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INTEGRATED COST-EFFECTIVENESS ANALYSIS OF ENERGY TECHNOLOGIES AND CO_2 ABATEMENT

The case of the Netherlands' EFOM-ENV/GAMS

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Framework of the study

In the year 1991 the synthesis report of the study 'Cost-effectiveness Analysis of CO_2 Reduction Options' was published by Directorate General Research & Development (DG XII). The study reported on EC country studies on the order of cost-effectiveness of energy supply and end-use technologies under a range of CO_2 emission reduction ceilings [1]. Cost-effectiveness of options was assessed by an integrated energy system approach, using the energy sector model EFOM-ENV.

Currently the cost-effectiveness of energy technologies is studied intensively, not only with respect to CO_2, but also in view of long term technological developments of energy systems. For this reason, DG XII initiated an update of the study 'Cost-effectiveness Analysis of CO_2 reduction options' in the framework of the JOULE I programme, under JOUM-0018 contract. In this update, a new time horizon, new view points, data and technological options are applied for the largest EC countries.

The Dutch contribution to the study was cofinanced by the Dutch Ministry of Economic Affairs. The Dutch national team of ECN Policy Studies contributed to the update by performing a country study for the Netherlands and developing soft-ware and methodology (ECN project number 7070). The presentation of these efforts is given in this report.

CONTENTS

1. INTRODUCTION

A guaranteed energy supply is a condition for national economies. Energy supply must be secure, affordable, clean, and safe. Therefore development of energy technology is an important policy issue.

Currently the trade-off between energy costs and CO_2 emissions is studied intensively, in order to assess CO_2 emission reduction strategies for mitigation of the greenhouse effect. The greenhouse effect is a long term environmental problem which urges for global structural changes in energy sector and economy. An integrated cost-optimization model of the national energy sector, such as the DG XII model EFOM-ENV, is a suitable tool for analyzing these aspects.

Cost-optimization models can provide policy makers with blue-prints of possible technological developments, including the accessory environmental aspects, and point out for a range of reduction targets which options are technical feasible, attractive, and worthwhile designing policy measures for.

This has been shown in for instance the CEC DG XII study 'Cost-effectiveness Analysis of CO_2 reduction options' in the framework of the JOULE I programme, of which the report was published in 1991 [1]. In 1993 DG XII initiated an update of this study, in order to extend the time horizon to the year 2020 and the technology database. Emphasis is put on the long term energy technology developments and their contributions to CO_2 emission reduction strategies.

Apart from these energy and environment related objectives, the Dutch national team has been asked to apply the new EFOM-ENV version in GAMS for the Dutch national study. This paper will report on the experiences with the model. Furthermore, a description will be given of some report facilities of EFOM-ENV/GAMS which help the expert in analyzing the integrated behaviour of the model and in translating model results to the level of single technology contributions.

2. METHODOLOGY

2.1 EFOM-ENV/GAMS

After the successful specification of a pilot version of the Netherlands EFOM-ENV in GAMS, the EFOM-ENV/GAMS model has been used and improved. The pilot version of EFOM-ENV/GAMS [3] already showed that:

- EFOM-ENV has become userfriendly, especially with respect to the input of data. The input data tables are divided into process-related data and scenario-related data.
- The model results have become more reliable since the report generation is part of the GAMS execution; when changes are made in the model, they are automatically included in the report.
- EFOM-ENV/GAMS is portable to many places since GAMS can be applied on mainframes, workstations, and personal computers.

The improved version of EFOM-ENV/GAMS now includes the following:

- The specification of the process-related data (of conversion processes and abatement technologies) are supported by a user-interface [5].
- Names of producers, units, processes, energy carriers, and structure are consistently and systematically applied in the model, herewith improving transparency and reliability of the model.
- Execution algorithm for automatic solving of the maximum emission reduction case.
- Execution algorithm for automatic execution of a set of emission reduction cases.
- Restart facility: after solving a Reference case the computation of reduction cases takes considerably (10 times!) less time.
- The report generation is extended with for example:
  - marginal abatement costs per period;
  - capacity bound markers which indicate whether a process is limited by its upper or lower capacity boundary;
  - cross-case reporting: a summary of results of a set of emission reduction cases.

It is possible to make a large series of runs due to the restart facility. Solving the large Dutch model without an emission constraint (Reference case) takes about 40 minutes on a SUN workstation. Without the restart facility a series of 30 runs takes more than 20 hours. Using the restart facility reduces this run time, including the Reference case, with a factor ten to 2 hours. On a large 486 PC run time is even lower.

A detailed description of the model EFOM-ENV/GAMS and its facilities is given in [6]. The manual for the user-interface is described in a separate report [5].

2.2 Integrated approach

Especially the integrated approach is an important feature of cost-optimization models. Substitution of contributions of technologies and/or measures in energy supply and demand, as well as substitution of fuels are crucial in assessing the costs of setting national emission (or other) targets. For example, energy savings are analyzed from a national point of view, taking into account avoided energy supply costs. For instance, marginal CO_2 abatement costs of wind energy are dependent on the fuel it can replace. Also interaction or even synergy between multiple system targets such as simultaneous CO_2, SO_2, and NO_x abatement, and the measures required, can be assessed with a model such as EFOM-ENV.

However, using an integrated approach causes some difficulty in analyzing results properly. The specific role of a single technology is hard to assess, since multiple changes in for instance technology mix take place simultaneously.

In order to address this problem, a cross case reporting is developed that reports over a large series of cases which cover the complete possible emission range. The reporting consists of a matrix of energy production increments of technologies for each national emission target and its accessory marginal emission reduction costs. In this way the contribution of a single technology in the energy system can be analyzed systematically.

The very detailed matrix of technologies supplies information on:
- penetration of technologies by their energy production in PJ in the Reference case, the Energy Saving case and subsequent CO_2 reduction cases;
- the order of penetration of technologies under a decreasing national CO_2 ceiling;
- the order of magnitude of CO_2 reduction potential and marginal costs of a certain technology in the energy system (integrated model approach).

Furthermore, the 'robustness' of contributions of options to a long term emission reduction strategy can be investigated. For instance, a high efficient gas power plant can have a large CO_2 reduction contribution at low marginal costs up to 20% national emission reduction, but for stronger reduction targets, being not effective enough, replaced by more expensive but more effective options such as CO_2 removal on coal fired plants. These switches in penetration of options can be observed in the penetration matrix. An example of a penetration matrix generated in the study can be found in the Appendix.

3. ASSUMPTIONS

Key assumptions in the scenario are the same as in the Dutch country report of the DG XII study 'Cost-effectiveness Analysis of CO_2 reduction options' [2]. Projected useful or final energy demand levels and fuel prices were those used in the Energy 2010 study and calculated by the MEDEE energy demand model of DG XVII. Since energy demand data were not available for the year 2020, expert judgements have played a large role in the extension to the year 2020 of the energy demands.

Population in the Netherlands is projected to grow from 14.6 million people in 1985 to 15.3 million in 2010. Hereafter population will be stabilized. Note, in reality the 1993 Dutch population consisted already of 15.3 million persons. Assumed GDP growth is around 2.6% p.a. Electricity demand is projected to grow even faster (3% p.a.). Oil prices are assumed to increase to 30 $-87 per barrel in 2010, coal prices grow to $ 60 per ton and natural gas prices are indexed to oil in the 90's but thereafter to coal prices. After 2010 annual relative price rises for all fuels are less than before 2010.

The Netherlands' version of EFOM-ENV includes many types of technologies, viz. efficient and clean fossil fuel technologies (FRET technologies), renewable energy technologies (DERE technologies), and additional energy saving (technologies) in end-use (MURE measures). More information on these technologies can be found in the country report of the former DG XII study [2]. Compared with this former study, some technologies, which may play an important role in the energy system on the longer term, are added (or extended) to the database. For instance:

- Energy saving options in industry.
- Compression heat pumps.
- Molten carbonate fuel cell.
- Electric cars.
- Integrated coal gasification cogeneration in combination with CO_2 removal (recovery and storage in depleted natural gas fields).

Neither of the technologies hydrogen production, CO_2 removal on natural gas consuming technologies, and nuclear power are considered in the scenario. For more detailed information on the technologies in the database, the reader is referred to table A2 in the Appendix.

4. RESULTS

4.1 Cases

In figure 1 the CO_2 emissions according to the Reference case (without additional energy savings in end-use) are represented by the upper thick solid line. In the period 1985-1990 CO_2 emissions increased strongly due to considerable economic growth. From 1990 to 2000 emissions are projected to grow more slowly due to a smaller (projected) economic growth and planned CO_2 reduction measures, which will be explained later. The Dutch emission target for the year 2000 is stabilization of emissions on 1990 level. This target is almost reached in the Saving case, which is represented by the medium solid line. The Saving case includes, unlike the Reference case, all energy saving options in end-use that are cost-effective from a national point of view at the discount rate of 5%, viz. decreasing the total discounted system costs with respect to the Reference case.

In the Reference case in the period 2000-2010 CO_2 emissions growth is larger than before, but after 2010 emission growth is decreasing again. The difference between the Reference and Saving case is in the period 2010-2020 slightly smaller, due to the fact that energy savings are competing with high efficient supply options.

The thin solid lines represent all CO_2 constrained cases which are run by the model, from Saving case to maximum feasible reduction case in reduction steps in 2020 of 1% of 1990 emissions. The lines give the CO_2 reduction path which can not be exceeded.

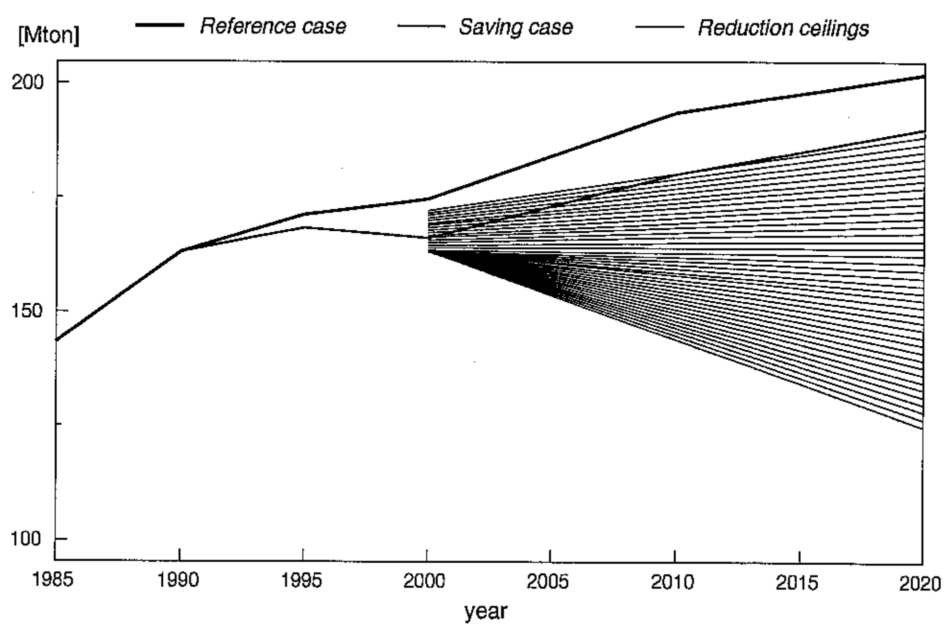

Figure 1 *Reference and Saving cases and CO_2 reduction paths applied from 2000 to 2020*

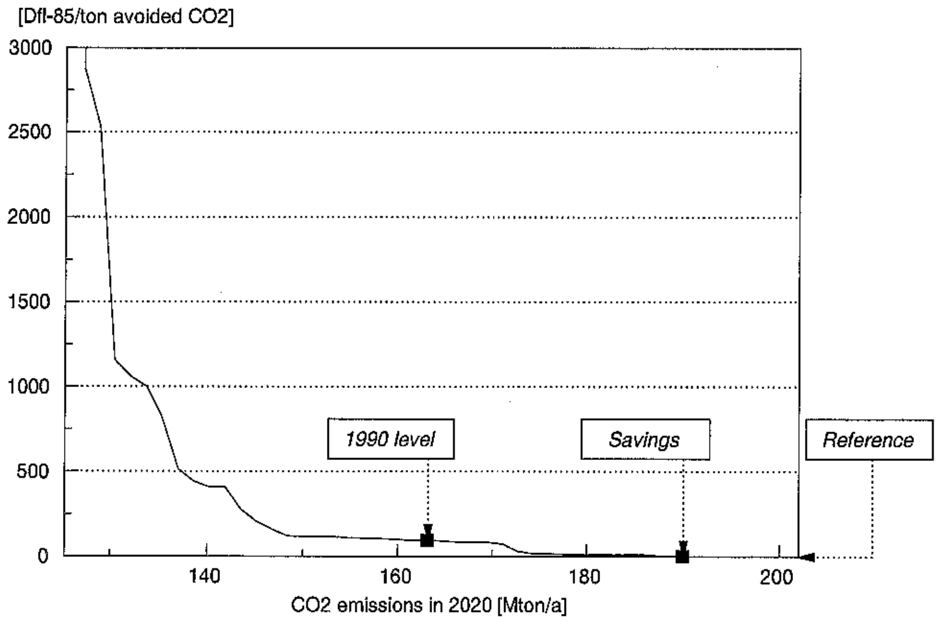

Figure 2 *Marginal costs of CO_2 emission reduction in the year 2020*

4.2 CO_2 reduction costs

A detailed marginal CO_2 reduction costs curve for the year 2020, which is generated by the Netherlands EFOM-ENV/GAMS model, is presented in figure 2. From Reference to Savings case emission reduction at zero marginal costs is due to penetrating Saving options in end-use. In fact, the system costs are negative or benefits.

In the curve some flat areas appear which indicate the penetration of a technology (group) with certain costs and a considerable CO_2 reduction potential. If the curve steepens, only a limited reduction potential is available at that certain marginal costs.

The currently available technology penetration matrix in the Appendix makes it possible to assess technology contributions at chosen points at the costs curve (marginal costs). For example in the range from 190 Mton to 170 Mton CO_2 emissions, advanced natural gas plants in the Public Electricity Generation sector penetrate at low marginal costs. Also gas engines and steam and gas turbines penetrate in the urban sector respectively the large industry. Wind power and fuel cells are available at about 75 Dfl/ton avoided CO_2. This can be assessed easily in table A1.

In the range from 165 to 145 Mton CO_2 emissions the large contribution of coal gasification in combination with CO_2 removal results in a flat area in the costs curve. Note that the area is not completely horizontal, since technologies which are replaced vary in their specific CO_2 emission.

The plateaux at 140 Mton CO_2 results from a cluster of options, viz. hydro energy, more expensive energy saving measures in multi and single family houses and industry, and electric car etc. More expensive options are for example heat pumps, high efficient future cars, and photovoltaic cells: marginal costs higher than 800 Dfl per ton avoided CO_2. However, the options at high reduction levels and their costs are unreliable since the available reduction potential in the model is exhausted.

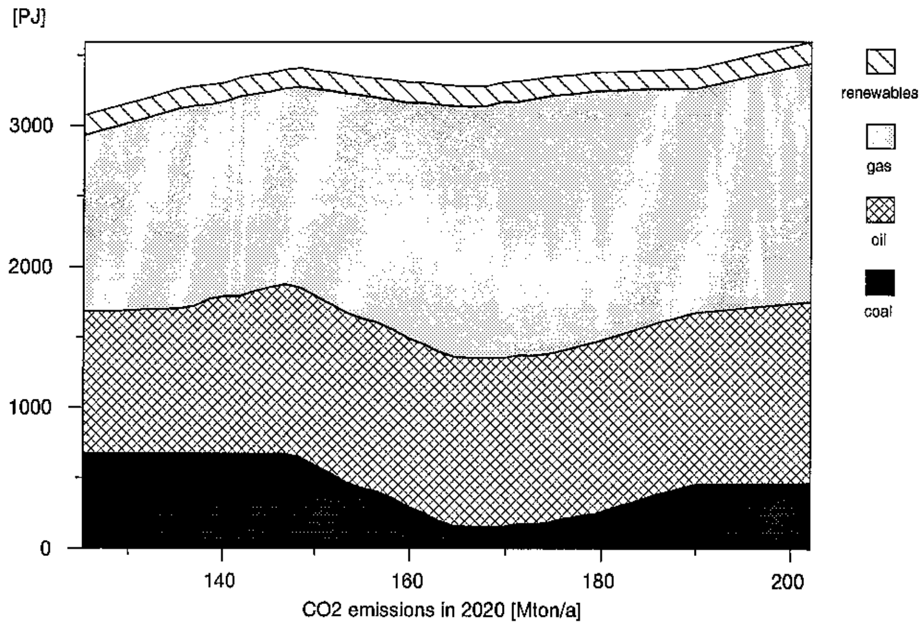

Figure 3 *Primary energy mix in the year 2020 for the Reference, Saving, and CO_2 reduction cases*

4.3 Fuel consumption

As can be seen in figure 3 the Reference case (202 Mton CO_2 emissions at the horizontal axe) can be described as a natural gas dominated scenario. This limits the reduction potential from Reference scenario to Maximum Reduction case. Emission reduction from Reference to Saving case (190 Mton) is obviously due to energy savings in end-use, which save natural gas and oil. Reduction from 190 Mton CO_2 down to stabilization at 1990 emission level (163 Mton CO_2) takes place by fuel switch from coal to natural gas. Also efficiency improvements occur (decreasing Total Primary Energy Requirement).

CO_2 removal on coal gasification plants leads to an increase of coal use (up to a limit of 8000 MWe) and an increase of TPER, since CO_2 removal results in an efficiency loss of about 10%. High reduction levels are reached by savings and efficiency improvements on oil (in refineries and transportation) and natural gas.

The share of renewable energy is increasing from 3% to 5% throughout the reduction path. In fact, waste combustion has disappeared completely, while it is the largest contribution in the Reference case, and is replaced by renewable energy sources such as wind, hydro, and solar. Nevertheless, the scope for renewables is limited in the Netherlands.

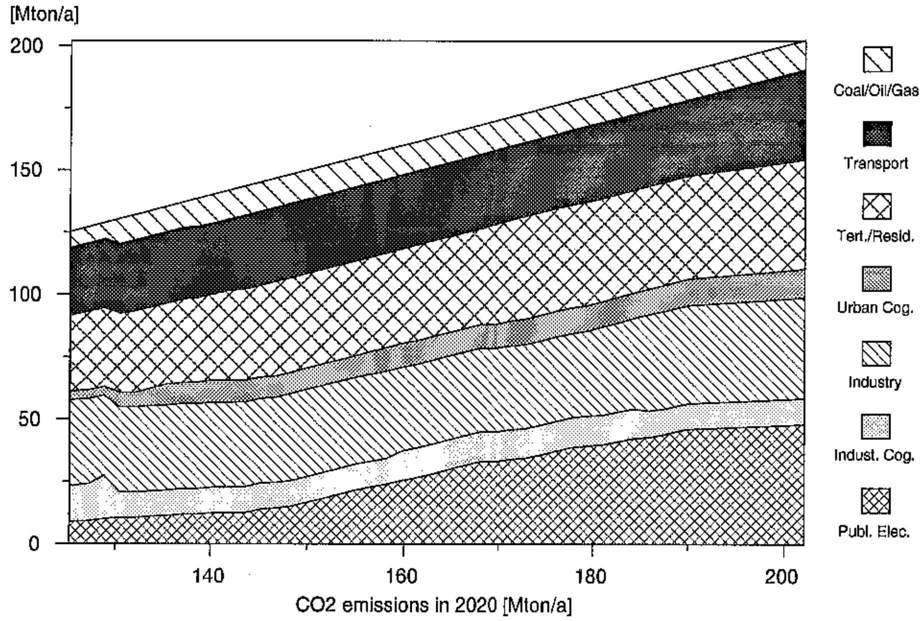

Figure 4 *Cumulative sectoral CO_2 emissions in the year 2020 for the Reference, Saving, and CO_2 reduction cases*

4.4 Sectoral contributions

Sectoral contributions to national CO_2 emissions are illustrated in figure 4. Obviously, the Public Electricity Generation sector has the highest CO_2 emissions, but also the largest CO_2 reduction potential. Mind that these reductions can be caused by savings in end-use or Combined Heat and Power generation in the Urban and/or Industrial sector(s). CO_2 emissions in Tertiary and Residential sectors can be reduced substantially by a large number of options, ranging from cheap to expensive. In Transportation a considerable reduction potential in the form of saving measures is available at low or negative costs. Other options like high efficient future cars penetrate at high marginal costs. Industrial CO_2 emissions decrease from Reference to 1990 emission level due to energy savings and CHP. However, industrial CHP decreases in favour of industrial savings when stronger reductions must be reached. If emissions must be lower than 130 Mton, industrial CHP appears again and peaks. In the supply sectors coal and gas no emissions take place. The oil sector (Refineries) does produce emissions which can be reduced by expensive imports. This is not a structural emission reduction.

Figure 5 resembles figure 4, but in stead of emissions, emission reductions per sector are drawn. This way the sectoral reduction potential is illustrated more clearly. Especially Transport saving measures are already effective without reduction targets. The Central Electricity Generation contributes over the complete range of reduction targets half of the emission reduction. The other sectors contribute more or less equally shared the other half of required reductions. Extreme reductions can be reached if additional (expensive) measures are taken in the Tertiary and Residential sectors, and Urban Cogeneration is reduced.

Most of the CO_2 reduction from the Industrial Cogeneration sector is negative, which is indicated by 'N'. Interpretation of this 'N'-area is as follows: this CO_2 reduction area reflects positive reduction contributions of as well the Public Electricity Generation sector as the Industry. Combined heat and power production replaces separate steam and electricity production, herewith increasing emissions in the Industrial Cogeneration sector, but decreasing national CO_2 emissions cost-effectively.

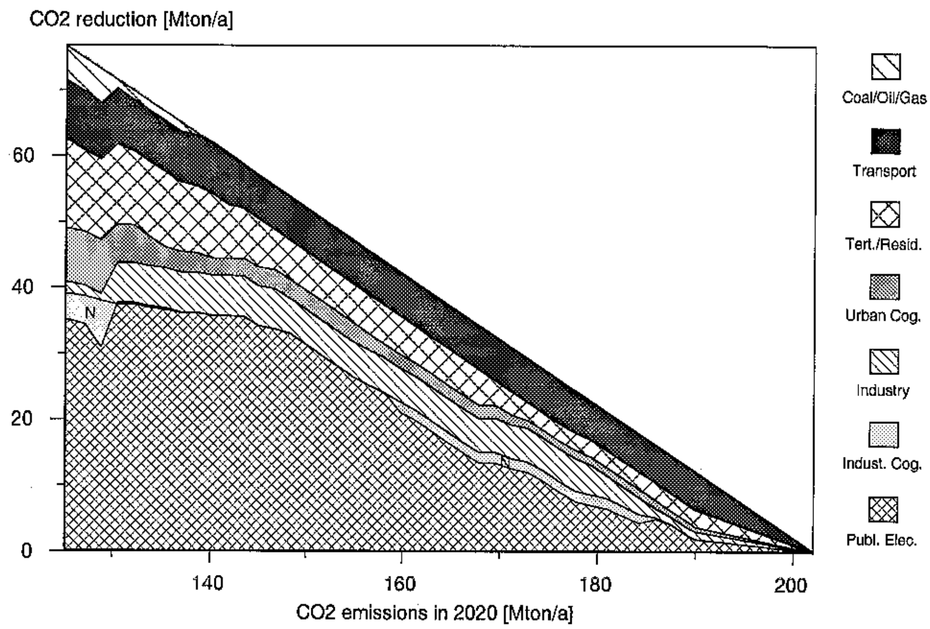

Figure 5 *Cumulative sectoral CO_2 emission reductions in the year 2020 for the Reference, Saving, and CO_2 reduction cases*

5. CONCLUSIONS

- Contribution of a single technology in the energy system can be analyzed systematically in EFOM-ENV with the help of the technology penetration matrix.
- The technology penetration matrix shows that penetration of technologies is dependent on the conditions of (constraints imposed on) the total energy system.
- Around 25% CO_2 emission reduction in 2020 with respect to 1990 emission level is technically feasible in the Netherlands.
- 25% CO_2 emission reduction potential is considerably larger than the 2010 reduction potential calculated in the study 'Cost-effectiveness analysis of CO_2 reduction options' [2]. This is due to a larger energy saving potential, and the addition of a number of options, a.o. CO_2 removal. Also technical potentials of some options are larger in 2020 than in 2010. However, the potential of renewable options is limited.
- The Central Electricity Generation contributes over the complete range of reduction targets half of the emission reduction. The other sectors contribute more or less equally shared the other half of required reductions.

REFERENCES

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APPENDIX A. TECHNOLOGY PENETRATION MATRIX

In table A1 for each step of additional CO_2 emission reduction, the additional energy production of an energy conversion technology is given. The reduction case is represented by the emissions in the periods 2000, 2010, and 2020 in Mton and in % reduction with respect to 1990 emissions. A negative reduction percentage means higher emissions than 1990 emissions. For each period, marginal CO_2 reduction costs are given; Period 2000 is lacking since marginal costs at the given targets in 2000 were 0 in all cases.

Only technologies penetrating under a CO_2 constraint are shown in this matrix. Penetration is given by the additional energy production in PJ, compared with the case before (column left), and must be positive in at least one case in order to be included in the matrix. For the Reference and Maximum Reduction case (first and last column) total energy production is given. The second column presents the Saving case. The codes of the technologies are explained in the model output in table A2.

Note that the penetration of a technology in the Maximum Reduction case means that this technology is resistant to strong emission reduction constraints. It does not necessarily imply that this 'robust' technology is a CO_2 lean technology. However, all technologies in the matrix have, at least in one column, a positive incremental contribution to cost-optimal realization of the national CO_2 constraint. By this broad definition all technologies in the matrix are to some extend (at some stage or time period in the abatement strategy) a CO_2 abatement technology. It would be more precise to call these technologies 'abatement robust' and define abatement technologies as technologies which have a larger penetration in the Maximum Reduction case than in the Reference case. This is more clear, although this is also dependent on the percentage of Maximum Reduction.

The EFOM-ENV/GAMS package automatically supplies the user with such a CO_2 emission reduction technology penetration matrix. It must be noted that the contributions of technologies can be analyzed with greater accuracy. Furthermore, the integrated least-costs modelling approach is illustrated by the penetration of a technology in different areas in the costs curve; the CO_2 reduction costs depend highly on the CO_2 emissions and costs of the technology which is to be replaced. Different options contribute in different reduction areas, and only some of them are robust and not pushed out by more expensive options with larger emission reduction capabilities.

Table A1 CO_2 emission reduction technology penetration matrix in the year 2020 (contributions in PJ_o)

CO2-RED.2000 [%]			-5	-4.3	-3.7	-3	-2.3	-1.7	-1	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
in Mton			171.2	170.1	169	168	166.9	165.8	164.7	163.6	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	
CO2-RED.2010 [%]			-10	-8.7	-7.3	-6	-4.7	-3.3	-2	-0.7	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.6	
in Mton			179.4	177.2	175	172.8	170.7	168.5	166.3	164.1	162.2	160.6	159	157.4	155.7	154.1	152.5	150.8	149.2	147.6	145.9	144.2	
CO2-2020	-23.9	-16.5	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15	17	19	21	23.2	
in Mton	202	190	187.5	184.3	181	177.7	174.5	171.2	168	164.7	161.4	158.2	154.9	151.6	148.4	145.1	141.9	138.6	135.3	132.1	128.8	125.3	
MARGINALS [F85 per ton CO2]																							
CO2-2010			3	5	12	20	36	45	73	76	76	92	93	100	107	169	181	288	430	442	465	731	
CO2-2020	REF	SAVE	6	11	12	14	17	74	85	91	94	106	110	118	121	209	407	442	824	1059	2534	11529	TOT
INL_HEF_S2[1]		3.6		-1.0	-0.2							1.2											3.6
INL_SBO_GR	5	0.3		15.8	4.9	14.7															-13.9	20.9	47.5
INL_SBO_S1		0.5		1.5	0.7	1.4															-1.7	2.0	4.4
INS_HEF_S2		4.3																					4.3
INL_ELT_S2		0.5																					0.5
RTA_BU1_B1		7.4																					7.4
RTA_BU2_B2		1.0																					1.0
RTA_FR1_F1		3.5																					3.5
RTA_FR2_F2		2.5																					2.5
RTA_FRE_FR		2.9																					2.9
RCM_SPH_G2	72	0.3	-0.3			0.4	0.1	-10.5	0.1	-0.1		-22.6						-6.3	-17.0		-0.7	-2.8	12.4
RMF_INS_SH		7.6															-1.2	-0.4					6.0
RSF_INS_SH		29.3																-5.3		8.5	8.0		40.5
TRS_CTF_SP		9.0																					9.0
TRS_CTU_SP		18.0																					18.0
TRS_CTX_SP		22.5																					22.5
TRS_RSA_ST		0.9																					0.9
TRS_SSA_ST		14.4																					14.4
UCO_BPT_FL	41	3.6				-0.4	-4.3	-0.7	0.3				4.8		0.3	-6.3	-38.0						0.1
EPR_CCP_GN	167	-10.0	12.7	7.3	13.8	-2.8	9.2	-9.0	5.6	-0.7	-24.5	-21.6	-14.0	-34.2	-42.1	-9.1	-10.5	-4.1	-5.0	-0.9	3.1	-5.3	24.9
EPR_TGN_GN	30	-5.3	4.3	1.7	4.7	-1.0	3.0	-2.7	1.8	-0.2	-8.3	-7.2	-4.4	1.6	-0.2	-2.8			-1.5	-2.8	-10.7		0.2
ICL_CCP_GR	27		6.5	-6.5																			27.1
ICL_GTU_GN	46		6.5					-0.1														-10.5	41.8
RMF_SPH_G2	52	-7.9	1.5	1.3		-0.1	2.2	-13.3	-3.1	0.1		0.4					-4.4	-1.6	-1.6	0.4	7.4	0.5	34.1
UCO_TES_G2			2.8	3.2		0.7	7.4	4.7	4.6				-0.4			2.7	2.9		3.4	-32.0		1.2	1.2
INL_SBO_GN	4	-0.2		11.5	9.4	12.1		-2.6													-16.4	15.8	33.5
ICL_CCP_GN	25		-6.5	6.5																			25.0
ICL_GTH_GR				6.1								-6.0											0.1
ICL_GTH_GN				12.2	4.2							-16.3											0.1
INL_HEF_GN					0.8	9.5						8.3				-3.6					-4.8	9.3	19.5
EPR_FUC_GN						7.9		6.3				-6.3					-3.1		3.3	-4.0	4.6	-5.1	3.6
EPR_WN2_RW	1					1.6		3.8															6.6
TR_VANF_GO						3.0	1.3																4.3
EPR_WN3_RW	0						3.7	6.0															10.0
RMF_HR_G2_	0						0.7	15.4	3.0														19.2
INL_SBO_S2								2.6													-1.1	1.2	2.7
ICL_GTU_GC	14							0.1															13.8
RCM_HR_G2_	1							10.5	-3.0			22.4						-1.7			-5.0	-8.5	15.3
RTA_SNG_RS	0							6.1															6.3
RTA_SRE_RS								0.6															0.6
RCL_AHP_G2	13							3.9															16.8
RSF_HR_G2_	1	-0.1						0.6	95.0	11.8											-81.5	-26.4	0.0
EPR_GTU_GN	2	-1.5							0.1	-0.1													0.1
RTA_SRG_RS	0								5.7														5.9
RCM_LEB_G2	0								3.0													-0.7	2.4
EPR_REM_CL										15.7	35.8	36.8	26.4	36.1	42.5	8.4							201.7
RCL_CHP_G2	0											4.1				12.6							16.9
INL_HEC_CL	5	-3.3		-0.6	-0.1							0.7											2.1

[1] For codes see Table A2.

(continued)

CO2-RED.2000 [%]			-5	-4.3	-3.7	-3	-2.3	-1.7	-1	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
in Mton			171.2	170.1	169	168	166.9	165.8	164.7	163.6	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	163.1	
CO2-RED.2010 [%]			-10	-8.7	-7.3	-6	-4.7	-3.3	-2	-0.7	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.6	
in Mton			179.4	177.2	175	172.8	170.7	168.5	166.3	164.1	162.2	160.6	159	157.4	155.7	154.1	152.5	150.8	149.2	147.6	145.9	144.2	
CO2-2020	-23.9	-16.5	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15	17	19	21	23.2	
in Mton	202	190	187.5	184.3	181	177.7	174.5	171.2	168	164.7	161.4	158.2	154.9	151.6	148.4	145.1	141.9	138.6	135.3	132.1	128.8	125.3	
MARGINALS [F85 per ton CO2]																							
CO2-2010			3	5	12	20	36	45	73	76	76	92	93	100	107	169	181	288	430	442	465	731	
CO2-2020	REF	SAVE	6	11	12	14	17	74	85	91	94	106	110	118	121	209	407	442	824	1059	2534	11529	TOT
INL_HEF_GR	36	-0.2		-10.2	-3.1	-9.5						4.3									4.8	-9.3	13.0
UCO_GEO_TH													0.2			0.1	1.4						1.7
INL_HEF_S1																3.6							3.6
INS_HEF_S1																4.3							4.3
UCO_CCP_GN	15														-0.5	7.3	55.1		-1.4	-6.4	-34.4	-1.2	33.5
RTA_LCG_S1																3.1							3.1
RSF_LED_G2	0															5.4							5.5
EPR_HY2_RH																	0.7						0.7
RGR_CHP_G1																	18.8	7.7	7.2				33.7
INL_ELT_S3																	1.2						1.2
RMF_GLA_SH																	5.6	2.0					7.6
TR_CR1F_EL																	12.4						12.4
RSF_GLA_SH																		29.4					29.4
EPR_WN4_RW																		7.3					7.3
OUT_HEF_GN																		0.1	45.2		-45.3		0.0
OUT_HEF_GR																		14.1			-14.1		0.0
OUT_SBO_GN	5																	14.4			-14.4		4.7
RCM_HEP_G2																		8.1	15.1	-3.0	1.8	-0.6	21.4
INL_ELT_S1																			1.2				1.2
RCM_RPP_SH																			0.9		3.8		4.7
RSF_HEP_G2																			9.9	8.7	107.9	37.5	164.0
EPR_PHO_RS																			3.4	0.1			3.5
ICS_BPT_G1																			9.3				9.3
RTA_LCG_S2																			1.7	0.4			2.1
RCL_HR_G2_	54							-3.9				-4.1				-12.6			0.3				33.6
RMF_HEP_EL																			0.3				0.3
RTA_LCE_S1																				25.4			25.4
RTA_WTH_G2	37							-6.7	-5.7											2.4	2.2		29.6
RGR_AHP_G1																				7.6	10.0	-0.3	17.3
TR_CR2F_GL																				12.1			12.1
RCM_HEP_EL																				0.6		-0.1	0.5
RSF_HEP_EL																				1.1			1.1
TR_TRKF_GO																					52.0		52.0
ICL_BPT_GN																					39.9	-39.9	0.0
ICL_GTR_GN																					67.6	6.7	74.3
ICL_GTR_GR																					6.7	-6.7	0.0
OUT_SBO_GR	14																	-14.4			14.4		14.4
RGR_HEP_EL																					0.5	0.1	0.6
TR_CR1F_GL																					29.7	54.4	84.1
RTA_LCE_S2																						17.5	17.5
GCV_CNG_GN																						0.2	0.2
RCM_FDG_SH																						12.1	12.1
RGR_SPH_G1	99																-16.4	-2.4	-5.9	-7.4	-10.5	0.2	56.5
TR_CRS_CNG																						0.2	0.2

Table A2 *List of codes of energy conversion technologies contributing in the CO_2 reduction technology penetration matrix used by EFOM-ENV/GAMS*

INL_HEF_S2	Save option Furnaces (control)
INL_SBO_GR	steam boiler (refinery gas) large
INL_SBO_S1	Save option Boilers (monit. & target)
INS_HEF_S2	Save option Furnaces sm. (control)
INL_ELT_S2	Save option motors
RTA_BU1_B1	saving bulb option 1
RTA_BU2_B2	saving bulb option 2
RTA_FR1_F1	saving fridge option 1
RTA_FR2_F2	saving fridge option 2
RTA_FRE_FR	saving freezer
RCM_SPH_G2	space heating com. building (exp. VEGIN)
RMF_INS_SH	saving heat with insulation (mfh)
RSF_INS_SH	saving heat with insulation (sfh)
TRS_CTF_SP	saving pers. km. with traffic measures
TRS_CTU_SP	saving pers. km. by tuning
TRS_CTX_SP	saving person km. by tax
TRS_RSA_ST	saving ton kil. for rail transport
TRS_SSA_ST	saving ton km per ship
UCO_BPT_FL	back press. turb. urban cogen (fuel_lsc)
EPR_CCP_GN	combined cycle power plant (natural gas)
EPR_TGN_GN	new topping gas plant
ICL_CCP_GR	comb. cycle cogen. (ref.gas) large
ICL_GTU_GN	gas turbine for cogen. (nat.gas) large
RMF_SPH_G2	space heating (exp. VEGIN) (mfh)
UCO_TES_G2	total energy system (expensive VEGIN)
INL_SBO_GN	steam boiler (natural gas) large
ICL_CCP_GN	comb. cycle cogen. (nat.gas) large
ICL_GTH_GR	gas turbine for cogen. (ref. gas) large
ICL_GTH_GN	gas turbine for cogen. (nat. gas) large
INL_HEF_GN	heat furnace (natural gas) large
EPR_FUC_GN	fuel cell (natural gas)
EPR_WN2_RW	wind power option 2
TR_VANF_GO	future van on gasoil
EPR_WN3_RW	wind power option 3
RMF_HR_G2_	high eff. boil for heat (exp. VEGIN) (mfh)
INL_SBO_S2	Save option Boilers (insulation)
ICL_GTU_GC	gas turbine for cogen.(coke gas) large
RCM_HR_G2_	high eff. boil. com. building (exp.VEGIN)
RTA_SNG_RS	wat. heat. with sol. en. newhouse (bup:gas)
RTA_SRE_RS	wat. heat. with sol.en. retrofit (bup:el)
RCL_AHP_G2	coll. absorption heat pump (exp. VEGIN)
RSF_HR_G2_	high eff. boiler (exp. VEGIN) (sfh)
EPR_GTU_GN	gas turbine for peak power
RTA_SRG_RS	wat. heat. with sol.energy retr. (bup:gas)
RCM_LEB_G2	heating low energy com. build. (exp.VEGIN)
EPR_REM_CL	combined cycle power (coal)+ co2-removal
RCL_CHP_G2	coll. compr. heat pump (exp. VEGIN)
INL_HEC_CL	heat furnace (coal) large
INL_HEF_GR	heat furnace (refinery gas) large
UCO_GEO_TH	geothermal installation back up by heat
INL_HEF_S1	Save option Furnaces (insulation)
INS_HEF_S1	Save option Furnaces sm. (insulation)
UCO_CCP_GN	comb. cycle power urban cogen (nat. gas)
RTA_LCG_S1	Saving elec. by control & impr. cooling
RSF_LED_G2	low energy dwelling (exp. VEGIN) (sfh)
EPR_HY2_RH	hydro power option 2
RGR_CHP_G1	greenhouse compr. heatpump (cheap VEGIN)
INL_ELT_S3	Save option refrigeration
RMF_GLA_SH	saving heat with double glazing (mfh)
TR_CR1F_EL	Future car on electricity (<2 liter)
RSF_GLA_SH	saving heat with double glazing (sfh)
EPR_WN4_RW	wind power option 4
OUT_HEF_GN	heat furnace (natural gas) refineries
OUT_HEF_GR	heat furnace (refinery gas) refineries
OUT_SBO_GN	steam boiler (natural gas) refineries
RCM_HEP_G2	heat pump in com. building (exp. VEGIN)
INL_ELT_S1	Save option Lighting
RCM_RPP_SH	Roof & parapet pane
RSF_HEP_G2	heat pump (exp. VEGIN) (sfh)
EPR_PHO_RS	photovoltaic
ICS_BPT_G1	st.boiler+back press.turb (ch. VEGIN)small
RTA_LCG_S2	Saving elec. by speed control
RCL_HR_G2_	coll. high eff. boiler (exp. VEGIN)
RMF_HEP_EL	electric heat pump (mfh)

RTA_LCE_S1	Saving elec. by control & impr. cooling
RTA_WTH_G2	water heating with natural gas
RGR_AHP_G1	greenhouse abs. heat pump (cheap VEGIN)
TR_CR2F_GL	future gasoline car (> 2 liter)
RCM_HEP_EL	electric heat pump in com. building
RSF_HEP_EL	electric heat pump (sfh)
TR_TRKF_GO	future truck on gasoil
ICL_BPT_GN	st.boi.+ back press.turb.(nat.gas) large
ICL_GTR_GN	gas turbine for cogen. (nat. gas) refin
ICL_GTR_GR	gas turbine for cogen. (ref. gas) refin
OUT_SBO_GR	steam boiler (refinery gas) refineries
RGR_HEP_EL	greenhouse electric heat pump
TR_CR1F_GL	future gasoline car (< 2 liter)
RTA_LCE_S2	Saving elec. by speed control
GCV_CNG_GN	production of cng from natural gas
RCM_FDG_SH	Saving heat by floor & double glazing
RGR_SPH_G1	greenhouse space heating (cheap VEGIN)
TR_CRS_CNG	car on cng