unit of emission of a primary pollutant. The distinction can be made between the damage within the country and the damage across the border, generated by the emission of a pollutant in one country, though at the country aggregation level it remains approximate, because the geographic location of the source can be important. The estimations for Belgium are given in the table below.

Table 7: Damage from emissions in Belgium (*10^6 BF90 per kton emission of pollutant)*

	Damage in Belgium	Total damage (in Belgium and abroad)
Nox	18.4	194.4
SO_2	54.5	183.3
VOC	0.6	9.9
PM	190.8	609.2
PM transp (PM2.5)	315.4	1006.8

It is clear that measuring environmental costs at the global level as in this model, raises different problems, which are extensively discussed in ExternE: transferability of the results from specific studies, time and space limits, uncertainty, the choice of the discounting factor, the use of average estimates instead of marginal estimates and aggregation. However, despite all these uncertainties, it is possible, according to ExternE, to give an informative quantified assessment of the environmental costs.

b) Model Adaptations

The objective was to adapt MARKAL to be able to take into account in the analysis of policy options the benefits/costs coming from local pollutants. Two approaches are modelled:

1. the environmental damage are computed ex-post, without feedback into the optimisation process
2. the environmental damages are part of the objective function and therefore taken into account in the optimisation process.

In the first approach this function is used to compute ex-post the damage associated with the model solution. In the second approach, a term is added to the objective function, which contains the sum of the damage-functions per pollutant. As the computation are based on dose response functions which give the incremental damage from air pollution, the results should also be interpreted in these terms, i.e. in terms of the change in total damage compared to a reference year.

c) Illustration with Policy Scenarios

(1) Definition of the policy scenarios

Three policy scenarios are considered, one focusing on local air pollution, a second one on GHG emission reductions and a third combining both types of policies. They are compared to a reference scenario in which no environmental policy is imposed.

For the local air pollution policy (LAP scenario), we impose an environmental tax on SO2, NOx, VOC and particulates emissions. The level of the tax is put equal to the total damage (in Belgium and abroad) generated by the pollutant emitted in Belgium, as given in Table 7. In a further stage, it might be interesting to relate this scenario to the different agreement Belgium has signed on local air pollutant. A more geographically disaggregated model, both at the level of the generation of emissions and at the level of the transformation and transportation of emissions[6], would clearly enhance the analysis because the damages from air pollution are 'location' dependent.

For the global warming policy (GW scenario), the EU Kyoto target, translated into a target for Belgium through the burden sharing agreement within the EU, is imposed on the greenhouse gas emissions in Belgium in 2010. This target consists in reducing the emissions of greenhouse gasses in 2008-2012 by 7.5% compared to the level of 1990. For after 2010, we have assumed that the GHG emissions must continue to decrease at the same rate: in 2030, they must be 15% below their 1990 level. We also 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. The links between the reduction of certain pollutants and global warming, e.g. the cooling effect of sulphur emissions, should be taken into account in this type of analysis, but this not done yet.

The third scenario, addressing both local pollution and global warming (LAPGW scenario), is a combination of the two scenarios. The focus of the comparison of scenarios lies, at this stage, on the mutual impact of the policies and not on the definition of optimal environmental policies or the choice of policy instruments.

(2) The scenarios comparison

The comparison between scenarios focuses, at this stage, on the cost differences and not on the technological options to reach the environmental targets neither on the distribution of the cost between sectors. The main results are given in Table 8 (for the entire horizon) and in Table 9 (per period).

Table 8: Welfare and Damages over the entire horizon (1990-2030)

(differences with reference scenario)

	LAP	GW	LAPGW
Discounted welfare, excluding environmental damage(10^6BF)	-41 869	-183 859	-203 623
Discounted local environmental damage (10^6BF)	-90 978	-60 596	-118 962
GHG emissions (Mton)	-487	-1 759	-1 761

Imposing a tax on local pollutants equal to the damage generated by these pollutant, reduces both local air pollution and GHG emissions. This reduction occurs through investment in abatement technologies and a decrease of the demand of energy services because of the increase in price. Investment in abatement technologies has an impact on the local pollutant, whereas the decrease in demand reduces both the local pollution and the GHG emissions. The abatement investment and the decrease in energy services demand reduce the welfare, but the total welfare change (including the environmental benefits) remains positive.

The cost of addressing local air pollution remains limited especially considering the reduction in damage such a policy induces. Those results are clearly dependant on the damage figures used and the abatement possibilities modelled in Markal. Moreover how specific policies regarding the local pollutants are modelled in the reference scenario is also important; for instance the progressive introduction of more stringent standards for cars and trucks in Europe which are partly taken into account in our database reduces the potential environmental benefits.

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[6] in this exercise the country is taken as 'one' grid.

When imposing a GHG constraint, the GHG emission are reduced up to the target but the local pollutants are also reduced. GHG reduction are obtained through energy efficiency improvement and through a decrease of the demand for energy services. However in this scenario no incentive is given to take into account the damage from local pollutant in the decision process.

When combining the local pollution scenario and the global warming, the interactions between pollutant is taken into account. The tax on local pollution creates an incentive for integrating the damage from these pollutant in the decision for GHG emissions[7]. For a same level of GHG emissions, the damage from local pollution is much lower than in the GW scenario and still further decreased compared to the LAP scenario. The cost in non environmental welfare is higher than in the GW scenario but lower than the sum of the cost in LAP and GW, but the total cost (non environmental and environmental) is lower.

When looking at the results per period (Table 9), the same conclusions can be drawn. However the gain in terms of cost decreases when higher GHG emission target are imposed because the gains from local pollution abatement are becoming marginal compared to the GHG abatement cost.

Table 9: Welfare and Damages per period

(undiscounted, differences with reference scenario)

	2010	2020	2030
Welfare, excluding environmental damage(106BF)			
LAP	-10 922	-16 829	-15 119
GW	-30 260	-112 468	-326 795
LAPGW	-35 780	-115 905	-329 237
Local environmental damage (106BF)			
LAP	-24 592	-30 177	-26 264
GW	-12 752	-32 764	-54 678
LAPGW	-31 979	-46 704	-55 062
GHG emissions (Mton)			
LAP	-8.94	-25.76	-14.55
GW	-27.32	-63.77	-104.1
LAPGW	-27.32	-63.77	-104.1

This is also observed in the marginal cost of GHG reduction, the shadow price of the GHG constraint (Table 10).

Table 10: Marginal cost of GHG reduction (BF/ton)

	2010	2020	2030
GW	-2160	-3888	-12624
LAPGW	-1423	-3290	-12666

(3) Conclusion

This exercise has shown the importance of examining jointly interrelated environmental problems for policy design. A policy to reduce GHG will simultaneously reduce local pollution and thus the benefits from the reduction of local pollutants should be included for a correct evaluation of the cost of the GHG policy. A policy aiming at reducing local pollution reduces also the GHG emissions and might therefore reduce the cost of reaching a GHG reduction target. Our results have shown that combining both policies would allow to get the same overall benefits at a lower cost. This is only a

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[7] When a constraint is binding, the shadow price of the constraint is equivalent to a GHG tax. If a constraint is not binding, there is no incentive to take the damage from the remaining pollutant into account when deciding on other pollutant.

first step in the analysis and our research will continue in two directions. The definition of the local air pollution policy should be related to the different agreements Belgium has signed for this type of pollution. The choice of policy instrument is a crucial element for a full exploitation of the interactions between pollutants and need to be further examined.

C. Contribution to the GHG policy of Belgium through policy studies

Analysis of greenhouse policies is one of the main goals of this project. The focus has been on the identification of the options to reach the Kyoto target for GHG emissions, both in terms of technological choices and in terms of policy instruments and this for the Federal Ministry of the Environment, the Ministry of Economic Affairs and the Ministry of Energy. Moreover the implications for investment in the electricity sector of policies regarding climate change and nuclear have also been investigated.

The different studies have been elaborated during the last two years of the project. Because of the continuous improvement of the database and the changing international environment, their results are not strictly comparable, however the broad messages remain the same. We will synthesise the main conclusions hereafter, for the full analysis it is necessary to consult the reports in annex. The policy studies were either undertaken jointly by the partners either done individually, however in both cases this activity benefits from the development by all partners. As a starting point to all studies lies the construction of a reference scenario, which elaborates the long term perspectives (30 to 40 years). It has to be consistent with other medium term forecasts (Planning Office, EC). It gives a path for the demand of energy and of the GHG emissions in Belgium until 2030, given assumptions regarding energy prices and economic growth.

1. The reference scenario

The procedure followed in the construction of the reference scenario is illustrated in

Figure 2.

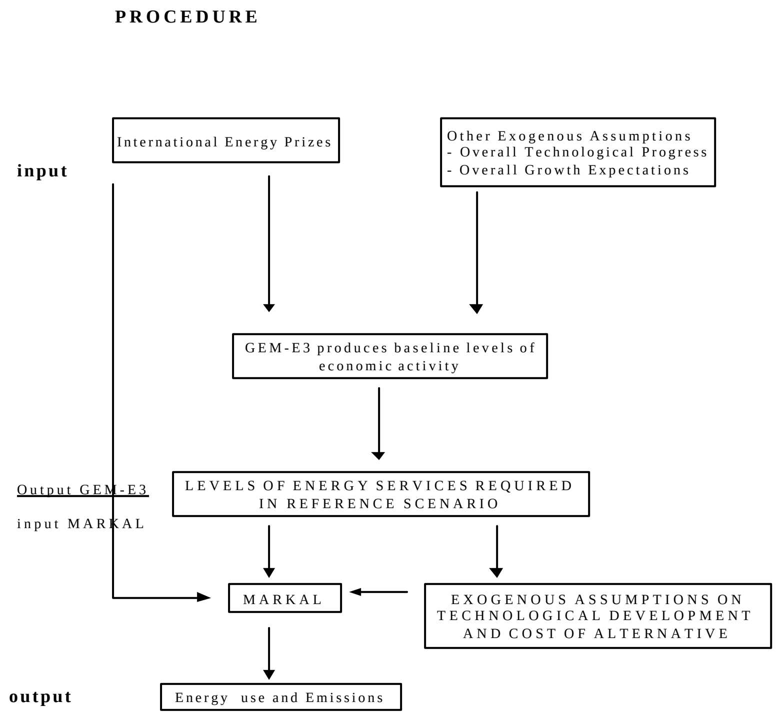

Figure 2: Construction of the reference scenario

It consists of 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, based on the 1999 study for the EU DG Research[9]. An average GDP growth of 2.5% is assumed till 2005, 2.1% between 2005-2020 and thereafter 1.6% for the OECD countries. The oil prices are increasing till 2010 given an assumption of relatively low oil reserves and the assumption on economic growth. Oil and gas prices are evolving in parallel.

Table 11: 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)	2.6%	2.5%	2.5%	1.8%
Gas ($90/boe)				
European market	4.2%	4.2%	3.6%	2.4%
Coal	0%	0.3%	0.2%	0.2%

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[8] Poles is a model, developed for DG Research under the Joule research program, that represents the world energy demand and supply.

[9] Energy Technology Dynamics and Advanced Energy System Modelling, Final Technical Report, July 1999, Chapter 5: World Energy Projections to 2030, P. Criqui (IEPE) and N. Kouvaritakis (ECOSIM)

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

Here the GEM-E3 model[10], a general equilibrium model for the 15 EU countries, 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 the line with the Belgium 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.

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. Table 12 summarises the main assumptions.

Table 12: 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
Commercial and service sector	1.5	1.9	1.8

Moreover, the policy measures regarding energy and GHG emissions taken between 1990 and 2000 are included in the reference scenario:

- a mandatory K55 insulation level for all new residential buildings from 1995 onwards.
- increases in excise duties on fuels in the residential, service, industrial and transport sectors
- the decided investments in new power plants (STAG) for 1990-2000.
- promotion of electricity saving technologies (more efficient light bulbs and electric motors, condensing boilers).
- nuclear moratorium: no new nuclear power stations before 2010 (as it takes at least 10years to build a new one). Investment in nuclear are possible after 2010.
- a subsidy of 2 BEF/kWh for wind energy, from 2000/2005 to 2030.

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 and the base year (1990) demand, 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 GHG 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.

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[10] The GEM-E3 model is a general equilibrium macroeconomic model for the 15 countries of the EU, developed for DG Research under the Joule research program.

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.

The final energy demand increases with 1.1% till 2010 and with 0.9% thereafter. The growth is highest in the transport sector. The electricity demand increases more than the fuel demand and there is a shift to heat produced in cogeneration plants from 2000 on. In terms of primary energy, the average growth is 0.8%. There is a shift from solids to gas till 2010, principally due to the replacement of coal power plants with gas power plants. This tendency is reversed afterwards when coal powerplants replace the nuclear power plants. Oil products keep a relatively high share because they remain the dominant fuel in the transport sector. Renewable energy do not break through given the energy price assumptions

This induces an increase in the GHG emissions linked to energy. They are in 2010 16% above the level of 1990 and continue to increase thereafter, especially after 2025 if coal power plants should replace the nuclear power plants. Belgium would therefore have to reduce its GHG emissions with 20% in 2010 compared to the baseline to reach its Kyoto target.

2. The policy scenarios

a) The Kyoto target

The objective of the study for the Federal Ministry of the environment was to evaluate measures and policy instruments to reduce the greenhouse gas (GHG) emissions in Belgium to the level agreed upon in the Kyoto protocol (-7.5% compared to the 1990 level). The policy evaluation had to take into account three constraints: the reduction target should be reached by measures that can be taken by policy makers in Belgium, the reduction of GHG should continue after 2010 at the same rate as the one decided for 1990-2010, no new nuclear power investments are allowed in the period 1990-2030.

Given the baseline assumptions (as described in the previous section), Belgium has to reduce its GHG emissions in 2010 by 20% compared to the reference level to reach the Belgian Kyoto target. The policy measures already taken or planned since 1990 to reduce the GHG emissions, will only contribute to a reduction of 1.8% in 2010.

Using a GHG emission tax as policy instrument, which is the least cost instrument for meeting an emission target, the cost per ton of GHG reduced reaches 1830BF in 2010 and increases sharply in 2030. This sharp increase is due to the investment in coal power plants at the end of the horizon in the reference scenario and the ban on new nuclear capacity. The total discounted cost of reaching the target for 2010 and 2030, in terms of loss in consumer/producer surplus, is approximately 4% of the 1990 GDP. The macroeconomic impact of the Kyoto target in 2010 remains very small.

In 2010 the greatest reductions are in the energy sector, -41%, followed by the industrial sector, -25.9% and the residential and service sector, -18.3%; the reduction in the transport sector remains more limited, -2.6%. The Kyoto target is reached through a least-cost mix of energy services reductions, changes in technologies and fuel switching that are triggered by the GHG emission tax. The demand for energy services is reduced by 8.5% in the industry and the residential & service sector, but only by 2.9% in the transport sector. There is a switch away from solid fuels and oil products towards natural gas and, in a more limited way, towards renewables. More efficient and energy saving technologies are used in the different sectors. Cogeneration is penetrating further in the industry and in the residential & service sector.

Using alternative instruments such as an energy tax or standards increases the cost of reaching the Kyoto target. An energy tax leaves out one option for emission reduction, as it does not give an incentive towards fuel switching. The loss in welfare is increased with 4.2% over the entire horizon

1990-2030 compared to the GHG tax. The use of standards will approximately double the loss in welfare: the reduction in the level of energy services is smaller, because the remaining emissions are not taxed and therefore stronger efficiency standards have to be imposed to reach the reduction target.

If the nuclear option is available, the total loss is reduced with 23%. The impact is rather limited until 2010 but becomes significant from 2025 onwards when the existing nuclear power plants are scrapped. The reduction effort is shifted towards the energy sector, allowing the other sectors to reduce their emissions far less.

This study was partly revised at the end of the project for the Federal Minister of Energy and Sustainable Development. The figures have slightly changed but the main conclusions remain the same. A full description can be find in the annexed report.

b) Excise tax policies

Two specific policies were evaluated with Markal for the Federal Minister of Energy and Sustainable Development: the harmonisation of excise taxes in the EU and the increase of Belgian excise taxes to the levels in the neighbouring countries. These policies contribute to a reduction of the CO2 emissions in Belgium, but are not sufficient to reach the Kyoto target, as can be seen in Table 13. Moreover the results show that the use of such policy instruments (an energy tax) increases the cost of the CO2 reduction compared to a CO2 tax, as observed in the previous study.

Table 13: GHG emissions changes in the excise tax & Kyoto target scenarios versus reference scenario

	2000	2005	2010	2020	2030
Excise neighbours GHG (CO2 eq.)	-1%	-4%	-5%	-8%	-7%
Harmonisation GHG (CO2 eq.)	0%	-2%	-2%	-11%	-6%
Kyoto GHG (CO2 eq.)	-1%	-2%	-16%	-35%	-48%

c) CO2 reduction potential of measures

For the Federal Ministry of Economic Affairs an estimation of the CO2 emission reduction potential for a number of exogenous defined measures has been made by VITO. The type of measures is summarised in the following table. The simulation period is 2000-2030. In this study, the Markal model has been used to evaluate the reduction potential, without any cost consideration.

Table 14: Different types of measures with their cumulative CO2 emission reduction potential.

	Description of the measure	Cumulative CO2 reduction (Mton)
Centralised electricity production	1000 MW additional nuclear power plant	85
	New coal fired plant replaced by STEG	142.5
	Limiting coal fired plant at 1200 MW	62.4
CHP	CHP as foreseen in the national equipment plan of the electricity sector	57
	CHP – additional 1200 MW in period 1995-2005	117.5
	Reduced delivery price gas for CHP modest reduction	270
	Reduced delivery price gas for CHP high reduction	211
Renewable	Additional wind energy	10.5
	35.000 ha biomass	4.5
	70.000 ha biomass	27

Taxes	EU proposal harmonising taxes	122
	Higher tax levels	355
	Tax on low voltage electricity consumption (1Bef/Kwh)	55.5
	Tax on low voltage (1 Bef/Kwh) and high voltage (0.1 Bef/Kwh)	207.5
Transport Sector	Increased road taxation	29.5
	Increased tax on motor fuels (petrol & diesel)	160
	Efficiency improvement cars (ACEA)	122.5
	Hybrid traction	76.5
Other	Efficiency improvement industry	27.3
	Improvement electrical appliances	27.5
	Combined action	**363**

d) Study for the Ampere Commission

This study focuses on the electricity sector and evaluates the choice of technologies in this sector for the period 2005/2010, under different constraints, i.e. the Kyoto target and the nuclear option. In all policy scenarios it is assumed, that the external costs of air pollution are internalised in all sectors from 2005 onwards, with the exception of the cost of GHG emissions (which is taken care of by a global emission limit)[11].

(1) The policy scenarios

The alternative policies considered are:

Nuclear power plants: after 2010, either the moratorium is extended towards 2030, or new nuclear power plants can be built with however a maximum of 8000MW on existing sites. In the reference scenario, there are no new investment in nuclear, based on cost comparison.

GHG emission constraints: either no GHG emission reductions are imposed over the entire horizon, or the Kyoto target is imposed in 2010 (7.5% reduction compared to the 1990 level, but corrected for the high temperature in 1990 this gives a reduction of 11%) and the same proportional reduction is imposed between 2010 and 2030 (15% compared to 1990, or when corrected for temperature 21%).

The scenarios considered are therefore:

1. New nuclear capacity, no GHG constraint
2. No new nuclear capacity, no GHG constraint
3. No new nuclear capacity, Kyoto GHG constraint
4. New nuclear capacity, Kyoto GHG constraint

(2) Results

The results of the different scenarios are summarised in Table 15. It gives the electricity demand and production by technology (in TWh) and the cost in terms of welfare for each scenario compared to the reference scenario (in % of the GDP in 2000).

The welfare cost, as considered in Markal, covers the cost for the whole energy system of the measures imposed, i.e. the increased cost of satisfying the energy needs (investment cost, operating cost, fuel cost,…), the loss in utility for the consumers due to the decrease in consumption of energy services minus the saved external costs (other than climate change related damages). When considering the welfare cost figures, one must keep in mind that the MARKAL model is a simplified representation of the energy system, where consumers and producers have an 'optimal' behaviour and

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[11] This assumption is made here to be consistent with the assumptions in the result of the Ampere Commission, but is not made in the other studies regarding GHG emissions.

where there is perfect coordination between demand and supply on the basis of social marginal costs. Additional policy actions might be needed to realise this 'optimal' set-up.

The welfare cost can be negative because in the reference scenario, external costs (other than GHG) are by assumption not internalised. The welfare gain in internalisation of non GHG related external costs increases from some 0.3 to 0.4% of GDP in 2010 to some 0.4 to 0.7% of GDP in 2030.

In interpreting Table 15, one should also be aware that a Kyoto constraint is imposed on the Belgian energy system and not only on the electricity sector. When it is relatively cheaper to reduce emissions in the electricity sector than in other sectors, the electricity sector will reduce its emissions more.

Table 15: 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[12]	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 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 less than 0.1% of GDP)

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[12] This scenario differs from the reference scenario only because of the internalisation of the external cost in all sectors (except GHG external cost)

- 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.

(a) Caveats

Some important aspects are not considered in our analysis:

- the opening of the electricity market and the impact it can have on the production and the investment in the electricity sector is not studied - in fact one has implicitly assumed that the transmission constraints are such that intensive trade is not possible – if intensive trade becomes possible one could envision scenarios where part of base load production is located in less densely populated areas (North of France ..) and more renewables are installed abroad
- the possibility of reaching the Kyoto target through international actions (tradeable permits, joint implementation) is not considered explicitly – the possibility of international trade would mitigate the cost differences between scenarios
- only one scenario of fossil fuel prices has been used; one could study the robustness of the conclusions when lower or higher fuel prices are considered or one could use stochastic programming techniques
- the Markal model is an energy sector model and is not appropriate to study the contribution of decentralised power to the overall reliability of the power supply, a model specific for the electricity sector would be more appropriate.

D. Participation in ETSAP network

This activity concerns on the one hand the participation to the ETSAP workshops, the presentation of the Belgian research results and the integration of the results for Belgium in common studies within ETSAP. On the other hand it concerns the continuous development of the Markal model. This participation is very important at this stage, as the ETSAP participants, including CES-KULeuven and VITO, are currently engaged in the development of a new Markal model, TIMES. The general model specification is still using the Markal paradigm (perfect foresight optimisation), but allows more flexibility and a further development of the model. It includes also an update of the database software.

IV. ASSESSMENT AND PERSPECTIVES

A. Assessment

The project involves two partners, the Centre for Economic Studies, KULeuven and the Flemisch Institute for technological research VITO. Each partner was responsible for some specific tasks (CES for the model development and VITO for the database management), though both partners contributed to all tasks when necessary. Regarding the case studies, some were done jointly by the partners whereas others were done under the responsibility of one partner. The cooperation between partners, though informal, has always been very fluent, contributing as such to the success of the project.

The principal goal of the MARKAL research consortium was to maintain the Markal expertise in Belgium and to make it available for policy studies. This goal has been achieved in the sense that Markal has been used as the principal policy tool in the study of greenhouse gas policies in Belgium and is the reference for energy policy studies.

The second goal has been to improve the Markal modelling tool itself. This goal has been achieved too. The stochastic model is probably the most complex but it proved to be relatively difficult to use for policy studies. The extension to Markal-Micro/ED (inclusion of demand function) was very successful and proved to be an important addition to the Markal model. The same holds for the inclusion of the secondary benefits in the objective function. Both are now included in the standard MARKAL model distributed to ETSAP members.

In order to achieve this goal it proved important to function in the international ETSAP consortium and to have a sufficiently stable research staff. Long term research contracts proved to be important in this respect.

B. Project perspectives

Both CES and VITO are considering the possibility to develop further the model to improve its capacity to evaluate climate change and energy policies. One is certainly the continuation of the contribution to the development of TIMES, the new Markal model. Further the model has to be extended to include the GHG emissions not linked to energy to allow for a consistent policy evaluation covering the GHG emissions from all sources. Because of the importance of international negotiations in climate change policy, there is a need to develop the international dimension of the model, e.g. to evaluate the possible contribution of the Kyoto flexibility mechanism to a national climate change policy.

LIST OF ANNEXED REPORTS

The MARKAL Database

CES-KULeuven and VITO, 2001, 'The Belgian Markal Database'

The Stochastic Modelling

J. Aertsens, S. Proost and D. Van Regemorter, 1999, 'Optimal Investment Strategy under uncertainty in the Belgian Energy System'

Secondary Benefits

Gary Goldstein (IRG), Ken Noble (ABARE), Denise Van Regemorter (CES KULeuven), 2001, 'Adaptation to Markal for including environmental damages'

S. Proost and D. Van Regemorter, 2000, 'Interaction between local air pollution and global warming policy and its policy implications'

Greenhousegas policy studies

Study for the Federal Ministry of Economic Affairs

VITO / Institut Wallon, 1999, 'Evaluatie van het potentieel van CO_2-emissiebeperking door middel van supplementaire maatregelen'

Study for the Ministry of the Environment

J. Duerinck, S. Proost and D. Van Regemorter, 1999, 'Prospective Study of the Emissions in Belgium until 2008/2012 of the Greenhouse Gasses included in the Kyoto Protocol, Cost and Potential of Measures and Policy Instruments to Reduce GHG Emissions'

Study for the Secretary of State for Energy and Sustainable Development

A. Henry, S. Proost and D. Van Regemorter, 2000, 'Evaluation of Policy Scenarios for reaching the Kyoto target in 2010'

Study for the AMPERE Commission

S. Proost and D. Van Regemorter, 2000, 'What do the Ampere Results imply for Future Electricity Production in Belgium – an analysis with MARKAL model',

Stef Proost and Denise Van Regemorter, 2000, 'How to achieve the Kyoto Target in Belgium, modelling methodology and some results', CES-ETE Discussion Paper n°2000-09