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COST-EFFECTIVENESS ANALYSIS OF CO_2-REDUCTION OPTIONS
THE CASE OF THE NETHERLANDS

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CONTENTS

1. INTRODUCTION

In the Netherlands much attention is focussed on the greenhouse issue. Over the past five years CO_2-emissions did increase gradually and a substantial rise for the year 2000 and later was expected. In May 1989 the Dutch Government presented the National Environmental Policy Plan (NEP), containing a set of energy policy measures to reduce SO_2-, NO_x- and CO_2-emissions substantially. In 1990 reduction measures such as energy conservation, fuel switching and recycling were recommended in NEP+ and the Energy Conservation plan of the Government to achieve CO_2-emission levels in 1995 similar to the 1989/90 levels and further reductions, from 3 to 5% below 1989/90 levels in 2000.

This report assesses CO_2-reduction policies in the Netherlands to achieve CO_2-levels recommended in the Commission's Communication to the Council on Community policy targets on the greenhouse issue (COM(90)496). An analysis of the cost-effectiveness of various reduction options is indeed essential to assist the policy makers in their preparation of action plans.

The study is based upon DG XVII's 'Conventional Wisdom'* scenario as far as useful energy demand and fuel price projections are concerned and uses the optimization model EFOM-ENV. The model has been adapted to analyse the scope and cost-effectiveness of CO_2-reduction policies. The project included data collection on different CO_2-reduction options. The DERE (Développement des Energies Renouvables en Europe) subprogramme concerns data collection on renewables. Another FRET (Fossil fuel Reduced Emission Technologies) subprogramme deals with CO_2-reducing energy technologies such as fuel cells and combined cycle plants. Finally, the MURE (Modèle pour l'Utilisation Rationnelle de l'Energie) subprogramme focusses on energy conservation options in the different end-use sectors. The project concerns detailed data collection on energy saving potentials and associated costs. By incorporating end-use conservation options in the energy sector model EFOM-ENV a consistent assessment and comparison of different supply and demand-oriented CO_2-reduction options in a single computing framework was obtained.

The major output of the study is the identification of the mix of least-cost options in the energy sector to reduce energy related carbon dioxide emissions to levels recommended in the Commission's Communication to the Council on Community policy targets on the greenhouse issue (COM(90)496) and their impacts on final and primary energy consumption. Furthermore SO_2- and NO_x-emissions and the costs and energy policy implications involved in meeting the targets are discussed.

* See Energy in Europe, Energy for a New Century: The European Perspective, July 1990

2. KEY ASSUMPTIONS

2.1 General

The quality of the results from a study such as this depends largely on the quality and consistency of the data used as input to the model. Consistency is important since, in the absence of overriding constraints, the modelling results are sensitive to relative fuel prices and investment and operating costs of the various energy technologies. The modelling results indentify important technical/economical CO_2-reduction possibilities and provide a starting point for a discussion on the implementation of CO_2-emission reduction policies.

For the purpose of this study, an internal discount rate of 5% was used in the optimization. The discount rate was applied to all subsystems and therefore model solutions represent a national optimum if all economic agents invest to maximise national net present value with a 5% discount rate.

2.2 Energy demand and fuel import prices

Import prices and useful demand are exogenous variables or model inputs and thus unaffected by the solution of the model.

Projected useful energy demand levels and fuel prices were those used for the 'Conventional Wisdom' scenario of the Energy 2010 study and calculated by the MEDEE energy demand model of DG XVII.

In fact the scenario served as a reference for the key assumptions in this study. Broadly the scenario contains the following assumptions. Assumed GDP growth for the Netherlands is around 2.6% p.a. (1985-2010). Electricity demand is projected to grow even faster ca. 3% p.a. Oil prices are assumed to increase to 30 $-87 per barrel in 2010, coal prices grow slowly to $ 60 per tonne and gas prices are indexed to oil in the 90's but thereafter to coal prices. Population will grow from 14.6 million in 1985 to 15.3 million in 2010 (see the report on the study Energy 2010, DG XVII).

2.3 Energy sector

First, CO_2-emission factors were specified in the model, see table 1 and reports [1,2]. For the representation of the energy sector in the model see reports [3,4]. For the present CO_2-study the tertiary/domestic, transport and power generation sectors were revised to incorporate renewables, conservation measures and other CO_2-reduction options. In the tertiary/domestic sector more efficient appliances and different insulation options were specified, see Appendix I.

Table 1. CO_2-emission factors for the Netherlands EFOM-ENV (t/TJ input)

Natural gas	56
CNG	60
Gas condensate	78
Crude oil	75
Heavy fuel oil HSC	78
Heavy fuel oil LSC	77
Gasoil, diesel	74
Naphta, kerosine	74
Gasoline	73
LPG	66
Chem. gas	56
Refinery gas	56
Petro-cokes	96
Metallurgical coal	94
Steam coal	94
Cokes	107
Coke-gas	47
Methanol	70
RDF	58
Municipal solid waste	98

The transport system in the model was completely revised in order to incorporate relevant CO_2-reduction options, see also Appendix I. In the transport sector representation, fuel is transformed by various transport modes to meet projected demands for passenger-kilometres (pkm) in the passenger sector and tonnes-kilometres in the goods sector to 2010. For cars, efficiency (10^9 pkm/PJ) and availability factors (pkm/vehicle) and other figures for various transport modes were obtained from recent studies on transport undertaken by ESC - Energy Studies [5,6,7]. Only limited competition between the different transport modes (modal split) was allowed for within the demand projections. DG XVII transport demand projections (scenario 1 of the Energy 2010 study) were augmented by ESC and CBS (Netherlands) data. The resulting figures are higher because saving measures are excluded in the reference case. Final fuel demand for transport rises from 335 PJ in 1985 to 493 PJ in 2010.

The maximum penetration of cogeneration was estimated based on recent studies in the Netherlands [5]. All figures for heat and steam in the demand sectors were obtained from MEDEE projections and CBS (Netherlands) data.

3. OPTIONS FOR CO_2-REDUCTION

For the CO_2-study the EFOM-ENV database was augmented to include data on renewables from the DERE subprogramme, 'clean' fossil fuel combustion technologies, the FRET subprogramme, and the MURE subprogramme on end-use conservation and efficiency measures. Collection and incorporation of these data are described below.

3.1 Renewables (DERE subprogramme)

There are a number of renewable energy sources available in the Netherlands ranging from natural resources such as wind, geothermal and solar heat to the combustion of various forms of waste including municipal solid waste, landfill gas and forestry waste. The relevance of renewable energy sources to the present study is of course their virtual absence of CO_2-emissions. But sometimes municipal waste contains plastics, thus is contributing to CO_2-emissions when combusted. Depending on the method of disposal the marginal contribution to CO_2-emissions from the productive combustion of these wastes can therefore not always be counted as zero [1,2].

The DERE data incorporated in the database was collected from consultations of different experts within ECN/ESC. In selecting the renewables for incorporation into the model, some judgement had to be made to trade off technical potential – and hence the ability to contribute substantially to CO_2-abatement – and economic attractiveness. In many cases, the economics of renewable resources are site dependent. Where this was the case, several data sets were collected for the resource and incorporated in the model as successively more expensive 'tranches'. In this way, the model could take up those tranches it calculated as cost effective and not be left with an all-or-nothing choice of a resource characterised by an average price. The sources chosen and their fundamental parameters are described in Appendix I.

The Netherlands has a favourable climate for windpower. However potentials are limited by the high degree of urbanization. Five tranches, see Appendix I are distinguished reflecting increasing cost due to less favourable siting. Of course the off-shore windpower option is most costly [8].

The potentials for solar boilers and photovoltaic are also promising. But before 2010 the contribution under normal conditions is relatively limited.

For many years municipal waste has been burned to generate heat and electricity in the Netherlands. However burning waste is not without environmental risks, e.g. emissions of dioxine and amounts of CO_2 too, due to the presence of plastics.

The estimates of renewable potentials are realistic and not overly optimistic. Obviously the scope for renewables rises for the period after 2010, which is not included in the present study. This is particularly true if more efforts are devoted to R&D in this area and energy prices become much higher than used in the present scenarios. A summary of the data used is provided in Appendix I, table 5. An alternative way of summarising the data, as resource cost (equivalent price of output) and potential contribution, is shown in two figures in Appendix III.

3.2 Low CO_2-emitting technologies (FRET subprogramme)

A switch from relatively high to relatively low CO_2-emitting fossil fuel technologies can also provide substantial CO_2-reductions. In the framework of the FRET subprogramme data are collected for all relevant technologies.

Low CO_2-emitting FRET technologies concern mainly advanced natural gas using technologies with the exception of integrated coal gasification with combined cycle plants. This technology is also included. Presently, the majority of the considered technologies already play an important role in the Dutch energy sector. In addition to FRET technologies heat-pumps were also considered to be an option for CO_2-reduction in the Dutch study.

Gas technologies are important to reduce CO_2-emissions by their lower fuel carbon content and with their significantly higher conversion efficiency, see Appendix I for the data.

3.3 Energy conservation

Conservation measures have an important part in reducing emissions and in particular CO_2. In the framework of the MURE subprogramme data on penetration potentials, costs and other parameters concerning conservation were collected by ESC. Energy saving potentials were costed for each measure and aggregated in tranches according to their cost figures, see Appendix I.

Emphasis in the model was placed on conservation in the domestic and transport sector providing the largest scope for conservation. Conservation in industry and tertiary (public buildings, service and aggriculture) sector was not yet explicitly considered in this study. However the final and useful energy demand projections for these sectors contain implicitly energy conservation measures.

Furthermore in the projections in the domestic sector is already accounted for conservation in new houses. Explicitly in the model are options such as wall insulation, double glazing, roof and floor insulation, more efficient electric appliances, see Appendix I. Around 80% of total passenger kilometres demand is related to car use, so conservation options on these cars have a more significant impact than advances in new transport modes. Measures such as tune-up campaigns, additional technological progress, motor power speed limit, green waves, traffic management, increasing speed limit control, car pooling etc. were implemented in the model. Furthermore CNG, methanol and electric cars are also specified in the model to represent new transport technologies. Some options such as encouraging car sharing and behavioural changes by additional fuel taxes are assumed to have negligible cost to the energy system. There are costs involved, but 'external' to the agents in the energy sector and thus not considered in this study.

4. RESULTS

4.1 Considered cases

The CO_2-abatement measures are analysed within the framework of different scenarios (cases). The following cases are considered:

- **Reference case**
  This scenario shows the developments of the energy sector and related emissions (CO_2, NO_x and SO_2) resulting from presently prevailing regulations, energy planning and expectations by Ministries, utilities etc. and using a least-cost methodology. The given useful energy demand and energy prices are more or less in accordance with the 'Conventional Wisdom' Energy 2010 scenario of DG XVII. However, the scenario already contains options from the FRET and DERE subprogrammes, but excludes explicitly specified conservation options in the domestic and transport sector from the MURE subprogramme.
- **Conservation MURE-case**
  This scenario results also from a least-cost solution for meeting the simular useful energy demand, but **includes** explicitly specified end-use conservation options based on data from the MURE subprogramme.
- **CO_2-reduction cases**
  CO_2-ceilings are added as additional constraints in the model in accordance with the Commission's Communication to the Council on Community policy targets. These ceilings imply a stabilization (at 1988 level) of CO_2-emissions by the year 2000 and different reduction percentages for the year 2010. The reduction cases which were analysed are presented in table 2.

The cases were run with the nuclear energy option restricted to presently existing facilities and new plants cannot contribute. Furthermore no limitations were placed on natural gas supply and coal availability.

Table 2. CO_2-reduction cases, percentages from 1988 level for different cases

Cases	1995/2000	2010
Constant	0%	0%
5%	0%	5%
6.5%	0%	6.5%

In addition to the MURE and CO_2-reduction cases, mentioned above, a nuclear power variant was run for these cases with an additional CO_2-reduction option, viz. new nuclear plants after 2000.

4.2 Reference case

Final energy consumption is growing at a rate less than 1% p.a. between 1985-2010, viz. from 1998 PJ in 1985 to 2432 PJ in 2010, see table 3.

A look at the specific sectors reveals that in particular in the transport sector final demand rises substantially from 335 PJ in 1985 to 493 PJ in 2010, due to an increasing number of automobiles (5.5 million in 1985 to 7.7 million in 2010). The share of diesel cars is also increasing over this period.

Table 3. Final energy demand per sector (PJ)

	1985	1990	1995	2000	2010
Tertiary/Domestic	765	807	831	834	833
Industry	898	962	985	1013	1106
Transport	335	361	393	417	493
Total	1998	2130	2209	2264	2432

CO_2-emissions in the reference case rise substantially after 1985 to 1995 and after 2000, see figure 1. However between 1995 and 2000, mainly due to further expansion of CHP, small amounts of renewables and an increasing share of gas-fired power plants, CO_2-emissions rise only slightly. Hence the CO_2-level in 2000 is 8.7% higher than in 1988. Consequently the reference scenario includes already the contribution of several advanced gas-using technologies such as new topping gas-fired (combi) plants and combined cycle plants see Appendix II. The contribution of CHP is also large and in line with present projections for electricity generation in 2010, viz. ca. 1700 MWe by public utilities and about 2800 MWe by private industries and companies. As a result CO_2-emissions for the reference case rise from 140 Mt/a in 1985 and 146 Mt/a in 1988 to 177 Mt/a in 2010 (a rise of 22% compared with 1988).

Renewables contribute for around 45 PJ in the reference scenario in 2010, with largest shares for wind power and waste incineration. Obviously, due to changing energy policies in 1990 CO_2-emissions grow less than envisaged before in the Netherlands [9].

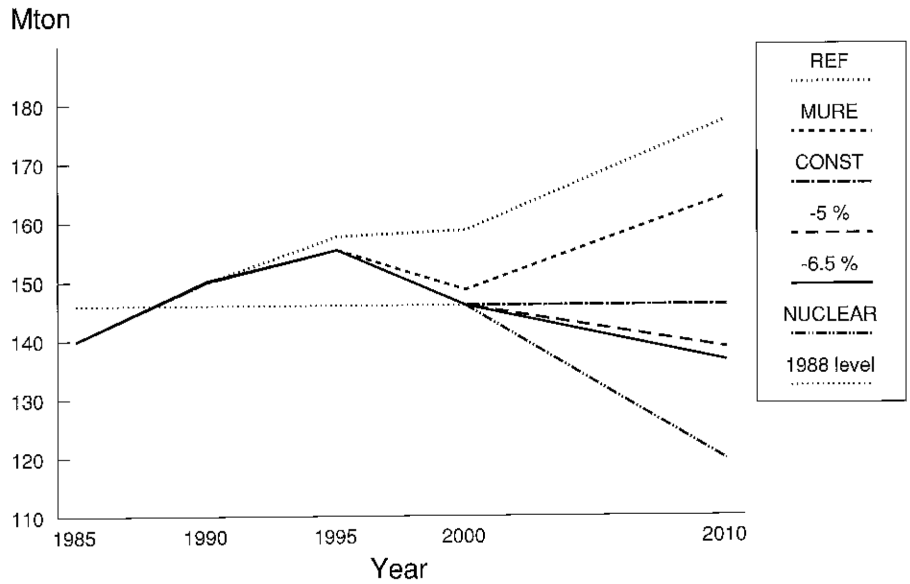

Figure 1. CO_2-emissions in the Netherlands (Mt/a)

4.3 Conservation (MURE) case

A major contribution in reducing CO_2 from the energy sector results from energy efficiency improvements and conservation measures in the end-use sectors. A large part of the potential conservation measures in domestic and transport sector prove to be cost-effective from a national view point, see also Appendix II. Implementation of the conservation measures results in national cost savings.

Except for expensive options minimum energy houses, double glazing and roof insulation all conservation measures such as more efficient lighting and appliances, wall-insulation etc. in the domestic sector are cost-effective. For the resulting final energy demand see figure 2.

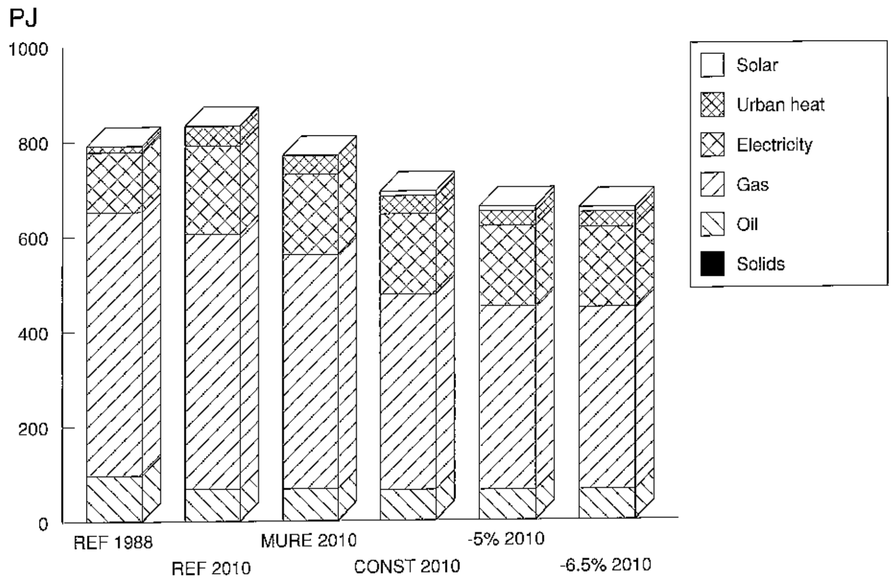

Figure 2. Final energy demand tertiary domestic sector (PJ)

But even more important is the reversal of the steep growth of fuel use for transport, if cost-effective conservation measures are applied in this sector. Changes in behaviour by additional fuel taxing, tune-up campaigns and speed limitation and most of all introduction of motor power speed limit contribute to a major decrease in fuel use, see also figure 3. Only high-efficiency cars, trucks and ships are not effective in this case.

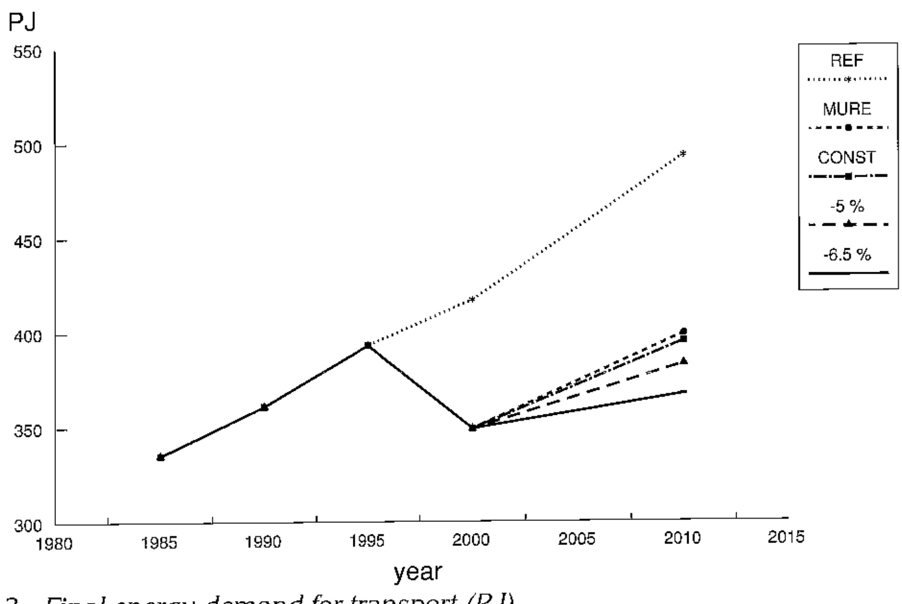

Figure 3. Final energy demand for transport (PJ)

Although the final energy demand in industry is not affected by the different cases, see Appendix III, the fuel mix and demand in the other sectors such as power, tertiary/domestic and transport sector changes due to conservation and improved conversion efficiency.

The impacts from final energy demand reduction (by conservation) on CO_2-emissions is impressive, see figure 1. CO_2-emissions are reduced from 177 to 164 Mt/a in 2010. In particular emissions in the transport sector decline in the conservation case, see Appendix III. Besides substantial cost, NO_x-reductions are also achieved in the conservation case, see figures in Appendix III. SO_2-reductions are smaller due to the large contribution of gas in the reference case.

In summary, after allowing explicitly energy savings in the model (MURE case), apart from these already implicitly in the useful demand projections, 18 PJ electricity was saved additionally by using more efficient lighting, freezers and fridges. In total ca. 63 PJ in the domestic sector and 94 PJ in the transport sector are additionally saved in 2010. The majority of savings, around 80% of the potential savings, seems to be cost-effective. Note that a substantial part of the savings in transportation can be achieved without additional energy cost, see Appendix I and II. Only high-efficiency cars, trucks and ships, double glazing, roof insulation and new minimum energy houses are not cost-effective in this case. CO_2-emissions decline in particular in the transport sector.

4.4 CO_2-reduction cases

By imposing increasingly higher reduction rates on the total allowable CO_2-emissions in the Netherlands for 1995/2000 and 2010 a substantial decline of CO_2-emissions in 2010 is attainable. Besides the three reduction levels, including explicitly specified conservation (MURE) measures, also two reduction cases (+12.6% and +5.6% compared with the 1988 level), excluding explicitly specified conservation measures are investigated, see figure 7. Furthermore the CO_2-reduction impact from allowing new nuclear capacity to contribute to electricity production was analysed with additional runs. Obviously a further imposed decline of CO_2 results in an implicitly higher cost of relatively higher CO_2-emitting fuels and thus a gradual reduction of their use on a least-cost basis, e.g. see figure 4.

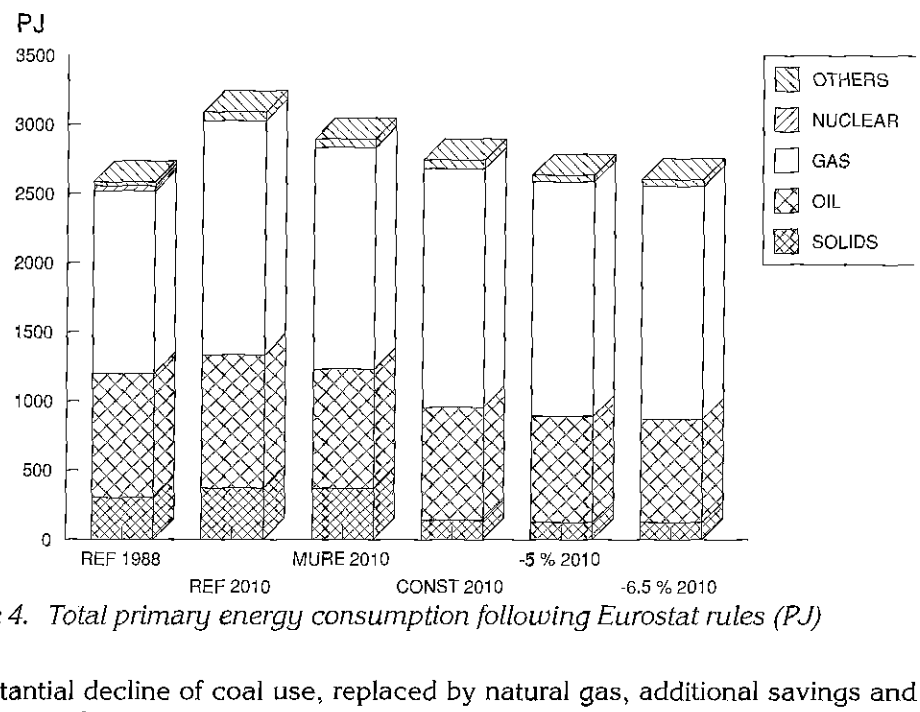

Figure 4. Total primary energy consumption following Eurostat rules (PJ)

A substantial decline of coal use, replaced by natural gas, additional savings and further penetration of renewables are required to attain a constant, 5% and 6.5% CO_2-reduction from the 1988 level in 2010, see Appendix II. These reduction rates can only be attained by not using coal-fired plants in the power sector build before 1995 and replace them by gas-fired combined cycle plants for electricity production.

Furthermore less waste incineration plants (CO_2-emitting) are used and more expensive saving measures such as minimum energy houses, very efficient cars, ships and trucks are penetrating in the extreme reduction cases.

Striking is the extensive penetration of heatpumps in the tertiary and domestic sector in the extreme reduction cases, see Appendix II. Space heating represents a significant part of the Dutch energy demand. Together with the mild winter climate and the long heating season this provides good opportunities for heatpumps.

The changes in the power generation sector are most notable, viz. a complete disappearance of coal use (replaced by natural gas fired technologies such as combined cycle, gasturbines, fuel cells, high efficiency topping gas fired plants etc.), see figure 5 and Appendix III.

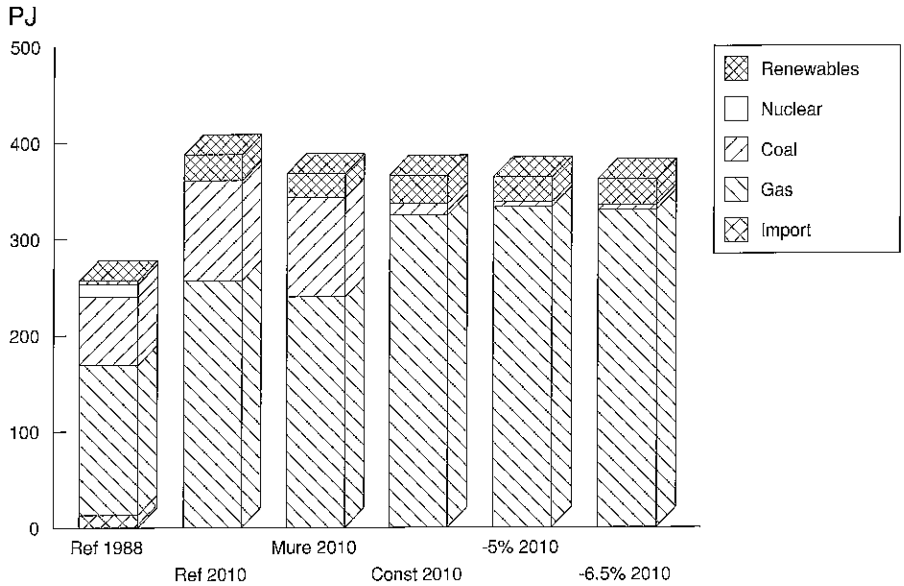

Figure 5. Total electricity production by primary energy sources (PJ)

The technology shift to relative low CO_2-emitting fossil fuel technologies is even more remarkable. The so called FRET technologies penetrate for 78% of the electricity production and the renewables contribute for 7.5% in 2010 in the -6.5% case, see Appendix III. Of course the results for the electricity generation are open for debate and strongly depending on the following assumptions:

- Acceptability of an almost complete dependency on natural gas supplies.
- Excluding nuclear energy.
- The penetration potentials of renewables.
- Premature retirement of coal-fired power plants.
- Neglecting price reactions from limited overall gas supplies.

4.5 Nuclear power variant

In this variant the MURE and CO_2-reduction cases are run with an additional CO_2 reduction option, new nuclear power plants. In the conservation case 4800 MW will be installed in the public electricity generation sector after 2000. According to the power generation planning (nuclear scenario) of the utilities nuclear capacity is allowed to expand to 5600 MW, producing more than 40% of the national electricity demand, in 2010 [10]. Compared with the conservation case without nuclear power, advanced coal-fired plant capacity is two times lower, modern topping gas plant capacity is reduced from 4700 MW to 1300 MW. Also a small reduction of wind power and combined cycle power plant CHP capacity occurs in the nuclear case.

In the constant case the nuclear capacity hardly grows compared with the capacity in the MURE-case. In contrast with the constant case without nuclear, new and retrofited coal plants and waste incineration plants keep producing. Wind and hydro power do not expand. Also additional conservation measures (insulation package 2 for single family houses, more efficient gasoline vans), gas heatpumps and solar boilers with natural gas back-up are not introduced.

To reduce 5% of the CO_2-emissions compared with the 1988 level, the model prefers to install a maximum nuclear power capacity of 5600 MW. The advanced topping gas plant capacity expands slightly and solar boilers with natural gas backup for new single family houses are introduced.

CO_2-emission reductions ranging from 5 to 18% are attained in a similar way as in the non-nuclear CO_2-reduction cases. But the public electricity generation costs are relatively lower than in the non-nuclear cases. Competition between electric heatpumps and other heating systems is not affected. The additional CO_2-reduction by nuclear power is 16.8 Mton. Furthermore the CO_2-reduction potential of electricity saving measures in the domestic sector is reduced by the penetration of nuclear power. However, the cost-effectiveness of the conservation options is not changed.

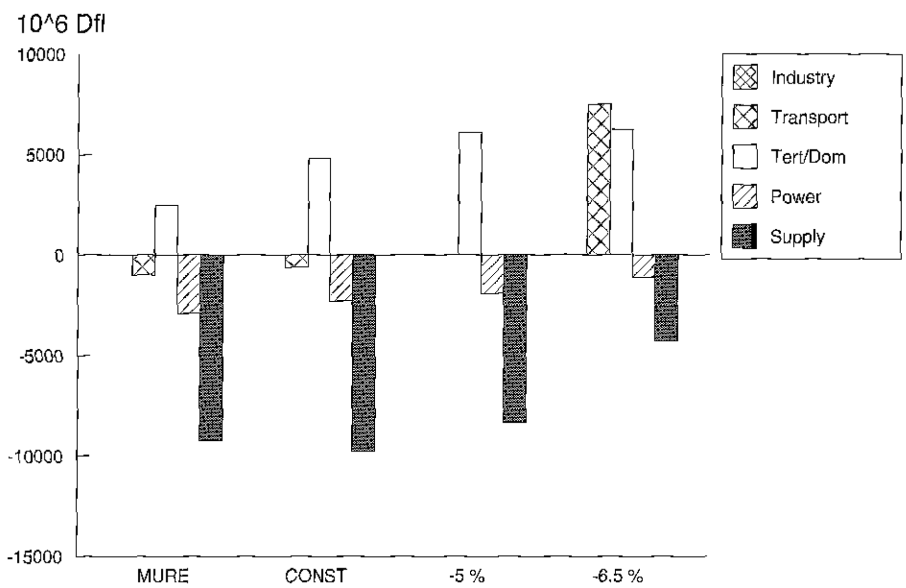

Figure 6. Sectoral cost differences with the reference case of CO_2-reduction cases (10^6 Dfl-85)

4.6 Costs and emissions

By comparing the different cases information about trade-offs between abatement cost and CO_2-reduction can be derived. Cost increases and emission reduction impacts vary among different sectors, see figure 6.

The conservation case clearly induces substantial energy cost reductions in the supply and electricity generation sectors by avoiding fuel and investment costs. In the transport sector the cost reductions are attained by 'saving' on fuel tax. Fuel cost savings are a large part of the cost reductions occuring in the supply sector.

Notably, the CO_2-abatement costs rise sharply in the transport and tertiar/domestic sectors *if CO_2-reductions of 5% of more are pursuited. Also the supply costs are higher* mainly due to increasing gasoil, gasoline, kerosine etc. supply costs resulting from rising imports instead of domestic production.

Furthermore coal-fired plants are prematurely retired and replaced by additional gas-fired capacity and more expensive renewables such as photovoltaics and offshore wind power, resulting in cost rises in the power sector. Conservation measures account for ca. 63 PJ in the domestic and ca. 94 PJ in the transport sector. However abatement costs are still a relatively moderate part of total sector costs, see Appendix III.

Changes in total discounted system costs of the energy sector resulting from a gradual CO_2-emission reduction are presented in figure 7. Three CO_2-cost reduction curves are presented in figure 7. CO_2-reduction without allowing for explicitly in EFOM-ENV defined conservation (MURE) measures results in CO_2-reductions of +12.6% and +5.6% in 2010 compared with the CO_2-level in 1988. Clearly, allowing for conservation measures reduces total discounted system costs of the energy sector substantially. The impact of conservation measures according to the MURE subprogramme is substantial and results in overall reductions of -6.5% in the non-nuclear variant. Allowing for expansion of new nuclear power plants to contribute to the CO_2-reduction increases the CO_2-reduction substantially.

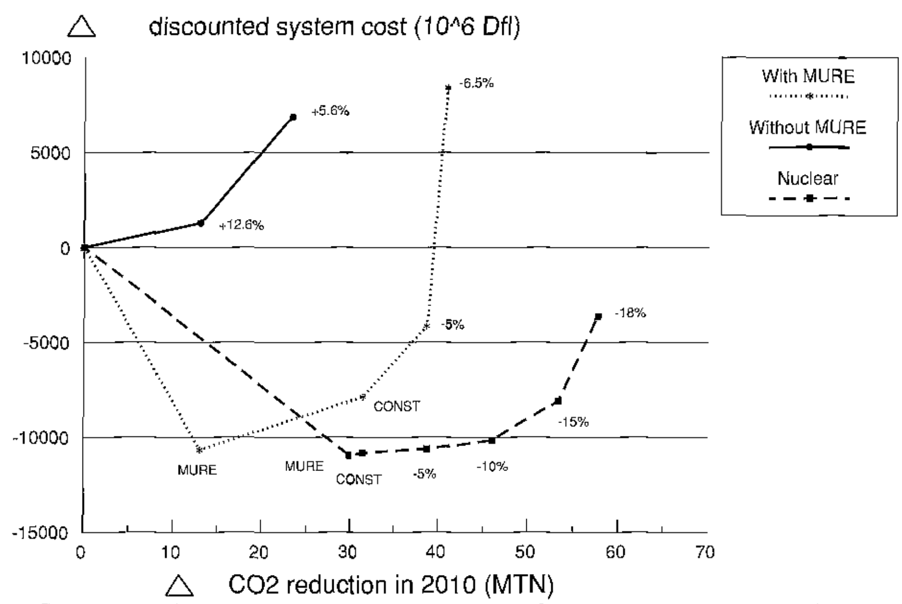

Figure 7. Discounted system costs versus CO_2-reduction, compared with the reference case (Mton, 10^6 Dfl-85) *

Given a fixed 5% discount rate, conservation leads to a reduction of system cost from a national point of view. Remember conservation results also in additional revenues by avoiding supply costs such as fuel, transport and production costs. In fact this integrated cost evaluation method points at implicit benefits from implementing conservation measures and penetration of renewables from a national point of view.

Clearly allowing for expansion of nuclear power capacity results in increasing CO_2-reductions against relatively lower additional costs. This variant is explained in section 4.5.

* Percentages refer to a change in CO_2-emission in 2010 compared to 1988.

5. DISCUSSION

5.1 Conservation

Figure 7 shows clearly the effectiveness of energy conservation to reduce CO_2. Supply efficiency options and end-use conservation measures are both incorporated in the model so that equal precedence would be given to demand and supply side technologies for reducing CO_2. The model takes up those measures it considers cost effective for an immediate impact on CO_2-emissions.

An implication of the methodology used is that the model calculates the attractivenes of energy saving on the basis that all investment decisions are made with a 5% (real) discount rate. It might be argued that the use of a 5% discount rate will overestimate the number of profitable investments which could be made by companies, who should perhaps use higher rates. However, the model results indicate that some of the ca. 230 PJ of cost effective energy saving measures available in 2010, are enough to keep energy demand in that year at the 1995 level. The figure of 230 PJ obtained in the model does not look unreasonable, and if anything may be an underestimate, because conservation in industry and tertiary sectors, e.g. agriculture was not included.

At this stage it is worthwhile to recall that the approach taken in this study is very much one of analysing what might happen given the behaviour of the various economic agents as specified in the model. In this and other studies of energy conservation it has been noted that consumers and even companies frequently do not invest in energy conservation and efficiency even though these investments have a positive net present value. As a result, this study can do no more than point to the possibilities of what could happen provided ways of implementing conservation measures can be found. Indeed, the reason for using a 5% rate was that the results so obtained show where investment should be encouraged through the use of policy measures. It is beyond the scope of this study to say what these policy measures should be although many have been discussed including efficiency regulations, appliance labelling and an energy tax.

However, without policy intervention, the investments will not always take place since they are partly non-optimal from the investors' perspective. But since there are fewer economic agents involved at the supply side, implementation of effective policies may be easier there than on the demand side of the energy sector. Assumed options here include investment subsidies, minimum quotas for low emission electricity production, or a carbon based fuel tax.

At this stage it is useful to remember other limitations of the modelling approach. For example there are other investment reasons than economic ones such as social and strategic, it is a partial (no feed-back via prices, rents etc. by the economy) analysis and market imperfections are limiting penetrations as calculated by EFOM-ENV.

6. CONCLUSIONS

The results from this study are clear: it is technical/economical possible to reduce CO_2-emissions by at least 6.5% of their 1988 level in 2010. By allowing building new nuclear power plants a CO_2-reduction of 18% can be attained. However, to achieve these reductions development of policies to persuade people to invest in energy saving measures are required. This study has analysed in depth the following cost-effective measures to reduce CO_2-emissions:

- Conservation in the domestic and transport sectors.
- Fuel substitution from coal to natural gas.
- Technology substitution to gas technologies with a high conversion efficiency (e.g. Fuel Cells, Heat Pumps, Combined Cycle Plants and CHP).
- Introduction of cost-effective renewables such as windpower, solar boilers etc.
- Nuclear power plants, if acceptable to the public.

Obviously more research on conservation options, in particular in industry and tertiary sectors, renewables and their market potentials, is required to arrive at more definite conclusions.

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APPENDIX I: DATA CO_2-REDUCTION OPTIONS

MURE: Energy conservation

Apart from some energy conservation measures implicitly considered in the scenario (for instance all kinds of insulation in new houses), the following measures are considered explicitly in EFOM-ENV:

Table I.1. Energy conservation data for the domestic sector

Insulation measures	cost Dfl-85/GJ/yr	potential PJ/yr
Floor (old houses)	95	8.9
Retrofit (old houses)	182	17.2
Cavity walls (old houses)	203	16.6
Total insulation tranche 1	172	43
Roof (old houses)	270	14.7
Double glazing (old houses)	432	9.2
Minimum energy houses (new houses)	459	10.7
Other wall (old houses)	527	10.7
Total insulation tranche 2	409	45
More efficient appliances	**marginal costs Dfl-85/kWh/yr**	**potential TWh/yr**
Lighting bulb 1	.05 – .02	1.6 – 2.1
Lighting bulb 2	.3 – .09	.24 – .27
Refrigerators 1	.07	.4-1
Refrigerators 2	.1	.3-.7
Freezers	.1	.3-.8
Note: cookers and washing machines are not considered		

For the transport sector the following measures were optional:

- More efficient vehicles:
  - tune up campaign;
  - technological (efficiency) progress;
  - motor power speed limit;
  - brake energy storage;
  - effectiveness improvement.
- Traffic control measures:
  - green waves;
  - adaptation of traffic lights;
  - traffic management.
- Behavioural changes:
  - speed limit control;
  - taxation;
  - car pooling.

Note that no modal split measures were considered yet.

Table I.2. Energy conservation data for passenger transport

	Saving		Cost (Dfl-85/vehicle)
Future passenger car 1	10%		3300
Future passenger car 2	10%		3300
Vans:	2000	2010	
Autonomous measures:			
New stock	10%	10%	–
Technological progress	4%	6%	–
Total	13%	15%	–
Additional:			
Technological progress	3%	4%	4000
Traffic control measures	2%	2%	50
Motor power speed limit	10%	17%	–
Tune up campaign	3%	3%	1000
Speed limit control	5%	5%	–
Total	21%	28%	5050

Table I.3. Energy conservation data for trucks and others

Trucks	Saving		Cost Dfl-85/vehicle
	2000	2010	
Autonomous measures:			
Efficiency improvement	12%	19%	10000
Effectiveness improvement	2.5%	3.5%	2000
Total	14.2%	21.8%	12000
Additional:			
Technological progress	2%	2%	3000
Effectiveness improvement	2%	2%	1000
Energy storage	3%		13000
		6%	25000
Total	7%		17000
		10%	29000
Trains	2000	2010	
Autonomous	8%	12%	2000
Additional	5%	8%	15000
Ships	2000	2010	
Autonomous	8%	12%	20000
Additional	4%	8%	100000

FRET: Low CO_2-emitting fossil fuel technologies

The following technologies are considered:

- Integrated coal gasification with combined cycle power plants (CGCCPP).
- Fuel cell.
- Combined cycle power plants (CCPP).
- Topping of gas firing power plants.
- Total Energy Systems or piston engines with heat recovery (TES).
- Gas turbines for power and heat.
- Back pressure turbine for power and heat.
- Heat-pump (electric and gas).

Table I.4. FRET technology data

FRET technologies	Inv cost	Var cost	Fix cost	Load fac	Eff.	Life time	Elec. share
	Dfl-85/ kW	Dfl-85/ GJ	Dfl-85/ kW			year	
Coal gasification CCPP	2260	4.7		0.8	0.42	25	1
Fuel cell	2000	1		0.5	0.6	25	1
Conv. topping gas plant	1430	2.865		0.8	0.46	25	1
New topping gas plant	1300	1.4		0.8	0.46	25	1
CCPP	1430	2.865		0.8	0.46	25	1
TES heat (self)	1200	2	36	0.5	0.82	15	0.48
TES (urb)	710	2	36	0.8	0.82	25	0.48
TES greenhouses (urb)	708	2	36	0.8	0.82	25	0.48
CCPP small (self)	709	1.41		0.5	0.84	15	0.37
CCPP (self)	466	0.93		0.75	0.84	15	0.37
CCPP (urb)	643	1.63		0.8	0.85	25	0.48
Gasturbine (self)	383	0.77		0.75	0.84	15	0.3
Gasturbine heat (self)	235	0.4		0.75	0.70	15	0.1
Gasturbine small (self)	575	1.2		0.5	0.84	15	0.3

Note:
urb =Public Urban Combined Heat and Power Subsector
self =Combined Heat and Power in Industry Sector
=Public Central Electricity Producing Sector

DERE: Renewable energy sources

The following technologies are considered:

- Wind turbines (onshore and offshore).
- Hydro power.
- Photovoltaics.
- Solar boilers.
- Geothermal energy.
- Waste incineration.
- RDF in TES.
- Sewage and effluent purification, landfill gas production and manure digestion.
- Waste wood in TES.
- Wood stoves.

Table I.5. Data DERE technologies in 2010

Technology	Potential	Inv cost	Var cost	Load fac	Effic. 'cy	Avail after year
Electricity plants	MW	Dfl-85/kW	Dfl-85/kWh			
Wind-on	2500	1510-1940	.017-.024	.24-.18	1	
Wind-off	500	5000	.032	.21	1	2000
Photovoltaic	500	15000	.09	.114	1	1990
Hydro	93	5-10000	.025-.051	.56	1	
Heat prod.	PJ	Dfl-85/GJy	Dfl-85/GJ			
Solar boiler	19	417-505	3.78-4.42	1	.82-.92	1990
Geothermal	1.2	175	5	1	1	2000
Waste heat	1.9	45	2.75	.8	.8	
CHP	MW	Dfl-85/GJy	Dfl-85/GJ			Elec. share
RDF TES	47	31.7	5.96	.8	.7	0.48
Waste water	410	31.7-38	5	.8	.7-.8	0.48
Inc. waste	1454	31.7	6.125	.8	.6	0.5
Waste wood	168	9.5	1	.43	.52	0.13

APPENDIX II: RESULTS FOR DIFFERENT CASES

Table II.1. Contribution central and decentral electricity producing technologies in 2010 (PJ)

Electricity and heat thermic production	Cases					
	REF	MURE	CONS	-5%	-6.5%	max[1]
Public Electricity						
LWR						0
Import						0
Gasturbine	13	9	27	30	30	
Oil/gas plant	4	4	5	7	6	18
Conv. topping gas plant						0
New topping gas plant	125	119	125	125	125	125
Fuel cell	8	5	8	8	8	8
CCPP	19	19	69	75	75	76
Coal gasification CCPP[2]	7	6	5	5	5	22
New coal plant	60	60	0			60
Cokegas plant	12	10	12	12		18
Retrofit coal plant	37	37	6	0	10	37
Conv. coal plant						0
Industrial CHP[3]						
Back-pressure small	10	10	10	10	10	12
Back-pressure	50	50	52	52	52	54
TES heat	1	1	1	1	1	1
CCPP small	17	17	17	17	17	17
CCPP	35	35	35	35	35	35
Gasturbine small	10	10	10	10	10	10
Gasturbine	55	55	55	55	55	55
Gasturbine heat	14	6	14	4	4	
Public CHP						
Back-pressure coal						
Back-pressure turbine						0
Back-up heat						
Diesel engine	1	1	0			13
TES	18	16	17	17	17	23
TES greenhouses	7	7	7	7	7	23
CCPP	29	29	35	33	33	58

[1] Maximum penetration with maximum capacity available (for large plants 0.8)

[2] CCPP is Combined Cycle Power Plants

[3] CHP is Combined Heat and Power

Table II.2. Central and decentral electricity producing DERE technologies in 2010 (PJ)

Electricity and heat thermic production	REF	MURE	CONS	-5%	-6.5%	max[1]
Hydro 1	1	1	1	1	1	1
Hydro 2			1	1	1	1
Wind 1 (self)	4	4	4	4	4	4
Wind 2	2	2	2	2	2	2
Wind 3	3	3	5	5	5	5
Wind 4	1	1	5	5	5	5
Wind 5 (off-shore)				3	3	3
Photovoltaics	0	0	0	0	2	2
Geothermal (urb)	0	0	0	1	1	1
TES waste (urb)	8	8	8	8	8	9
TES RDF (urb)	1	1	1	0		1
Waste incineration (urb)	21	19	12			37
Waste incineration heat (urb)						2
TES waste water (self)	1	1	1	1	1	1
Wood (TE and stoves) (self)	2	2	2	2	2	2
TOTAL	576	548	552	536	535	

[1]Maximum penetration with maximum capacity availability (for large plants 0.8)

Note:
urb = Public Urban Combined Heat and Power Subsector
self = Combined Heat and Power in Industry Sector
= Public Central Electricity Producing Sector

Table II.3. Contribution on production in useful energy by CO_2-reducing technologies in Tertiary/Domestic sector in 2010 (PJ)

Technology	REF	MURE	CONS	-5%	-6.5%	max
Solar share boil gas (old houses)	0.2	0.2	5	5	5	5
Solar share boil gas (new houses)	0.2	0.2	4	4	4	4
Solar share boil elec (old houses)	0.5	0.5	0.5	0.5	0.5	0.5
Solar share boil elec (new houses)	0.4	0.4	0.4	0.4	0.4	0.4
High eff. gas boilers (sfh heat)	135	115	93	93	93	
High eff. gas boilers (mfh heat)	29	24	26	22	22	
High eff. gas boilers (comm. heat)	40	40	40	24	24	
High eff. gas boilers (coll. heat)	57	54	49	46	46	
Gas-heatpump sfh heat			22	31	31	
Gas-heatpump commercial heat			5	25	25	
Gas-heatpump collective heat	0.2	0.2	26	25	25	
Gas-heatpump greenhouse heat				42	42	
Elec-heatpump sfh heat					2	
Elec-heatpump mfh heat					0.5	
Elec-heatpump commercial heat					0	
Elec-heatpump greenhouse heat					0.8	
Saving bulb 1		7	7	7	7	7
Saving bulb 2		1	1	1	1	1
Saving fridge 1		4	4	4	4	4
Saving fridge 2		3	3	3	3	3
Saving freezer		3	3	3	3	3
Insulation mfh 1		9	9	9	9	9
Insulation mfh 2				9	9	9
Insulation sfh 1		34	34	34	34	34
Insulation sfh 2			36	36	36	36

Note:
sfh is single family houses
mfh is multi family houses

Table II.4. Contribution in useful energy by CO_2-reducing measures in Transport sector

Measures	REF	MURE	CONS	-5%	-6.5%	max
Fuel tax impact		21	21	21	21	21
Traffic measures		8	8	8	8	8
Tune up and speed limit		17	17	17	17	17
Savings ships (goods)					9	9
Savings rails (goods)		0.7	0.7	0.7	0.7	0.7
Efficient trucks	48	48	48			48
Extra efficient trucks				48	48	48
Efficient vans gasoline			2	2	2	2
efficient vans gasoil				3	3	3
Car1 motor power limit		82	82	82		82
Car2 motor power limit		11				11
Car1 extra techn. progress					82	82
Car 2 extra techn. progress			11	11	11	11
CNG car	0.1	0.1	0.1	0.1	0.1	0.1
Methanol car	0.4	0.3	0.3			03 - 0.4

APPENDIX III: ADDITIONAL FIGURES OF RESULTS

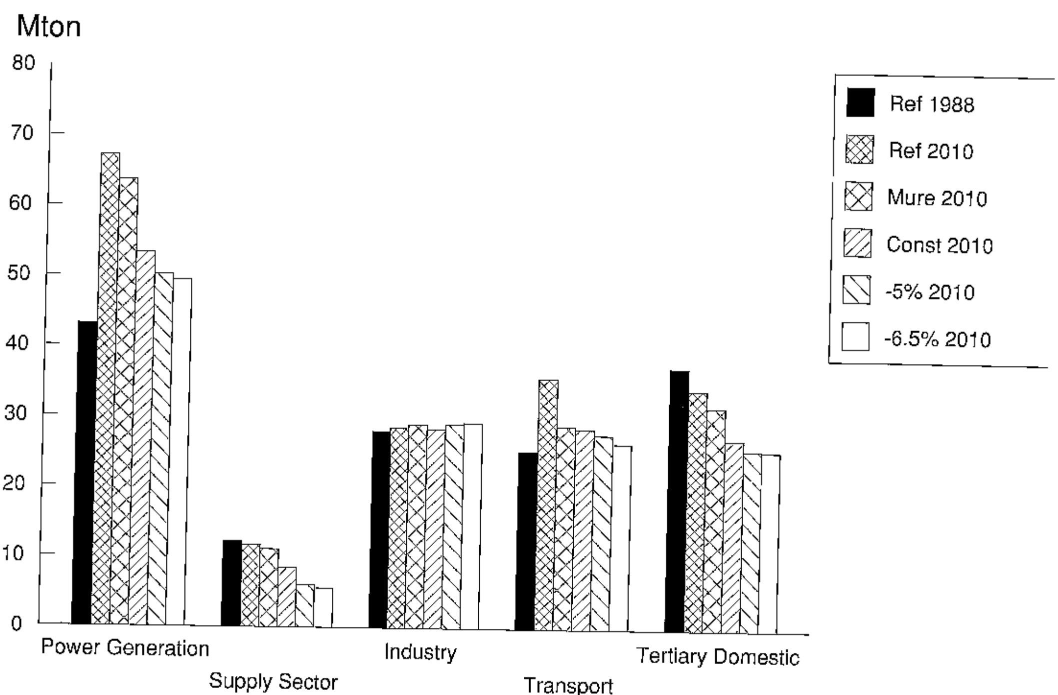

Figure III.1. Sectoral CO_2-emission (Mton/y)

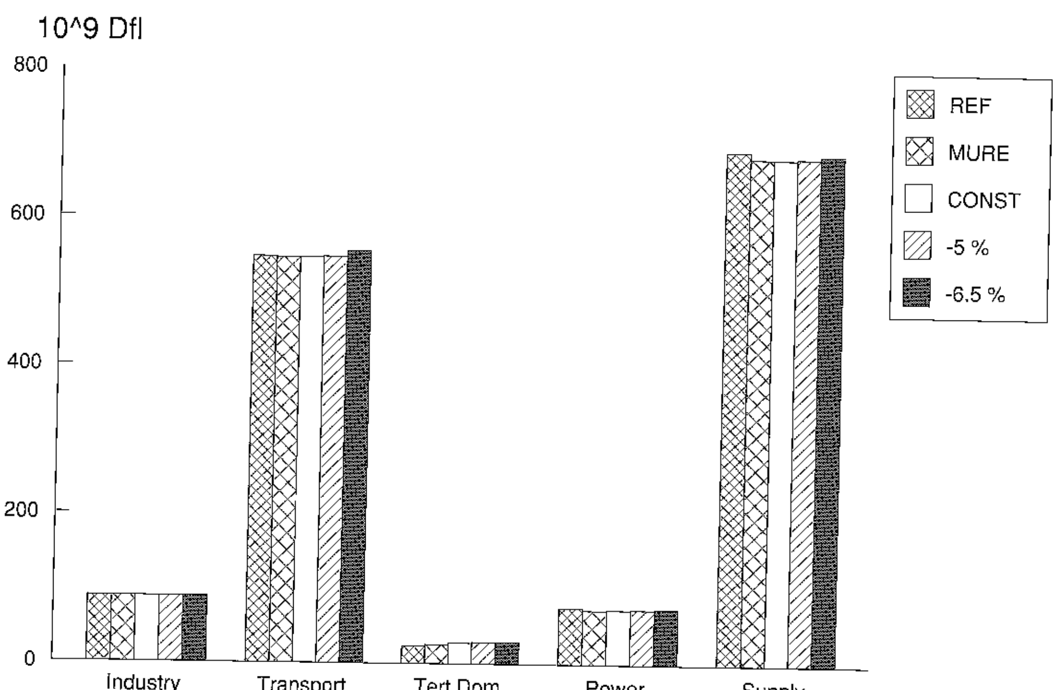

Figure III.2. Sectoral costs (10^9 Dfl-85/y)

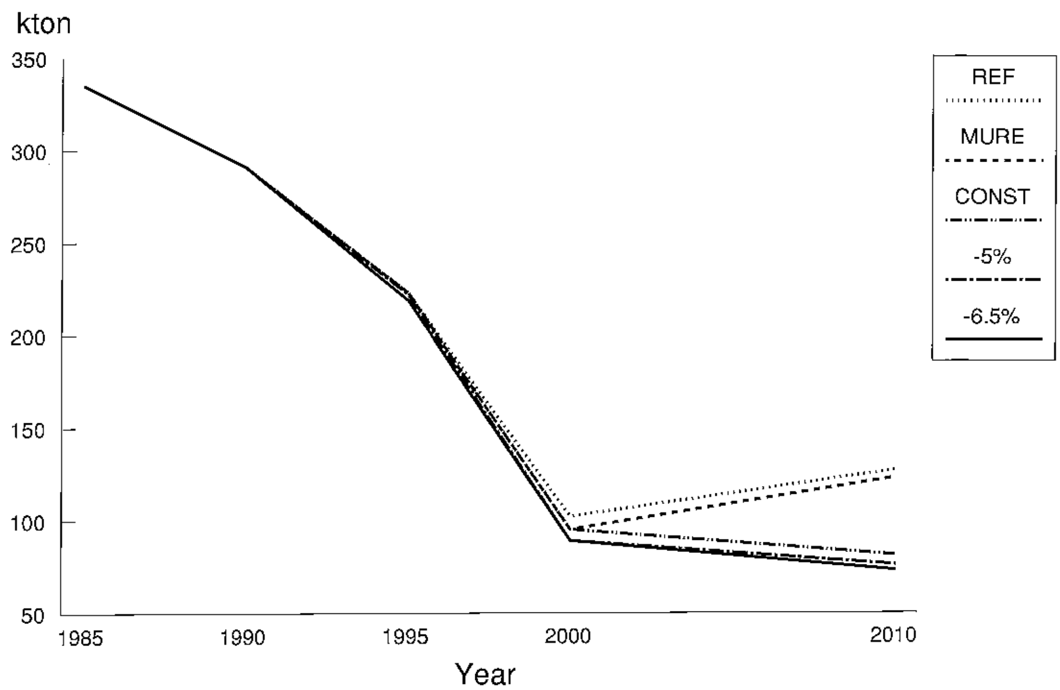

Figure III.3. SO_2-emissions 1985-2010 (kton/y)

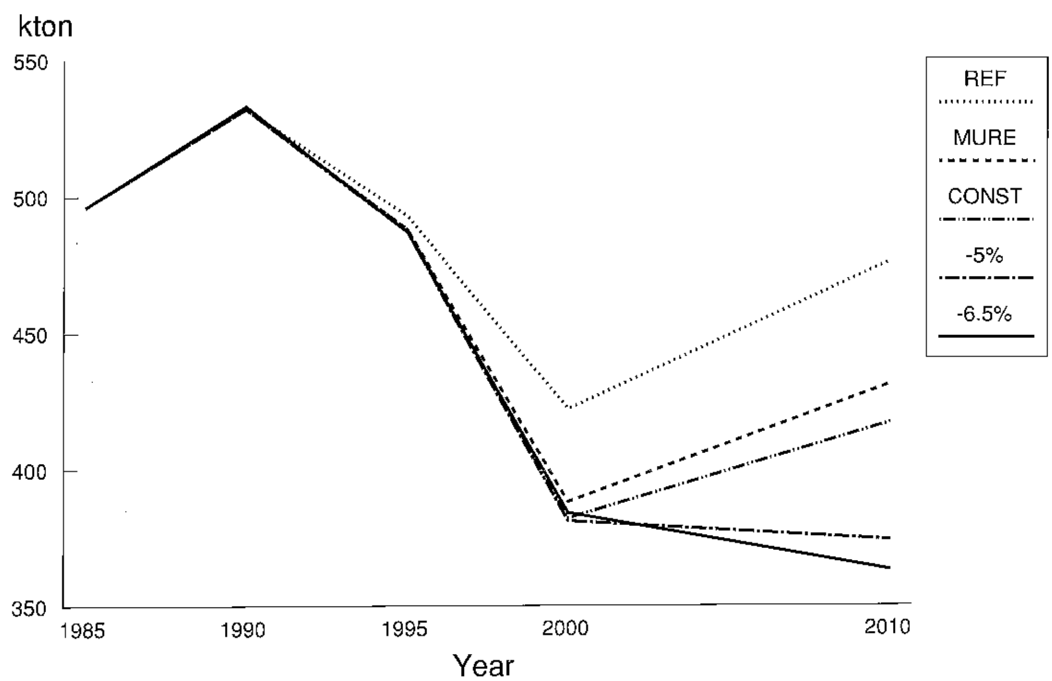

Figure III.4. NO_x-emissions 1985-2010 (kton/y)

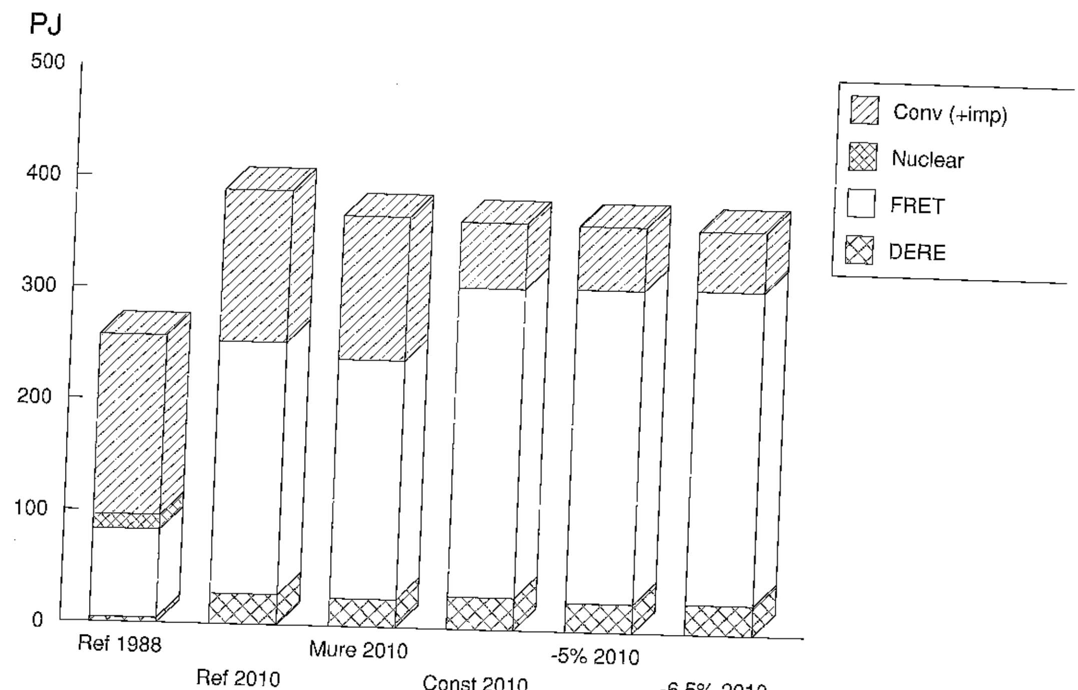

Figure III.5. Electricity production by different types of technologies (PJ/y)

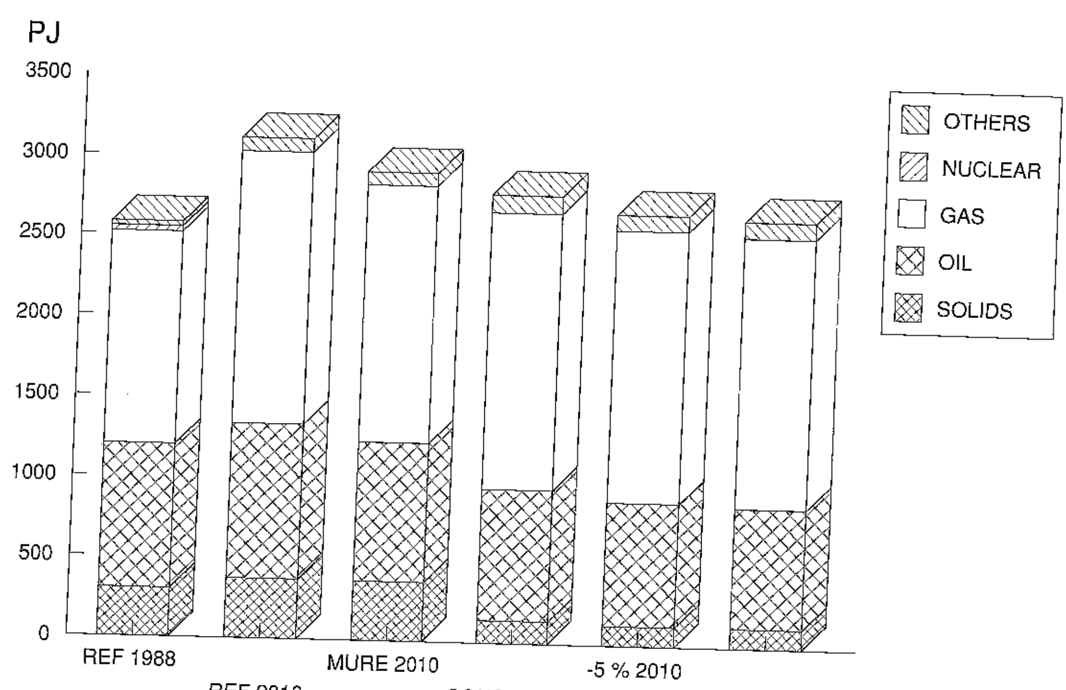

Figure III.6. Primary energy requirements following OECD rules (PJ/y)

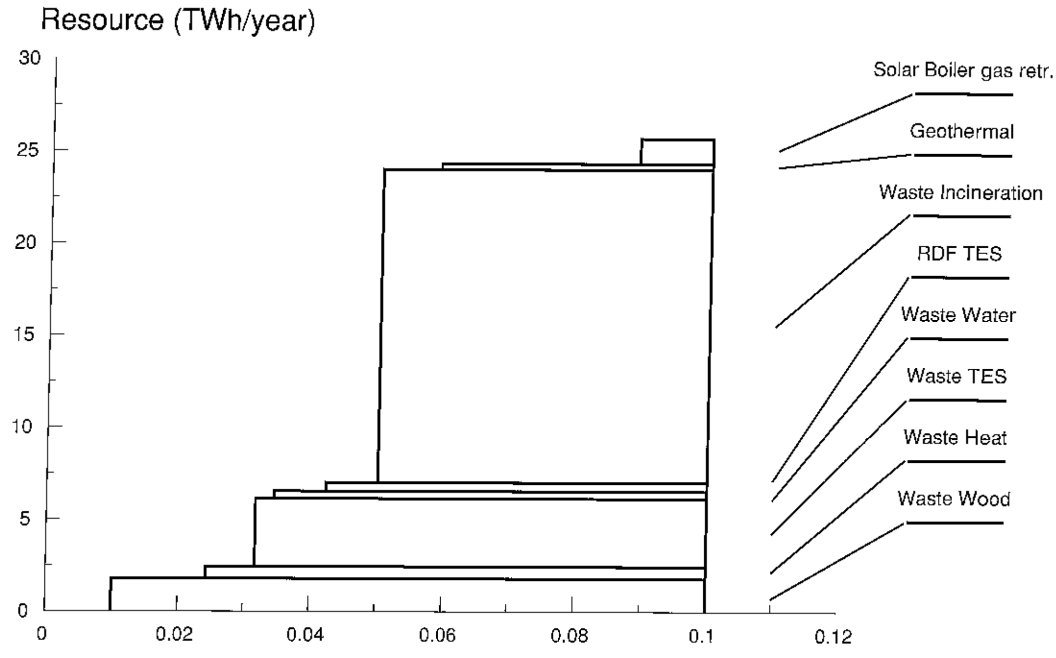

Figure III.7. Cost-curve heat and CHP DERE technologies (TWh/y)

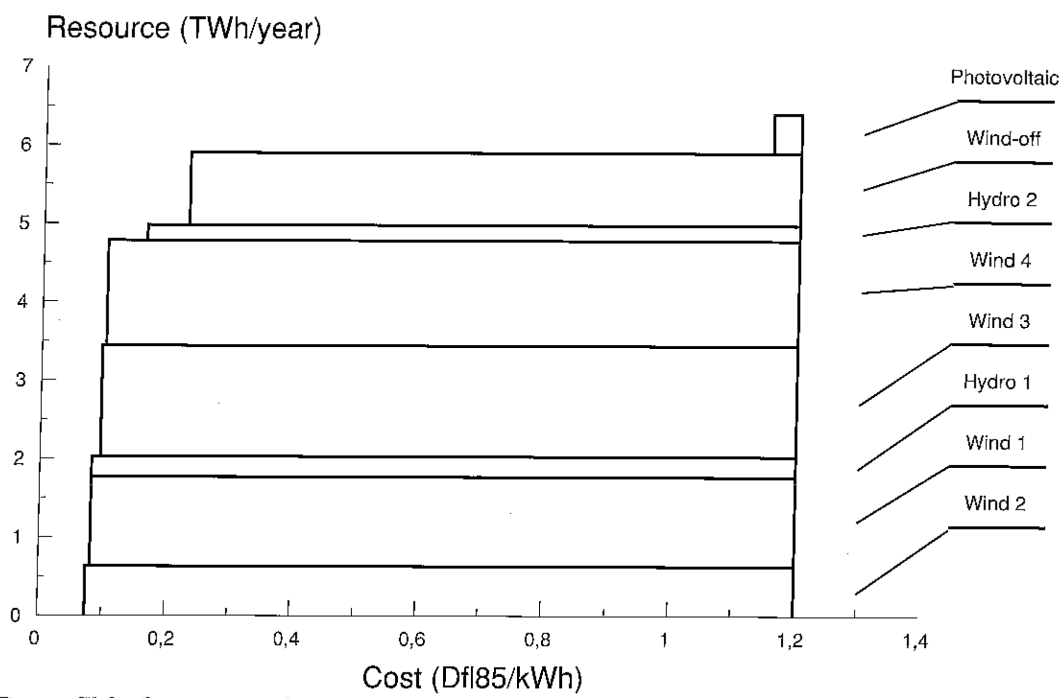

Figure III.8. Cost-curve electricity DERE technologies (TWh/y)

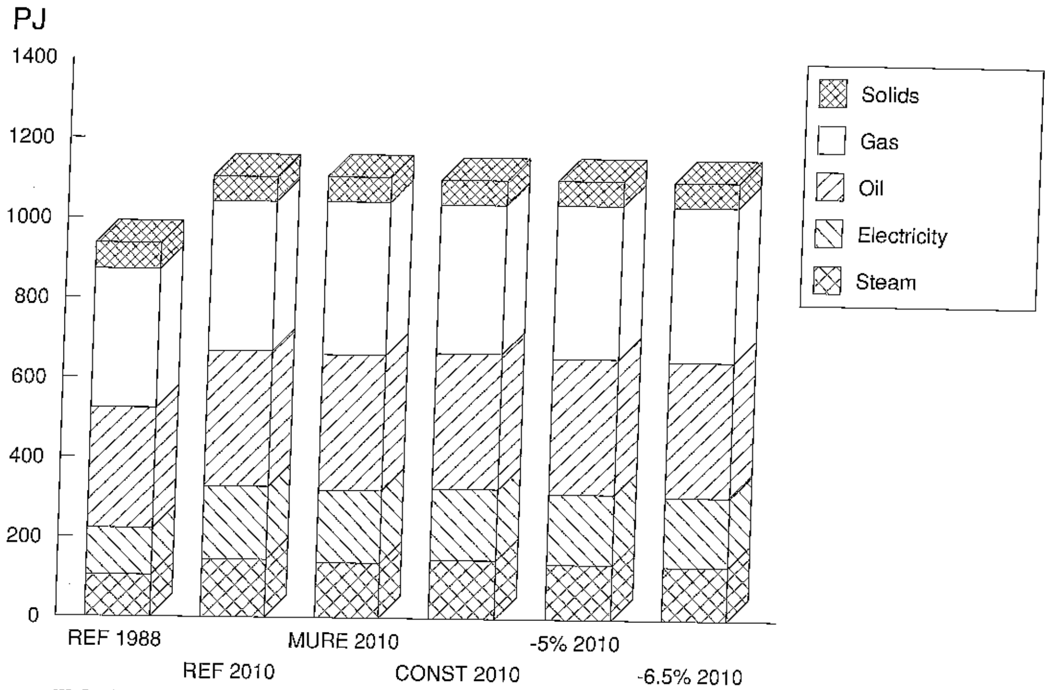

Figure III.9. Final energy demand industry sector (PJ/y)