Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change

Comparison of 'Top-down' and 'Bottom-up' Analysis of Emission Reduction Opportunities for CO_2 in the European Union

Memorandum
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Content

1. INTRODUCTION

In 1997 the countries that are party to the United Nations Framework Convention on Climate Change agreed upon the Kyoto protocol. In this protocol industrialized countries committed themselves to limit and reduce greenhouse gas emissions in the period 2008 – 2010. The Member States of the European Union jointly committed themselves to reduce their emission in this period by 8% compared to 1990.
This target is valid for all important greenhouse gases that are emitted through human activity: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF_6. For the latter three categories 1995 can be taken as a base year instead of 1990.

An important guideline in developing policies for the mitigation of greenhouse gas emissions is the cost-effectiveness of the various options. For the European Union as a whole it is worthwhile to focus on those emission reduction options that show the lowest costs per unit of greenhouse gas avoided, disregard the country, the sector or the type of gas. Up to now extended overviews of costs of emission reduction were lacking.

Within the project "Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change", a first attempt is made to cover the whole range of greenhouse gases, sectors and countries. The objective of this project is to:

- identify the most cost effective distribution of emissions reductions between different sectors and gases to meet the EU quantitative reduction objective for greenhouse gases under the Kyoto protocol;
- determine a package of cost-effective policies and measures for all sectors and gases towards meeting the goals.

In this project two approaches are used:

- an integrated modelling analysis of the energy system and the associated emissions with the PRIMES model developed by the National Technical University of Athens (or 'top-down approach'), and
- an engineering-economic analysis of individual emission reduction options (or 'bottom-up approach'), based on sector studies performed by Ecofys and AEA technology and analysed with the GENESIS database.

In this memorandum the results of the two approaches are compared and discussed for energy related emissions of CO_2. The models are shortly presented in section 2 and 3. Section 4 concerns the comparison.

2. THE PRIMES MODEL ('TOP-DOWN ANALYSIS')

The PRIMES model[1] and its use within the Shared Analysis project quantified a set of scenarios for the European energy demand and supply system [Capros, 1999]. PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the European Union (EU) member states. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply match the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships.

The model is behavioural but also represent in an explicit and detailed way the available energy demand and supply technologies and pollution abatement technologies. The system reflects considerations about market economics, industry structure, energy/environmental policies and regulation. These are conceived so as to influence market behaviour of energy system agents. The modular structure of PRIMES reflects a distribution of decision making among agents that decide individually about their supply, demand, combined supply and demand, and prices. Then the market integrating part of PRIMES simu*lates market clearing.* PRIMES is a general purpose model. It is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon. It is modular and allows either for a unified model use or for partial use of modules to support specific energy studies.

The projections for the demand and supply sectors were designed to be consistent with the rest of the energy system. Scenarios that reduce emissions are assumed to simulate a response of the entire energy system to globally imposed emission constraints. In this sense, the scenarios are top-down oriented, since the model simulates the allocation of the collective emission reduction effort to each of the sectors. The model follows an explicit representation of technologies, engineering constraints and plants.

For each energy demand sector, the model answers the following question: *'What is the least cost, optimal configuration of the sector so as to generate a certain level of added value, while satisfying constraints that represent technical, fuel availability and emission restrictions?'*

It is assumed that a representative agent of the sector performs a stepwise set of decisions to configure production and energy use in the sector. Physical production, recycling if applicable, possible structural changes in sub-sectors and production processes must be defined. In addition technologies for each energy use must be chosen, the capital replacement procedure needs to be managed

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[1] PRIMES is a partial equilibrium model for the European Union energy system developed and maintained at the National Technical University of Athens, E3M-Laboratory led by Prof. Capros. The most recent version of the model used in this study covers all EU member-states, uses EUROSTAT, has a five year periodicity and uses 1995 as the base year. PRIMES is a result of collaborative research under a series of projects supported by the programme Joule of directorate General for Research of the European Commission.

and the fuel selected. This is considered to be a simultaneous decision, taking into account fuel and electricity prices as given from other sub-models of PRIMES. The sector addresses then to these other sub-models demand for derived and primary energy forms.

The behaviour is simulated using sector-specific discount rates: industrial sectors, services and agriculture: 12%; households and passenger transport: 17.5%; public transport: 8%; aviation, navigation, trucks: 12%; power and steam generation: 8%.

The energy demand sectors are, to a considerable extent, split into several sub-sectors. The industry sector is subdivided into nine main sectors and several sub-sectors. Residential demand is broken down into five typical households. The tertiary sector is split into five sub-sectors. Finally transportation identifies categories of means and transport mode.

For the electricity and steam generation system, the model answers the following question: *'What is the least cost, optimal operation and configuration (including new investment) of the system that produces electricity and steam, separately and/or jointly, so as to meet demand, while satisfying technical, fuel availability and emission restriction constraints?'*

The aim of the electricity and steam sub-model of PRIMES is to simulate the behaviour of agents that use fuels and other energy forms to produce, transmit and distribute electricity, industrial steam and district heating. This behaviour concerns the choice of equipment and the fuel mix to satisfy demand, the setting of selling prices and the purchase of fuels from the energy markets. The model design is adapted to the very nature of the energy forms produced in this sub-model, related to the impossibility to use storage, the high degree of capital intensive equipment and the importance of technology choice for energy strategy.

The emergence of heat and power cogeneration possibilities and the prospects for increasing decentralisation of production led to the adoption of a unified modelling for power and steam production. PRIMES puts emphasis on the different nature of producers that will operate in the market and the interaction between electricity and steam markets, as enabled by cogeneration. For example, it is necessary to distinguish producers according to their scale, but also according to the captive markets they might address. A utility can exploit high economies of scale, but can hardly benefit from the market of steam, as steam cannot be self-consumed. On the contrary, an industrial independent producer will operate at smaller plant size, loosing competitiveness as far as the economies of scale are concerned, but obtaining benefits from a high base load demand for steam that he can supply.

3. THE GENESIS DATABASE ('BOTTOM-UP ANALYSIS')

The second approach is the engineering-economic analysis of individual emission reduction options. This approach consists of the following steps:

- For each sector (or sub-sector) the various processes that cause energy use and greenhouse gas emissions are identified.
- For the relevant processes an inventory is carried out of the emission reduction options that are available.
- The options that can make a contribution to emission reduction in the year 2010 are characterized on the following aspects: emission reduction potential; investment costs; operation and maintenance costs; operational benefits (e.g. energy cost savings); lifetime.

The information is collected in a database information system, GENESIS. The information on the individual options can be used to calculate total emission reduction potentials and associated mitigation costs by sector, by country and by gas.

For the year 2010 a frozen technology reference level is designed in which the emissions in 2010 differ from the 1990 base year emissions because of changes in activity levels only. The changes in activity levels between 2010 and 1990 are taken from the Shared Analysis baseline scenario (the PRIMES model).

The database GENESIS contains technology and cost information on over 250 reduction options for both energy related CO_2 emissions, process emissions and non-CO_2 greenhouse gas emissions. It should be noted that even this level of detail does not cover the full variation in options that is present. The potential and cost will often depend on local conditions that can not be covered in a general database. Moreover, there are differences between the Member States, e.g. differences in climate makes building insulation more effective in Finland than in Spain. Nevertheless, the total gives a reliable approximation of the emission reduction potentials and associated costs on the sector or the country level and on the European Union sector level.

The information is used to generate an overview of emission reduction options. The total potential of emission reduction is given, including the part of the potential that is expected to occur autonomously. This is done to provide a complete overview of all the options; also for the options for which it is expected that they will occur autonomously it may be important to monitor whether they will actually be implemented.

For the calculation of the specific mitigation it is necessary to choose a discount rate. In our calculation a social discount rate is used . As a standard value 4% is taken.

Table 4.1 Result of the analysis using the model PRIMES at different levels of the value of avoided CO_2. The 2010 baseline[*] is in italics and shaded. All emission figures are in Mt of carbon dioxide

Year	**1990**	**1995**	**2000**	**2005**	**2010**																	
Value of avoided CO_2 (euro 1990/tonne)					***0***	**0.3**	**0.5**	**1.4**	**3**	**5**	**11**	**14**	**19**	**30**	**44**	**60**	**79**	**101**	**125**	**153**	**191**	**245**
TOTAL	**3068**	**3029**	**3127**	**3236**	*3289*	**3283**	**3272**	**3260**	**3240**	**3192**	**3100**	**3067**	**2991**	**2858**	**2749**	**2600**	**2455**	**2317**	**2197**	**2060**	**1898**	**1719**
Industry	**424**	**379**	**384**	**384**	***378***	**378**	**377**	**376**	**374**	**370**	**364**	**360**	**355**	**347**	**338**	**327**	**307**	**288**	**272**	**256**	**240**	**224**
Iron and Steel		153	143	135	*124*	124	124	123	121	119	115	113	110	107	103	97	85	73	64	57	50	43
Non-ferrous metals		12	13	13	*13*	13	13	13	13	13	13	12	12	12	12	12	11	11	11	10	10	9
Chemicals		20	24	23	*21*	21	21	21	21	21	20	19	19	18	18	16	15	14	12	12	10	9
Building materials		86	90	93	*95*	95	95	94	94	94	93	92	92	90	89	87	84	81	79	76	72	68
Paper and Pulp		9	10	11	*12*	12	12	12	11	11	11	11	11	11	11	11	10	10	9	9	9	9
Food, drink, tobacco		11	12	13	*14*	14	14	14	14	13	13	13	13	13	13	12	12	12	11	11	11	10
Engineering		31	35	37	*39*	39	39	39	39	39	38	38	37	37	36	35	34	33	32	30	29	28
Textiles		2	2	2	*2*	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Others		54	56	58	*59*	59	59	59	59	59	59	58	58	57	57	56	54	53	51	49	47	46
Others																						
Transports	**735**	**800**	**869**	**936**	***994***	**994**	**993**	**992**	**990**	**984**	**975**	**970**	**960**	**940**	**914**	**888**	**861**	**832**	**802**	**753**	**684**	**590**
road	624	668	720	767	*795*	795	795	794	793	791	787	786	782	772	759	745	729	710	689	652	604	532
train	82	7	5	2	*0*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
aviation	9	105	121	143	*172*	171	171	170	169	166	160	157	152	141	128	117	108	98	90	79	60	41
navigation	21	20	22	25	*27*	27	27	27	27	27	27	27	27	26	26	25	24	23	23	22	20	16
Households	**447**	**427**	**449**	**447**	***444***	**443**	**443**	**442**	**440**	**437**	**430**	**426**	**418**	**405**	**389**	**371**	**355**	**327**	**306**	**282**	**261**	**242**
Tertiary	193	**203**	**219**	**223**	***220***	**220**	**220**	**219**	**216**	**210**	**199**	**194**	**186**	**174**	**157**	**142**	**128**	**116**	**106**	**98**	**90**	**82**
services		184	197	199	*194*	194	194	192	190	184	173	169	161	149	134	120	106	95	86	78	71	64
agriculture		19	22	24	*26*	26	26	26	26	26	25	25	25	24	23	23	22	21	20	19	19	18
Power and steam generation	1212	1162	1148	1191	***1202***	**1196**	**1187**	**1180**	**1169**	**1140**	**1083**	**1067**	**1022**	**945**	**903**	**825**	**761**	**711**	**671**	**632**	**585**	**545**
industrial generators					*359*	358	356	351	348	335	321	317	307	284	272	253	238	229	224	224	216	220
other generators					*47*	47	47	47	46	45	43	43	42	38	37	33	31	30	29	28	26	26
utilities					*795*	791	784	782	775	760	720	707	674	622	594	539	492	452	417	380	343	299
Energy Branch	**57**	**59**	**57**	**56**	***52***	**52**	**51**	**51**	**51**	**51**	**50**	**50**	**49**	**48**	**48**	**46**	**44**	**42**	**41**	**40**	**38**	**35**
Biofuels production	**0.0**	**0.0**	**0.0**	**0.0**	***0.0***	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Hydrogen production	**0.0**	**0.0**	**0.2**	**0.2**	***0.2***	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	**0.5**	**0.7**

[*] The baseline 2010 presented in this table differs in small details from the one used in the remainder of this report (overall effect is 15 Mt of CO_2).

4. COMPARISON OF GENESIS RESULTS WITH PRIMES MODEL RESULTS

4.1 INTRODUCTION

The PRIMES and GENESIS approaches are different in a number of aspects. As both approaches are often used in emission mitigation studies, it is interesting to compare both. In the next sections the main results of the analysis using the PRIMES model and the GENESIS database will be provided. In section 4.4, results will be compared and - as far as possible - an interpretation of the differences will be given. The comparison focuses on carbon dioxide, as the PRIMES analysis is limited to energy-related emissions CO_2 emissions only.

4.2 RESULTS OF THE ANALYSIS WITH THE PRIMES MODEL

The PRIMES model was run with various valuations of the emitted carbon dioxide[2]. Point of departure is the outcome from the Shared-Analysis project with baseline CO_2 emissions of 3289 Mt.[3] The range of values for carbon dioxide is from zero to 245 euro per tonne. The results are presented in Table 4.1. The model gives very substantial reductions, to nearly half of the baseline level, if the valuation of CO_2 is high enough. An emission reduction of carbon dioxide by 8% compared to the 1990 level is achieved at a carbon dioxide value of 34 $euro_{1990}$ per tonne.

4.3 RESULTS OF THE ANALYSIS WITH THE GENESIS DATABASE

Figure 4.1 shows the results of the bottom-up analysis in a cost curve (calculated with a discount rate of 4%, energy related CO_2 emissions only)[4]. The reduction potential should be compared to the frozen technology reference level of 4194 Mt CO_2 (energy related CO_2 emissions only). So the -8% level of 2823 Mt CO_2 can be reached with an emission reduction compared to the FTRL of 1372 Mt CO_2. From the figure (and the database behind it) it can be derived that the marginal costs are about 33 $euro_{1990}$ per tonne of CO_2 for this level.

This figure is very close to the PRIMES result, but for a real comparison a different approach is needed.

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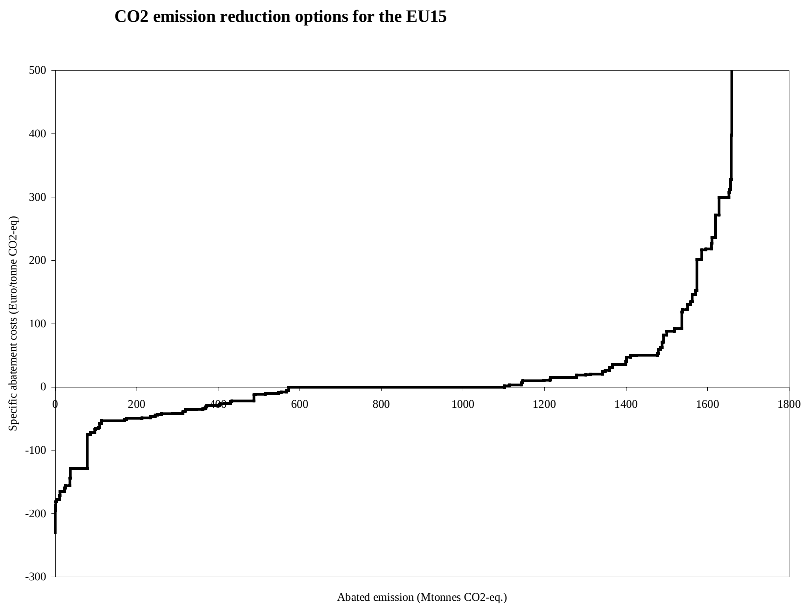
[2] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down analysis of greenhouse gas emission reduction possibilities in the EU, National Technical University of Athens, Athens, January 2001

[3] The baseline 2010 presented in this table differs in small details from the one used in the overall analysis (overall effect is 15 Mt of CO_2). This doesn't influence the main conclusions of the comparison.

[4] C. Hendriks, D. de Jager, K. Blok et al. (2001): Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU, Ecofys and AEA Technology, Utrecht, January 2001

*Figure 4.1 Cost curve for **energy related CO_2** emission reduction in the EU15 (2010) (4% discount rate, all economic sectors, EU15)*



Source: Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU (2001)

4.4 COMPARISON OF GENESIS AND PRIMES RESULTS

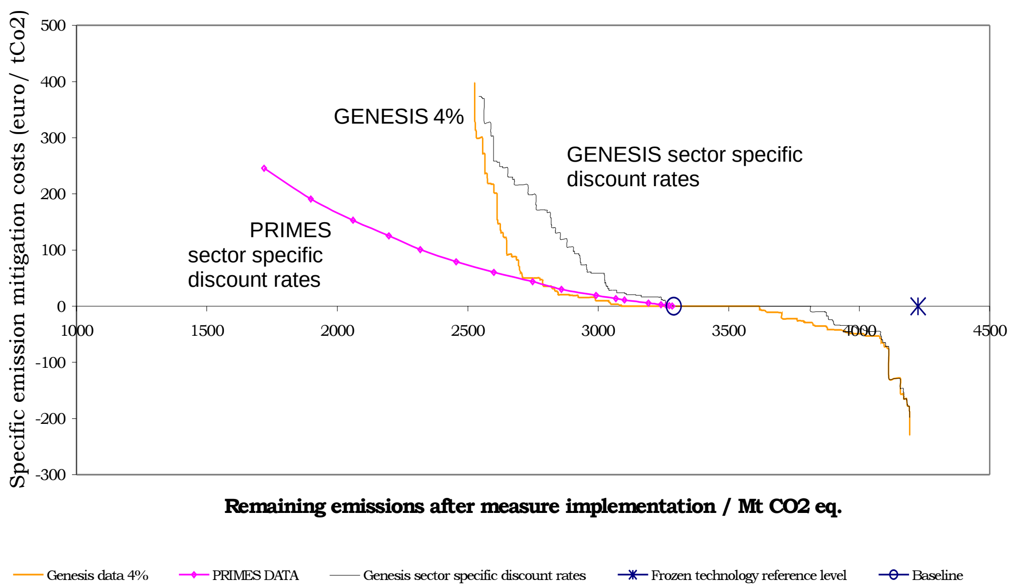
There are a number of differences between the two approaches, which may lead to differences in outcomes. Such differences include:

- the GENESIS information system intends to give an overview of emission reduction options whereas the PRIMES model projects future energy use and emissions under a variety of different assumptions;
- in the GENESIS approach - as a default - social discount rates (e.g. 4%/year) are used whereas PRIMES simulates the behaviour of actors by using sector specific discount rates that reflect time preferences of these actors;
- PRIMES is a full energy-economy model explicitly modelling interactions in the energy system, whereas in the GENESIS approach these interactions are accounted for on an ad hoc basis;
- the GENESIS approach focuses on options that are generally considered as climate change response options (i.e. energy efficiency improvement, fuel shift, renewable energy, etc.) whereas PRIMES also allows other reactions of the energy-economy system, such as structural changes and other substitutions;
- the technology data differ between the two approaches. In general, GENESIS is more detailed in emission reduction options, especially in the area of end-use energy efficiency, but is less detailed in the energy supply sectors. PRIMES also comprises technology information, but it is particularly detailed in the power and steam sector, but less detailed and less complete in the energy demand sectors. However, PRIMES does include some

options (like a shift from primary to secondary materials and modal split changes in transportation) that are not included in GENESIS;

- the cost curves provided by GENESIS reflect the amount of options available below certain costs on a project basis whereas the cost curves provided by the PRIMES approach give emission reduction as a function of shadow carbon costs (which can be interpreted as the effect of a carbon dioxide tax in ideal conditions, i.e. no market barriers and market imperfections).

Figure 4.2. Cost curves for the GENESIS and PRIMES approaches (energy related CO_2 emissions). The figure shows the 2010 Frozen Technology Reference Level of the GENESIS approach (X) and the baseline level of PRIMES (O) as well as the costs of increasing emission reductions from those levels in the different approaches. The -8% emission level is 2823 Mt CO_2.



PRIMES vs. GENESIS-4%

Nevertheless, it is interesting to compare the results of both approaches and to see whether the results are comparable. First of all, in Figure 4.2 cost curves are presented for both approaches. In the range around 3000 Mt CO_2 the results are surprisingly close to each other (with a similar carbon value at the -8% target level (see above)). In both cases costs gradually increase from zero in the baseline to about 50 euro per tonne CO_2 in case of a 500 Mt reduction.

Differences are:

- The GENESIS database also includes the negative cost figures in the range between the 2010 frozen technology level and the baseline level. The PRIMES model already incorporates negative cost options in the baseline.

- In the PRIMES analysis substantial emission reductions occur below 2700 Mt CO_2 at carbon values between 100 and 300 euro per tonne CO_2. No further emission reductions result from the GENESIS data. This can be mainly explained by the fact that in GENESIS the reduction options become exhausted, whereas PRIMES allows for further reactions of the system, like a dynamic expansion of the market potential for the various emission reduction options, indirect interaction of demand and supply for energy and structural changes.

PRIMES vs. GENESIS-sector specific

In Figure 4.2 we also present outcomes from GENESIS using the sector specific discount rates that are the same as those used in PRIMES. It turns out that the cost curve is substantially higher than the one of PRIMES.

Next, results are presented on a sector by sector basis. In Table 4.1 an overview is given of the emission breakdown in case of a total carbon dioxide emission that are approx. 8% below the level of 1990. The results show that the outcomes of the GENESIS approach give emission reductions that are somewhat more allocated in the industrial and households (4% case) end-use sectors and less so in the energy supply sector and service sector.

Table 4.1 Comparison of results for a total level of 8% below the 1990 level (which equals to approximately 2823 Mt CO_2.). As a reference, the 2010 baseline is given. For all end-use sectors the total emission (direct and indirect) is given. Numbers refer to energy related CO_2 emissions only.

Energy related CO_2 emissions (Mt CO_2) Sector	**1990/1995**	**2010** **PRIMES top-down analysis**		**2010** **GENESIS bottom-up analysis**		
		Baseline (excl. ACEA)	Under Kyoto target conditions	FTRL	Under Kyoto target conditions with discount rate: 4%	sector specific
Industry	1131	982	889	1613	829	771
Transport	757	1028	949	1068	998	994
Households	749	747	633	841	558	632
Services	413	492	328	647	417	399
Agriculture	17	26	24	24	24	24
Total	**3068**	**3274**	**2823**	**4194**	**2826**	**2821**
Energy supply sector (power and steam generation and energy branch)	1269	1238	979	1960	1251	1169
Level of carbon value or marginal CO_2 abatement costs (euro$_{1990}$ per tonne of CO_2)		0	34		33	145

To a large extent, the differences between the PRIMES results and the GENESIS results can be explained on the basis of the types of options or effects included. First of all, structural changes are included in the PRIMES analysis that are not taken into account in GENESIS; for a total difference between the baseline and the –8% level, they account for 52 Mt. An option that is not included in GENESIS is nuclear energy. This is responsible for 46 Mtonne of emission reduction between the baseline and the –8% level. Furthermore, material efficiency options (like recycling) to some extent are included in PRIMES but not in the present version of GENESIS.

On the other hand, there are also options that are more prominent in GENESIS than in PRIMES. An example is industrial energy efficiency. Compared to the frozen technology level the reduction of specific energy use in the PRIMES approach is in the range between 0 and 5%[5] whereas in GENESIS information system reductions of the specific energy use are 20-25%. In other sectors the reduction of specific energy use in PRIMES is higher than in industry but still substantially below those considered attainable according to GENESIS data (i.e. in the range below 35 $euro_{1990}$/ton of CO_2 and therefore below the carbon value of the -8% target). The availability of substantial amounts of energy efficiency options in the end-use sectors (often at net negative costs) also can explain why in the sectoral breakdown the emphasis in the GENESIS approach is more on emission reduction in the end-use sectors than in the PRIMES approach. However, it should be noted here that PRIMES already incorporates technology improvement in the demand side under baseline conditions. This explains why CO_2 emissions in 2010 differ substantially between PRIMES baseline and the frozen technology approach (3274 compared to 4194 Mt of CO_2).

5. CONCLUSIONS

This memorandum presents a first comparison of the results obtained by the PRIMES top-down and GENESIS bottom-up approach. It should be noted that for an extensive comparison a more thorough and detailed analysis is required, which was outside the scope of this project.

It can be concluded that the differences between the two approaches can not be fully explained or quantified, as the nature, output structure and purpose of the two approaches is different and more or less incomparable. Given the more complex structure of the PRIMES model and the modelling of the interactions of the energy and economic system, this model is in principle capable of performing an integrated energy/economic analysis under various emission reduction constraints. The information available in the GENESIS database indicates that other emissions and options are not taken into account in PRIMES (e.g. non-CO_2 greenhouse gas emissions and CO_2 process emissions, and CO_2 removal as a reduction option).

The modelling of the interaction of energy and economy is not incorporated in the bottom-up approach of GENESIS, which is also capable of incorporating 'non-economical behaviour' in the analysis. For instance, many options with net

[5] These figures for specific energy use are derived from detailed tables of the PRIMES results.

negative specific costs are not implemented due to numerous non-technological barriers. On the other hand, options with high specific costs may be implemented because of various other psychological or cultural reasons. These implementation barriers or supports can be incorporated in the estimate of the reduction potential in the GENESIS approach (e.g. by using market forecasts or expert opinions). The information from the PRIMES model shows that the GENESIS database is currently not taking into account all structural changes, modal split changes in transportation, shifts from primary to secondary materials, and nuclear energy.

For policy makers both approaches are relevant: PRIMES can present the optimum sectoral breakdown for certain carbon dioxide emission constraints, taking many system interactions into account. The PRIMES results can be used to formulate and evaluate generic policies and measures, such as the effects of carbon taxation, emission trade, regulation policies (i.e. emission constraint at a sectoral or country level), standards on technologies etc.

The GENESIS approach identifies the most cost-effective reduction options and supports the formulation of sector or option specific policies and measures, that should take away the implementation barriers (e.g. environmental legislation, labelling, etc.). Furthermore, the frozen technology reference approach shows which and to what extent sectors need to adjust in the period 1990-2010 in order to meet the Kyoto target or even to reach their baseline level.

Both approaches, both bottom-up and top-down, are valuable instruments in the process of policy formulation, as was demonstrated in the process of the European Climate Change Programme.

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BOTTOM-UP METHODOLOGY GENESIS

Summary report

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