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UNEP Greenhouse Gas
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Abstract The report contains phase two of the Danish contribution to the UNEP Greenhouse Gas Abatement Study, which has the main purpose of developing a common methodology for undertaking a cost assessment of greenhouse gas abatement, and to carry out a number of country studies by using this methodology.

The methodological possibilities for constructing cost curves - showing the marginal cost of the CO_2 reducing options and the related quantity of CO_2 reduced - are analyzed and the developed methodology is tested for Denmark.

Following the development of a baseline scenario, two main reduction scenarios are constructed: a) a 20% reduction scenario for year 2005, and b) a 50% reduction scenario for 2030, taking as its starting point the 20% scenario for 2005.

Based on these two reduction scenarios the medium-term cost curve for 2005 and the long-term cost curve for 2030 for CO_2 reduction are established. The economically most attractive and the most efficient options with regard to CO_2 reduction are discussed. Finally, a number of robustness and sensitivity analyses are performed.

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Front cover photo: Misty morning in May, Fussingø at Randers.

Grafisk Service, Risø, 1993

Contents

1 Introduction

1.1 The contents of the report

The UNEP Greenhouse Gas Abatement Study was started in the autumn of 1991. Its main purpose was to develop a common methodology for undertaking cost assessment of greenhouse gas abatement, and to carry out a number of country studies by using this methodology.

Phase one of the UNEP project consisted of a detailed study of the underlying issues in estimating the abatement costs, including a review of already existing costing studies and estimates at the national level. Results for Denmark are given in ref. 1.

The present report contains the results for Denmark of the second phase of the study. Phase two comprises the development of a common methodological framework and a national test of this methodology using common assumptions on international fuel prices, discount rate and emission factors. The main part of the Danish technology data are based upon the Energy 2000 plan, though the current status of energy consumption and supply and a forecast for the year 2005 have been updated.

The report contains a methodological part and a comprehensive test comprising the set-up of two major scenarios for Denmark for the years 2005 and 2030, sensitivity analysis on energy price development and the real interest rate, and analysis of alternative development paths for the energy system.

Chapter 2 describes the methodological framework, illustrating the simplest version of the cost curve and the integrated cost-curve approach. Chapter 3 gives a short introduction to the tools used for calculation, the calculation methodology and the philosophy behind the scenario development.

Chapter 4 describes the main characteristics of the baseline scenario, while chapter 5 outlines the possible CO_2-reduction options in the demand and supply sides, and reports the results of the partial analysis of the options including the potential CO_2 reduction and the related costs.

Chapter 6 gives the results of the two main scenarios: 20% reduction of CO_2 emissions compared to baseline in the year 2005 and a 50% reduction in 2030. The results are illustrated by developing the cost curves using the retrospective approach, and sensitivity analyses are performed for alternative developments of energy prices and the real interest rate.

Chapter 7 looks into the possibilities for alternative developments of the energy systems - what is possible using a natural gas strategy, is it possible to rely only on the introduction of biomass etc. Chapter 8 analyses the sensitivity of the main assumptions outside the framework of the energy system: How will changes in economic growth, population development or the settlement of population affect CO_2 emissions?

Finally, chapter 9 states the main conclusions.

1.2 The organization of the study

The Danish project is part of the UNEP Greenhouse Gas Abatement Study in two ways:

- Denmark has participated in the development of the common methodological framework through a collaboration with the UNEP Centre for Energy and Environment and through a participation in the workshops organized by the

UNEP Centre.

- The methodological framework is tested on Danish conditions, applying Danish planning tools, data and energy system forecasts, but using the common assumptions given by the UNEP project.

The Danish study was financed by the Danish Ministry of Energy and followed by an advisory group consisting of:

Claus Andersen, Danish Ministry of Energy

Lise Backer, Danish Ministry of Energy

Peter Bach, Danish Energy Agency

Jørgen Birk Mortensen, Institute of Economics, Copenhagen University

Per Callesen, Danish Ministry of Finance

Henrik Duer, Danish Environmental Protection Agency

Lennart Emborg, Technical University of Denmark

Peder Andersen, Danish Economic Council

Flemming Møller, Danish Environmental Research Institute

The participants in the project are thankful for fruitful discussions and comments given by the advisory group.

2 Theory of cost curves

Section 2.1 outlines some of the basic assumptions behind the cost curve. Following this, section 2.2 describes different approaches for constructing the cost curves, and section 2.3 evaluates the pro and cons of these approaches.

2.1 Definition of a reduction cost curve

A cost curve for reducing CO_2 emissions is a simplified way to illustrate the possibilities - mainly given by the technological options - of how to reduce CO_2 emissions by using different technologies and the associated costs.

Given a specific target for CO_2 reduction it is possible from the cost curve to prioritate the economically most attractive CO_2 reducing options to use.

A simple definition of a cost curve for CO_2 reduction is:

- a relationship between the marginal quantity reduced of CO_2 and the associated marginal costs per unit of CO_2 by introducing given energy technologies into the energy system, substituting parts of the baseline development.

The technological options are normally ranked according to their costs, starting by the one with the lowest reduction cost per unit of CO_2. An example of a cost curve is shown in Figure 2.1.

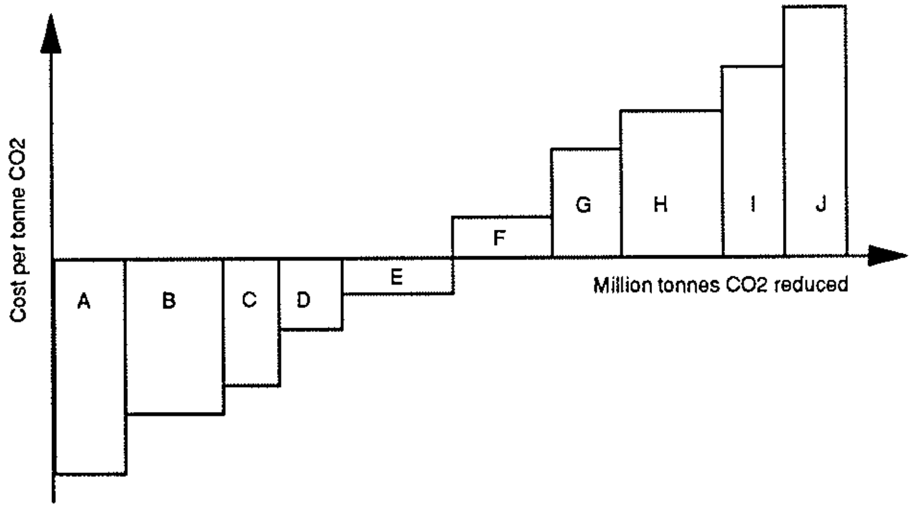

Figure 2.1 Example of a cost curve.

It is important that the cost curve be developed marginally to a baseline development, where the baseline might be a scenario of the total energy system or - in the simplest case - merely a number of reference projects.

Normally, the cost curve is well-defined for the energy system, alone. This implies, that the cost curve can be interpreted in a meaningful manner only if:

1. the given macroeconomic assumptions are unchanged, i.e. for a given set of assumptions on GNP, the interest rate, energy prices etc. If for example the development of energy prices is changed, it might affect not only the level of the cost curve, but change the total ranking of the options as well.
2. the cost curve is defined for a specific year, and the reduction options are assessed for that year. (This will always apply for the simple cost curves, but might not be the case for the integrated cost curves, where it is possible to introduce a time dimension, see section 2.4).

The cost concept behind the cost curve is based upon the direct costs only (see ref. 2). This means, that no implementation costs, search cost or project-relevant financial costs are incorporated.

In section 2.2 different ways to construct the cost curve will be analyzed.

2.2 Methods for constructing cost curves

2.2.1 The partial approach

When establishing a cost curve for emission reduction, it will always be necessary to start with the specific technological options. The partial approach is without doubt the most used, the simplest and at the same time theoretically the most unsatisfactory.

In the partial approach all technological options are evaluated separately with respect to the increased costs and the CO_2 emission, and - project by project - then compared with the reference case. The reference case might be a number of independent projects or a total reference scenario. The important thing is that the reduction project is substituting for a reference project, or a well-specified part of the reference scenario. The marginal changes in CO_2 emission and costs are calculated and ranked according to the cost as shown in Figure 2.1, where project A is chosen as the most economically attractive, implying lower costs and a substantial CO_2 reduction compared to the baseline.

The partial approach has one outstanding weakness, however - no interdependences among the options are allowed. All options are assumed to be separable concerning costs as well as CO_2 reduction, an assumption which of course does not apply to the real world.

It is most striking that when more CO_2-reducing options are introduced at the supply side, less CO_2 will be reduced when introducing demand-side options, which of course will imply higher prices for CO_2 reduction. In an energy system context part of the options are physically interconnected - options that reduced the demand for space heating might at the same time reduce the possibility for using combined heat and power (CHP).

2.2.2 The retrospective approach

This approach requires the development of a reference case with which to compare the abatement case. It includes the use of an energy systems framework (simple or complex) that enables interdependences to be evaluated in the energy system. The first step in this approach is a separate ranking of the technology options (as in 2.2.1), using the energy systems framework. In the next step the most valuable project (project A in Figure 2.1) is included in the model run, and incremental results compared to the reference case are calculated to provide numbers for each block in the cost curve. Next, the second most valuable project is included in the model and a new calculation performed. Results are compared to the former ones, a new cost-curve block is established, and so on.

This approach has the advantage of taking into account the interdependence between the given project and every other previous project on the cost curve. The results for project B will thus depend on the introduction of project A, while project C will depend on both projects A and B, and so on. A drawback is that the results for project A are independent of less valuable projects (B, C, D, ...), although in reality a dependence might exist. Furthermore it is important to notice that one aspect of the retrospective method is that once an abatement option is included in a scenario, it will be a permanent part of all subsequent scenarios.

The retrospective approach is certainly a step forward compared to the partial approach. But still it represents only part of the whole picture.

As mentioned the retrospective approach includes all previous introduced options. A special version of this approach is the *perfect foresight approach*, where all succeeding options are included but not the preceeding. If a specific reduction target is determined and a corresponding scenario developed, using this approach it is possible to "split" the scenario into the different CO_2 reducing components, indicating the costs and the associated CO_2 reduction of each option. The starting point of this approach is the developed reduction scenario, moving backwards to end in the baseline scenario. Similar to the retrospective approach, the perfect foresight approach has the drawback that all dependences are not taken into account, although in this approach it is the dependences introduced by the previous options, that are not included.

2.2.3 The integrated approach

This approach requires the existence of a well-defined reference case, and a fully developed energy system model. The idea is to determine any point on the cost curve as the least cost solution for the total energy system, where in principle all demand and supply system parameters can vary.

The procedure follows the steps below:

1. Ranking of possible technological options on a partial or retrospective basis related to a reference case calculated on an energy system model.
2. Introduction of different "baskets" of CO_2-reduction technology options (chosen with the starting point in the first step) calculating a large number of scenarios for possible CO_2 reductions and related costs.
3. Choice of the lowest costs for a given reduction of CO_2, thus establishing an envelope curve for the annual CO_2 emissions reduced and the annual costs related.

This approach aims at taking into account all the interdependences within the system as represented by the energy systems model.

Figure 2.2 shows an example of a cost curve constructed by the integrated approach. In Figure 2.2 the squares represent the "efficient baskets" of options - moving towards higher degrees of CO_2 reduction the scenarios, corresponding to the squares, will include an increasing number and/or quantity of the CO_2 reducing options. Given a considerable number of scenarios it is possible to construct the envelope curve for these efficient baskets of CO_2 reducing technologies. Of course, all scenarios will not be efficient solutions - illustrated by the circles in Figure 2.2. As shown in the figure different baskets exist for different targets of reduction. Actually, more baskets might exist for the same reduction target, which might (or might not) be economically equivalent.

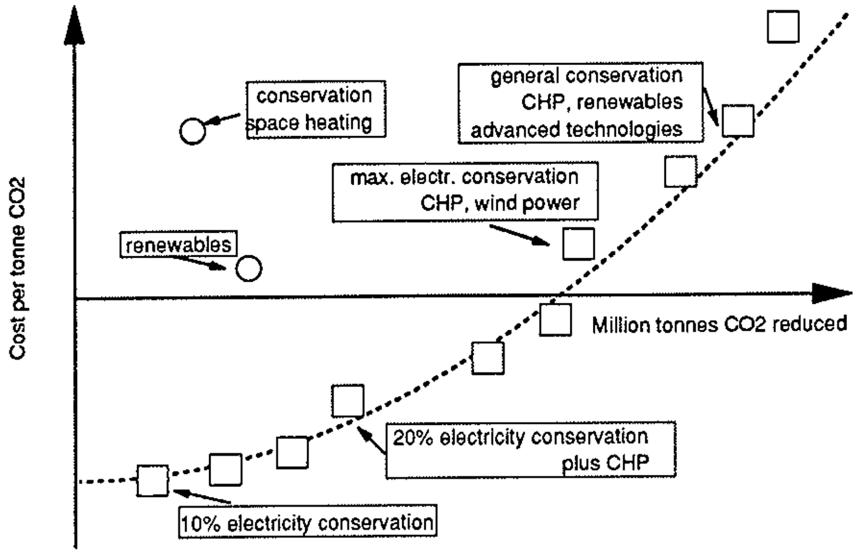

Figure 2.2 Cost curve based on the integrated approach.

Given the limitations of the energy systems model, the integrated approach provides the most "realistic" representation of the reduction options and the associated costs. A drawback of this method is that it is not possible to identify the most promising options. A total "basket" of options is identified given the CO_2 reduction target.

On the the other hand, the use of baskets might be more relevant when seen from a policy/planning viewpoint. In a policy context no single option is identified and exploited to the limit before the next option is introduced. What is most relevant is to develop the use of the given technology over time, having more technological options in play at the same time - thus, a basket representation seems to be more realistic seen from a policy viewpoint.

Finally, the cost curve of the integrated approach might easily be developed to include a time dimension. If different time-specific targets of CO_2 reduction are defined, it is possible to construct the cost curve as the result of a continuous development of a CO_2 reduction scenario, where the basket of technological options is expanded gradually, following a realistic introduction of the new technologies.

2.3 Assessment of the different cost-curve approaches

Results from the different approaches might turn out to be quite different. Figure 2.3 gives a comparison of the results from the partial approach and the retrospective approach (for illustrative purposes, only).

By and large, the most attractive options will be evaluated similar in the *partial* and the *retrospective approach.* But moving to economically less attractive options significant differences may appear, becoming more serious the higher the quantity of CO_2 reduced. Due to overlap of CO_2 reduction the last introduced option will reduce less CO_2 than expected because a share of the potential is realized through other options. This will not be taken into account in the partial approach, introducing a serious error, but is included in the retrospective

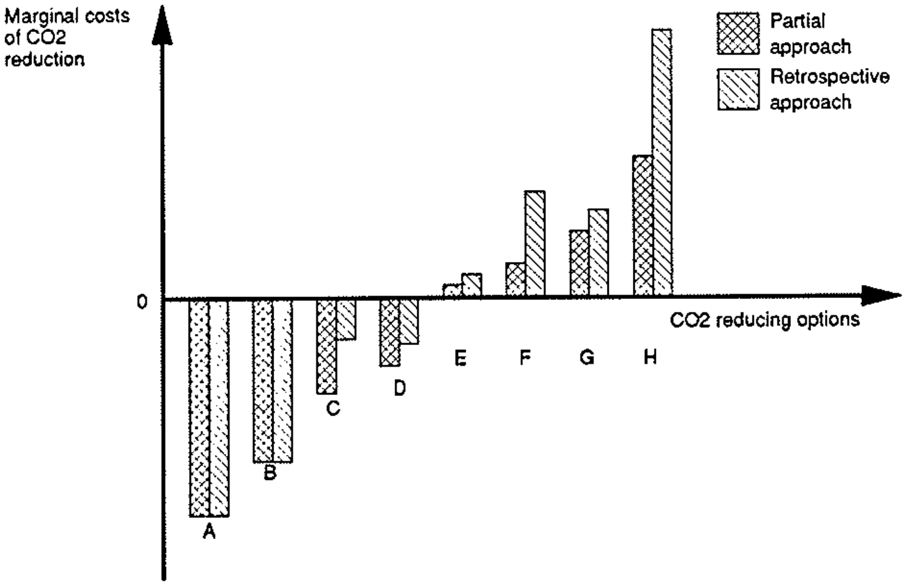

Figure 2.3 Illustrative comparison of results from the partial and the retrospective approach.

approach, to the extent that the systems interdependences are treated in the used model.

Moreover, not only are the last introduced options less valuable in terms of CO_2 reduced than expected in the partial approach, but there might exist physical and/or economic depencences in the energy system that change the possibilities of the options. A typical example is the use of CHP as a CO_2 reducing option. If all electricity is coproduced with heat, there is no need in the energy system for the electricity produced from windturbines. But if conservation in space heating is introduced as an option, decreasing the demand for heat and thereby the quantity of coproduced electricity, this will introduce the possibility for windturbines given the demand for electricity.

Thus Figure 2.3 shows that due to overlap of CO_2 and due to economically and physical interdependences not only the costs of CO_2 reduction will change, but the ranking of the options might change as well, invalidating the results of the partial approach.

As mentioned, the reduction cost of the most economically attractive options (say A and B in Figures 2.1 and 2.3) tend to be calculated identical by the partial and the retrospective approach. And if only those two options are undertaken the results will be fairly correct, both in average and marginal. But if all the options shown on the cost curve are undertaken, the marginal cost for these most attractive options will tend to be underestimated (numerical) by both approaches, while the marginal quantity of CO_2 reduced tends to be overestimated.

This point is illustrated in Figure 2.4 using the marginal cost curve for the *retrospective approach* and the *perfect foresight approach.* Given a specific reduction target the retrospective approach tends to underestimate (numerical) the marginal costs of the economically most attractive options (and overestimate the quantity of CO_2 reduced), while the marginal costs of the economically least attractive options tend to be overestimated (and to underestimate the quantity of CO_2 reduced). The perfect foresight approach illustrates the opposite situation: the marginal costs of the most attractive options are overestimated (numerical), and underestimated for the least attractive options. The two approaches thus can supplement each other: taking the average of both approaches will give a fairly close approximation of the "real" marginal cost of the CO_2 reducing options.

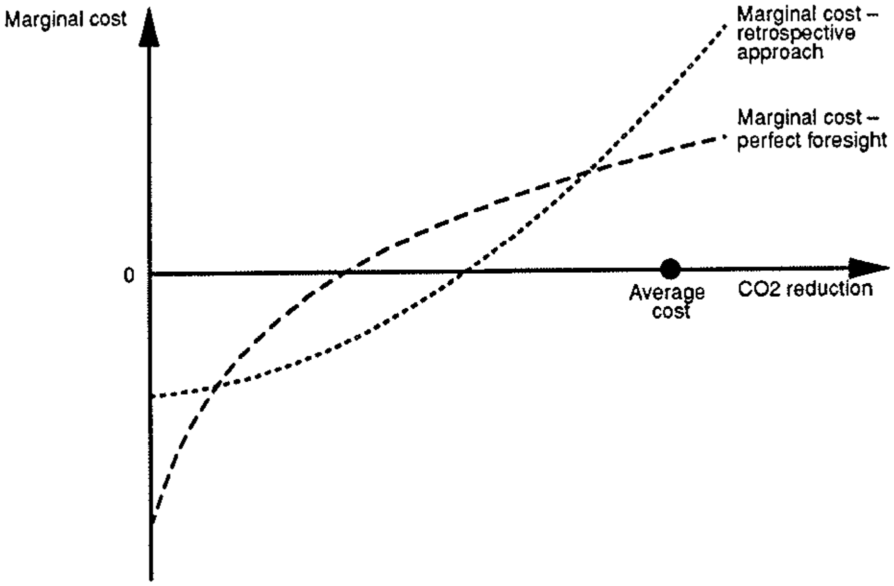

Figure 2.4 Illustrative comparison of the retrospective approach and the perfect foresight approach.

The development of average cost will follow the pattern of marginal costs for the two approaches, but will be identical for the CO_2-reduction target of course.

The *integrated approach* is the most cumbersome to use. Each point on the envelope cost curve is a total scenario, taking a considerable time to develop and fine-tune. It is necessary to develop a large number of scenarios if the costs of a large potential of CO_2 reduction are to be illustrated. If a simulation model is used for calculation one can never be sure to have estimated the final envelope curve of least cost solutions - only by applying a linear programming model this can be assured, and then introducing the limitation of linearity and restricted disaggregation level required by this modelling type.

The integrated approach is most valuable when a few reductions targets are to be specified, only. Thus a fruitful collaboration could take place between the integrated approach and the retrospective approach (or the perfect foresight approach), the latter generating a priliminary priority list of the options, and then performing the final calculations by the integrated approach.

If the cost curve is used as a tool to prioritate the necessary options to reach a specific reduction target, then the following observations can be reported:

- *the partial approach* tends to underestimate the cost of CO_2 reduction. This is partly due to an overlap of CO_2 reduction, the last-introduced option will reduce less CO_2 than expected because a share of the potential is realized through other options. Partly it is due to economic dependences. Not only is the level of the cost curve affected, but even the ranking of the options.
- *the retrospective approach* tends to underestimate (numerical) the marginal costs of the most attractive options, and to overestimate the marginal cost for the least attractive options.
- *the integrated approach* specifies only a recommended basket of different CO_2-reducing options. The method gives limited insight into the prioritization of different technologies. It includes the technology

dependences, but only if these are included in the energy systems model.

- *the retrospective approach* and *the integrated approach* tend to complement each other. The retrospective approach gives a single option ranking, not totally satisfactory theoretically, but as close as it is possible to get. This approach generates the background for assigning priorities for the different options. As a consequence the input to the integrated approach can be constructed, generating the mix of options to be used for a specific target or for specifying the necessary development of the energy system over time to reach a specific target.

3 Methodology of calculation

A large number of CO_2-reducing options are listed in chapter 5, evaluated with respect to the reduction costs incurred and the estimated volume of carbon dioxide reduced by each. Moreover, the possibilities and realities in implementing the given options are analyzed and discussed.

In this chapter the methodology behind the evaluations is described. The BRUS model, used for the calculations, is described briefly in section 3.1, the method for evaluating the CO_2-reducing options is given in section 3.2 and, finally, the setup used for scenarios is discussed in section 3.3.

3.1 The BRUS model

The calculations are carried out using the BRUS model, which was developed by Risø for use in the latest Danish Energy plan, Energy 2000 (ref. 3). BRUS is a long-term simulation model (mostly "bottom-up" based) with a time horizon to the year 2030. The model includes a huge range of energy demand and supply technologies to setup a wide variety of long-term scenarios for the energy system.

The main characteristics of the BRUS model are:

- long-term simulation model which projects to the year 2030,
- subdivision into different sectors of energy demand and supply which are integrated to provide a useful and comprehensive tool,
- energy demand and the development of energy production capacity are driven from the demand side,
- possibility to choose different saving options for thermal insulation in buildings, electrical appliances, and industrial processes, and
- possibility to choose from a large number of energy-conversion technologies.

The structure of the BRUS model is shown in Figure 3.1. The model consists of submodels starting with society at large, demand modules for domestic purposes and industry, supply modules related to the production of electricity and district heating, and modules concerned with emissions and economic consequences. This modularity gives possibilities for partial recalculations, thus obtaining quick answers to partial questions.

BRUS is developed in close relation to the unique feature of the Danish energy system: the three supply grids for electricity, district heating and natural gas and the very complex way these grids interact. A very large part of district heating is supplied by combined heat and power plants so that it is closely related to the electricity production. At the same time most of the natural gas is used for heating domestic buildings, supplying the same heating market as district heating and introducing constraints on both these supplies. Finally, an increasing fraction of the natural gas supply is used in electricity generation.

Results from the model are given as gross energy consumption split into different fuels, emissions of CO_2, SO_2 and NO_x and, finally, the capacity and economic consequences of the setup of a specific system.

An important aspect of the BRUS model is the incorporation of relevant long-term constants. Examples of these long-term constants are the idling use of energy in piped systems and oil furnaces during the summer and the continuous use of energy for heating water in the domestic and commercial sectors, although the

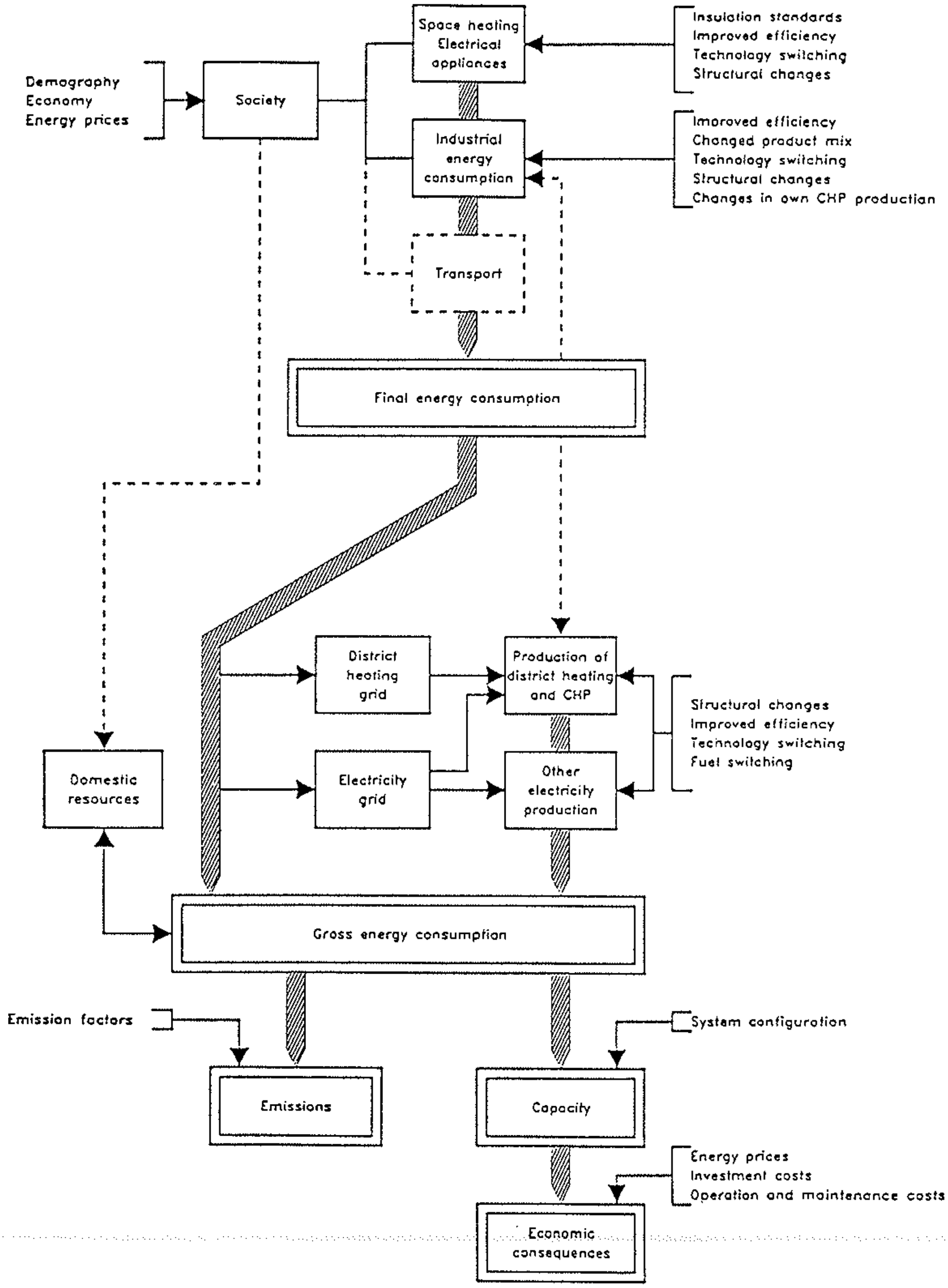

Figure 3.1 Structure of the BRUS model.

space and water heating demand is reduced significantly. If these constants are not taken into account, the results obtained might be misleading.

The costs in BRUS are related to the energy system. Total investment costs are calculated for the energy supply system, including electricity plants, oil furnaces etc., and levelized according to the lifetime of the technologies. Annual O&M costs are defined as a percentage of investments. Finally, after adding fuel costs we are able to estimate the annual average cost over the lifetime of the technologies.

Additional costs of improvements are calculated separately, e.g. retrofitting of buildings, additional insulation and more energy-efficient appliances, and then treated in the same way as supply technologies, resulting in an average cost over the lifetime of the technology.

Thus, the BRUS model treats costs as an ordinary investment analysis. Costs of CO_2 reductions are obtained by comparison with a reference case.

The BRUS model was constructed using commercial spreadsheet software and its details are specific to the Danish case. The methodology and general model structure are however applicable to other national or regional energy systems.

The BRUS model is described in detail in ref. 4 (in Danish).

3.2 Method for calculation

The starting point for the calculations is the baseline scenario. The baseline is constructed following the historical trends in the Danish energy system, including the measures that have been agreed upon to reduce the greenhouse effect. This scenario is described in detail in chapter 4.

The calculations are performed in two ways:

a. As *partial evaluations* of the different CO_2-reducing options, seen in comparison with the baseline.

b. As *total scenarios*, where a 20% reduction scenario is set up for the year 2005, and a 50% reduction scenario is calculated for 2030, both seen in comparison with the baseline.

When evaluating the single *CO_2-reducing options partially*, in comparison to the baseline, it is important to know what the new CO_2-reducing technologies actually do substitute in the energy system. Figure 3.2 shows the chosen calculation methodology.

The CO_2-reducing options are evaluated separately on the energy demand and energy supply sides. When looking at the supply side, the calculations are fairly straightforward. Here it is possible to make a direct substitution for one technology with another in many cases. For example, a coal-fired electricity-producing power plant may be substituted by a biomass-based power plant, and the consequences for CO_2 emissions calculated directly. But even at the supply side things are not always that straightforward. If the plants are CHP plants as is often the case in Denmark, then the ratio of heat to power production might not be the same for the two technologies. This implies that the rest of the energy system will be involved in the calculation.

It is even more complicated to evaluated CO_2-reducing options on the demand side. If an electric saving device is introduced in demand, then the main consequences will be visualized in the energy supply, through a lower electricity production and to a certain extent by a lower demand for electricity-generating capacity. The BRUS model is totally demand driven, which means that the total production capacity in the energy system is determined by the demand side; thus

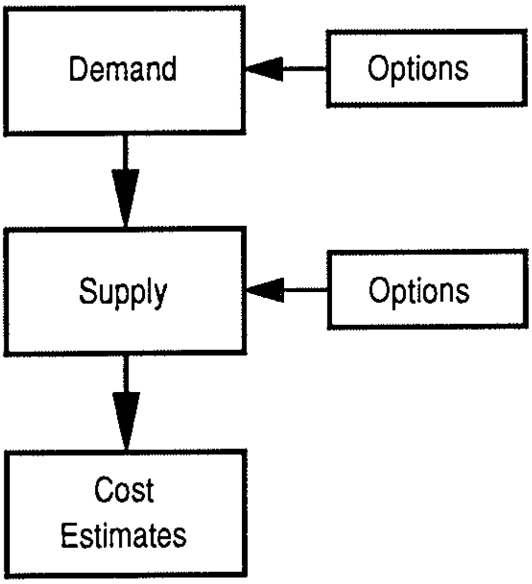

Figure 3.2 The calculation methodology

the model is well-suited to analyzing demand-side changes. But, of course, the given configuration of the energy supply will have a substantial impact upon the results obtained. If the demand for electricity were reduced but the electricity supply were totally based on biomass, the conservation will have no implications for the CO_2 emission. As shown in Figure 3.2, the evaluation of demand options thus is dependent on the supply side.

To facilitate the comparison of the results we have therefore decided to use an average energy supply system for calculating the partial options. This means that the relative structure of the energy supply is unchanged no matter what the level of demand is. There will be the same percentage of windpower, coal-fired CHP plants, photovoltaics etc. in the electricity saved, independent of the extent of the conservation measures. This gives a neutral comparison of the demand options.

3.3 Development of total scenarios

The partial calculations are the starting point for the construction of total scenarios. The most promising partial options are evaluated according to the possibilities for implementation, and then introduced into the scenario in a realistic manner:

- for demand-side options a conservative/realistic view is taken with regard to implementation. In general demand-side options are economically attractive, but difficult to implement. Results are very sensitive to the assumed degree of realization of potential on the demand side.
- supply-side options depend heavily on the ability to install new capacity. Scrapping of existing capacity follows the expected development plans by the utility companies, and care is taken not to introduce further capacity than is needed. The reserve capacity of the system is kept at the same level as in the baseline scenario.

Fine-tuning of the scenario is done by an iterative approach, reaching the desired mix of different technologies and the specified reduction target.

4 Baseline scenario

The baseline is developed using the Danish Energy 2000 plan as the starting point (ref. 3). The Energy 2000 base case is updated and adjusted to a wide extent, briefly summarized in section 4.1. The assumptions behind the development of the baseline are given in section 4.2, and finally section 4.3 gives the main quantified characteristics of the baseline.

4.1 Updating and adjusting the Energy 2000 base case

The Energy 2000 base case is updated in a number of ways

- 1992 is introduced as the new base year. It is the starting point for the calculations, and prices are given in 1992-level (constant prices).
- For the base year energy consumption and supply are updated following the latest statistics.
- The existing capacity of the energy system is updated to the base year, and the survival rates of existing and planned power plants are incorporated in the supply development.
- New forecasts are introduced for electricity demand, following the official Danish projections, adjusted for the latest statistics, among others the new population projections.
- New forecasts are introduced for energy consumption in industry, construction, agriculture and services.
- Technology data are to a wide extent carried over from the Energy 2000 base case, adjusted to 1992-prices.

4.2 Policy assumptions behind the baseline

At the time of writing Denmark is in a quandary. The latest Danish energy plan approved by the government, commits the country to a 20% reduction of CO_2 by the year 2005 compared to 1988.

Part of the policy measures that make this reduction possible has by now been approved by the government, but the bulk of necessary measures has not yet been introduced. So we are in the midstream of CO_2 reduction, making it very difficult to develop a baseline scenario. The concept chosen for the baseline has been the following:

- The already approved policy measures are incorporated in the baseline. This includes the Danish carbon dioxide tax introduced in 1992, which will have a substantial impact on the future consumption of energy and the development of decentralized CHP plants.
- Expected policy measures as the introduction of norms for household appliances are not included in the baseline projections.

Following this, the baseline incorporates "business as usual" trends for the CO_2 reduction measures already begun, but no further measures are put into work.

Thus, the baseline is characterized by moderate energy savings, especially for electricity. The supply system is based on the well-developed Danish concept of combined heat and power plants, operating mainly with highly efficient coal-fired burners. The use of CHP is significant, but not utilized to the limit. For decentralized small-scale CHP plants especially, a fast growth has been initiated by the CO_2 tax, and approximately 1200 MW of these plants are expected to be in operation by 2005. These plants are mainly fired by natural gas, which is exempted from the CO_2 tax. Moreover, the government has decided that all district heating plants are to be fired by biomass, or converted to CHP plants, that eventually will burn natural gas.

Renewable energy, especially as produced by wind turbines, has a well-established position in the Danish energy system, where approximately 400 MW of wind turbines have been sited to date. The development of renewable energy technologies is expected to follow the historical trend, reaching approximately 1000 MW of wind turbines in 2005.

4.3 Main characteristics of the baseline

In the following the main characteristics of the baseline scenario will shortly be given.

Table 4.1 gives the development in the macro-indicators, GNP, population and productivity growth.

Table 4.1 Development of the baseline.

	Year			1992-2030 % p.a.
	1992	2005	2030	
GNP, bill. DKK, 1980-prices	458	616	843	1.6
Population, 1000	5162	5266	5093	-0.04
Productivity, 1992 = 1.0	1.0	1.32	1.87	1.7

By 2030 it is expected that the GNP will be 1.85 times as large as today (1992-prices). This leaves every human being in Denmark nearly twice as well-off in pecuniary term as today.

Development in energy prices follows the assumptions given in the UNEP guidelines, adjusted for the cost of domestic transport of the fuels. Biomass prices are based on Danish forecasts. Table 4.2 shows the UNEP assumptions (ref. 2), the adjusted energy prices in Danish currency, and the assumed price development for biomass.

The natural gas price is expected to follow the oil price. Assumptions for prices of straw and woodchips seem to be quite low, the development following the latest Danish prognosis.

The assumed developments in goods and energy services are shown in Figure 4.1. The use of appliances in households is expected to grow by 0.8% p.a. and the number of residential square meters per person by 0.7% p.a. Nearly twice as much goods and transport per person will be available in 2030 compared with today, if the forecasts come through.

Efficiencies in demand and production are expected to increase moderately. The assumptions are given in Table 4.3.

Table 4.2 Development in energy prices.

		Year			1992-2030 % p.a.
		1992	2005	2030	
UNEP assumptions *					
- crude oil	US$/bbl	-	21	23	-
- coal	US$/TCE	-	49	48	-
Danish currency					
- gasoline	DKK/GJ	45.9	50.4	54.3	0.48
- gasoil	DKK/GJ	39.9	43.7	46.9	0.43
- coal (power plants)	DKK/GJ	11.8	13.4	13.2	0.30
- natural gas	DKK/GJ	18.3	20.3	22.0	0.47
- straw	DKK/GJ	11.5	11.5	11.5	0
- woodchips	DKK/GJ	13.7	13.7	13.7	0

* Following the abatement case (ref. 2).

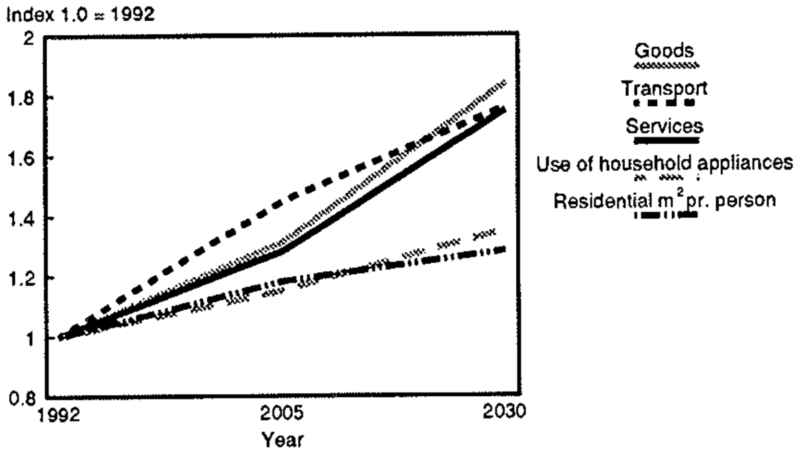

Figure 4.1 Developments in available goods and energy services.

Table 4.3 Developments in efficiencies in demand and production.

		Year			1992-2030 % p.a.
		1992	2005	2030	
Household appliances	use/TWh index 1992=1.0	1.0	1.09	1.22	0.5
Space heating	m^2/GJ	2.4	2.45	2.5	0.16
Service appliances	mill. DKK/GWh	46.7	49.0	46.7	0
Industry	mill. DKK/GWh	6.0	7.1	8.3	0.9
- of this electricity	mill. DKK/GWh	23.8	25.0	27.0	0.3
Transport	1000 km/GWh	0.85	1.21	1.37	1.25

The total final energy demand in the baseline is given in Figure 4.2. Final demand is expected to grow by 0.4% p.a. from 1992 to 2030. The main growth will take place in electricity by 1.1% p.a. Demand for energy for space heating and transport will be stagnating, while a moderate growth will take place in industry and electricity demand for service appliances, especially.

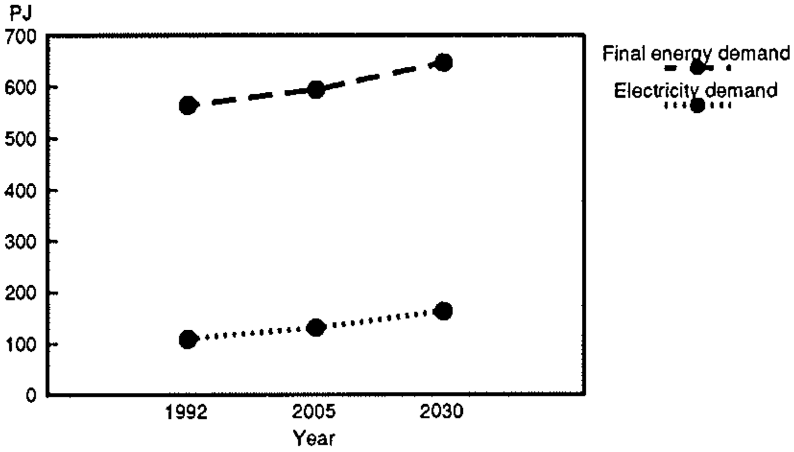

Figure 4.2 Development in total final energy demand and electricity demand.

Today district heating contributes 48% of total net space heating demand. In the baseline this will increase moderately to approximately 53% in 2030. Of this CHP has a share of approximately 60% today, increasing rapidly to nearly 90% in 2005. Natural gas will increase its share of total energy demand from 11% today to 15% in 2005.

The development of gross energy consumption and the related CO_2 emissions are shown in Figure 4.3.

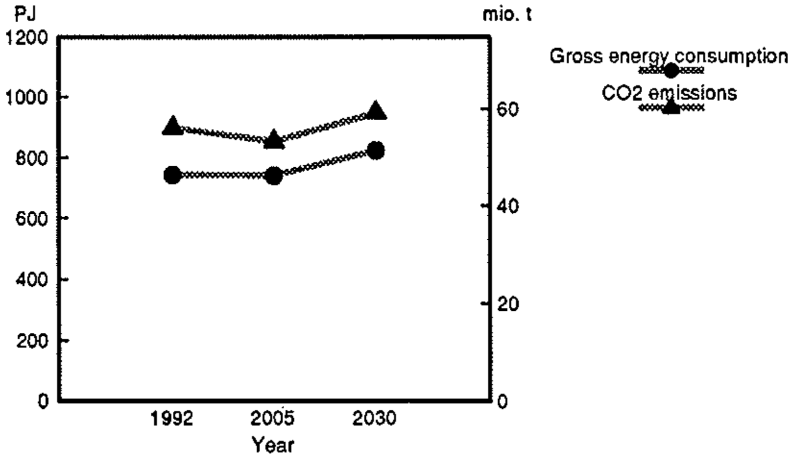

Figure 4.3 Development in gross energy consumption and CO_2 emissions.

CO_2 emissions are calculated to increase by 0.18% p.a. from 1992 to 2030, while the increase for gross energy consumption is 0.3% p.a. Natural gas and renewables will increase their share in gross energy consumption.

The total capacity installed in the power sector will increase by approximately 3000 MW from 1992 to 2030. The development on different plants is shown in Table 4.4.

Table 4.4 Development of installed capacity for electricity production.

	Year		
	1992	2005	2030
	MW		
Total capacity	9900	10400	12800
Centralised capacity	9000	8000	10000
Decentralised capacity	300	1200	1200
Renewables	450	1000	1400

Figure 4.4 shows the development in the annual costs of the energy system, split into fuel costs, operation and maintenance costs and levelized investment costs. The costs of the energy system amounts to approximately 3.5% of gross national product in the 1992. In the baseline this is expected to decline to 2.9% in 2005, and 2.6% in 2030.

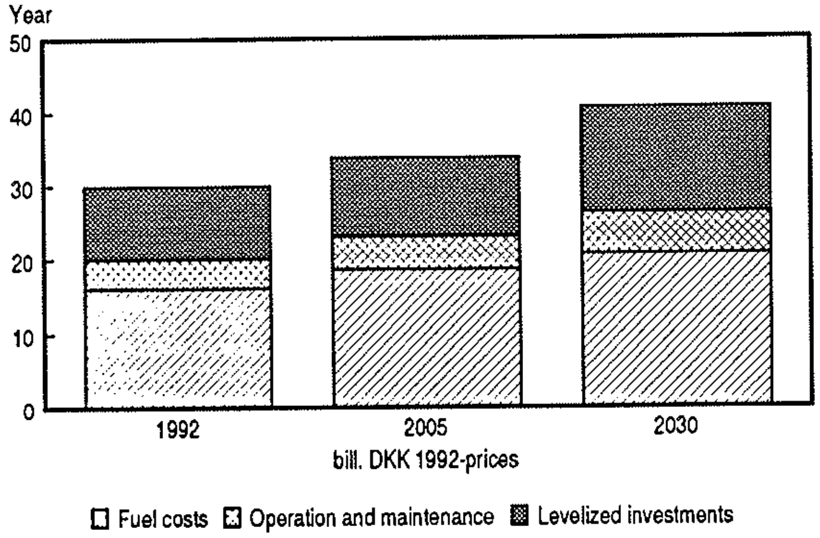

Figure 4.4 Development in annual costs of the energy system.

5 CO_2 reduction options

In the following a large number of CO_2 reduction options will be evaluated in terms of the cost per reduced ton of carbon dioxide as well as the potential volume of carbon dioxide that is possible to reduce using the given options.

All options in this chapter are evaluated in comparison with the baseline scenario - that is, all evaluations are partial. Of course, there do exist interdependences among these options that will influence the costs and change the potential volume of reduced CO_2. These interdependences are not taken into account in this chapter, however, but will be treated in the total scenario analysis in chapter 6.

5.1 Demand-side options

A number of energy conservation measures exist at the demand side. The following options are evaluated in this section:

- conservation in room heating for households and services (5.1.1)
- electricity conservation in households (5.1.2)
- electricity conservation in private and public services (5.1.3)
- energy conservation in industry, construction and agriculture (5.1.4)

Although transport energy is included in the base year and in the projections, energy conservation in transport is not analyzed in this section.

5.1.1 Space heating for households and services

In the baseline, net energy demand for space heating amounts to approximately 175 PJ in the year 2005. Of these 175 PJ 35% is for individual houses, 15% is supplied by the natural gas network, and approximately 50% is supplied by the district heating network of which approximately 85% is based upon waste heat from the power plants (CHP) (all percentages from the baseline). In the past years there has been a tremendous effort in Denmark for energy conservation in buildings (retrofitting, wall and roof insulation, etc.), causing the energy demand for space heating to decrease substantially.

These are the background and main reasons for the rather costly estimates of space heating options given in Table 5.1.

It is expensive to reduce energy consumption in existing average buildings in Denmark. The figures in Table 5.1 include fuel savings, but due to the large share of relatively inexpensive CHP used for space heating, the total cost saving is limited. Table 5.1 is calculated for a total reduction of net space heating of 35% and 65% in 2005 and 2030, respectively. The highest number is very close to realizing the given potential for conservation in space heating.

Table 5.1 states the average costs of reducing CO_2 emissions compared to the baseline. The marginal costs of the reduction gets much higher, both for existing and new buildings.

Compared to the baseline costs of reducing CO_2 are lower in 2030 than in 2005. This is partly due to a gradual reduction of the cost of insulation materials over time as productivity increases, but the main reason is the rising energy prices.

Table 5.1 Space heating - costs and potential quantities of reduced CO_2.

Conservation in	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	5.0	-	4.7
Existing average buildings				
- 35% conservation	1375	2.4	975	2.3
- 65% conservation	1950	4.6	1475	4.4
New buildings				
- 35% conservation	380	0.3	100	0.3
- 60% conservation	1530	0.4	1500	0.3
Buildings with individual supply				
- 35% conservation	700	1.7	-	-

It must be stressed that the estimated CO_2 reduction costs for existing buildings are very uncertain, and that large variations exist within the average. Without doubt it is possible to find houses where conservation in space heating gives a high rate of return.

As shown in Table 5.1 new dwellings are more easily able to conserve heat energy than existing buildings. The 35% conservation case gets close to a break-even case in 2030, again mostly due to increased energy prices and lower costs of insulation materials. The CO_2 reduction cost increases rapidly, however, when moving to higher degrees of insulation standards for new buildings.

A main reason for these high reduction costs is the dominant use of waste heat from the power plants. If space heating conservation is limited to buildings with individual heat supplies, the CO_2 reduction cost is reduced significantly compared to the cost for average existing buildings (see Table 5.1), although it still is not economically attractive. However, large cost variations must be expected even for buildings with individual supply.

We conclude that only moderate savings in space heating can be recommended, concentrating on new buildings and houses with individual supply.

Implementation: There is a long-standing tradition in Denmark for applying standards for new buildings, and improving the efficiency of existing buildings by invoking subsidy schemes. For new houses it would be possible to introduce stricter building standards.

The savings potential in individual houses could be realized by regionalizing the existing scheme for conservation and maintenance subsidies.

For an ongoing conservation in space heating it is important that energy prices be maintained at the existing high level.

5.1.2 Electricity conservation in households

Consumption of electricity in households accounts for a little less than 1/3 of total electricity demand. Of this approximately 70% is used for electric appliances and lighting. Table 5.2 summarizes the results for electricity conservation in households.

If the total potential for household appliances and lighting were realized a total of 1.8 mill.t of CO_2 would be eliminated in 2005, and 3.4 mill.t of CO_2 in 2030.

Table 5.2 Appliances and lighting in households - cost and potential CO_2 reductions.

Increased efficiencies in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	1.8	-	3.4
Lighting	-550	0.5	-580	0.2
Wash	-550	0.3	-570	0.7
Cooking	-550	0.2	-500	0.5
Cooling	-550	0.4	-480	0.8
Realistic implementation	-550	0.8	-540	2.8

The most promising areas for improved energy efficiency are lighting and cooling. Within the last 5 years *compact fluorescent lamps* have had a succesful penetration in the Danish market. It is expected that up to 20% of the lighting market in households today is covered by low-energy lighting.

A large part of the potential energy reduction by using low-energy lamps is expected to be realized in the baseline, which is the reason for the lower CO_2 reduction calculated for year 2030.

Efficiency in *cooling* has increased substantially within the past years, and highly efficient refrigerators and freezers have been developed. The success on the market for these low-energy appliances has been more doubtful than for low-energy lamps. When households renew their worn out appliances a number of different circumstances are behind the new choice - and energy efficiency might be a nearly non-significant factor. The potential CO_2 reduction by increased cooling efficiency is nevertheless significant (cfr. Table 5.2).

For other appliances such as washing machines and dish washers the efficiency has improved substantially, although not to the same extent as cooling appliances. Table 5.2 shows the potential savings for washing and cooling devices.

The cost of CO_2 reduction is nearly the same for all appliances. By 2005 no extra costs are expected in the manufacture of low-energy appliances. Thus the reduction in operating costs is related to the lower electricity consumption. For a further development of the energy efficiency extra costs are expected in 2030, but these costs are expected to be fairly small.

Figure 5.1 gives the variation in energy efficiencies between a standard appliance and the best appliance expected on the market in 2005.

The possible CO_2 reduction achieved by introducing the most energy-efficient appliances for household use amounts to approximately 3% of CO_2 emission in 2005, and approximately 6% in 2030, making it worthwhile to look at the possibilities for implementation.

Implementation: For lighting it seems reasonable to assume a high market share of compact fluorescent lamps in the year 2005 (75%) and close to full market cover by 2030 (90%). These percentages can turn out to be even higher, seen in the light of the rapid technological development of the compact fluorescent lamps making them suitable for nearly all purposes.

Part of the reason for this rapid penetration of low-energy lamps is of course the high domestic price of electricity in Denmark. This high price has to be maintained or even gradually increased if the assumed penetration of low-energy lamps is going to take place. In the baseline the share of low-energy lamps is

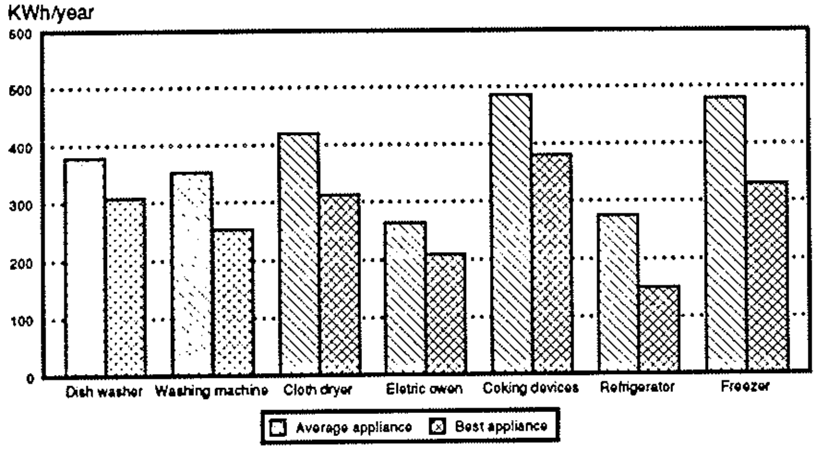

Figure 5.1 Energy efficiencies for selected appliances.

assumed to be 50% in the year 2005.

As mentioned above, the penetration of low-energy cooling appliances has been less successful than for low-energy lamps. But the technological development is at hand and it should be possible to increase the efficiency by introducing standards. For cooling appliances it should be possible to make a fast introduction of standards and then gradually tighten the standards, making it possible for the manufacturers to develop their products. In the calculations it is assumed that the efficiency of cooling appliances will be improved by 50% by 2005 compared with today. This should be possible to realize, especially when one considers that some of the cooling appliances on the market today already have an energy efficiency exceeding the assumed standard in 2005.

For appliances such as washing machines and dish washers it appears to be more complicated to reach agreement on harmonized standards. In the calculations it is assumed that a standard will be in place within the next 5 years, leading to an increase in efficiency in 2005 of 20-30% compared with today.

As shown in Table 5.2 this realistic mixture of increased efficiencies - mainly obtained by introducing standards - could reduce CO_2 emissions by 0.8 mill.t in 2005 (1.5% reduction compared to baseline), and be economically attractive at the same time. A substantial increase in appliance efficiencies has already taken place in the baseline.

5.1.3 Electricity conservation in private and public services

The private and public services account for a little less than 1/3 of total electricity consumption. Lighting accounts for somewhat less than 40% of this, ventilation approximately 20%, and heating for almost 10%.

A total realization of the estimated potential in services would bring about a reduction of CO_2 in 2005 of 2.8 mill.t, corresponding to approximately 35% electricity conservation in the service sector.

Table 5.3 shows the results for the service sector for the most important end-uses, for a 50% to 100% realization of the conservation potential for the two years, respectively.

The most important end-use in year 2005 is lighting giving a reduction potential of 1 mill.t of CO_2.

Table 5.3 Service - cost and potential CO_2 reductions.

Electricity conservation in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	2.8	-	2.6
Lighting				
- 50% realized	-630	0.3	-700	0.2
- 100% realized	-440	1.0	-450	0.6
Heating				
- 50% realized	-480	0.2	-480	0.2
- 100% realized	-330	0.5	-280	0.5
Ventilation				
- 50% realized	-370	0.3	-360	0.3
- 100% realized	-125	0.7	-50	0.8
Miscellaneous				
- 50% realized	-470	0.3	-510	0.3
- 100% realized	-125	0.7	-280	0.7
Realistic implementation	-500	0.9	-440	1.3

All price estimates are negative, indicating low extra costs of low-energy devices, dominated by the savings of lower electricity consumption. The figures in Table 5.3 are calculated as average estimates to the baseline. Figure 5.2 shows the development in marginal costs for selected end-uses in the service sector.

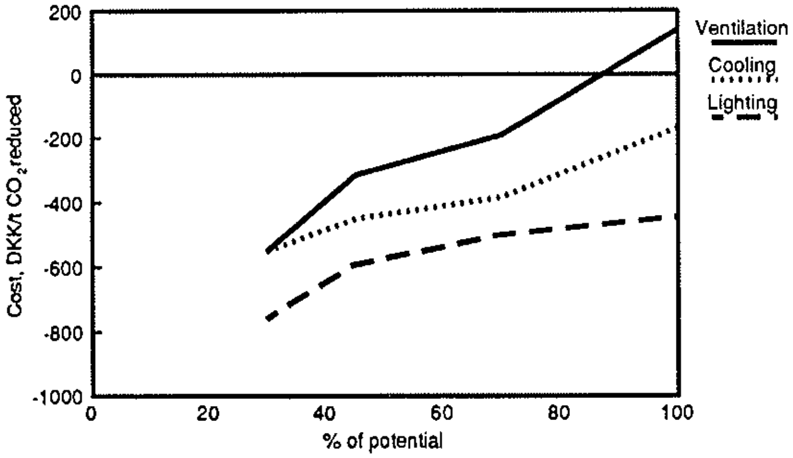

Figure 5.2 Marginal costs for selected end-uses in the service sector.

As seen from Figure 5.2 marginal costs do increase rapidly for ventilation and cooling.

Implementation: As for private households, as noted earlier it is expected that the most promising areas for efficiency improvements are lighting and cooling, due to the rapid development of these technologies. In the calculations it is assumed that 75% of the estimated potential can be realized within lighting and cooling. For cooling it is assumed that this can be reached by introducing standards as in private households. For lighting stronger measures are required - the incentive could be obtained by introducing environment taxes on the service sectors, although a low price elasticity should be expected.

Electricity use for other purposes in the service sector is much more difficult to get hold on, although an environment tax would affect these purposes as well as lighting (and cooling). A 20% realization of potential is assumed in 2005 gradually increasing to 40% in 2030.

Totally, this gives an energy conservation of approximately 20% of electricity demand in the service sector both in 2005 and 2030.

Table 5.3 gives the results for a realistic implementation in the service sector.

5.1.4 Industry, including agriculture and construction

Energy use in industry accounts for a little less than 30% of total final consumption. Electricity consumption in industry (including agriculture and construction) accounts for approximately 1/3 of total electricity consumption.

The total estimated potential of CO_2 reductions in industry amounts to approximately 4.4 mill.t in 2005 and 5.8 mill.t in 2030. To estimate how much of this can be realized and at what cost is very close to being impossible. Table 5.4 summarizes the results obtained, based upon cost and CO_2-reduction possibilities in the Energy 2000 plan.

Table 5.4 Industry, including agriculture and construction - cost and potential CO_2 reductions.

Energy conservation in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential		4.4		5.8
Industry - 100% realized	-280	3.3	-280	4.5
Agriculture - 100% realized	-200	1.0	-210	1.2
Construction -100% realized	-250	0.1	-300	0.1
Solid fuels (50% realized) Electricity (50% realized)	-80 -510	0.9 1.3	-80 -560	1.3 1.6
Realistic implementation	-180	0.5	-250	1.2

The estimated reduction costs are about the same in the three subsectors: industry, agriculture and construction. Conservation of electricity seems to be more economically attractive than conservation of solid fuels. It must be stressed that the given results are very uncertain.

Implementation: Over the past years there has been significant energy conservation in industry, implying a decrease in total energy intensities of 15-20%. But history shows clearly that the main reductions have taken place for solid and liquid fuels, while reductions in the energy intensity for electricity have been small if any at all.

This picture is carried out into the future in the realistic conservation mixture, reducing industrial energy consumption of solid and liquid fuels by approximately 25% of the estimated potential in 2005, while only 5% of the estimated potential for electricity conservation is realized. If no special policy measures are introduced, even this might turn out to be too much. Without doubt, an increase in the environment tax on industry would facilitate energy conservation in this sector, although the long-term price elasticity in general could not be expected to be higher than 0.3-0.4 (a 10% price increase reduces consumption by 3-4%) (ref. 5 and 6). 25% of the estimated potential for energy conservation in industry amounts to 11 PJ (6% final energy consumption). Given a price elasticity of 0.3, to realize this part of the potential requires a price increase of 20%. Increasing prices gradually over several years would make it easier for the industry to adjust.

The result of the realistic implementation is shown in Table 5.4.

5.2 Supply-side options

The following supply-side technologies are evaluated concerning reduction costs and possible quantities of CO_2 reduced:

- connections to the district heating and the natural gas network (5.2.1)
- use of combined heat and power (5.2.2)
- individual houses: use of solar collectors for heating water (5.2.3)
- conventional electricity supply (5.2.4):
  - intensified use of natural gas (combined-cycle plants)
  - use of biomass (biomass-gasification plants)
  - use of advanced technologies (fuel cells)
- extended use of renewable technologies, that is wind power, photovoltaics and wave power (5.2.5)
- introduction of CO_2 absorption and disposal (5.2.6)

A number of these supply technologies compete on the same market and can replace each other. For this reason it is not meaningful to quantify the possible extent of CO_2 reduction unless the total system configuration is taken into account. The possible CO_2 reductions mentioned in this section are therefore only to be taken as a rough indication of these CO_2 quantities. A precise analysis of the supply options are given in the description of the total scenarios, chapter 6.

5.2.1 Connections to district heating and natural gas network

As mentioned earlier, approximately 50% of the net heating demand is supplied from the district heating network, and approximately 15% from the natural gas network. Both networks will be fully developed by the turn of the century, but the capacity is not expected to be fully utilized, that is there still would be a large number of consumers that could be connected to the network, where only the cost of the connection and the in-house constructions would be incurred.

District heating

For the *district heating* network the total potential of CO_2 reduction, given by a full capacity utilization, would be 2.1 mill.t in 2005 and 1.6 mill.t in 2030 (the decrease is caused by an increasing capacity utilization in the baseline).

Table 5.5 shows the results for the connection of new and existing dwellings.

Table 5.5 Connection to the district heating network.

Energy conservation due to increased connection in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	2.1	-	1.6
Existing dwellings (95%)	-820	1.5	-850	0.8
New dwellings (98%)	-830	0.1	-850	0.3
Realistic implementation	-820	1.7	-860	1.1

The costs of reducing CO_2 are almost the same for new and existing dwellings. It seems to be economically very attractive to increase the number of connections to the district heating network, which of course is due to, that the major part of the investments (transmission and distribution network) are already undertaken.

Increased connection to the district heating grid is to be seen in relation to the extended use of combined heat and power (see section 5.2.2).

Implementation: The Danish municipalities have already today the possibility of making connections compulsory, so that over a span of years (typically 9 - 10 years) the number of connections could be close to 100%. Lately, the government has introduced a subsidy to finalize the district heating network, if connections are made compulsory. For many new dwelling areas it is obligatory to be connected to district heating. This does suggest that a high rate of connection could be obtained in the future if the instruments already at hand are used. For existing areas a connection of 95% is assumed, for new areas the figure is 98%.

Table 5.5 shows the results.

Natural gas

For the *natural gas* network the total potential of CO_2 reductions, given a full capacity utilization, is estimated to be 0.4 mill.t of CO_2 in both 2005 and 2030. The potential is not nearly as large as that for district heating.

Table 5.6 shows the results for the connection of new and existing dwellings.

The investments in the natural gas network are sunk costs. Only the costs of the connection and the in-house installation have to be undertaken, and this is the main reason behind the highly negative cost estimates. Thus, seen from a societal viewpoint it is economically very attractive to be connected to the natural gas network.

Implementation: Connections to the natural gas network are not compulsory today. Consequently, it is important that there be a price incentive to encourage households to connect. An increased use of environment taxes would presumably

Table 5.6 Connection to the natural gas network.

Energy conservation due to increased connection in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	0.4	-	0.4
Existing dwellings (85-95%)	-1640	0.2	-1870	0.2
New dwellings (95%)	-1260	0.1	-1500	0.1
Realistic implementation	-1570	0.2	-1760	0.3

increase the number of connections to the natural gas network. Table 5.6 shows the results of assuming connections of existing houses in 2005 of 85% increasing to 95% in 2030, and for new houses of 95% from 2005 and onwards.

Increased connections to the natural gas network do not change the CO_2 emission substantially.

5.2.2 Use of combined heat and power

Approximately 60% of the district heating consumption is supplied by waste heat from power plants that deliver combined heat and power. Nearly 90% of this heat comes from central CHP plants and the rest from decentralized (small) CHP plants.

The heating markets determine the potentials for utilizing CHP. The total potential of CO_2 reduction by increasing CHP (not taking into account an increase in connections to the network) amounts to 0.5 mill.t in 2005 and 0.9 mill.t in 2030. A rapid increase in the utilization of CHP (especially small-scale plants) is already incorporated in the baseline. The costs of a 100% utilization of small and medium-term heating markets by CHP is shown in Table 5.7. The medium heating market is dominated by natural gas decentralized plants, while the small markets are more biomass based.

Implementation: The Danish government has decided that all district heating plants have to be fuelled by biomass or converted to CHP plants that use either natural gas or biomass. This, seen in relation to the newly introduced tax on CO_2 emissions, has started a rapid development of decentralized CHP plants using natural gas or biomass. Around the turn of the century it is expected that the capacity of decentralized CHP plants wil be more than 1000 MW, more than three times the present value. If this development is enhanced about 1700 MW can be expected in 2005 (1200 MW is already in the baseline). This estimate is used in the "realistic utilization" in Table 5.7, which also includes a small increase in the share of central-produced combined heat and power.

If the extended use of CHP is seen in relation to increased connections to the district heating network, the option seems very economically attractive both in 2005 and in 2030 (cfr. Table 5.7).

Table 5.7 Extensive use of combined heat and power.

Increased energy efficiency by CHP use in:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Total potential	-	0.5	-	0.9
Small heating markets	-70	0.3	-160	0.3
Medium heating markets	-450	0.2	-570	0.6
Realistic utilization	-90	0.2	-500	0.8
Increased connection and CHP	-720	2.1	-780	2.4

5.2.3 Use of solar collectors for domestic hot water

The use of solar collectors for producing hot water is relevant in the residential and commercial sectors with individual supply as oil furnaces. The solar collectors provide the possility of turning off the oil furnace during the summer. This will not only reduce the direct energy consumption for hot water but save the idling consumption in the oil furnace as well.

The results of a moderate use of solar collectors are shown in Table 5.8.

Table 5.8 Use of solar collectors for domestic hot water.

	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Solar collectors for hot water	550	0.05	350	0.1

The price is rather high and the potential CO_2 reductions are limited if the collectors are used only in houses with individual supply.

5.2.4 Conventional electricity supply

How much CO_2 reduction can be obtained in the conventional electricity system depends heavily upon the "room" for new technologies in the supply mixture. Before 2005 about 4000 MW of the present existing capacity is expected to be phased out due to age. By 2030 all of the existing capacity will vanish - at least for normal operation. The existing approved development plants include new natural gas capacity of approximately 450 MW and new coal-fired capacity of approximately 400 MW. These plants are expected to be on stream at the end of this decade.

This leaves room in the year 2005 for approximately 3000 MW, given the projections for electricity and heat in the baseline. If heating and electricity savings are carried out it will decrease the need for new production capacity.

Table 5.9 summarizes the results of the analysis performed for the conventional power system.

Table 5.9 Introduction of new technologies in the electricity system.

Changed energy consumption due to the use of:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Centralized plants				
- combined cycle (400 MW)	-150	(1.0)		
- biogasification (400 MW)	-40	(1.8)	-40	(1.8)
- fuel cells (400 MW)	-	-	630	(0.8)
Decentralized plants				(0.3)
- combined cycle (350 MW)	-270	(0.4)	-310	(0.1)
- biomass (200 MW)	300	(0.5)	275	(0.4)

The use of combined cycle plants looks very promising, as is the case of biogasification. Biogasification plants are assumed to be developed to a technological commercial level and to be economically close to break-even in 2005. Is this not the case, they might be replaced by bio-combustion plants to a slightly higher price. Fuel cells are introduced only in 2030, and are rather expensive at the expected investment costs in 2030.

All estimated quantities of CO_2 reduction are related to the baseline case, and are supposed to change in an actual reduction scenario.

5.2.5 Renewable technologies

The most promising renewable technology in Denmark today is windturbines. Approximately 3% of the electricity consumption is supplied by wind power, with a capacity of approximately 450 MW. If the historical trend of wind capacity development is enhanced, approximately 1400 MW can be expected in the energy system by 2005 (1000 MW is already in the baseline).

Table 5.10 summarizes the results for a wind power development as mentioned above, and an introduction of photovoltaics and wave power.

Table 5.10 Increased utilization of renewable technologies.

Utilization of:	2005		2030	
	Cost DKK/t CO_2	CO_2 reduced mill.t	Cost DKK/t CO_2	CO_2 reduced mill.t
Wind power (+400 MW)	~0	(0.6)	~0	(1.7)
Photovoltaics (500 MW)	-	-	700	(0.6)
Wave power (350 MW)	-	-	550	(1.1)

As expected, wind power is the most competitive of the three technologies. It must be stressed that the CO_2 reduction costs for these technologies are very uncertain, even for wind power in the year 2005. A realiable cost estimate necessitates the use of a detailed model for estimating the capacity value of the technologies, and possible loss of energy in the interplay with the remaining electricity system.

As for other electricity supply technologies the quantities of CO_2 reduced are calculated in relation to the baseline scenario, and may change substantially in an integrated CO_2 reduction scenario.

5.2.6 Introduction of CO_2 absorption and disposal

The Danish utility company, ELSAM, has undertaken a project on the possibility of absorbing CO_2 at the combustion plant and depositing it in large caverns or empty oil fields. The following description and results are from this project (ref. 7 and 8).

Three possibilities are analyzed for CO_2 absorption:

a. conventional combustion plants, using a chemical absorption approach,
b. an integrated solution in connection with the introduction of coal gasification plants (IGCC), and
c. crunched coal-fired plants with pure oxygen combustion and recirculation of CO_2.

All of these technologies have a substantial impact upon the efficiency obtained at the power plants. The efficiency of electricity production is calculated to decrease from approximately 47% to approximately 35% for the combustion solutions, while the IGCC will imply a decrease from approximately 41% to approximately 34%.

The estimated reduction cost is shown in Table 5.11. The figures are to be used with great caution and are subject to a high degree of uncertainty.

Table 5.11 Estimated cost of absorption of CO_2 at the power plants.

Absorption method	CO_2 reduction cost DKK/t CO_2
a) Conventional combustion with chemical absorption	207
b) IGCC	82
c) Combustion using pure oxygen	88

Disposal of CO_2 is possible in large caverns or in emptied oil fields. The estimated cost of cavern deposition is calculated as approximately 90 DKK/t CO_2. As much as 650 mill. t of CO_2 is disposable in CO_2 caverns located in Jutland/Funen.

Conclusively, the ELSAM project calculates the total cost of absorption and disposal of CO_2 to be approximately 300 DKK/t CO_2.

5.3 Afforestation

The Danish government has approved an afforestation plan, doubling the Danish forest area over the next 80 years. The present Danish forests cover approximately

450,000 ha, and the afforestation plan expects this area to increase to approximately 850,000 ha, about 5000 ha per year.

If an increase of forest area of 5000 ha per year is assumed, the consequences of CO_2 sequestering in the year 2005 and 2030 are shown in Table 5.12.

Table 5.12 The consequences of the afforestation plan.

	Year 2005	Year 2030
Afforestation		
Increase in forest area, ha	65,000	190,000
CO_2 sequestering, mill. t	0,6	1,7
- reduction to baseline	1.1%	2.8%

Normally, it will take about 20 years before a tree attains conditions of optimal growth. This optimal growth will then be obtained the following 50 years. In Table 5.12 it is assumed that the forest in Denmark can give approximately 5 t dry matter per ha per year, which is a conservative estimate, resulting in a sequestering of 9 t CO_2/ha/year. The assumed annual increase in forest area is 5000 ha, although the realized afforestation has only been 2000-2500 ha/year, in the period 1989-91. Thus, an increased effort is needed if the afforestation plan shall be fulfilled within the expected timehorizon.

6 Total scenarios

With the partial calculations as starting point two scenarios are developed:

a. a 20% reduction scenario is setup for the year 2005

b. a 50% reduction scenario is setup for 2030, taking as starting point the 20% reduction scenario in 2005

The reduction in both scenarios is obtained relative to the baseline scenario.

6.1 Main assumptions for the two reduction scenarios

The reduction scenario is developed taking the main part of the components from the partial scenarios. An important aspect of the scenarios has been the taking of a realistic view of the possibilities for implementing the chosen options. For this reason greater emphasis is put on the supply-side options than the identified potentials seem to justify.

The main assumptions are:

Space heating: Moderate increase in insulation in existing buildings - unit heat demand decrease by 10% in 2005 and 25% in 2030. Increased standards for new buildings - approximately 35% and 45% in 2005 and 2030, respectively

Household electricity demand: For lighting and cooling a significant improvement in efficiency is expected. 75% of the lighting need in 2005 is met with compact fluorescent lamps, leading to an efficiency increase of approximately 50% compared with today. Likewise for cooling appliances a rapid introduction of norms is expected to increase their efficiency by approximately 50% and 75% in 2005 and 2030, respectively. Other appliances will have more moderate efficiency increases (for further details see section 5.1.2 the "realistic implementation").

Electricity conservation in services: The assumptions are based on the "realistic implementation" in section 5.1.3, putting emphasis on lighting and cooling as in private households.

Conservation in industry: Conservation in industry is expected to have a large potential. On the other hand, this is the most difficult sector to treat both concerning cost estimates and the possibilities of realizing the potential. For this reason very moderate savings are introduced in this sector. For electricity, only 5% of the potential within industry, agriculture and construction is assumed to be realized by 2005, increasing to 10% by 2030. For solid and liquid fuels the realized share of potentials is assumed to be 20% in 2005, increasing to 30% in 2030. Thus, unrealizable "no-regret" options in industry should not distort the picture in this analysis.

Conservation in transport: Projections for the use of energy in transport are included in overall energy consumption, but no energy conservation options are evaluated in this study.

Connection to collective networks: It is assumed that capacity utilisation for both the district heating and natural gas networks will increase substantially (cfr. section 5.2.1). For the former grid connections are assumed to be 95% for existing buildings and 98% for new buildings in the year 2005, maintaining that level during the rest of the analyzed time period. For the latter the connections are assumed to be 85% for existing buildings in 2005 increasing to 95% in 2030. 95% of new buildings are assumed to be connected from the year 2005 and onwards.

Use of combined heat and power: Approximately 1300 MW of decentralized combined heat and power plants are assumed in the year 2005, increasing to 1400 MW in 2030. This is a moderate increase compared to the baseline, where 1200 MW is assumed. In 2030 approximately 95% of the district heating market is supplied by CHP. The electricity supply is assumed to be based on a mix of biogasification plants, combined cycle and conventional natural gas plants.The decentralized 1300-MW CHP plants are in 2005 assumed to be based on an equal mix of biomass and natural gas. Approximately 85% of the assumed 1400 MW in 2030 is based on biomass (including waste) and approximately 15% is based on natural gas.

Solar collectors for hot water production: Approximately 10% of houses with individual supply (e.g. oil furnaces) are assumed to have solar collectors for producing hot water in 2005, increasing to about 30% in 2030.

Conventional electricity supply: Given the development of decentralized CHP-plants approximately 900 MW new conventional capacity can be installed in the time period until 2005, supplementing the approximate 850 MW already planned capacity development (450 MW natural gas and 400 MW coal). Compared to the baseline the availability for capacity development has decreased substantially, mostly due to electricity conservation and the development of windturbines (see the following section). This 900 MW "gap" is assumed to be filled with approximately 650 MW biogasification plant and approximately 250 MW natural gas combined cycle to be on stream in the year 2005. In 2030 there are no restrictions from the existing capacity. The electricity supply is assumed to be based on 1500 MW biogasification plants, 1000 MW combined cycle, 4000 MW natural gas combustion, and 1000 MW fuel cells based on natural gas.

Renewable technologies: Wind power is assumed to dominate electricity production from renewable technologies. 1300 MW of wind power is assumed in year 2005, increasing to 1800 MW in 2030. Photovoltaics are introduced with a total of 800 MW in year 2030.

6.2 Results for the main scenarios

The main results of the scenarios are shown in Table 6.1. This indicates that it should be possible to reduce CO_2 substantially without heavy economic burdens in the years 2005 and 2030 - seen from the viewpoint of society. The total cost of the scenario is -100 DKK/t CO_2 reduced in 2005, and +40 DKK/t in 2030.

A major obligation to the results in year 2030 is the availability of energy resources. The long-term scenario indicates the use of biomass and natural gas, especially. The total use of biomass is calculated to 162 PJ in 2030 - the total potential of biomass is estimated as 100 PJ in the Energy 2000 plan excluding possibilities for energy harvest. The potential might be increased by the laying fallow of 15-20% of farmland, but how much it will increase is very uncertain. Finally, although the potential does exist, there might be problems with the localization of the biomass.

Table 6.1 Results of the two scenarios.

	1992	2005	2030
Energy consumption			
Net heating demand, PJ	166	156	140
- reduction compared to baseline	-	11%	26%
Electricity for appliances, PJ	59	57	61
- reduction to baseline	-	15%	27%
Industry (final demand), PJ	161	173	200
- reduction to baseline	-	3%	6%
Total final energy consumption, PJ	564	550	551
- reduction to baseline	-	7%	15%
Gross energy consumption, PJ			
- oil	289	255	240
- natural gas	80	126	200
- coal	286	181	24
- biomass	46	98	162
- renewables	8	35	42
- electricity import	35	0	0
Total	744	687	668
- reduction to baseline	-	9%	21%
System capacity, MW			
- conventional plants	9000	6900	7600
- decentralized plants	300	1300	1400
- wind power	450	1300	1800
- photovoltaics	-	-	800
Reserve capacity, MW	3000	1900	1600
Reserve capacity, %	45%	27%	20%
Total electricity capacity, MW	9900	9800	11700
- reduction to baseline	-	6%	9%
CO_2 emissions, mill.t	56.2	42.9	31.3
- reduction to baseline	-	21%	48%
Annual costs, bill.DKK (1992)			
- fuel cost	16	17	17
- O&M cost	4	4	5
- lev. investments	10	12	20
Total	30	33	42
- increase to baseline	-	-3%	3%
Average cost of CO_2 reduction DKK/t	-	-100	+40

The assumed price development for biomass follows the latest Danish prognosis, where biomass mainly is looked upon as a by-product from agricultural production (straw). If the possibilities for energy harvest are to be utilized, where biomass for energy purposes will be the main product, this might be more costly. Finally, if biomass resources are to be utilized to the limit this might in general increase the price of biomass.

Although there is a considerable consumption of natural gas each year it seems realistic that this resource will be available, either from domestic sources or as imported, but a fast increasing demand for natural gas might lead to unfavourable price changes on this fuel. Eventual costs for expanding the natural gas transmission grid is not taken into account.

A few other reservations have to be stated. The costs in this study include the direct costs only. Prices are stripped of taxes and subsidies to give a picture of the "real economic costs" - no extraordinary profits are allowed.

The cost of implementation is not taken into account, that is administration costs, extraordinary search costs etc. are not included. It is important that already existing governmental bodies are used in the administration, and that the identification of energy conservation options is an integral part of ordinary maintenance in industry and services.

No costs are added due to forced implementation of CO_2 reduction options. It is important that the energy-efficient solutions are introduced when the old appliances and plants are worn out and ready for replacement.

Moreover, eventual welfare losses, due to the imposition of environment taxes, compulsory connections to public networks etc. are not taken into account. Of course, such welfare losses do not exist only within the energy field, but everywhere in society where the public intervenes.

Finally, the uncertainties related to these long-term calculations are of course enormous. Given these reservations, however, there seems to be sufficient economic background to conclude that even a substantial reduction of CO_2 will not put heavy burdens on the Danish national economy.

6.3 Cost curves for CO_2 reduction

Based on the two reduction scenarios the medium-term cost curve for 2005 and the long-term cost curve for 2030 are constructed using the retrospective approach. The marginal and average cost curves are given in Figures 6.1 and 6.2 for the two scenarios, respectively.

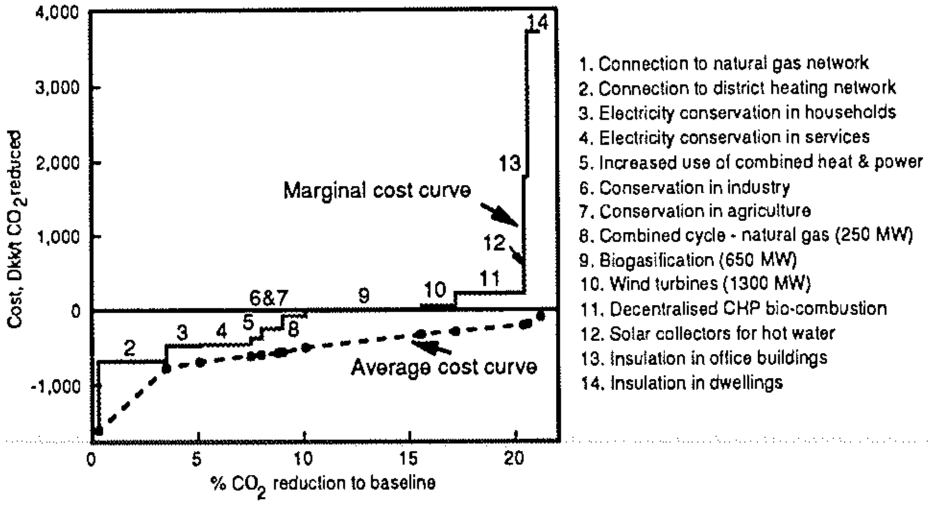

Figure 6.1 Medium-term cost curve for CO_2 reduction.

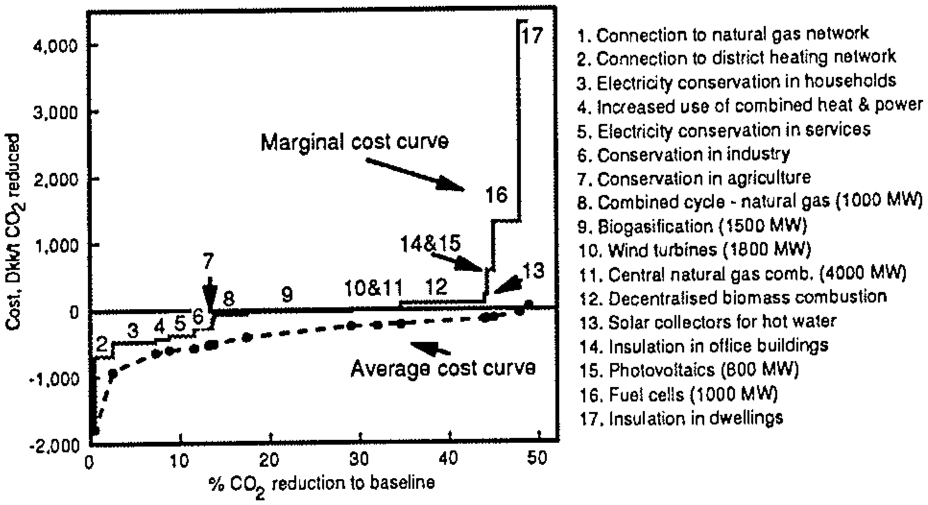

Figure 6.2 Long-term cost curve for CO_2 reduction.

For both scenarios the economically most attractive and the most efficient options with regard to CO_2 reduction can be grouped into three:

- *The utilization of the existing excess capacity* in the Danish natural gas and district heating networks. For both networks the major part of the investments (transmission and distribution networks) are already undertaken, implying that only the marginal cost of connection and the in-house constructions are to be incurred. In 2005 almost 4% CO_2 reduction can be achieved by these options to an economically very attractive cost (negative costs). In 2030 the CO_2 reduction by these options are reduced because of an increasing capacity utlization in the baseline. In spite of this, utilizing the network capacity has a very favourable impact on the average cost of CO_2 reduction in Denmark. Leaving these options out for year 2005 would decrease the CO_2 reduction to approximately 17% compared to the baseline and increase the average cost to approximately 25 DKK/t CO_2 reduced.[1]
- *No-regret options on the demand side*, that is options that are economically attractive and CO_2 reducing at the same time. The most important of these options are electricity conservation in households and services and energy conservation in industry, reducing CO_2 emissions by approximately 6% in 2005 compared to the baseline. In 2030 the total demand side contributes with approximately 10% CO_2 reduction, or approximately 20% of the total CO_2 reduction. As stated above a high degree of uncertainty is related to the implementation of these demand-side options, although a conservative view is taken in both scenarios with regard to the realized potential.
- For the supply side *utilization of biomass resources* dominates the results in both scenarios. In 2005 biogasification reduces CO_2 emission by approximately 5% and the use of decentralized CHP-bio combustion reduces CO_2 emission by approximately 3%. In 2030 the use of biomass reduces CO_2 emissions by approximately 20%. It is clear that the availability of

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[1] Due to interdependences in the energy system it is difficult to leave part of the chosen options in the scenarios out, and the given figures are to be taken as rough estimates, only.

biomass resources (at least 98 PJ in 2005, and 162 PJ in 2030, including straw, woodchips and waste) is crucial to the results. Biogasification plants are assumed to be developed to a technological commercial level and to be economically close to break-even in 2005. Is this not the case, it will increase the cost of CO_2 reduction, depending on the alternative cost of bio combustion.

The use of natural gas is increased significantly until 2030, amounting to 200 PJ that year. Due to the possibilities for importing gas this is not a major limitation to the results, although a fast increasing demand for natural gas might lead to unfavorable price changes on this fuel.

For both scenarios it is observed that the supply side plays a dominating role - approximately 3/4 of the total CO_2 reductions is achieved on the supply side.

As shown in chapter 2 there are theoretical problems in calculating these cost curves due to the interdependences among the options. It should be stressed that the results can be taken only as a rough indication of the magnitude of the cost and CO_2 quantities reduced, because the sequential ranking does not take into account that the estimated cost of the preceeding options might change when new options are introduced. The correct approach theoretically is to observe the scenario as an integrated analysis.

6.4 Sensitivity analysis on main scenarios

In this section the two main scenarios on the medium and long term will be tested using different assumptions on the real interest rate and energy price development.

6.4.1 Sensitivity to the real interest rate

The normally used interest rate in Denmark is 7%, which applies to both main scenarios. Table 6.2 gives the results for 3% p.a. and 10% p.a. real interest rate compared with the normal 7% for the year 2005. Table 6.3 shows the corresponding results for year 2030.

Table 6.2 Sensitivity of the real interest rate year 2005.

	Real interest rate % p.a.		
	3	7	10
Energy systems costs, bill. DKK			
- fuel costs	16.5	16.5	16.5
- O & M costs	3.7	3.7	3.7
- lev. investments	8.1	12.5	16.1
Total	28.3	32.6	36.3
Costs per t/CO_2 reduced, DKK	-169	-100	-38

Not surprisingly, the real interest rate is seen to have an important impact upon the results, indicating that there might be substantial differences on estimates prepared in developed countries, compared with those from a developing country. For an industrial country it will be very unlikely to see such large variations in the real interest rate as appear here.

Table 6.3 Sensitivity of the real interest rate year 2030.

	Real interst rate % p.a.		
	3	7	10
Energy systems costs, bill. DKK			
- fuel costs	17.3	17.3	17.3
- O & M costs	5.1	5.1	5.1
- lev. investments	12.4	19.4	25.4
Total	34.8	41.8	47.8
Costs per t/CO_2 reduced, DKK	-28	+40	+100

6.4.2 Changes in the development of energy prices

In this section assumptions on the development of energy prices are tested:

1. Development of energy prices corresponding to the UNEP reference case, adjusted to Danish conditions.
2. Using the latest Danish prognosis for the development of energy prices, resulting in approximately 20% higher prices in year 2005, and approximately 70% higher prices in 2030.
3. Fixing prices at the 1992 level.
4. Doubling the price of biomass.
5. Doubling the price of natural gas.

The results are shown in Table 6.4 for 2005 and 2030.

We conclude that prices are, of course, important for the calculated results. But even within large variations the results seem to be quite robust. Although biomass is the dominant resource, doubling of its price does not change the results decisively.

Table 6.4 Sensitivity analysis on changing price assumptions.

Cost per t/CO_2 reduced DKK-1992	Year	
	2005	2030
Price assumption:		
1) UNEP reference case	-119	+23
2) Danish official price forecast	-124	0
3) Constant 1992-prices	-73	+58
4) 2 x biomass price	-47	+81
5) 2 x natural gas price	-98	+96
Ref. price - UNEP abatement case	-100	+40

7 Alternative developments of the energy system

7.1 Alternative strategies

In this chapter alternative developments to the main scenarios are analyzed. The starting point for the analysis is the baseline, with the addition that the utilisation of CHP and connection to collective networks are identical to the assumptions made in the main scenario. Thus, energy conservation is taken no further than in the baseline, and the energy system is developed according to the alternative strategies.

Given this starting point the following strategies are analyzed:

a. a *natural gas strategy:* How far can we reach by using natural gas, only, especially in the energy supply system?

b. a *biomass strategy:* Already in the main scenarios biomass is used to a wide extent. How far can we get by an intensified use of biomass in combustion and biogasification?

c. a *conservation strategy:* In the main scenarios the conservation potential is not utilized to the limit. How much more CO_2 reduction can we achieve of by going to the limit of the possibilities in conservation?

7.2 A natural gas strategy

The assumptions on connections to the natural gas and district heating systems, and conversion to CHP are identical with the main scenarios. No further extension of the natural gas system is envisaged, so that no additional use of natural gas is assumed for individual houses.

For decentralized CHP plants the use of natural gas is already substantial in the baseline scenario. Thus, the use of natural gas can mainly be expanded in the utility sector for use in central power and CHP plants. This will mainly comprise the use of combined-cycle plants, natural gas combustion plants and fuel cells based on natural gas (year 2030, only).

The results of the analysis are given in Table 7.1 for the years 2005 and 2030, showing the CO_2 reduction achieved, the marginal costs and the average reduction cost compared to the baseline.

Combining the assumptions on connections to collective systems and natural gas use, it is possible to achieve a fairly high degree of CO_2 reductions - approximately 10% in 2005 and approximately 30% in 2030. Of course, this requires a substantial supply of natural gas - approximately 200 PJ in 2005 increasing to approximately 400 PJ in 2030. Although resources might be available, a high demand might increase the price of natural gas above the assumed level. It should be stressed, that the different plants in Table 7.1 substitute each other, for which reason Table 7.1 shows the maximum achievable CO_2 reduction by the use of natural gas.

Table 7.1 Main results of a natural gas strategy.

Options	CO_2 reduction * %	Marginal cost ** DKK/t CO_2	Average cost * DKK/t CO_2
Year 2005			
a) Connection and CHP +	4	-	-750
a1) Natural gas combustion	9	30	-300
a2) Combined cycle	11	-40	-290
Year 2030			
a) Connection and CHP +	4	-	-650
a1) Natural gas combustion	23	~0	-100
a2) Combined cycle	27	-120	-200
a3) Fuel cells	33	700	500

* Compared to the baseline scenario.

** Using assumptions on CHP and connections to collective systems as introduced in the main scenarios.

7.3 A biomass strategy

Assumptions on connections to collective systems and the use of CHP are identical with the main scenario.

The following possibilities exist for intensified use of biomass:

- biomass in central power plants mainly for biogasification or biocombustion
- conversion of natural gas decentralized CHP plants to biomass.

Results are shown in Table 7.2 for 2005 and 2030.

Table 7.2 Main results of a biomass strategy.

Options	CO_2 reduction * %	Marginal cost ** DKK/t CO_2	Average cost * DKK/t CO_2
Year 2005			
a) Connection and CHP +	4	-	-750
b1) Biogasification	18	~0	-150
b2) Dec. CHP bioplants	6	250	-300
b3) Biogasif. + Dec. CHP	23	65	-80
Year 2030			
a) Connection and CHP +	4	-	-650
b1) Biogasification	50	-20	-70
b2) Dec. CHP bioplants	7	200	-300
b3) Biogasif. + Dec. CHP	56	~0	-40

* Compared to the baseline scenario.

** Using assumptions on CHP and connections to collective systems as introduced in the main scenarios.

As shown in Table 7.2 it should be possible to introduce biomass to a wide extent in the energy supply system and thus achieve a substantial CO_2 reduction - up to a maximum of approximately 20% in 2005 and approximately 50% in 2030. But the supply of biomass could be the limiting factor. A biomass strategy as shown in Table 7.2 would require a supply of biomass of approximately 125-175 PJ in 2005, and approximately 325-375 PJ in 2030. It seems that it might be difficult to obtain these quantities of biomass - an upper limit of domestic biomass resources is estimated to be in the range of 150-200 PJ. Finally, the use of such huge quantities of biomass might increase the marginal production price of biomass substantially.

It should be stressed that the cost figures for biomass conversion technologies are very uncertain.

7.4 A conservation strategy

None of the main scenarios utilises the potential of energy conservation to the limit, mainly due to restrictions on the implementation. Table 7.3 shows the results of a maximum conservation strategy, given the potential as estimated in the Energy 2000 study. It must be stressed that the results are uncertain, mainly due to expected increases in cost for searching, implementing and financing the projects, which are not included in the calculated reduction costs.

Table 7.3 Results of a maximum conversion strategy.

Options	CO_2 reduction * %	Marginal cost ** DKK/t CO_2	Average cost * DKK/t CO_2
Year 2005			
a) Connections and CHP +	4	-	-750
c1) Conservation in main scenarios +	10	-	-240
Increased conservation:			
c2) electricity in households and services +	12	-430	-275
c3) industry +	16	-375	-250
c4) insulation in buildings	18	330	~0
Year 2030			
a) Connections and CHP +	4	-	-650
c1) Conservation in main scenarios +	17	-	-130
Increased conservation:			
c2) electricity in households and services +	19	-230	-140
c3) industry +	27	-260	-180
c4) insulation in buildings	31	660	230

* Compared to the baseline.

** Using assumptions on connections to network, use of CHP and conservation measures as introduced in the main scenarios.

The starting point for the analysis in the conservation strategy is the main scenarios, including assumptions on connections to network, use of CHP and conservation, but excluding the possible supply options (natural gas, biomass, etc.).

Not surprisingly, a number of conservation options do have a large CO_2 reducing potential at a very low price. In year 2005 approximately 15% can be reduced at negative cost (direct cost, only), and only insulation proves to be quite expensive. In 2030 a reduction of approximately 25% could be achieved at negative cost, if implementation, financial and hidden costs are not taken into account.

7.5 Comparison of strategies

Figures 7.1 and 7.2 illustrate the possibilities in the different strategies. Each point on the figure corresponds to a strategy given in Tables 7.1 to 7.3, and is to be seen as a total scenario. Thus, the figures illustrate the application of the integrated cost curve approach, although no attempt has been made to develop the lower boundary of this curve.

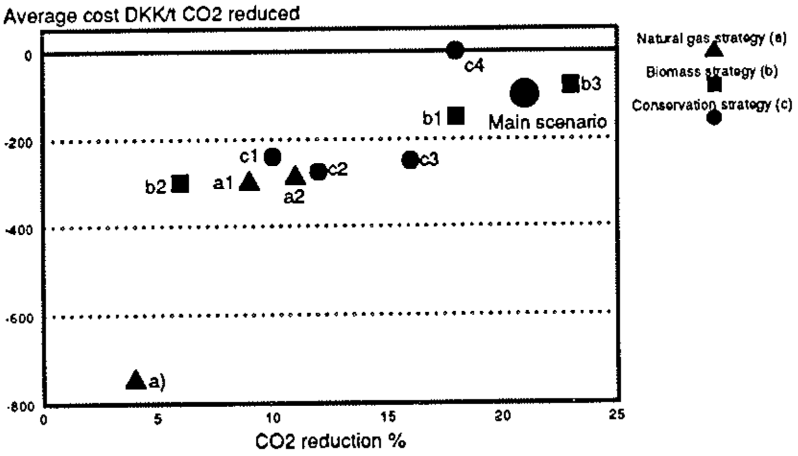

Figure 7.1 Illustration of different strategies for the year 2005.

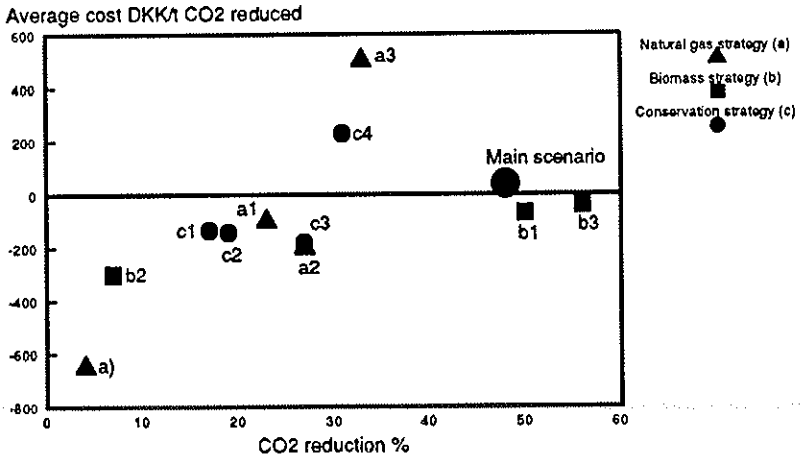

Figure 7.2 Illustration of different strategies for the year 2030.

The figures illustrate that the cost of CO_2 reduction seems to be quite robust. When moving towards higher targets of CO_2 reduction, the development of reduction costs seem to be fairly parallel, independent of the chosen strategy.

8 Driving factors behind the CO_2 emissions

The preceeding chapters have concentrated on evaluating the possibilities for reducing the CO_2 emission, given the development in economic activity, population and comfort level of society. A major assumption behind these calculations is that the service level from our use of energy is not to be affected and that the volume of goods and services in the economy is going to develop as if the greenhouse effect was not a reality. The analyses look at the possibilities of reducing CO_2 emission within the frame of the energy system.

In this chapter the analyses go beyond this "energy system" frame and look at the main causes of the development in CO_2 emissions.

Of course, these analyses should have been carried out by a model system integrating the "bottom-up" and "top-down" approaches. Unfortunately, this is not yet possible in Denmark. For that reason, the BRUS model is used for these calculations, although this limits the general validity of the results. Consequently, the results given in this chapter should be regarded as rough indicators of the importance of these driving factors.

The following driving factors for CO_2 emissions are briefly touched upon:

- economic growth - what will be the impact on CO_2 emissions if the growth rate is halved.
- demographic factors - development in population and the average size of households.
- the structure of new building - localization policy and changes in the type of new dwellings.

8.1 Economic growth

The average economic growth rate in the baseline is 1.6% p.a. over the time-period until year 2030, starting with 2.3% p.a. until year 2005 and falling to 1.2% p.a. by the end of the analyzed time period. These growth rates mean that the pecuniary welfare per capita over a forty-year period will have increased by approximately 85%.

In this analysis it is assumed that the economic growth rate will be halved and that around the year 2030 the per capita pecuniary welfare will have increased only by nearly 40%.

In the analysis the baseline assumptions are adjusted in the following way:

- The growth rate for industry, agriculture and construction is reduced by 50%. A production elasticity of 0.9, 0.45 and 0.35 for the three sectors, respectively, are used to calculate the consequences for energy consumption (ref. 5).
- The growth rates in transport for goods and personkilometres are reduced by 50% and their consequences calculated.
- In services the growth in the number of m^2 is halved and the production growth rate is reduced by 50% separately in each of the sectors: retail trade, wholesale, private and public services. The consequences are estimated using production elasticities of 0.5, 0.3, 0.6 and 1.0 for these four sectors,

respectively (ref. 9).

- For private households the growth in the penetration of electric appliances is halved and the fall in the number of persons per household is reduced by 50%.

These assumptions are introduced in the BRUS model and the results are shown in Table 8.1.

Table 8.1 Results of halving the economic growth rate.

	1992	2005	2030
Economic development			
- GNP bill.D.kr. (1980-prices)	458	531	622
- GNP/capita, 1000 DKK/person	89	101	123
- GNP/capita index	1.0	1.13	1.38
Gross energy consumption, PJ	744	685	691
- reduction to baseline, PJ	-	55	133
- % reduction to baseline	-	7.5%	16.1%
CO_2 emission, mill.t	56,2	49.2	49.4
- reduction to baseline, mill.t	-	4.2	9.9
- % reduction to baseline	-	7.8%	16.7%

Consequently, a reduction of approximately 7-8% of the CO_2 emission is obtained in the year 2005, and 16-17% in the year 2030. Of course, these results are to be used cautiously. A major presumption here is that the existing trend in technology development may be influenced by the low economic growth and therefore the same energy efficiency will not be obtained. Or it might be that the technologies are present, but the low economic growth prevents the industry from adopting to them. But it is evident that economic growth is a significant factor in determining future CO_2 emissions.

8.2 Demographic factors

Two factors are identified in the demographic development as being important for the emission of CO_2: the general population development and the development in the number of persons per household, both being of prime importance in calculating the expected demand for housing.

8.2.1 The population development

The new population projection estimates that the size of the Danish population will increase until the beginning of the next century and then slowly decline. The main difference from earlier projections is that immigration is expected to be positive. This implies that this new projection is approximately 120,000 persons higher in 2005, and approximately 350,000 higher in 2030. The number of new dwellings needed is estimated to increase by 5-7000 a year until 2030.

Given the assumption that immigration is zero the decrease in CO_2 emissions is shown in Table 8.2.

Table 8.2 Expected decrease in CO_2 emissions due to lower population.

	2005	2030
Decrease in CO_2 due to lower population, mill.t	0.3	1.0
% of baseline	0.5	1.6

8.2.2 Size of household

The number of persons per household determines the need for new dwellings. In the baseline this number is expected to fall from 2.22 in 1992 to 1.68 in 2030. If this number is assumed to be constant at the 1992-level it will have some impact upon the expected CO_2 emission. The results are shown in Table 8.3.

Table 8.3 Consequences for CO_2 emission if the household size is kept constant.

	2005	2030
Decrease in CO_2 due to constant number of persons per household	0.9	3.2
% of baseline	1.6	5.4

In 2030 especially, the calculated consequences show an essential decrease of approximately 5% in CO_2 emission compared to the baseline case.

8.2.3 Combination of immigration equal to zero and constant size of household

If the lower population development from section 8.2.1 and the constant size of household from section 8.2.2 are combined, it gives a significant impact on CO_2 emission, shown in Table 8.4.

Table 8.4

	2005	2030
Lower population and constant household size, mill.t CO_2	1.2	3.9
% of baseline	2.2	6.6

8.3 The structure of new buildings

8.3.1 Changes in the types of dwellings

In the baseline it is assumed that the major part of new dwelling construction will be terrace or row houses, lowering the costs and use of energy. About 50% is expected to be terrace or row houses, approximately 20% single-family houses and a little more than 30% flats. The existing structure is a little less than 50% single-family houses, 12% terrace or row houses and approximately 40% flats.

If the existing structure is assumed to continue, the CO_2 emission will increase by 0.1 mill.t in the year 2005 (0.2% compared to baseline) and 0.2 mill.t in 2030 (0.3% compared to baseline). It seems that the types of new buildings, whether they be terrace houses or not, are not of paramount importance for the results.

8.3.2 Localization of new dwellings

Localization might be important because a large share of the Danish space heating need is supplied by district heating (using combined heat and power) and the natural gas network, both supplying areas with a relatively high population density.

If it is assumed that a high percentage of all new dwellings are located in an area with a district heating or natural gas network, the calculated CO_2 emission will decrease by 0.1 mill.t by 2005 and 0.3 mill.t by 2030. The analysis shows that the results are not very sensitive to the localization of new dwellings.

9 Conclusions

The main tasks of the Danish country study were to analyse the methodological possibilities for constructing cost curves - showing the marginal cost of the CO_2 reducing options and the related quantity of CO_2 reduced - and to test the developed methodology on two main scenarios for Denmark for the years 2005 and 2030, respectively.

9.1 Methodology - approach and evaluation

In the Danish country study the methodological possibilities for constructing CO_2 cost-reduction curves are analyzed using the BRUS simulation model developed for use in the Danish Energy 2000 plan.

Three main cost-curve approaches are identified:

The very simplistic *partial approach*, where the single options are evaluated independently of each other. If the partial approach is used to set up a mix of different options to reach a specific reduction target, it might lead to serious misinterpretation or even wrong results.

The *retrospective approach*, where the single options are evaluated in a iterative procedure, comes closer to reality and is certainly a step forward compared to the partial approach. The retrospective approach incorporates the interdependences existing among all previously introduced options.

The *integrated approach* incorporates all interdependences, given the limitations of the energy systems models. A drawback of this method is that only baskets of options are identified, while a ranking of the single options is not possible. Nevertheless, this is the most satisfactory approach, as well from a theoretical as a pragmatic viewpoint.

If the cost curve is used as a tool to prioritate the necessary options to reach a specific reduction target, then the following observations can be reported:

- *The partial approach* tends to underestimate the cost of CO_2 reduction. This is partly due to overlap of CO_2 reduction, the last introduced option will reduce less CO_2 than expected because a share of the potential is realized through other options, partly it is due to economic dependences. Not only the level of the cost curve is affected, but even the ranking of the options might be changed.

- *The retrospective approach* tends to underestimate (numerical) the marginal costs of the most attractive options, and to overestimate the marginal cost for the least attractive options.

- *The integrated approach* specifies a recommended basket of different CO_2 reducing options, only. The method gives limited insight into the prioritation of different technologies. It includes the technology dependences, only if these are included in the energy systems model.

- *The retrospective approach* and *the integrated approach* tend to complement each other. The retrospective approach gives a single option ranking, not totally theoretically satisfactory but as close as it is possible to get. This approach generates the background for priority among the options, thus constructing the input to the integrated approach generating the mix of options to be used for a specific target or for specifying the necessary development of the energy system over time to reach a specific target.

9.2 Main results

The results indicate that it should be possible for Denmark to reduce the emissions of CO_2 substantially compared to the baseline scenario.

A 20% reduction scenario, compared to baseline, is setup for the year 2005, and a 50% reduction scenario is developed to the long term, year 2030.

The results show that it should be possible to reduce CO_2 emissions significantly at reasonable costs, both in the medium term (2005) and in the long term (2030). Reduction costs for the year 2005 are estimated as –100 DKK/t CO_2 reduced, and +40 DKK/t CO_2 reduced for 2030.

Approximately 1/4 of the reduced quantities of CO_2 are realized through demand-side options. An important issue in the study is to use only realistic, realizable demand-side options - unrealistic no-regret options should not distort the results. Reductions in demand are assumed to be realized mainly through the introduction of standards for appliances, and a gradually increasing environment tax.

Approximately 3/4 of the reduced quantities of CO_2 are realized through supply-side options. The most important of these are increased numbers of connections to networks, comprehensive use of combined heat and power and a development of the supply system towards an extensive use of biomass (biogasification plants), natural gas (combined cycle) and renewable technologies, especially wind power.

The main reservation to the results is the intensive use of biomass. The resources are available in the medium term, but problems might arise due to the localization of biomass and development of the necessary infrastructure. In the 2030 scenario biomass is used to the limit and both availability and localization of the biomass might be a problem. Finally, the intensive use of biomass might increase the marginal production price of biomass significantly, especially for resources from energy harvest.

The results are quite sensitive to the price of biomass. If the biomass price is doubled the reduction prices will be -50 DKK/t CO_2 reduced in 2005 and +100 DKK/t CO_2 in 2030. Moreover, the real interest rate is seen to have a substantial impact upon the results. If the discount rate is varied between 3 and 10% p.a., the reduction cost will vary respectively between -170 to -40 DKK/t CO_2 reduced in 2005, and between -30 to +100 DKK/t CO_2 reduced in 2030.

Alternative reduction strategies to the two main scenarios are of course plausible. The analysis shows that the results are reasonably robust with respect to alternative strategies, although it seems obvious that it is inevitable that one may achieve a substantial CO_2 reduction without reliance on as well conservation, the use of biomass and - to a certain extent - the use of natural gas.

The most promising options are seen to be the use of biomass and conservation of electricity, to the extent that implementation costs do not limit the potential of the latter one.

It should be stressed that the analysis is performed using socio-economic prices, that is prices stripped of taxes and subsidies. Moreover, only direct costs are included in the calculations. Costs incurred in implementing the conservation measures, search costs to identify the options, adjustment costs in industry and services, and welfare losses due to public intervention are not included.

In spite of these reservations, it seems realistic to conclude that substantial reductions in the CO_2 emissions in Denmark can be achieved without imposing heavy economic burdens on the Danish society.

The above-mentioned analysis includes changes within only the energy system. If the analysis were expanded to extend beyond this frame, the most important factors would be economic growth and development in demography. If the assumed economic growth were reduced by 50%, CO_2 emissions would then be reduced approximately 7-8% in 2005, and approximately 16-17% in 2030, both relative to the baseline scenario. If it is assumed that population projections are based on immigration equal to zero and a constant household size, it would imply a decrease in CO_2 emissions by approximately 2% in 2005 and approximately 6% in 2030, relative to the baseline.

The Danish afforestation plan, doubling the area covered with forest within an 80-year period, is expected to decrease CO_2 emission in year 2005 by approximately 1% compared to the baseline, and approximately 3% in 2030.

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The cost of CO_2 reduction in Denmark - methodology and results

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Abstract (max. 2000 characters)

The report contains phase two of the Danish contribution to the UNEP Greenhouse Gas Abatement Study, which has the main purpose of developing a common methodology for undertaking a cost assessment of greenhouse gas abatement, and to carry out a number of country studies by using this methodology.

The methodological possibilities for constructing cost curves - showing the marginal cost of the CO_2 reducing options and the related quantity of CO_2 reduced - are analyzed and the developed methodology is tested for Denmark.

Following the development of a baseline scenario, two main reduction scenarios are constructed: a) a 20% reduction scenario for year 2005, and b) a 50% reduction scenario for 2030, taking as its starting point the 20% scenario for 2005.

Based on these two reduction scenarios the medium-term cost curve for 2005 and the long-term cost curve for 2030 for CO_2 reduction are established. The economically most attractive and the most efficient options with regard to CO_2 reduction are discussed. Finally, a number of robustness and sensitivity analyses are performed.

Descriptors INIS/EDB

AIR POLLUTION ABATEMENT; BIOMASS; CARBON DIOXIDE; COST ESTIMATION; DENMARK; ECONOMIC ANALYSIS; ENERGY ANALYSIS; ENERGY CONSERVATION; ENERGY SYSTEMS; EVALUATED DATA; GREENHOUSE EFFECT; GREENHOUSE GASES; SENSITIVITY ANALYSIS.

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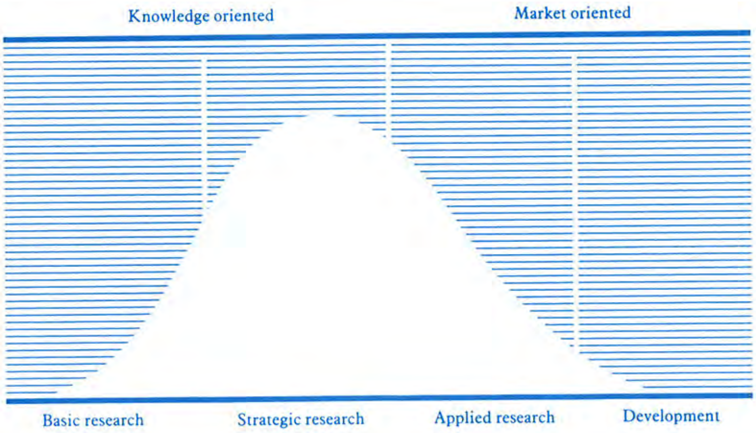

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