DWTC/SSTC

Final Report

Executive Summary

MARKAL, A MODEL TO SUPPORT GREENHOUSE GAS REDUCTION POLICIES

partners

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Executive Summary

1. OBJECTIVE AND RESEARCH STRATEGY

1.1. 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 greenhouse emission targets, which Belgium can achieve in the long term
- determine which sectors or technologies have to be considered in priority

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

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 MARKAL 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

The research has focused on three components to achieve its objective:

- the maintenance of the Markal model
- the development of the model
- the development of scenarios and policy analysis with Markal

and the results obtained regarding these different aspects are described hereafter.

2. THE RESULTS

2.1. Extension, maintenance and quality control of the database

To have a basic version of Markal directly available for policy analysis, it needs to be maintained and it has been an important activity in the overall project, as the technology database is the basic element of MARKAL and as it is essential to be able to take the potential development of technologies into account in the long term studies. 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. VITO was mainly in charge of this activity.

A first task consists in a continuous update of the parameters of the technologies already included and in a transformation of the data for technologies under development into suitable data for the model formulation. Secondly, as industry is an important user of energy and an important emitter of CO2, its modelling has been extended: a further decomposition of the industrial sectors into subsectors and revision of the data for existing subsectors with a special attention for the evaluation of the potential and the associated investment- and variable cost of energy saving technologies.

2.1.1. The electricity sector

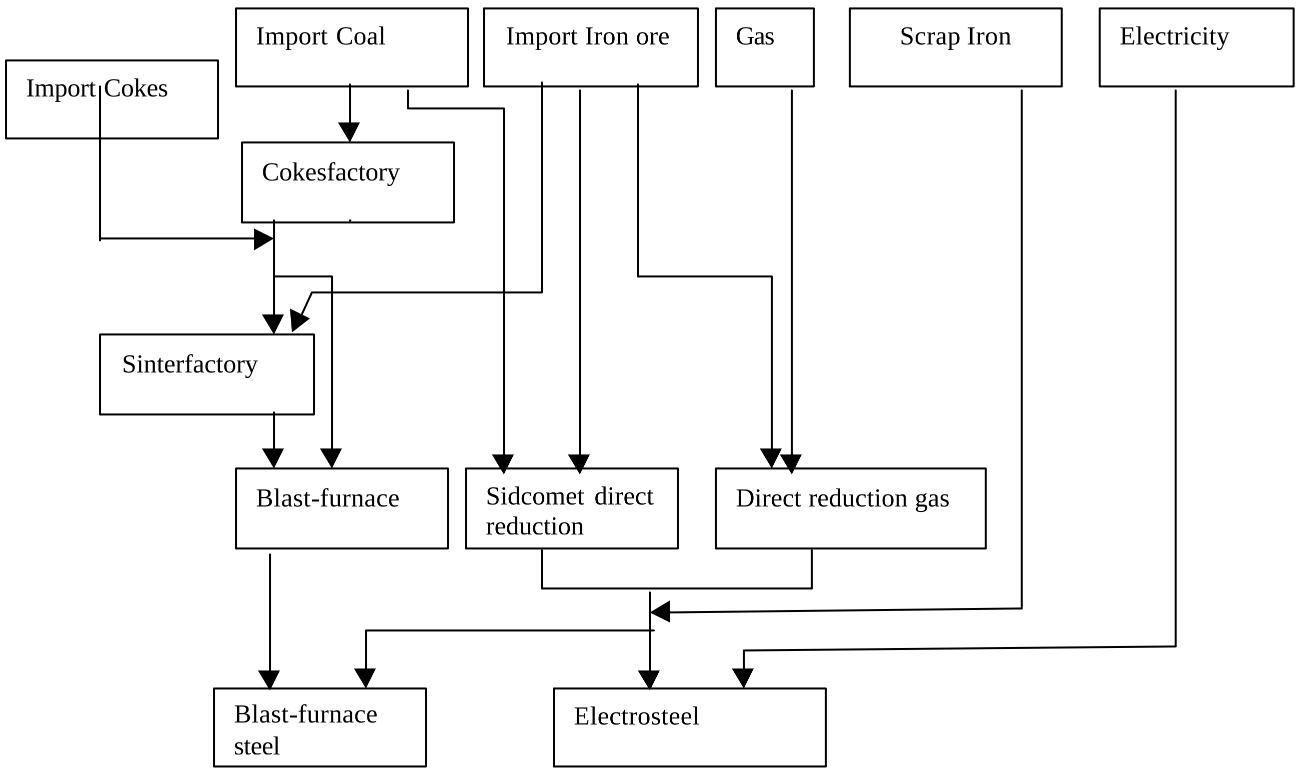
The data concerning the electricity sector were updated based on data collected within the Ampere Commission. A complete database with the cost and technical data on potential electricity generation technologies in Belgium until 2030 was established with the help of the Ampere reports on each technology, 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.

2.1.2. The industrial sector

A decomposition of the most energy intensive sectors was done with a complete revision of the technological and economic data associated with these sectors. 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 CO_2 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 these flows are considered.

2.1.3. 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.

2.1.4. 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

2.1.5. Quality control

To maintain a consistent national database it is necessary to involve national and international reference- and review groups to make an analysis and quality control of the database. Within ETSAP it is for instance possible to link in this way technological and non-technological factors. This control is required to use of the database in the long-term policy studies.

2.2. The development of the model

2.2.1. Development of MARKAL-STOCHASTIC

This version of MARKAL 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. It was decided to implement this version, as there are no other models in Belgium that take this uncertainty element into account. 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.

The experimental version of MARKAL-STOCHASTIC was developed, within the ETSAP network, in the Netherlands and Canada, based on "multi-stage stochastic programming". This version has been adapted to the Belgian case. Its implementation started with an overview of the literature on uncertainty and the GHG effect. Scenarios have been built for climate change, each with its associated probabilities and they have been translated into operational terms for MARKAL. The model has been applied to the Kyoto scenario. Four possible states of nature are considered for the cumulative CO2 constraints to be imposed in 2030. It is assumed that it will only become clear which cumulative constraint is relevant after 2010. Thus, one path is followed until 2010 and starting from 2011, four different paths are possible, one for each alternative emission constraint. The path to 2010 contains the optimal hedging strategy. This strategy was then compared with the results from deterministic scenarios.

2.2.2. Representation of secondary benefits

The model is reformulated to take better into account the secondary benefits of CO2 emission reduction, as a reduction in greenhouse-gas emissions is often justified by the secondary benefits it would bring. 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). Those secondary benefits accrue to the country making the reduction contrary to the climate change reduction that has more diffuse and long term benefits.

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, an EU research project on the evaluation of the cost of pollution. This approach can be illustrated by the following figure taken from ExternE

EMISSIONS
↓
DISPERSION
↓
IMPACT
↓
DAMAGE VALUATION

The Markal database has been extended into three directions:

- emission coefficients for pollutants such as NOx, SO2, VOC and PM,

- transfer coefficients for those pollutants, i.e. coefficient for the translation of emissions into deposition and concentration, inclusive the transportation mechanism
- impact of deposition/concentrations and their monetary valuation.

The last two parameters are derived from the ExternE study and are used to compute a damage value per unit of incremental emission in Belgium.

The Markal model was adapted to take into account in the analysis of policy options the benefits/costs coming from local pollutants, following two approaches:

- the environmental damages are computed ex-post, without feedback into the optimisation process
- the environmental damages are part of the objective function and are 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, which is more global, a term is added to the objective function, which contains the sum of the damage-functions per pollutant. This allows, when evaluating long term options, to make a more complete assessment of different policies.

The new model specification has been used to evaluate a GHG policy associated with a local air pollutant policy. Taking into account the environmental damage of local pollutants in the optimisation process, i.e. implementing a local air pollution policy, reduces the damage from these pollutants with only a slight increase in total cost (investment, fixed and variable costs) and reduces also the CO2 emissions. Moreover, combining a CO2 policy and a local policy allows to benefit at the local level without increasing the cost of the CO2 policy. This shows that secondary benefits are not negligible and this affects also the structure of the optimal greenhouse policy.

Both development of Markal were undertaken by the CES

2.3. The development of scenarios and policy analysis with Markal

Regarding policy analysis, 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. Such studies imply the following steps:

- the elaboration of long term perspectives (30 to 40 years) which have to be consistent with other medium term forecasts (Planning Office, EC)
- the transposition into MARKAL of the already taken measures
- the analysis of the policy questions and their translation into MARKAL
- reporting to the policymakers

Different studies were made for the Federal government during 1999 and 2000. The results are briefly described hereafter, starting with the baseline scenario which is the reference for the different policy studies.

2.3.1. The baseline scenario

A baseline scenario was built with the Markal model in preparation of the case studies. 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. The assumptions regarding these exogenous variables are based on the 1999 study by the EU DG Research with the energy world model POLES[1]. 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

[1] 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)

reserves and the assumption on economic growth. Oil and gas prices are evolving in parallel. All this gives an average growth for Belgium of 2.1% till 2010 and 1.8% thereafter.

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 22% in 2010 compared to the baseline to reach its Kyoto target.

2.3.2. Policy Studies

a) The Kyoto target

The objective of this study 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 approximately 1000BF 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.

b) Excise tax policies

In 2000, some specific policies were evaluated by CES with Markal for the Federal Minister of the Environment: 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. 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.

c) Reduction potential for technological and policy 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.

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**

2.3.3. Study for the Ampere Commission

- This study focused on the electricity sector, it was made by CES. Besides the full up-date of the MARKAL database concerning this sector, it evaluates the choice of technologies in this sector for the period 2005/2010, under different constraints, as the Kyoto target and the nuclear phase-out.

The case studies activity were either undertaken jointly by the partners either done individually, however in both cases this activity benefits from the development by all partners.

2.4. 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. The new model is being tested out now.

3. ASSESSMENT AND PERSPECTIVES

3.1. Assessment

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 (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.

3.2. 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. Moreover the opening of the EU energy market reinforce the need for the international dimension.