The cost effectiveness of CO_2 emission reduction achieved by energy conservation

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The potential for improving energy efficiency in the Netherlands up to the year 2000 is discussed with the help of a database containing 300 energy conservation techniques. Investigations show that technically it is feasible to reduce emissions by 41% by applying all the energy conservation techniques. The policy of the Dutch government is directed to increase energy efficiency between 1990 and 2000 by about 20%. From our study we conclude that this figure is feasible and can be reached by applying energy conservation techniques with net negative CO_2 emission reduction costs. However, we also conclude that stronger incentives for energy conservation are probably required than applied at present.

Keywords: Energy efficiency; Energy conservation; CO_2 emission reduction

A wide range of technical options is available to reduce the emission of CO_2 into the atmosphere. These include energy conservation, nuclear energy, renewable energy, a fuel switch from coal to natural gas, CO_2 removal and afforestation. It is normally accepted that, in the short term, energy conservation is the best and cheapest option available to reduce the total energy consumption and hence the emission of CO_2.

In order to pursue an effective energy conservation policy it is necessary to obtain data on the potential of energy conservation in the various economic sectors and on the costs associated with it. Furthermore, from a macroeconomic point of view, it is important to choose the energy conservation options which are most cost effective. Knowledge about the cost effectiveness is not yet widely available. Until now, the emphasis in many studies has either been on the conservation potential per sector or on the costs of a (non-complete) set of specific conservation techniques.[1]

In this article we will explore the role which a database on energy conservation techniques, containing both types of data, can play in the formulation of an energy conservation policy as part of a CO_2 emissions reduction policy. First of all we will describe such a database, called ICARUS, which we have recently constructed. We will then perform calculations on this database for the year 2000. We will present results from the Netherlands relating to the energy conservation potential per sector, the cost effectiveness of the conservation techniques and the possible effect of stimulating measures taken by the government. On the basis of these results we can evaluate the feasibility of the energy conservation policy of the Netherlands, aimed at reducing the emissions of CO_2 in the year 2000 by 3–5% compared with the year 1990.

In this article we use a broad definition of energy conservation. We define energy conservation techniques as measures which lead to a decreased consumption of exhaustible primary energy carriers but which do not reduce the level of the activity for which the energy is used. We therefore include end-use energy conservation (eg wall insulation and heat recovery), improved conversion efficiency (eg more efficient power plants and combined generation of heat and power – CHP) and the utilization of renewable energy sources. The definition also covers an increase in the magnitude of an activity at constant energy consumption. The definition does not cover a shift to fuels with a lower carbon emission. However, in some cases such a fuel shift might be a side effect of the application of a conservation technique (eg in the case of CHP).

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Table 1. The Dutch energy balance for the year 1985.

Sector	Energy consumption (PJ) Gas	Oil	Coal	Electricity	Other[a]	Total	CO_2 emissions (Mt)	Growth factor[b]
Greenhouse horticulture	87	4	0	2	0	93	5.2	1.56
Other agriculture	5	18	0	5	0	28	1.6	1.56
Dairy industry	9	0	0	3	5	16	0.5	1.63
Other food and drug industry	30	3	1	10	10	54	2.0	1.63
Textile industry	5	0	0	2	1	8	0.3	1.56
Paper and board industry	6	0	0	6	10	22	0.4	1.94
Fertilizer industry	108	0	1	5	11	125	6.1	1.25
Inorganic chemicals	12	2	4	13	17	49	1.2	1.68
Petrochemical industry	53	208	5	13	44	323	18.6	1.25
Other chemical industry	17	1	0	4	3	25	1.1	2.08
Building materials	21	4	4	4	1	35	1.9	1.94
Basic metals (ferrous)	12	4	65	6	7	95	7.6	1.80
Basic metals (non-ferrous)	4	1	0	18	0	23	0.3	0.50
Other metal industry	20	10	0	10	1	41	1.9	2.40
Other industry	16	22	0	6	0	44	2.5	1.94
Passenger transport	0	217	0	4	0	220	15.8	1.35
Freight transport	0	105	0	0	0	106	7.7	1.75
Households	424	16	1	58	5	504	25.0	1.16[c]
Building and construction	3	6	0	1	0	11	0.6	1.25
Commercial services	46	8	0	22	0	77	3.2	1.68
Catering	14	0	0	6	0	20	0.8	1.68
Health care services	16	5	0	2	0	22	1.2	1.11
Non-commercial services	40	8	0	10	0	57	2.8	1.11
Other	35	22	9	5	0	71	4.4	1.60
Total final consumption	946	700	91	220	118	2075	112.9	
Cogeneration CHP	103	22	12	−20	−88	29	8.6	
Waste incineration	0	0	0	−2	9	8	–	
Refineries	10	112	0	−0	−11	111	9.0	
Electricity supply	301	7	150	−190	31	298	31.5	
Other energy conversion	18	6	13	11	−1	47	2.7	
Total energy consumption	1378	846	266	20	58	2568	164.4	

[a] Mainly comprises heat eg from CHP units. [b] Expected growth of value-added of the sector in the period 1985–2000. [c] For household appliances the growth factor is 1.63.

The database ICARUS

All the calculations presented in this article are based on data contained in the database ICARUS (version 1.1), which is an acronym for Information system on Conservation and Application of Resources Using a Sector approach. The database consists of the three components which are interconnected and contain the following types of data:

- a database on energy conservation techniques;
- the 1985 energy balance of the Netherlands, giving the energy consumption for all economic sectors subdivided into coal, oil products, natural gas, electricity and other energy carriers;
- a database containing additional data, like CO_2 emission factors and energy price figures, which are needed in the calculations of, for example, the payback time of energy conservation investments and the reduction costs of CO_2 emissions.

The database is contained in a Lotus/Symphony spreadsheet. The structure of the database is such that improvements in basic assumptions can easily be implemented.

In this section we will first describe the contents of the 1985 energy balance and the database containing additional data. We will then describe the structure of the database of energy conservation techniques and the way in which the data were acquired.

Databases with general starting points

One of the databases in ICARUS consists of energy consumption figures for a base year. In our study the base year is 1985. The energy balance for the Netherlands in 1985 is given in Table 1, subdivided into the economic sectors distinguished in this study. All these figures are derived from figures supplied by the Netherlands Central Bureau of Statistics.[2] The total domestic energy consumption in 1985 was

2570 PJ. Note that all fuel quantities in this study are given as lower heating values.

From the figures on energy consumption we can calculate the emission of CO_2 by using appropriate emission factors.[3] In this study we take into account the CO_2 emissions associated with Dutch domestic primary energy consumption, as defined in the national statistics.[4] This excludes deliveries to international ship and air transport but includes the use of fuel as feedstock. On this basis the total CO_2 emissions in 1985 are calculated to have been 164 million tonnes (Mt) per year. The figures are also given in Table 1, broken down into sectors. It should be noted that part of the emissions calculated in this way were not actually emitted: part of the energy carriers is used as feedstock and converted into plastics etc. It is calculated that due to this effect actual emissions in 1985 were about 10% lower than the emissions calculated on the basis of the input of primary fuels.[5]

For economic development up to the year 2000 we use the data given by the Netherlands Central Planning Bureau – with some exceptions.[6] Growth factors per sector from the year 1985 up to the year 2000 are shown in the last column of Table 1. For the productive sectors the growth factor indicates the growth in the value-added (in financial units). In this study it is assumed that the growth factor in physical terms (eg tonnes of product) equals the growth of the value-added per sector (in financial units). In reality growth in physical terms may well deviate from the growth in value-added terms, but no figures are yet available to quantify this deviation.

If the energy demand in each sector were to grow as fast as its production volume (which means that there would be no improvement in energy efficiency), the total energy consumption would rise to approximately 3550 PJ in the year 2000. Assuming a fuel mix in the electricity production as proposed by the Dutch utilities and an unchanged fuel mix in other sectors, this would lead to an emission of CO_2 of 235 Mt in the year 2000.[7]

In our calculations we use energy price projections made by the Dutch Ministry of Economic Affairs for the year 1995.[8] The prices of the main energy carriers are shown in Table 2. All financial values in this article are given in Dutch guilders (1 Dfl = US$0.57, March 1991).

Table 2. The price of the main energy carriers in 1995 used in our calculations.

Type of energy carrier	Expected price 1995 (Dfl/GJ)
Natural gas: small consumers	15.1
Natural gas: large consumers	8.4
Coal (steam coal)	3.9
Uranium	2.5
Electricity: small consumers	46.4
Electricity: large consumers	38.0
Electricity: very large consumers	26.9
Petrol	42.4
Diesel fuel	30.2

Source: Electricity Plan 1991/2000, Dutch Electricity Generating Board, Arnhem, March 1990.

Structure of the database of energy conservation techniques

The main component of ICARUS is a database on energy conservation techniques. Each record of this database contains the data for one conservation technique. The following characteristics are given for each technique:

- the name of the conservation technique;
- the economic sector in which the technique can be applied;
- whether the technique concerns fuel or electricity conservation;
- the part of the fuel or electricity consumption of the sector to which the conservation technique applies (in %);
- the part of the fuel or electricity consumption which can be saved by the technique (in %);
- the degree to which the conservation technique leads to an increase in the consumption of the other type (ie electricity or fuel) of energy carrier (in % of the savings);
- the capital investment for the technique (in Dutch guilders per gigajoule fuel or electricity saved per year);
- the operation and maintenance costs (in Dutch guilders per gigajoule fuel or electricity saved);
- the average lifetime of the equipment associated with the technique (in years).

Data acquisition using a sector approach

The inventory of energy conservation techniques is compiled sector by sector; the method is presented schematically in Figure 1. The various economic sectors in the Netherlands are subdivided into a number of subsectors. This is done on the basis of the subdivision used by the Netherlands Central Bureau of Statistics (CBS) and the Netherlands Central Planning Bureau (CPB). The breakdown of the energy demand is determined for each of the subsectors. This is done separately for fuel and electricity. The major energy consuming processes (eg those involved in manufacturing a certain material) within each subsector are identified. Subse-

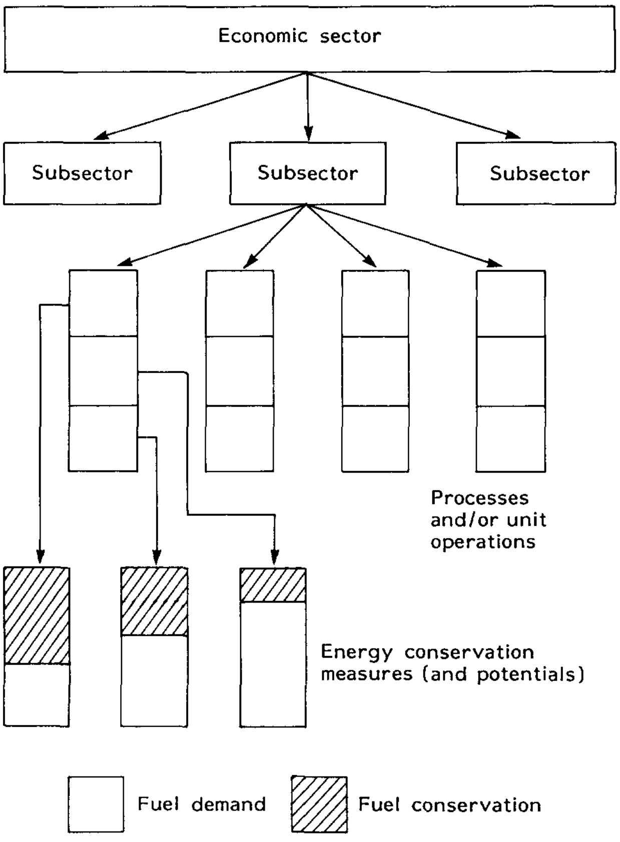

Figure 1. Schematic description of the approach followed in the acquisition of data for ICARUS. First energy consumption is broken down into sectors and into processes or unit operations within these sectors. Subsequently the required energy conservation figures for each of these processes or unit operations are determined.

quently in most cases a number of unit operations (eg drying, pumping) can be identified within a process. The breakdown of energy demand both into processes and into unit operations is carried out mainly on the basis of existing Dutch sector studies and in some cases on the basis of foreign sector studies.

In some cases it turns out to be impossible to obtain the information that is needed to build up a complete picture of the subsector concerned. In these cases assumptions have to be made. Generally one assumes that the situation is comparable to that of other subsectors using similar production technologies. An extended description of this work is given elsewhere.[9]

Once the information on the specific processes (and eventual unit operations) and their energy consumption has been collected, the next step is to identify data on the energy conservation techniques. On the basis of the current status of the energy efficiency, we then estimate the potential of the various applicable conservation techniques and the costs associated with investment and with operation and maintenance. These data are obtained from (sectoral) studies in the Netherlands and other countries, from case studies and practical experience described in the literature, by analogy with other processes (and unit operations) or from personal communications with people working in the field of research or the (industrial) sector concerned.

In some cases, capital investment data are not available. In these cases rough estimates have to be made. Again this is done mainly on the basis of similarity of a process to other processes and unit operations. An extended overview of energy conservation measures and the origin of the data included in the database is given elsewhere.[10]

Conservation techniques are not included in the database if the specific mitigation costs (see Equation (2)) turned out to be higher than Dfl500/t CO_2.

In a database structure like this it is difficult to incorporate conservation techniques that influence each other. For instance, if wall insulation is applied in dwellings the savings associated with the use of condensing boilers will become smaller and vice versa. If such conservation techniques are recorded for a given process or unit operation, energy conservation close to end-energy consumption (eg wall insulation) is given priority. Afterwards, upstream conservation techniques (eg condensing boilers) are corrected for the savings associated with the measures already taken downstream. Similar problems occur if competing techniques have to be included. If, for a given process or unit operation, two competing techniques are encountered, the most cost effective is incorporated first in the database. If the less cost effective technique gives higher energy savings this technique is also incorporated in the database. However, to avoid double counting, the figure incorporated for the second technique is the difference between the savings effected by the first technique and the savings effected by the second technique. Similarly the specific capital investment is calculated on the basis of the additional investment and the additional savings.

We are continuing to collect data about energy conservation techniques in order to obtain more detailed information and to improve the reliability of the data.

General results concerning energy conservation potentials

We will now summarize for each sector the main options contained in the database. The part of the fuel or electricity (the latter indicated by subscript e) consumption of the sector which can be saved by the measure is given in parentheses. (This figure is the product of the fourth and fifth items in the database of energy conservation techniques.)

In greenhouse horticulture, which is the main energy consumption sector within agriculture in the Netherlands, energy-efficiency improvements can be achieved by crop upgrading (14%) and a higher cultivation density (12%). Furthermore, technical measures like the use of insulation screens (8%), condensing boilers (6%) and heat pumps (4%) can be implemented. Finally, CO_2 fertilization using external CO_2 supply (5%) could also be effective.

In the dairy industry, which is the main sector in the Netherlands food and drug industries, savings can be achieved by applying multistage evaporation (12%), mechanical vapour recompression (16%), by introducing improved drying techniques for milk powder (6%) and whey powder (6%), and by achieving process integration (5%) and efficient cooling ($4\%_e$). In several other sectors in the other food and drug industries similar conservation measures can be applied eg heat recovery and process integration (16%), mechanical vapour recompression (6%), heat pumps (7%), speed control motor drives ($25\%_e$) and efficient cooling ($3\%_e$). Furthermore a number of sector specific applications can be applied, like elimination of beet pulp drying in the sugar industry (6%), heat recovery from singeing furnaces in slaughterhouses (1%), the production of biogas from waste water in the beer industry (3%) and separation of mixtures of fluids by membrane techniques in the edible oil industry (6%).

In the fertilizer industry primary energy can be saved by upgrading the pre-reformer (2%), by applying improved CO_2 absorption processes (2%) and by using speed controlled compressors ($25\%_e$). In the petrochemical industry, efficiency can be improved by integrating heat flows (4%), combusting fuel at higher pressures (1%), applying selective steam cracking of naphtha (1%), applying smaller motor drives ($8\%_e$) and using speed control ($20\%_e$). For specific processes energy saving can be achieved by the application of spheriform production of polypropylene (0.2%), the reduction of monomer losses in LDPE production (0.2%), the application of improved catalysts in the manufacturing of styrene (2%), introduction of the Lurgi combined process for methanol synthesis (1%) and application of mechanical vapour recompression (1%). In the inorganic chemical industry the shift to highly efficient membrane processes for chlorine production (11%) is important.

In the production of building materials, a substantial level of energy conservation can be achieved by the application of improved burners and furnaces (4%), the reduction of heat leakages (14%), the insulation of furnace wagons (5%), heat recovery from flue gases (6%) and process integration (4%).

In the production of iron and steel, energy can be saved by applying dry coke quenching (3%), by changing from oxysteel to electric arc furnaces (12%), by using improved soaking pits (1%), by the recuperation of waste heat (3%), by applying energy management systems for air separation ($3\%_e$), and by introducing power speed control ($9\%_e$) and continuous casting into the electrosteel industry ($3\%_e$). For the production of aluminium, a shift to the Alcoa process ($23\%_e$) and more scrap recuperation ($23\%_e$) are possible energy conservation techniques.

The fuel demand of service buildings can be largely reduced by applying double glazing (9%) and by making several other types of insulation improvements (17%); other possible measures are the reduction of the ventilation rate (4%), the application of ventilation heat recovery (7%); building control can be improved (5%) and boiler efficiency increased (13%). Electricity consumption can be reduced by using energy efficient lamp fittings ($12\%_e$) and by introducing lighting control that is dependent on the daylight level and the presence of people ($12\%_e$). Furthermore, the energy consumption of fans and pumps can be reduced, particularly by applying speed control to motor drives ($5\%_e$).

In households efficiency was already improved considerably between 1985 and 1989 (8%). Ongoing improvement to the insulation of dwellings, broken down into floor (4%), roof (6%), wall (11%) and window (4%) insulation, remains the main heat conservation option. In new dwellings this can be extended with enhanced passive application of solar energy and heat recovery systems which are part of a so-called minimum energy dwelling concept (7%). Condensing boilers can improve the efficiency of heat production (4%). Energy consumption for hot water supply can be reduced by using water saving shower heads (3%), by changing from electric appliances to gas fired appliances (9%) and by installing hot water appliances without a pilot flame (3%). Electricity consumption can be largely reduced by using energy-efficient fluorescent light bulbs instead of incandescent lamps ($25\%_e$). Efficiency improvement of refrigerators and freezers can be achieved by improving wall insulation and a number of other measures ($8\%_e$). Furthermore it should be possible to decrease considerably the energy consumed by other household appliances like washing machines

Table 3. Potential energy conservation per sector as a percentage of the current consumption. The resulting net CO_2 emission reduction per sector is also shown.

Sector	Fuel savings (%)[a]	Electricity savings (%)[a]	CO_2 avoided (Mt)
Agriculture	65	64	8.1
Food and drug industry	52	14	3.3
Fertilizer industry	5	25	0.7
Petrochemical industry	12	11	3.5
Other chemical industry	20	10	2.0
Building material industry	42	26	2.0
Basic metal industry	21	34	4.2
Other metal industry	35	25	2.6
Other industry	34	26	6.7
Services	52	42	10.6
Households	51	54	23.7
Transport	25	0	9.0
Cogeneration			11.8
Renewables			4.2
Energy supply sector			3.1
Total			95.6

[a] In these figures the increased use of one type (ie electricity or fuel) of energy carrier as a result of conservation of the other type is subtracted from the conservation of the former.

($4\%_e$), dish washers ($1\%_e$) and tumble driers ($1\%_e$).

In passenger transport, the main options are more efficient cars (electronic motor control, reduced air and rolling resistance, 13%), advanced transmission systems (4%), recovery of braking energy for buses (1%) and trains ($16\%_e$) and a shift to public transport (8%).[11] In freight transport the same types of efficiency improvements are applicable eg the efficiency improvements of trucks (12%) and the recovery of braking energy (3%). Shipping can be made more energy efficient by the application of improved screw propeller systems (6%), combined with a number of smaller measures (5%).

As far as the energy supply sector is concerned, combined generation of heat and power (CHP) is the most important option. It can be applied widely, increasing the total CHP capacity of 7500 MW_e. The main sectors are greenhouse horticulture, the food and drug industry, the chemical industry and office buildings. Central electricity production efficiency in general can be increased from 39% to 42% on average; this can be achieved mainly by changing from conventional steam cycle plants to combined cycle plants. The production of biogas resulting from the anaerobic digestion of cattle manure, solid waste and waste water and the production of heat by the combustion of residual paper and wood waste can contribute to the energy supply. The same applies to wind energy and hydropower, although the potential of the former is restricted up to the year 2000 due to implementation problems.

In total, approximately 300 separate energy conservation techniques have been identified in our inventory. About half of the conservation techniques included in the database have been summarized above. These account for about three-quarters of the potential CO_2 emission reduction.

The technical potential for energy conservation is shown in Table 3, broken down into sectors. The energy saved per sector is given as a percentage of the final energy consumption of the sector concerned. It should be noted that in some cases, electricity conservation is partly offset by a shift from fuel to electricity. The effects of CHP and renewable energy are shown separately in this table.

If no energy conservation measures were taken, the total Dutch energy consumption would grow from 2570 PJ in the 1985 to 3550 in the year 2000. It should be noted that this is a theoretical assumption because one would expect some conservation measures to be taken autonomously. If we add together the potentials of all the conservation measures, we find a conservation potential of 1390 PJ of primary energy, which is 39% of the estimated demand. The associated reduction in CO_2 emissions is 96 Mt (41% of the uncontrolled emissions). It should be noted that these savings include the savings which would take place autonomously.

The cost effectiveness of energy conservation

The cost effectiveness of energy conservation techniques can be expressed as a supply curve. This supply curve is constructed as follows.

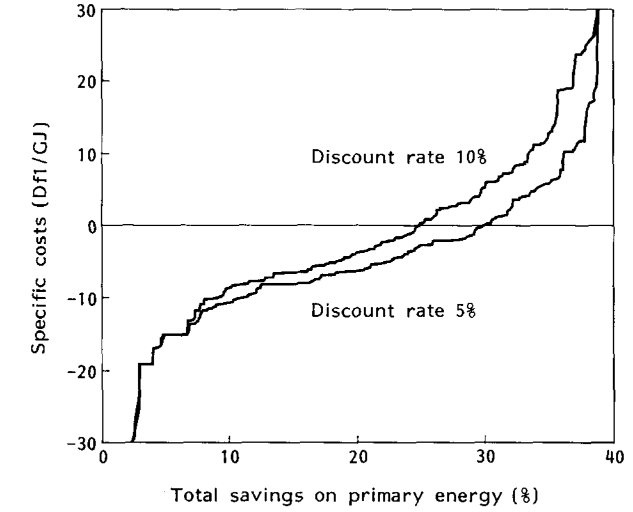

Figure 2. The supply curves for energy conservation techniques. On the horizontal axis the cumulative amount of primary energy saved is given. Vertically the marginal cost of the last measure is depicted for discount rates of 5 and 10%.

As a first step, we calculate for each technique the specific cost C_{spec} which is defined as the net cost per unit of primary energy saved. The C_{spec} is expressed in the following equation:

$$C_{spec} = \frac{\alpha.I + OM - SEPC}{\text{Annual amount of primary energy saved}} \quad (1)$$

where

- α = an annuity factor depending on the interest rate r and the depreciation period n: $\alpha = r/(1-(1+r)^{-n})$
- I = the initial capital investment, expressed in Dutch guilders per annually saved unit of final energy consumption (fuel or electricity)
- OM = operation and maintenance cost expressed in Dutch guilders per saved unit of final energy consumption
- $SEPC$ = saved energy purchase costs, expressed in Dutch guilders per unit of final energy consumption saved

The term in the denominator of formula (1) is calculated as the amount of primary energy saved per unit of final energy consumption saved.

The resulting specific costs are expressed in Dutch guilders per gigajoule primary energy saved. Of course this quantity can be negative in cases where the benefits (avoided energy purchase costs) are larger than the costs (capital costs and operation and maintenance costs).

In this study the annuity factor is calculated using real interest rates of 5 and 10% respectively and using the lifetime of the equipment associated with the measure as the depreciation period.

The second step in the development of the supply curve is to range the conservation techniques in order of increasing specific costs.

The last step is to construct the supply curve itself. The specific costs are shown on the vertical axis whereas the amount of primary energy that can be saved at costs lower than or equal to these specific costs is shown on the horizontal axis. The supply curves are depicted in Figure 2 for discount rates of 5% and 10% respectively.

So far the cost effectiveness has been calculated from the point of view of primary energy saved. More important in connection with CO_2 emission reduction policy is the cost effectiveness from the point of view of CO_2 reduction. The specific CO_2 mitigation costs, $C_{spec,CO2}$, are calculated as follows:

$$C_{spec,CO2} = \frac{\alpha.I + OM - SEPC}{\text{Annual amount of } CO_2 \text{ avoided}} \quad (2)$$

In this expression the same symbols are used as in expression (1). The amount of CO_2 avoided is expressed in tonnes per unit of final energy consumption saved. The results are the specific costs expressed in Dutch guilders per tonne of CO_2 avoided. Of course this quantity can be negative, too. The resulting shape of the supply curves is given in Figure 3.

As is shown in Figures 2 and 3 part of the energy conservation measures turns out to have net negative mitigation costs, depending on the discount rate assumed. Some key figures for the whole set of conservation measures contained in ICARUS and for the part with net negative CO_2 mitigation costs at discount rates of 5% and 10% are given in Table 4.

The possible effect of stimulating measures

On the basis of the data contained in the database ICARUS we investigated the possible effect of policy measures taken to stimulate the application of energy conservation techniques. In this section we will make a preliminary analysis in order to demonstrate these possibilities.

As can be seen in Figures 2 and 3, the majority of the technical options have net negative specific CO_2 mitigation costs; this means that, evaluated over the technical lifetime of these measures, the benefits are

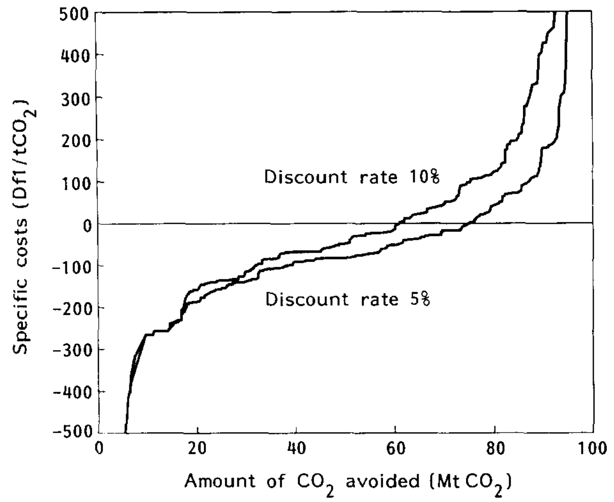

Figure 3. The supply curve for CO_2 reduction achieved by energy conservation techniques. On the horizontal axis and cumulative amount of CO_2 reduction is given. Vertically the marginal cost of the last measure is depicted for discount rates of 5 and 10%

greater than the costs. However, decision makers concerned with energy conservation investment in the industrial and private sector generally apply stricter criteria. A commonly used criterion is the simple payback time, defined as the capital investment divided by the annual revenues. Industrial companies in the Netherlands are using payback time criteria ranging from two to seven years, the majority (over 80%) being between two and five years.[12] For other decision makers, especially in households, decision criteria are less well defined, but we will assume the same figures are valid. In this article we will make calculations for payback times in the middle (three years) and at the higher end (six years) of the range.

In this section we will make some calculations based on the assumption that decision making about investment in energy conservation depends only on the question of whether or not these investments satisfy a preset payback time criterion. It should be noted that in reality not all techniques which satisfy this profitability criterion will be applied in practice.

From the data contained in ICARUS, we can calculate the amount of CO_2 which can be saved by applying the profitable energy conservation techniques. The results are depicted in Figure 4. The figure shows that the energy conservation techniques that satisfy a payback time criterion of three years achieve a CO_2 emission reduction of 34 Mt. This will increase to 57 Mt at a payback time criterion of six years.

We have made this evaluation as a base case. However, we can go further and evaluate the possible effect of a policy that stimulates the conservation of energy by:

- investment grant: generally, the application of this instrument means that the government refunds a fraction of the capital investment. This instrument has often been used in the Netherlands to stimulate energy conservation. The subsidized fraction depended on the type of investment and varied from time to time but generally ranged between 12 and 40%.[13]
- A carbon tax: a carbon tax generally takes the form of a charge for each unit of carbon (or CO_2) emitted. A carbon tax is relatively new but has been proposed or studied in some countries and in international organizations as an instrument of CO_2 reduction policy.[14] In Sweden, for instance, a parliamentary commission proposed a CO_2 tax of SKr250/t CO_2 (approximately US$140/tC).[15] Another example is the figure used in a study performed by the IEA on a tax dependent on the carbon content of the fuel, corresponding to US$50/t of coal (approximately US$65/tC).[16] The effects of a carbon tax of up to US$100/tC have been studied by the US Congressional Budget Office.[17]

For each energy conservation technique contained in ICARUS we will recalculate the payback time by subtracting an investment grant from the capital investment and by adding a carbon tax to the energy

Table 4. The amount of energy conservation and CO_2 reduction for three sets of conservation measures.

Key figure	All measures	Discount rate 5%	Discount rate 10%
Savings of primary energy (PJ)	1390	1060	890
as percentage of consumption without efficiency improvement	39	30	25
Avoided CO_2 emissions (Mt)	96	75	62
as percentage of unabated emissions	41	32	27
Total capital investment (10^9 Dfl)	121	57	32
Total costs saved annually (10^9 Dfl)	20	17	14

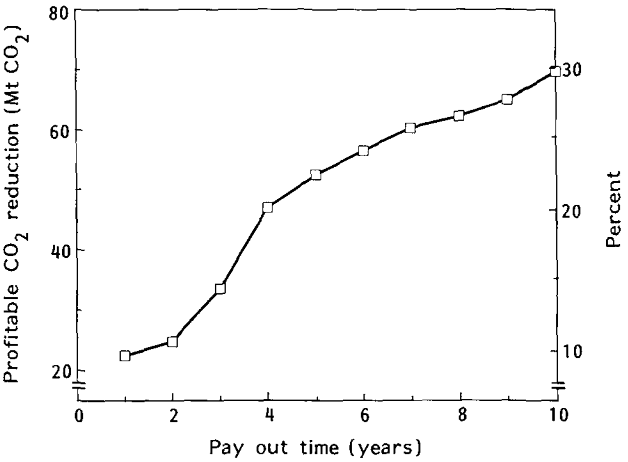

Figure 4. The profitable CO_2 reduction potential as a function of the value of the profitability criterion used in this study: the simple payback time.

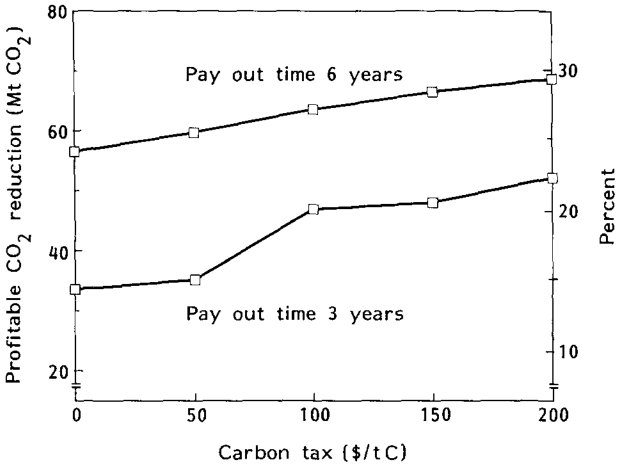

Figure 6. The effect of a carbon tax varying from zero to US$200/tC on the profitable potential of CO_2 emission reduction by energy conservation. The effect is depicted for two different payback time criteria: 3 and 6 years.

cost. We will consider investment grants ranging from 0 to 40% and carbon taxes ranging from US$0 to US$200/tC.

Figures 5 and 6 show the effect of both types of measures on the profitable potential of CO_2 emission reduction. The figures show that with a three year payback time criterion, the profitable potential of CO_2 reduction options increases from 34 to 46 Mt, with an investment grant of 25%, and to 48 Mt if a carbon tax of US$140/tC is levied, as proposed in Sweden.

Discussion

In this section we will discuss the research method. Furthermore we will compare and contrast our results with the targets of the government energy conservation policy which was adopted in the Netherlands in 1990.

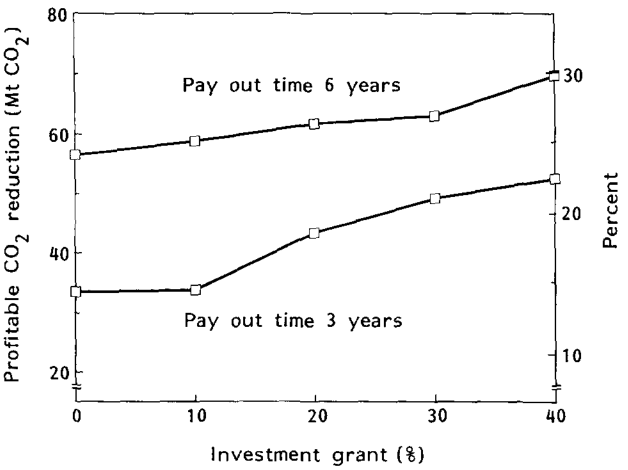

Figure 5. The effect of an investment grant varying from zero to 40% on the profitable potential of CO_2 emission reduction by energy conservation. The effect is depicted for two different payback time criteria: 3 and 6 years.

Discussion on the research method

Comments have to be made about the construction as well as the use of the database.

The result of an inventory like the one contained in ICARUS probably represents a lower limit of the technical potential for energy conservation. Additional measures, which have not yet been explored at all, are conceivable. These are likely to include techniques with positive specific CO_2 mitigation costs, since such techniques were not worth investigating in conventional energy conservation policy. Furthermore, certain types of conservation measures, such as energy-efficient behaviour, are difficult to quantify and have not always been included in the database.

We also comment on the capital investment data incorporated in the database. At best these data are average figures for the sector under consideration. They can never therefore be applied to individual companies or individual projects. In addition these cost data are liable to changes, either upward (eg as a result of additional costs which were neglected in single demonstration projects) or downward (eg due to further development of the technology or by the effects of mass production). Only the future will show how reliable the cost estimates have been.

One final comment: the database is likely to be of use primarily in studies concerning energy conservation in the fairly short term (eg 10–15 years). For longer timescales it is not sufficient to collect data

Table 5. A comparison of the goals for the period 1989–2000 of the government energy conservation policy with the technical and economic potential of the options contained in the ICARUS database (energy conservation in %).

Sector	Governmental policy plan	ICARUS technical potential	ICARUS economical potential (discount rate 5%)
Fuel			
Households	25	44	38
Manufacturing industry	15	17	14
Services	30	51	41
Transport	20	20	20
Agriculture	30	65	60
Electricity			
Households	25	51	48
Industry	15	19	20
Services	30	43	43
Energy supply			
Refineries	15	20	20
Power plants[a]	20	65	64
Total	20	35	26

[a] In these savings the downstream savings by combined generation of heat and power, electricity conservation etc are included.

from existing sources because currently unknown or hardly elaborated energy conservation techniques might also have an impact. More detailed studies of energy conversion processes, also in end-use applications, might help to elaborate this point.

We also wish to comment on how the data contained in ICARUS can be used. As the database has a structure of linearly ordered records it is only the order of these records which can be processed. In the case of competing or interacting conservation techniques the incorporation gives some problems. As we indicated earlier, these problems were avoided to ensure that the conservation potential were not overestimated. We expect any errors to be small. In order to avoid this problem a transition should be made to more complicated models in which interlinked networks of energy conversion processes can be simulated. An example is the Markal model.[18]

Finally, it should be emphasized that calculations in which only economic criteria are used do not tell the whole story. As already indicated, the question of whether an investment in energy conservation will be made or not depends not only on the question of whether the payback time is lower than a preset value. A decision maker might have other investment priorities or might pay no attention to energy conservation. The same uncertainty applies to the calculation of the effect of stimulating measures taken by the government. The effect of the measures can be enhanced, for instance, by the idea of getting something free (in the case of investment grants) or by shock effects (in the case of a carbon tax). In addition a carbon tax also stimulates, for instance, a shift to less energy intensive industrial sectors. More research is required to reduce the uncertainties about these effects.

Comparison of our results with the goals of the Netherlands energy policy

Recently the Netherlands policy on CO_2 reduction has been reformulated. The goal is now to reach by the year 2000 a 3–5% reduction in CO_2 emissions compared to the average emission in 1989 and 1990.[19] Since the average emission in these years is estimated to have been 182 Mt this means that the CO_2 emission in the year 2000 should be restricted to between 173 and 177 Mt.

The policy has been elaborated in a recent Memorandum on Energy Conservation.[20] In this Memorandum it is assumed that, if government policy remains unchanged, an efficiency improvement of 1% per annum will be attained. The goal of the government, as set out in the Memorandum, is to enhance energy conservation policy in such a way that this efficiency improvement rate doubles. Together with measures in other policy sectors, namely waste and traffic, the Netherlands government hopes to attain the goal for CO_2 emission reduction.

In the field of energy conservation, government policy includes measures which have already been used for the last 15 years. Examples are the financing of research and development, the support of demonstration projects, dissemination of information on energy conservation, the support of feasibil-

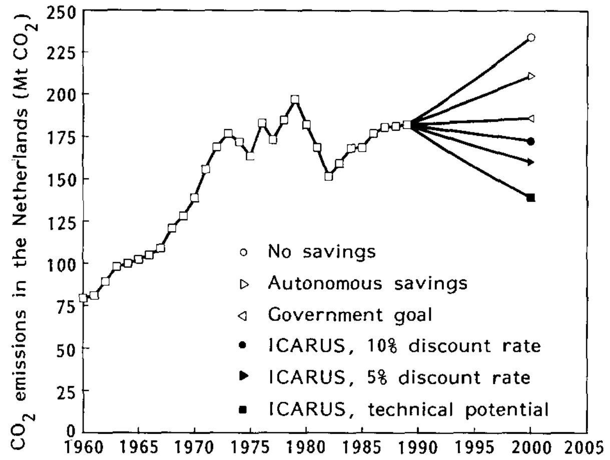

Figure 7. Overview of the historical development of CO_2 emissions together with a number of (theoretically) possible future development.

Note: [a] Our base case – indicated with 'no savings' – includes the fuel shift in electricity production, which has already been fully implemented by the utilities. The government aims at a 20% reduction in CO_2 emission by energy-efficiency improvement, indicated here as 'governmental goal'. Further reductions in the CO_2 emissions to a level of 173–177 Mt in the year 2000 are to be reached by a (further) shift from private to public transport, a reduction in the coal consumption of the manufacturing industry and changes in waste policy.

ity studies and the application of investment grants. Investment grants of 25% will be given for investments in a limited number of energy conservation techniques: CHP, heat pumps, heat recovery from waste gases, process control equipment and power speed control. For insulation of dwellings and service buildings investment grants of 30% and 20% respectively are available.[21] Furthermore, investment grants are available in connection with the application of wind power and solar energy. A new instrument consists of entering into agreements (covenants) with industrial sectors. This implies that on the basis of an inventory of energy conservation measures per sector, an agreement is made between the government and the sector concerned on the energy conservation goal to be attained by the sector and on the government budget to be provided for R&D, energy management and information dissemination. Finally, energy distribution companies are expected to make an important contribution to the realization of energy conservation; these companies have recently published a plan stating that they will invest Dfl13 000 million in order to achieve a 9 Mt per year reduction in CO_2 emissions in the year 2000. They plan to invest in CHP, wind energy, insulation of offices and dwellings, condensing boilers and energy-efficient lighting in offices and dwellings.[22]

The conservation goals of the government energy conservation policy can be compared with the technical or economical potential of the options contained in our database. The comparison is presented in Table 5. Government goals are expressed as efficiency improvement figures for the year 2000 in comparison with 1989–90, whereas the ICARUS figures apply to the period 1985–2000. The ICARUS figures have been corrected for the efficiency improvements which took place in the period 1985 to 1989.[23] From the comparison in Table 5 we see that the government goal is well within technical limits and can be attained by applying measures that have net negative CO_2 emission reduction costs. Furthermore, the results show that there is still room for additional measures, especially in households, agriculture and services and in electricity conservation in general. In Figure 7 an overview is given of possible developments in CO_2 emissions, both according to the government figures and if the technical or the economic potential of energy conservation as calculated from ICARUS were realized.

The CO_2 reduction which the government wishes to achieve by stimulating energy conservation can be estimated to be approximately 50 Mt compared with the situation without any efficiency improvement. From Figure 4 we can conclude that this requires the realization of all the measures with a payback time of less than four years. If we consider stimulating measures we can derive from Figures 5 and 6 that this will require an investment of 26% for all measures or a carbon tax of US$100/tC (again these figures are based on the simplified assumption that an investment will be made as soon as the payback time is less than three years). As present policy measures in the Netherlands are not so forceful we conclude that the government goal is most probably not attainable with the policy measures currently in place. However, in coming to this conclusion the effect of the agreements with industrial sectors is not taken into account, as the ultimate effect of these agreements is still uncertain.

More detailed study is necessary to calculate the real effects of the complicated set of policy instruments that will be applied in the Netherlands. In particular, more information is needed about the behaviour of decision makers with regard to energy conservation investment.

The recent version of the National Environmental Policy Plan mentions future research to evaluate the effects of additional policy instruments for energy conservation.[24] These instruments include the imposition of an energy tax and the integration of CO_2 emission limits within the framework of the granting of air pollution permits. The database structure ICARUS will be used in this evaluation.

We conclude that a 25-30% reduction in the specific energy consumption is economically viable, depending on the discount rate. This conclusion agrees well with an estimate made by the IEA in 1987: if energy conservation measures which are now economically viable were fully implemented by the year 2000, energy efficiency would be more than 30% higher than current levels.[25]

Conclusions

A database that includes an inventory of potentials and costs of energy conservation techniques allows us to obtain an overview for the Netherlands of the types of techniques that can be applied, to obtain insight into the conservation potentials per sector, to arrange the techniques in order of their cost-effectiveness and to make a preliminary evaluation of the effect of government measures.

Our conclusion is that the government goal to achieve an energy efficiency improvement of 20% is technically feasible, and attainable by applying measures that have net negative CO_2 emission reduction costs. It is uncertain whether the reduction can be attained by the policy measures at present in force.

Since the information system that we used is relatively simple, the database ICARUS turns out to be a useful instrument for policy makers in the field of energy conservation and CO_2 emission reduction.

This work was made possible by financial support from the Netherlands Ministry of Housing, Physical Planning and Environment.

[1]Examples of studies of conservation potential per sector are: N.R.A. Krekel, P.A.M. Berdowski and A.J. van Dieren, *Renewable Energy Resources*, Krekel Van der Woerd Wouterse, Rotterdam, The Netherlands, 1987 (in Dutch); *Energy Use and Energy Efficiency in UK Manufacturing Industry up to the Year 2000*, Vols 1 and 2, Energy Efficiency Series 3, HMSO, London, 1984; W. Maier and G. Angerer, *Rationelle Energieverwendung durch neue Technologien*, Vols 1 and 2, Verlag TÜV Rheinland, Köln, 1986; A.G. Melman, H. Boot and G. Gerritse, *Energy Conservation Potentials 2015*, Netherlands Organisation for Applied Scientific Research TNO, Apeldoorn, August 1990. Some studies of conservation techniques are: the *CADDET Database* of the IEA/OECD (administered by CADDET/NOVEM, Sittard, the Netherlands); the *SESAME Database* of the European Community (Eurobases, Brussels, Belgium); *Efficient Use of Electricity in Industry: 80 Ideas for Conservation*, VEEN, Arnhem, 1989 (in Dutch).
[2]*Energy Supply in the Netherlands, Annual Figures 1985*, Netherlands Central Bureau of Statistics, SDU, The Hague, 1986. It should be noted that the energy balance presented here differs slightly from that presented in Ref 9. Some minor deviations from the figures to the Netherlands Central Bureau of Statistics still occur due to statistical differences and rounding errors.
[3]K. Blok, J.J. Bijlsma, S. Fockens and P.A. Okken, *CO_2 Emission Coefficients for Fossil Fuels in the Netherlands*, Netherlands Energy Research Foundation, ESC-WR-88-12, Petten, The Netherlands, 1988 (in Dutch).
[4]*Op cit*, Ref 2.
[5]P.A. Okken and T. Kram, *Calculation of Actual Emissions from Fossil Fuels*, Netherlands Energy Research Foundation, ECN-RX-90-048, Petten, The Netherlands, 1990.
[6]*Three Scenarios for Energy Consumption in the Netherlands up to 2010*, Central Planning Bureau, Working Document No 10, The Hague, August 1986 (in Dutch). For the data on the growth of the number of dwellings we used more recent information contained in a personal communication from R. ter Bogt, Ministry of Housing, Physical Planning and Environment, Leidschendam, January 1990. The development of the energy supply sectors is brought into line with the expected development of the amount of energy the sector concerned delivers.
[7]*Electricity Plan 1991/2000*, Dutch Electricity Generating Board, Arnhem, March 1990.
[8]*Note on Energy Price Paths*, Ministry of Economic Affairs, The Hague, October 1987 (in Dutch). In our calculations we used the central price scenarios.
[9]K. Blok, E. Worrell, R.A.W. Albers and R.F.A. Cuelenaere, *Data on Energy Conservation Techniques for the Netherlands*, Department of Science, Technology and Society, University of Utrecht, April 1990.
[10]*Ibid*.
[11]This measure is included as it was part of government policy when ICARUS was compiled. In between an on-going shift has become part of government policy: see *National Environmental Policy Plan-plus*, SDU, The Hague, June 1990. It should be noted that a measure of this type cannot be regarded as energy conservation as defined in our introduction.
[12]L.W. Koot, M.H. Brascamp, G. Gerritse, G.J.A.M. Meijer, A.G. Melman and H.J. Munter, *Evaluation of the Operation and Effectiveness of the Energy Bonus of the WIR Base Grant*, ref. no. 84-03462, Dutch Organisation for Applied Scientific Research TNO, Apeldoorn, March 1984 (in Dutch).
[13]*Ibid*; K. Blok, 'The development of industrial CHP in the Netherlands', in *On the Reduction of Carbon Dioxide Emissions*, PhD thesis, University of Utrecht, November 1991; A.F.C.P.M. Tromp, 'Government supports energy-consciousness of entrepreneurs', *Energiebesparing*, 9/1980 (in Dutch); *Energy Policies and Programmes of IEA Countries, 1989, Review*, OECD/IEA, Paris, 1990.
[14]*Ibid*, OECD/IEA; *Policy Measures and their Impact on CO_2 Emissions and Accumulations*, International Energy Agency, Paris, December 1989; G. Kowalski, 'CO_2 emissions, energy policy and global links', presented at *Symposium on the Climatic Effects of Increased Fossil Fuel Burning and Energy Policy Implications for the Asia-Pacific Region*, 12–14 December 1990, Tokyo, Japan; *op cit*, Ref 11; *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels*, The Congress of the United States, Congressional Budget Office, August 1990.
[15]*Op cit*, Ref 13, OECD/IEA.
[16]*Op cit*, Ref 14, IEA.
[17]*Op cit*, Ref 14, US Congress.
[18]L.D. Hamilton, 'A system approach to a technology-based response to the greenhouse gas issue', from *Energy Technologies for Reducing Emissions of Greenhouse Gases: Proceedings of an Experts' Seminar*, OECD, Paris, 1989.
[19]*Op cit*, Ref 11.
[20]*Memorandum on Energy Conservation*, Department of Economic Affairs, The Hague, June 1990.
[21]*Subsidy Regulation on Energy Conservation and Renewable Energy 1991*, Staatscourant, 28 December 1990 (in Dutch).
[22]*Environmental Action Plan of the Energy Distribution Sector*, Steering Committee on the Integrated Environmental Action Plan of the Energy Distribution Sector, Arnhem, February 1991 (in Dutch).
[23]*Op cit*, Ref 20.
[24]*Op cit*, Ref 11.
[25]*Energy Conservation in IEA Countries*, OECD/IEA, Paris, 1987.