Publication Year 2002

The Climate Report 2001

Böcker och rapporter utgivna av Statens
energimyndighet kan beställas från
Energimyndighetens förlag.
Orderfax: 016-544 22 59
e-post: forlaget@stem.se

Upplaga: 100 ex

ER 6 2002

ISSN 1403-1892

Preface

The UN Framework Convention on Climate Change (UNFCCC) requires the parties to the Convention to submit regular national reports describing their progress in respect of actions taken in accordance with the Convention and in changes in emissions etc. Sweden's first National Report was produced in 1994, followed by the second in 1997. The third report is due to be submitted to the Climate Convention Secretariat in November 2001.

The Swedish Energy Agency has been instructed by the Government to assist the Environmental Protection Agency in preparing material for the third National Report to the Convention. As the Report is intended to cover the country's entire spectrum of climate work, it would become unmanageably large if all details were included. The Swedish Energy Agency decided that it would be helpful to produce a complementary report, which would allow climate work in the energy sector to be described in a more detailed and more unified manner. This has facilitated a more in-depth description of measures taken and of the expected future development of carbon dioxide emissions from the energy sector. Detailed documentation is also needed in order to comply with the requirements in respect of the overview of the country's climate policy that the Climate Convention intends to undertake.

The report has been prepared by a working party within the Agency, consisting of Tea Alopaeus-Sandberg, Åsa Elmqvist, Karin Hermanson, Ann Lagheim, Anita Larsson, Susan Linton, Anna Lundborg, Johan Nylander and Peter Rohlin, under the leadership of Thomas Levander. Neil Muir, of Angloscan Manuscript Ltd, has translated it into English.

Karin Hermanson and Thomas Levander have carried out final editing.

Thomas Korsfeldt

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Summary

Itemised summary conclusions

- Sweden has reduced its carbon dioxide emissions by over 40 percent between 1970 and 1990: since then, emission levels have remained essentially unchanged.
- The country's energy and carbon dioxide taxation policy is the most effective measure for reducing carbon dioxide emissions, although other measures intended to encourage the efficiency of energy use and the use of renewable energy also contribute. It is expected that, as a result of the various incentive programmes, carbon dioxide emissions will have been reduced by 3-4 million tonnes by 2000/2005, of which a significant part will have been reduced in other countries.
- It is expected that the aggregated effect of the country's energy and carbon dioxide taxation, together with encouragement of renewable energy sources, will reduce CO_2 emissions by 5 million tonnes in 2000 and by about 10 million tonnes in 2010. This means that Sweden is on its way to stabilising its CO_2 emissions at the 1990 level.
- The programme for reducing emissions of greenhouses gases in Eastern Europe is cost-efficient, and is resulting in other benefits to the recipient countries.
- Sweden is among the leaders in research and development in the bio energy field. There has also been a technological breakthrough for wind power in the development of the *Windformer.* The Ångström Solar Center in Uppsala is one of the world leaders in research into solar cells.
- Until 2010, it is expected that carbon dioxide emissions will be essentially unchanged at the 1990 level. However, developments vary between sectors: Emissions are still increasing from industry and the transport sectors, but are declining in connection with the production of district heating and electricity. Emissions from small-scale heating will also have fallen by 2010.
- It is expected that, until 2020, carbon dioxide emissions will increase by 5 percent in the scenario alternative for continuation of nuclear power production, and by 11 percent in the alternative that foresees the nuclear power stations being shut down after a 40-year life.
- The scenario calculations foresee a relatively substantial increase in the use of renewable energy sources such as bio fuels for district heating production and CHP production, as well as in the use of wind power. The scenario alternative that foresees the shutdown of nuclear power stations after a 40-year life involves a doubling in the emissions of carbon dioxide from the electricity production sector through the entry of new natural gas-powered electricity production into the country's energy system.

- Important assumptions that affect the results of the scenarios include those relating to the applicable energy and carbon dioxide taxes, together with assumed support for electricity production from renewable energy sources. Within the transport sector, it is assumed that the agreement between the European automotive industry and the European Commission will accelerate the rate of efficiency improvement in the use of energy by private cars. Energy use is expected to increase more slowly during the second period, partly due to the fact that it is assumed that there will be a reduction in the rate of growth of GNP.

Introduction

At the 1992 Rio de Janeiro Environment Summit, Sweden signed the UN Framework Convention on Climate Change (UNFCCC). The convention came into force in 1994. Under the terms of the climate convention, the signatories to it have undertaken to submit progress reports of the steps that they have taken, of changes in emissions of greenhouse gases and to make forecasts of their future emissions. Sweden's first report was submitted in 1994, and the second in 1997. The third report will be submitted to the convention secretariat in November 2001.

The Swedish Energy Agency has participated in the work of preparing the third report, involving a description of developments in the energy sector. Among the points included are a description of steps that have been taken, an assessment of their effects and the production of scenarios for future emissions of carbon dioxide from the energy sector.

Background

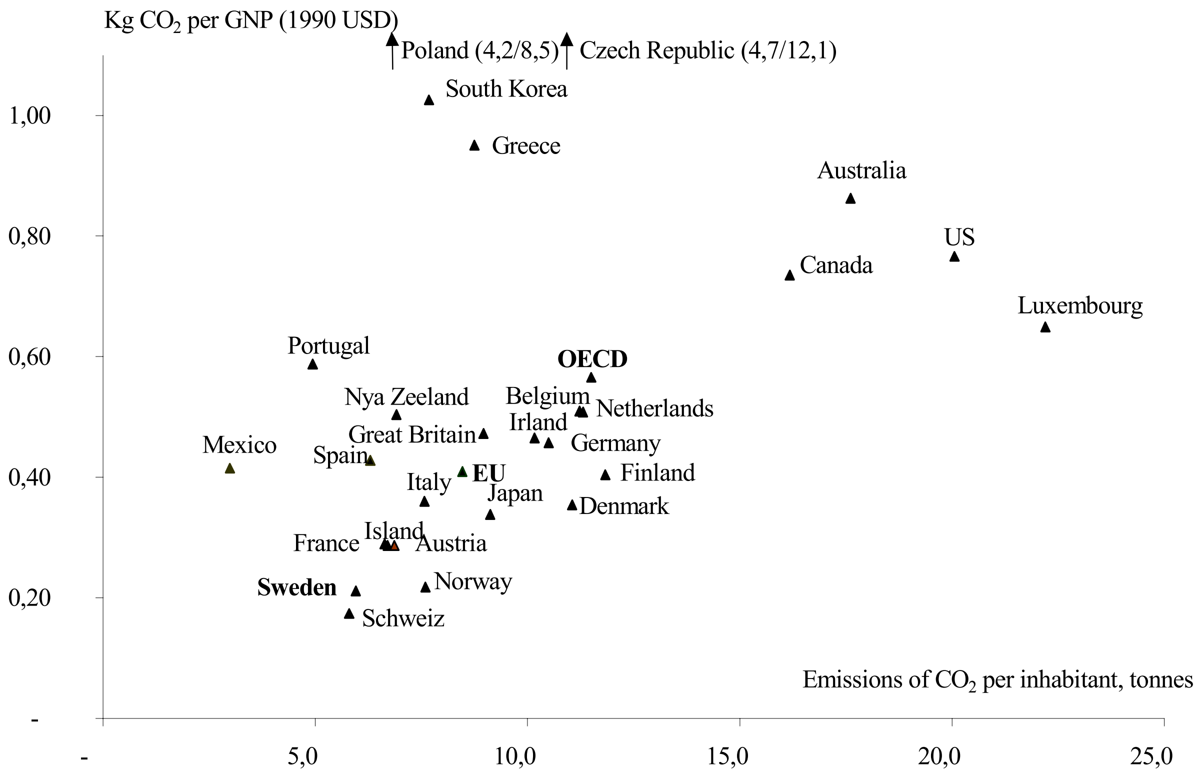
Today, carbon dioxide emissions from the energy sector amount to about 51 million tonnes[1] and constitute about 80 percent of Sweden’s total greenhouse gas emissions. Emissions have increased only marginally - by less than 1 percent - during the 1990s.

Between 1970 and 1990, emissions fell by over 40 percent. Much of this reduction occurred as a result of the change from oil to electricity and other forms of energy. Since 1970, the proportion of the country's total energy supply met by oil has fallen from 77 percent to 33 percent, facilitated partly by an expansion of hydro power production and nuclear power production. The use of bio fuels, too, has increased at the cost of oil products, from 9 percent of total energy supply in 1970 to 15 percent in 1999.

In comparison with other industrialised countries, Sweden's emissions are relatively low. One-way of making comparisons between countries is to calculate specific emissions per inhabitant: another is to relate them to GNP (see *Figure 1*).

[1] Excluding foreign transport.

Figure 1. Emissions of carbon dioxide per inhabitant and as a function of GNP for a number of industrialised countries[2]



Energy policy development

Historically, everyday work has been characterised by the need to combine different views within the energy sector. This can be seen from the country's 1991 energy policy: Namely, of assuring the necessary supply of electricity and other forms of energy on competitive terms for Swedish industry, of fulfilling the phasing-out of nuclear power and of protecting the environment. Combining these different objectives has been - and is - a challenge to the work of implementing the various energy policy decisions.

The conditions surrounding and relating to Swedish energy policy have changed in several respects during the 1990s. Sweden became a member of the European Union in 1995, which involved new methods of working and a new political

[2] The figure for OECD does not include Turkey. For some countries, emissions data from 1998 are missing. The latest emission data from the UNFCCC home page has been used (Island 1995; Japan 1997, Luxembourg 1995, South-Korea 1994, Mexico 1990). In "Energy balances" published by OECD, two methods are given in order to make comparisons with specific country GDP-data. In this study exchange rates has been used. Sources: www.unfccc.de, Energy balances for OECD countries, 1997-1998, Edition 2000.

framework. This has had a considerable effect on Swedish interests in terms of energy, industrial and environmental policy, with a steadily growing international feel.

The energy markets have been progressively deregulated, so that trade in electricity across national borders is today a reality in Northern Europe. As a result, individual states have largely abandoned their policies of ensuring self-sufficiency in terms of electrical energy. Deregulation also means that individual national policies cannot differ too much from those of other countries, in order not to distort the markets. Finally, environmental aspects - and particularly the need to bring about sustainable development - have become increasingly important in countries' policies. In this respect, the Kyoto protocol, intended to reduce emissions of greenhouse gases, marks an important stage in this process.

The three main foundations of sustainable development - the environment, the economy and social development - have become increasingly important in discussions in recent years, and are now often used as a common platform in many areas of policy. Increasingly, too, various sectors of society have to take more and more responsibility for the environmental effects of their activities and operations. As a result, ministries and public authorities have become increasingly responsible for the application of environmental policy.

During the 1990s, there have been three important trends:

- An increasing extent of European and global cooperation
- Growing importance attached to the work of limiting greenhouse gas emissions
- Individual sectors accepting more responsibility for environmental matters and sustainable development.

Sweden's present energy policy dates from 1997. Essentially, it confirmed the 1991 energy policy, with the addition of an undertaking to close the two Barsebäck nuclear power reactors. However, 2010 was no longer seen as a cut-off date, by which all the reactors would have to be shut down. Instead, the policy is now for the reactors to be phased out at such a rate that the country suffers no adverse effects in the form of higher electricity prices, shortage of electricity for industry, the country's power balance, the environment or the climate. The Swedish Parliament subsequently passed a new Act concerning the phase-out of nuclear power. The country's overall framework for the safety of nuclear power has not been changed as a result of these developments in energy policy.

The energy policy area of politics is divided into two sub-areas, *energy market policy* and *sustainable energy system policy.* The latter policy area consists of the programme for improvement in the efficiency of energy use, encouragement of the use of renewable energy and continued research and development in the energy sector. The effect of this programme is described in the next section below.

Policies and measures to reduce emissions

Several policies and measures

Sweden has applied several measures intended to limit or reduce carbon dioxide emissions from the energy sector. The most significant of these measures is carbon dioxide and energy taxation. Other measures and actions have been progressively taken, although in many cases the primary objective has not only been to limit emissions of greenhouse gases, but also to:

- Improve the efficiency of energy use
- Reduce the use of electrical energy for heating purposes
- Encourage the use of renewable forms of energy
- Improve the security of electricity supply in Southern Sweden
- Encourage sustainable development
- Encourage construction of environmental adapted residential buildings
- Extend international cooperation *and*
- Carry out work in other countries that will reduce carbon dioxide emissions.

Carbon dioxide taxation has increased in a number of stages, so that it now amounts to 530 SEK/tonne of emitted carbon dioxide. In the interests of encouraging competition, the tax rates are not the same for all users. Electricity production is exempted from all energy and carbon dioxide taxation. Some sections of industry benefit from reduced energy and carbon dioxide taxes. The Swedish Parliament has decided a policy of progressively increasing environmentally related energy taxation by transferring taxation from labour and income taxation to taxation on energy products: it is expected that the energy taxation structure and the various rules for reducing taxation levels for certain users, will be overhauled. The State's revenues from environmentally related energy taxes have increased by more than 50 percent since 1990.

What are known as pilot project dispensations from the energy taxation regulations are granted in order to encourage the use of renewable motor fuels. This means that no carbon dioxide tax is levied on motor fuels derived from bio fuel sources.

New programmes to improve the efficiency of energy use, reduce the amount of heating provided by electrical energy and encourage the production of electricity from renewable energy sources were introduced in conjunction with the 1997 energy policy[3]. To some extent, the 1997 Bill was a continuation of the 1991 energy policy programme. Investment support to increase the use of renewable

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[3] Sustainable energy supply (Bill. 1996/97:84, bet. 96/97 NU:12, rskr. 97/97:272)

forms of energy, such as small-scale hydro power, wind power and bio fuelled CHP, complemented the effects of energy taxation, as electricity production is exempt from carbon dioxide tax. The special operational subsidy for small-scale electricity production was introduced in 2000, complementing the special environmental bonus for wind power production that had been introduced in 1995. *Table 1* shows the present values of current investment support and production subsidies in SEK/MWh. It can be seen from the table that the greatest support is provided for wind power, amounting a present to somewhat over 300 SEK/MWh.

Table 1. Present support for electricity production from renewable sources.

Electricity from:	Present support[4] SEK/MWh
Wind	
Investment support, max 15 %.	40-50
Environmental bonus	181
Small-scale electricity production, max 1500 kW,	
Temporary support	90
Small-scale hydro power	
Investment support, max 15 %.	30-40
Small-scale electricity production, max 1500 kW.	
Temporary support	90
Bio fuels	
Investment support, max 25 %.	50-70

Sweden was involved at an early stage in an investment programme to encourage improvements in the efficiency of energy use and the use of renewable forms of energy in the Baltic countries and in the rest of Eastern Europe. These programmes were subsequently integrated into the UNFCCC pilot programme for joint implementation. This work was then continued and extended by the subsequent energy policy Bill. A special programme of research and development was started with the countries around the Baltic: the effects of this programme are described separately elsewhere.

Table 2 shows the economic frameworks for restructuring the country's energy system. New measures are planned for the 2003 budget year: parliament has, for example, decided to introduce a new market-based system of support for renewable energy, based on trading in certificates in combination with quotas for required proportions of renewable energy. Measures to support research and development are described separately.

[4] The calculations are based on a discount rate of 5 % and the following return of returns; wind power 15 years, CHP:s 15 years and hydro power 30 years.

Table 2. Funding from the 1997 energy policy decision for restructuring the country's energy system

Type of support	Economic planning framework 1998-2002 SEK million
Reduction of electricity use	1650
Subsidies for investments in electricity production from renewable energy sources	1000
Measures intended to improve the efficiency of energy use	450
Heat supply in Southern Sweden	400
Work in other countries motivated by climate policy considerations	420[5]

Two larger state programmes of support for sustainable development have been introduced since the energy policy Bill: 1998 saw the introduction of support for local investment programmes for ecological sustainability by the country's district councils (LIP), while a new programme to support ecological sustainability in the construction of residential buildings was introduced in 2001. These programmes cover a wide span, so that they include not only the social sector but also the environmental sector as a whole. An important part of the work of achieving sustainable development within the environmental field is to reduce the use of fossil fuels. The programmes therefore include substantial elements of measures intended to reduce carbon dioxide emissions. About 50 percent of the total funding available for the LIP programme has been used for climate-related projects. SEK 7200 million have been granted for application to the programme between 1998 and 2003.

The ecological building support programme runs for three years until 2003, with funding of SEK 635 million available.

The action programmes have produced results

The steps that Sweden has taken to reduce emissions of carbon dioxide have had several objectives. Nevertheless, the programmes have been important in reducing carbon dioxide emissions from the energy sector. The country is also well on the way to stabilising its carbon dioxide emissions at the 1990 level, in accordance with the objectives of the UNFCCC[6]. Total emissions from the energy sector[7] have increased only slightly, from 51.3 million tonne/year to 51.7 million tonne/year, or by less than 1 percent, between 1990 and 1999.

Table 3 summarises the steps taken to limit greenhouse gas emissions from the Swedish energy sector. It shows who is responsible for each particular implementation area, the programme costs and, where appropriate, a calculation

[5] For 1998 - 2004. Also includes joint research in the Baltic region.
[6] Item 4.2, a and b
[7] Sweden's report to the UNFCCC-secretariat, April 2001. See www.environ.se

of the emission reductions. It is expected that, as a result of the various support programmes, and with the funding so far granted up to 2000, emissions of carbon dioxide will fall by 3-4 million tonne/year, with a significant proportion of this reduction occurring in other countries. 1-2 million tonne/year of this amount has been calculated as being due to the work of the energy system restructuring programme. At the end of the 5-year period, it is calculated that there will be a further reduction of about 0.2-0.4 million tonne/year.

In several cases, the purpose of the measures has been to reduce the use of electrical energy. Electricity production from renewable sources has also increased as a result of the support that it has received. Sweden shares a common electricity market with Norway, Finland, Germany, Denmark and Poland, which means that there is a substantial exchange of power between these countries. During the winter, when the demand for electricity is high, there is generally an import of power to Sweden, the opposite applying during the summer when there is surplus capacity in Swedish power production facilities. It is therefore open to question as to exactly which type of electrical energy is replaced by the Swedish measures. The Agency has based its calculations on one case in which the electrical energy replaces electrical energy from existing coal-fired cold condensing power production in Europe, and on another alternative in which the electrical energy replaces electricity production from natural gas-fired combined cycle power plants in Europe. This means that the actual emission reductions have also occurred in countries other than Sweden. Direct investments in Eastern Europe are expected to reduce emissions by about 0.3 million tonne/year of carbon dioxide.

The effects of energy and carbon dioxide taxation have been apparent primarily within the district heating sector and in individual heating of residential buildings and commercial premises. Energy taxation has made it economic to use energy having low or no carbon dioxide emissions. The effect has been most significant in the district heating sector, where fossil fuels are nowadays generally used only for peak loads or for about 10 percent of the total annual heat demand.

Table 3. Actions applied and guide measures in the energy sector to limit emissions of greenhouse gases, over and above energy and carbon dioxide taxation.

Effects are calculated on the basis of grants up to and including 2000.

Action/ policy and measure	Target group	Greenhouse gas	Type of measure	Status Year Funding (total grant)	Authority having responsibility	Calculated effect 2000/2005
Restructuring of the energy system[8]	All sectors	Carbon dioxide	Various economic guide measures, procurement projects and information	Completed 1998-2002 see table 2	Swedish Energy Agency and others	2200 GWh electricity 920 GWh oil 1 – 2 million tonne CO_2
Measures in other countries in accordance with the Climate Convention rules	All sectors	Carbon dioxide Methane	Grants Loans	Completed 1993-2004 SEK 267 million (627)	Ministry of Industry, Employment and Communications, Swedish Energy Agency.	0.3 million tonne CO_2
Other international cooperation within the Baltic region	Energy sector	Carbon dioxide Other objectives	Grants	Completed 1996 – SEK 264 million	Ministry for Foreign Affairs SIDA, The Swe. Energy Agency.	Not calculated
Action-related research and development	All sectors	Carbon dioxide	Support	Completed 1998-2004 (about SEK 5000 million)	Swedish Energy Agency and others	Not calculated
The Green Car joint project between the State and the automotive industry	Transport sector	Carbon dioxide Other environmental objectives	Grants	Completed 2000-2006 (SEK 1800 million, of which SEK 500 million from the State)	Swedish Energy Agency Vinnova[9], The Swedish Research Council	Not calculated

[8] Includes measures to encourage electricity production from renewable energy sources, improvements in the efficiency of energy use and conversion of electric heating to other forms of heating.

[9] The Swedish Agency for Innovation Systems

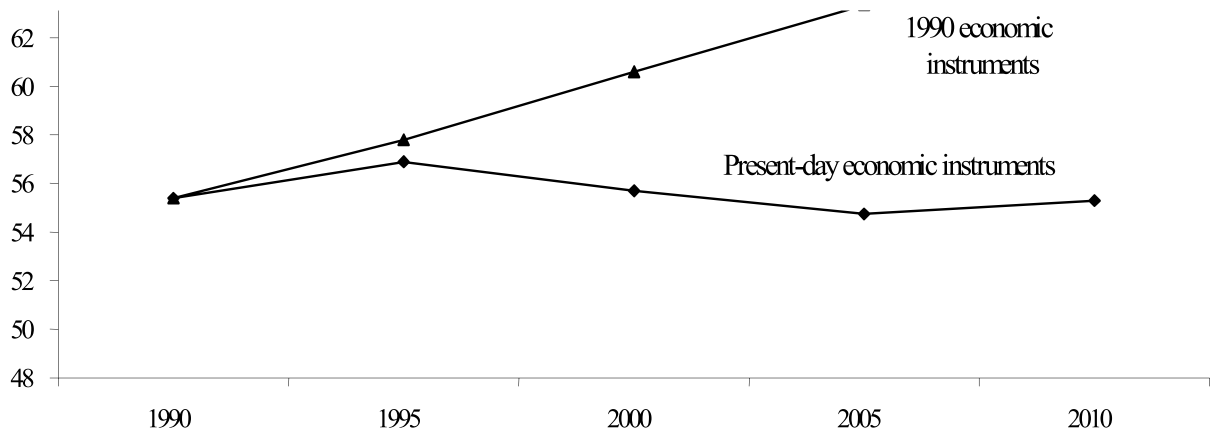
Table 3 continued

Pilot project dispensations for bio-sourced motor fuels	Transport sector	Carbon dioxide	Reduced taxation	Completed SEK 63 million (lost tax revenue)	Ministry of Finance (The Swedish Energy Agency)	Gross about 55 ktonne[10] CO_2 in 2000
Local investment programmes	All sectors	Carbon dioxide Methane Other environmental objectives	Grants	Completed 1998-2003 2629 MSEK (SEK 7200 million)	Ministry of the Environment	430 GWh el 1,6 million tonne[11] CO_2
Investment grants for ecological building	Residential sector	Carbon dioxide Methane Other environmental objectives	Grants	Completed 2001-2003 (SEK 635 million)	Ministry of Finance (The National Board of Housing, Building & Planning)	New programme
Standards for energy use in residential buildings and commercial premises	Residential sector	Carbon dioxide	Regulations	Completed	The National Board of Housing, Building & Planning	Not calculated
Local authority energy planning	Energy sector	Carbon dioxide Methane	Legislation	Completed 1977-	Swedish Energy Agency	Not calculated
Local initiatives	All sectors	Carbon dioxide	Voluntary initiatives EU grants	1998-	-- Swedish Energy Agency	Not calculated

In order to analyse the longer-term effects of the economic instruments, the model calculations have been based on two different sets of policies and measures measures: the 1990 economic instruments and present-day economic instruments. In the latter case, it has been assumed that the present energy and carbon dioxide tax rates would continue to apply throughout the period under investigation. Sulphur tax is also included. The model has further assumed that the present financial support system for electricity production from renewable energy sources will have been replaced by a new market-based system, in accordance with Parliament's 2001 decision[12].

[10] Possible emissions of carbon dioxide in connection with ethanol production not included.
[11] These measures have not been evaluated: the assessment is based on local authority information in their applications.
[12] In the calculations, this is simulated by a support of 150 SEK/MWh.

Figure 2. Total carbon dioxide emissions as envisaged by the two guide measure scenarios, million tonnes of carbon dioxide



Source: Swedish Energy Agency Report ER 15:2001, Calculations using MARKAL - input for the Agency's 2001 Climate Report (in Swedish)

The calculation based on the 1990 policies and measures, assumes that it is the 1990 tax rates that apply throughout the period under investigation. At that time, there was no carbon dioxide tax. On the other hand, energy tax also applied to the use of energy by industry. There was no value-added tax on the use of energy, and the sulphur tax had not yet been introduced. There was no operational support for wind power or small-scale power production, and nor where there any investment grants for special technologies.

It can be seen from the figure that present-day economic instruments should be able essentially to keep carbon dioxide emissions down to the 1990 level throughout the period under investigation. In 2000, the reduction is expected to amount to about 5 million tonnes of carbon dioxide/year, while in 2010 the reduction should have increased to about 10 million tonne/year. However, these calculated differences very probably represent an underestimate of the true effect, as the model calculations do not include the effects on energy use resulting from differences in energy prices.

Varying costs and efficiency

As previously indicated, energy and carbon dioxide taxation remains the most important guide measure for limiting and reducing carbon dioxide emissions. It has also had other favourable effects on the environment, such as through reducing sulphur emissions as a result of the greater use of bio fuels.

Targeted State subsidies to certain sub sectors within the energy sector have increased since Sweden's last report to the Climate Convention, primarily through larger concerted programmes within the environmental sector. Total State subsidies up to and including 2000, and either directly or indirectly reducing carbon dioxide emissions, amount to more than SEK 5000 million. This sum does not include grants for infrastructure investments. To this must be added grants for research and development, amounting to about SEK 5000 million for the energy sector.

The largest individual programme is that devoted to local investments, and is expected to make the greatest contribution to reducing carbon dioxide emissions. However, its effects have not been evaluated: instead, the calculations are based on the applications submitted by local authorities. On the basis of information from local authorities in their applications to the Ministry of the Environment, it is expected that the programmes will result in an annual saving of about 0.43 TWh of electricity, and a reduction of 1.6 million tonne/year in carbon dioxide emissions.

Evaluation of other programmes has shown that the conversion programmes, intended to change heating supplies from electricity to district heating or some other types of heating systems, and to reduce the overall power demand, have not had the intended effects. In many cases, conversion to other forms of heating is expensive. In addition, the relative running cost differences between district heating and electricity are unfavourable to district heating. At present, therefore, conversion is not economically justifiable for individuals.

The investment grant programmes for bio fuelled CHP and for wind power have been essentially successful, with the various objectives set up for them having been reached. However, a drawback of the investment grants is that they have not been designed in such a way as to result in any significant technical development. Operating subsidies, on the other hand, produce long-term effects that are difficult or uncertain to overview, both for the State and for the recipients of the grants.

It has been calculated that the total effect of the investment programmes for conversion and investment in renewable forms of energy should reduce electricity demand by about 0.4 TWh/year, and increase electricity production from renewable forms of energy by about 1.3 TWh/year. In terms of reduced carbon dioxide emissions, this is equivalent to about 0.8-1.6 million tonne/year.

Table 4 sums the effects of the investment programmes for which the Agency has been responsible. It shows the carbon dioxide reductions, expressed as specific quantities in relation to the State investment only. It can be seen from the table, for example, that it is generally more effective to supply a new quantity of renewable energy than to convert electric heating to other forms of heating.

Table 4. Specific performance of certain elements of the energy conversion programme, expressed as carbon dioxide reductions in terms of kg/SEK.

Investment programme	Carbon dioxide reduction, kg/SEK
Conversion from electric heating to individual heating	0.2
Conversion from electric heating to district heating	0.4
Reduced power demand	0.1
Investment grants for small-scale hydro power	0.8
Investment grants for wind power	0.7
Investment grants for bio fuelled CHP	1.1

Note: The above calculations are based on the assumption that the renewable forms of energy and the reduction in electricity demand for heating replace electricity production in natural gas-fuelled combine cycle power stations.

It is difficult to evaluate the effects of the various forms of support intended to encourage improvements in the efficiency of energy use. Technology procurement is used to facilitate and accelerate the development and introduction of new technology to the market, e.g. to encourage greater use of more energy-efficient and reduced-environmental-impact products. There are no obvious methods for assessing how successful a technology procurement project has been in improving the efficiency of energy use. These difficulties are due to a number of factors, such as that the effects do not usually start to become visible until three or four years later, and cannot be said to be widely distributed until after perhaps six-eight years. Some of the funding is used to support information measures from regional energy advisory centres, trade associations etc. Although these information activities are important for the implementation of energy policy, regardless of its direction, they are difficult to evaluate.

Sales statistics can give some idea of the effect of technology procurement and energy marking on the markets are particularly low-energy products. Adding together all the various projects devoted to improving the efficiency of energy use, it has been calculated that they have saved about 0.4 TWh of oil and 0.4 TWh of electrical energy. In terms of carbon dioxide emissions, these savings are equivalent to about 100–200 ktonne/year. However, not all of this reduction can be ascribed to the State efforts to improve the efficiency of energy use, but can also be partly the result of spontaneous technical development. Nor does any such description catch what is known as the rebound effect, i.e. that the improvement in the efficiency of use of resources can leave capacity for greater consumption in the same or some other area.

Cost-efficient measures in the Baltic countries and other Eastern European countries

Emissions of greenhouse gases have environmental effects, regardless of where they occur around the globe. However, the costs of reducing the emissions vary from sector to sector and from country to country. Sweden was therefore early out in starting an investment programme to encourage improvements in the efficiency of energy use and the use of renewable forms of energy in the Baltic states and other Eastern European states. Various programmes were gradually incorporated in the UNFCCC pilot programme for joint implementation (Activities Implemented Jointly, AIJ). A total of about SEK 627 million has been granted for these projects between 1993 and 2002.

The purpose of the programme is to reduce emissions of carbon dioxide and other environmentally detrimental substances, to improve the efficiency of the Baltic states' energy systems, and to introduce renewable energy sources. To date, over 70 projects have been initiated by the Agency (by its predecessor, NUTEK), of which 64 have been reported to the UNFCCC secretariat. Projects have been carried out in the district heating sector in the Baltic states, and in St Petersburg and the Kaliningrad areas of Russia. A biogas project has been started in Poland. *Boiler conversion projects* are concerned primarily with conversion of district heating boilers in the 3-10 MW range, so that fossil fuels such as heavy fuel oil or coal can be replaced by bio fuels, such as woodchips, forest waste and waste products from wood-based industries. *Distribution projects* are concerned with the upgrading of district heating distribution systems by replacement or re-insulation of piping systems, water treatment to extend system life and installation of consumer service units and control equipment etc. *Efficiency improvement projects* in buildings cover measures such as conversion or re-insulation of roofs, installation of district heating consumer service units, heat exchangers, metering and control equipment, balancing of systems, weatherproofing of windows and doors etc.

These projects have been financed by loans to the recipient countries on beneficial terms, with the Agency paying the costs of consultants, e.g. for feasibility studies. Loans to plant owners or equivalent bodies generally run for ten years, with the first two years being repayment-free. Interest rates are as published by STIBOR[13], or in some cases 0.5 percent higher. The ambition of the projects is that they should have a payback time that is shorter than the term of the loan. The payback time of boiler conversion projects averages out at about 5 years, while that of distribution projects varies between about 2 and 12 years, depending on to what extent new pre-insulated district heating pipes are needed. As far as the building projects are concerned, those intended solely to improve the efficiency of energy use have a payback time of 7-9 years, while renovations in the building stock that are regarded as essential for efficient energy use have a payback time of 16-20 years.

Table 5 shows the results of completed projects, with details of the emission reductions associated with the respective projects and countries. Table 6 shows the specific cost expressed in SEK/tonne of reduced emissions over the life of the project, calculated as the average of the results in all countries for the particular group of projects.

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[13] Stockholm Inter Bank Official Rate

Table 5. Effects of Swedish work in the Baltic states and Russia

Country	Number of projects	Investment costs SEK million	Transaction costs SEK million	Sum SEK million	CO_2 reduction, in 2000 Tonnes	Accumulated CO_2 reduction, to 2000 Tonnes	Accumulated CO_2 reduction over the Project life, Tonnes
Estonia	21	68	21	89	96 000	433 000	1 531 000
Latvia	22	59	20	79	72 000	370 000	1 305 000
Lithuania	9	40	16	56	30 000	127 000	629 000
Russia	12	30	17	47	23 000	81 000	538 000
Total	**64**	**197**	**74**	**271**	**221 000**	**1 011 000**	**4 003 000**

The costs have been divided up into investment costs and transaction costs. The investment costs represent the total investment, including interest charges, in this case being loans that are to be repaid. The transaction costs consist of consultancy support and administrative costs, in some cases, write-offs of loan or interest claims. The projects have been carried out as part of the Climate Convention's AIJ programme. The assignment of costs and accrediting of the resulting emission reductions between countries for real JI projects is a matter for negotiation between the parties.

The total cost of the projects amounts to SEK 271 million, of which the transaction costs met entirely by Sweden amount to SEK 74 million. Largely the recipient country, through loans from the Swedish Energy Agency, meets the investment cost. However, the advantageous loan conditions, with interest rates far below commercial interest rates, can be seen as an expense for Sweden.

Total emissions of carbon dioxide until 2000 have been calculated as about 1 million tonnes since the project started.

Table 6. Investment and transaction costs per kg of carbon dioxide reduction

Type of project	Investment costs SEK/tonne of carbon dioxide reduction	Transaction costs SEK/tonne of carbon dioxide reduction	Total SEK/tonne of carbon dioxide reduction
Conversion projects	43	14	57
District heating projects	79	43	122
Energy efficiency improvement projects	270	160	430
Total	**49**	**18**	**67**

Table 6 shows the cost of carbon dioxide reductions in SEK/tonne as the total cost over the entire life of the project, which varies between 10-25 years. There may be additional transaction costs for reporting and monitoring results, which can therefore slightly increase the costs. The table does not include revenue for the recipient country in the form of reduced costs for fuels resulting from conversion to other forms of energy or energy conservation measures. Nevertheless, the table shows that the projects are cost-efficient in comparison with costs in Sweden, where the marginal cost of reducing carbon dioxide emissions generally exceeds 500 SEK/tonne.

The projects that have been carried out within the framework of the Climate Convention's pilot phase for Activities Implemented Jointly (AIJ) show that it is possible to carry out projects in accordance with the flexible mechanisms criteria, i.e. that they should be cost-efficient and achieve substantial emission reductions with relatively modest means. At present there are no further AIJ projects planned, as new projects must be carried out in a form that qualifies for credits in accordance with a coming UNFCCC rules on joint implementation. However, the Agency is concluding a few AIJ projects that were authorised prior to 1999 but which, for various reasons, could not be started until later.

The programme has been constantly evaluated by local experts and by independent consultants, and has attracted international attention due to its cost efficiency and efficient implementation. It has attracted attention not only as a result of its greenhouse gas reductions, but also because of other positive effects, both in Sweden and in the recipient countries. It has had a positive effect on attitudes towards environmentally aware energy supply and energy use, on the part of those in the recipient countries who have been involved or who have been in contact with the programme. Attitudes have been changed, and awareness (e.g. of the UN outline convention) has been improved. The programme has also had a beneficial effect on the formation of local markets for bio fuels and bio-fuelled boilers. In addition, it has contributed to the establishment of long-term cooperation between Swedish companies and companies in the recipient states, including cooperation on third party markets. Finally, it has contributed to good relations between the Baltic states energy and environment ministries and departments, thus hoping to establish long-term reliable cooperation with Sweden in the form of the Swedish Energy Agency.

Research and development in the longer term

Climate changes represent a long-term environmental problem. Although steps are now being taken to reduce emissions of greenhouse gases, continued technical development is required in order to resolve long-term problems. The Swedish strategy to create a sustainable energy system with limited environmental impact is based on research, development and demonstration. An overall objective of Swedish energy research and energy technology support is that it should ultimately reduce the costs of using renewable forms of energy, such that they become economically viable alternatives to nuclear power and the use of fossil fuels. The proportion of electricity and heat produced from renewable energy sources must be substantially increased over the next 10-15 years. However, for this to be achieved, new technology must be developed so that it is commercially available and economically viable.

The Swedish Energy Agency finances both research and development. Research programmes are financed entirely by the Agency, while development programmes are financed jointly with industry. Areas in which research is needed are often identified, and programmes drawn up, in conjunction with scientists, industry and public authorities involved. Programmes usually run for about 2-4 years, but can be extended by further terms in order to achieve better continuity of research. Areas to which particular priority is to be given are:

- Based-based CHP
- Supplies of bio fuels, with associated ash handling considerations
- New processes for ethanol production, based on cellulose-rich raw materials
- Alternative motor fuels
- New technology for large-scale utilisation of wind power and offshore wind power
- Solar cells
- Research and development work for improving the efficiency of energy use in the built environment, in industry and in the transport sector.

In 1997, the Swedish Parliament made about SEK 5000 million available over a seven-year period, starting in 1998, for research and development of energy technology[14]. *Table 7* shows a breakdown of this funding within various sectors. It is available to several public authorities, but it is the Swedish Energy Agency that is responsible for coordination.

[14] The Bill on *Sustainable energy supply* (Bill. 1996/1997: 84, bet. 96/97 NU:12, rskr 96/97:272)

Table 7. Granted and expected funding for research and development, 1998-2004, SEK million.

Grant/grant item	1998 SEK million	1999 SEK million	2000 SEK million	2001 SEK million	Expected 2002 SEK million	Expected 2003 SEK million	Expected 2004 SEK million	Total SEK million
Energy research, total[15]	320	335	402	431	461	426	426	2901
Energy technology support	90	130	130	130	130	130	130	870
Introduction of new energy technology	160	230	230	230	230	230	300	1610
Total	**570**	**695**	**762**	**791**	**821**	**786**	**856**	**5881**

Hydro power

The starting point for work in the hydro power area is to retain and improve existing production facilities. The Agency is financing research in this area via two programmes: *Water turbine technology* and *Hydro power – environmental effects, measures and costs in currently developed river systems.* Aims of the first programme include assisting the development of water turbines with a high efficiency and flexibility for varying outputs. The second programme, which considers river systems on a case-by-case basis, is intended to provide information for technical and economic evaluation of various ways of achieving desired environmental objectives.

The overall objective of the turbine technology programme is to enable hydro power to be further developed in order to meet future requirements in respect of efficiency and environmental aspects, and to ensure that the power utilities and manufacturing industries will be able to draw on a long-term pool of personnel familiar with the water turbine field. An important element of the work is to provide practical verification of theoretical work and models in experimental and pilot installations. In this connection, the Powerformer design provides a means of improving efficiency by enabling the power output to be connected directly to the grid, thus eliminating transformer losses.

The *Hydro power – environmental effects, measures and costs in currently developed river systems* group research programme is jointly financed by the Swedish Energy Agency, the National Board of Fishery and the Swedish Electrical Utilities R&D Company, with the Environmental Agency as a further participant in the work. The overall objective of the programme is to develop a common scientific base for assessment of the environmental impact of hydro

[15] The Swedish Energy Administration distributes about 80 % of the grant, with the rest being distributed by Vinnova, Formas (The Swedish Council for Environment, Agricultural Sciences and Spatial Planning) and the Swedish Research Council.

power production, and to ensure that the best use can be made of hydro power with due consideration of national environmental quality objectives and directives in respect of water quality, fishing, ecological function, biological diversity and genetic variation. The work will involve testing hypotheses and theoretical studies in experimental and pilot installations, as well as in natural waters.

Wind power

In the short term, wind power has the greatest technical potential to achieve market success, when compared with other forms of renewable energy. Swedish work in this area has recently resulted in a technical breakthrough, in the form of the Windformer, which is expected to have considerable impact. As with hydro power generators (mentioned above), this design principle eliminates the need for a step-up transformer, with its associated losses, so that the generator can be connected directly to the grid. This reduces costs and improves efficiency.

Sweden possesses knowledge and expertise in these areas at a number of departments in institutes of technology and universities, in companies working in the sector and in wind power development companies. Swedish technology lies well to the fore in an international perspective. The country is also well advanced on the offshore side, having the world's first offshore wind power plant in operation. An example of successful research is the fact that commercial manufacturers of wind power plants nowadays use blade profiles developed by Swedish aerodynamic research.

Wind power is becoming increasingly large-scale, not only for wind farms but also for individual units. While other countries were previously concentrating on small-scale wind power, Sweden has instead concentrated on the development of large wind power plants with outputs of the order of 1 MW and up, although this is not so far resulted in any commercial product. However, it has resulted in a substantial acquisition of knowledge over a long period, which may well become of decisive importance when large-scale technology is introduced commercially. As yet, the investment costs of wind power are still far too high to be able to compete unassisted in any of the EU states, which means that some form of financial support is essential. This can take the form of preferential taxation, investment or operating grants or market-based guide measures such as Green Certificates.

Solar cells

In the long term, electricity production from solar cells may also become competitive. Sweden has a small but growing market for the standalone solar electricity systems as used, for example, on beacons, on recreational craft or in caravans, i.e. for applications where power supply by a more conventional means is not possible for practical or economic reasons. So far, standalone systems are the most common. The technical potential for solar electricity in Sweden amounts to about 5-10 TWh/year, without involving extra cost for energy storage in the grid by using hydro power as a buffer. Solar cell technology as such is tested and reliable, with research now being concentrated on finding materials and methods of manufacture that are suited to competitive large-scale production.

Swedish research into solar electricity is today centred around two large research programmes. *SolEl 00-02* is investigating the potential for using solar cells in the existing electricity system on reasonable economic terms, and is also looking to see what development is needed in order to enable solar cells to play a significant part in Swedish electricity production. The work includes analysis of the environmental impact of various aspects of solar cell technology, such as the obtaining of raw materials, transport, production technology, recycling and disposal. The *Solar cells in buildings* sub-area is concentrating on competence development and the dissemination of information to the building industry and architects. The use of reflectors is an interesting element in the mounting of solar cells, increasing insulation on the cells and reducing the total energy production cost.

Research at the Ångström Solar Center in Uppsala, which is 50 percent financed by the Swedish Energy Agency, is devoted to areas such as thin film solar cells, nanocrystalline solar cells and 'smart windows'. The Center at present holds the world record for a thin film module using CIGS solar cells. As far as thin film technology is concerned, the work is concentrated on developing large-scale manufacturing processes for low-cost production of cells of this type. This includes research and development of CIGS-type thin film cells. As far as nanocrystalline solar cells (NSC) are concerned, the work is still mainly at the fundamental research stage. However, it is possible to manufacture NSC cells very simply in the laboratory, which indicates that prospects should be good to produce solar cells at an acceptable price in the future. In the 'smart window' field, work includes development of windows of which the transparency can be varied by application of an electrical voltage. The objective of this work is to develop a window with excellent optical properties and good long-term stability.

Fuel-based electricity and heat production

In comparison with international conditions, Sweden uses a significant proportion of bio energy. Bio fuels are used primarily for the heating market and by the forest products industry. The main proportion is made up of by-products from sawmills and the pulp and paper industry, although the use of felling residues and thinnings from forestry is increasing. There is a significant potential in primary forest fuels, technically and ecologically available and at a reasonable cost, but not greatly used. Within 20 years, supply of about 130-150 TWh of the country's energy requirements can be a realistic bio fuels potential[16], which would represent as increase of about 50 percent over the present level. In the longer term,

[16] From the Administration's input to 'A Proposal for Swedish Climate Strategy', SOU 2000:23

intensively cultivated forests could provide further fuel. The technology for compacting felling residues into large bales reduces intermediate unloading and reloading requirements and cuts costs. This method is close to market establishment. Cultivated bio fuels, primarily in the form of *Salix* energy forests, are at the market introduction stage. The country possesses fundamental knowledge concerning the cultivation of energy crops, and forest fuels can be recovered in an environmentally responsible manner. However, fully ecologically sustainable supply of felling residues presupposes that appropriate plant nutrients, such as the ash from combustion should be returned to the land. Technologies for the return of ash have been demonstrated, but are not yet common.

Current research is aimed at improving the entire bio fuel chain, from production, ecology, handling, transport and possible cultivation, to energy conversion and most efficient utilisation. Research into the ecological, economic and technical aspects of forest fuels production of bio energy, including the return of ash, energy forests and energy crops, as well as into intensively cultivated forests, is intended to determine just how large the potential of bio fuels would be in practice.

The Agency is running several research and development programmes intended to develop technologies for the use of bio fuels for electricity and heat production with higher efficiencies and reduced environmental impact and, in the longer term, at competitive cost levels. Particular working areas include the reduction of health-hazardous substances from small-scale combustion. For large plants, involving steam boilers to power turbines, materials and systems are being developed to avoid corrosion in superheaters and to raise steam data and overall process efficiencies. In the case of natural gas-fired power production, it is gas turbines that are at the centre of attention. Several technologies are of interest for commercialisation within the next ten years, such as evaporative gas turbines, the Bio-IGCC process, indirectly fired gas turbines, Stirling engines and micro-turbines.

Sweden is carrying out fundamental research into a process for hydrogen production by artificial photosynthesis, with the aim of creating a system for the production of hydrogen from water and sunlight. Swedish research in this area is at the leading edge of international research, and is expected to reach the application phase in 5-10 years. The potential market for hydrogen produced by artificial photosynthesis in a sustainable and competitive manner is enormous, e.g. for use in combination with fuel cells. It is expected that demonstration plants could be produced in about 15-20 years, with market establishment expected in about 20-25 years.

Stationary fuel cells have significant environmental benefits, and represent an area in which development is proceeding extremely rapidly. At the international level, the market is expected to develop over the next few years in step with falling costs. Research into stationary fuel cells is being carried out in close conjunction with industry, with the aim of achieving commercial applications through concentration on aspects such as operational optimisation, properties of materials, improved performance, suitable operating characteristics for various applications, different types of fuels, application areas, reliability etc. Research into the solid oxide fuel cell, for larger stationary plants, is concentrated on linking the cell to a gas turbine to increase efficiency, as well as on other ways of producing more energy.

Industry

Improving the efficiency of energy use in industry is a continuous process that advances in a series of many small steps. The development or improvement of technologies to reduce climate effects is an important working area for the future. Swedish work spans the entire innovation system, from fundamental research in special areas, via development at universities and in industry, to market introduction.

The Agency is operating the *process integration* research programme. This is concerned with the development of methods for the design and modification of industrial processes in order to reduce investment and running costs. Unit processes in industry cover the strategically important and energy-demanding process stages in various manufacturing processes, such as blast furnaces in the steel industry and sulphate pulp production in the pulp and paper industry. After the industry itself, the Swedish Energy Agency is the single largest financier of energy-related industrial development. An important element of the Agency's work is to identify important process stages and/or unit processes for future efficiency improvements.

The provision of support to pilot projects operated by the various industry sector research institutes is important in order to support technical development in heavy industry. The Agency supports research and development through cooperation with organisations such as the Forest Industry Technical Research Institute (STFI) and the Metallurgical Research Foundation (MEFOS). The membrane method for production of chlorine/alkali is an example of such development within the chemicals industry. Other examples include development of black liquor gasification in the sulphate process, and a new technique for high-temperature combustion for improving the efficiency of furnaces, which is at present being tested in an experimental furnace at the Royal Institute of Technology in Stockholm. In addition, the Agency and the Swedish Foundry Association are working to improve knowledge of energy-efficient casting methods.

Transport

It is expected that technical development of electrical and electrical hybrid vehicles will improve efficiencies and reduce emissions. Improvements in battery technology will widen the range of applications for such vehicles, and also provide an introduction for the use of fuel cell technology. The fuel for a fuel cell can be either fossil or bio-based. Development of bio-based motor fuels seems to be the best way of reducing emissions from heavy long-distance road transport. The Agency is also funding demonstration projects to improve the efficiency of energy use for goods transport by water and rail in order to reduce total emissions of carbon dioxide from present road transport.

The Agency has started a programme of which the objective is to construct a pilot facility for gasification of forest raw materials, with associated production of bio-based motor fuels. The aim is to be able to produce ethanol from forest raw materials at a cost similar to that of the production of ethanol from cereals. There are today no direct platforms for cooperation into gasification aimed at the production of motor fuels such as methanol, dimethylether, bio paraffin or bioalkylate. In the longer term, it is felt that the prospects for the production of ethanol and methanol will be essentially similar, and there are plans to build pilot plants for the production of ethanol from cellulose and of bio-based methanol.

Present-day Swedish knowledge in the field of *combustion* is good, with the Swedish automotive industry being a leader in the research and development of combustion engines. An important area of new technology in the future is to bring combustion engines and electrical technology together into a hybrid vehicle. The 'Green Vehicle' is a recently started joint research and development programme between the Swedish automotive industry and the State, with the aims of reducing the environmental impact of vehicles and of improving the competitiveness of the Swedish automotive industry.

The work of the Agency is important for the overall development and knowledge of the Swedish industry. A number of larger joint research and development projects are in progress, involving industry, universities and the State, and aimed at the demonstration of *electrical transmission technology.* The Agency has assisted the accumulation of knowledge through the now concluded electrical and hybrid vehicle technology programme and the current *energy systems in road vehicles* programme.

Buildings

The State supports research and development in the field of *improving energy efficiency,* primarily by further development of known and proven construction and building services systems technology, and also through the development of new materials, components, methods and systems. Increasing attention is being paid to the requirements or behaviour of users when working on improving the energy efficiency of a building. Unfortunately, as a result of the present low rate of new building construction, energy efficiency improvements and energy conservation measures in new buildings are having only little effect. An energy-aware approach to conversion and rebuilding is therefore important, but as this is also an area in which little is being done at present, any and all such efficiency improvement measures should also be suitable for application in connection with normal maintenance work. However, this is a sector with substantial potentials: with new commercial technology, the average consumption of, for example, newly-built detached houses can be reduced to about 8000 kWh/year, in comparison with a present national average figure of about 14 000 kWh/year.

Long-term financial support for research and development in connection with energy use in buildings is at present being provided for areas such as solar heating, district heating, heat pump technology and small-scale bio fuel applications. With many years' experience of use of *solar heating*, Sweden possesses an excellent fund of knowledge in this field. Work in *solar heating* research, development and demonstration is being carried out via an integrated programme that brings together research scientists, manufacturing industry and purchaser groups.

Sweden's knowledge and expertise in the field of *heat pumps* is at the very forefront of international levels, and the country has a leading position in experience of replacing environmentally hazardous CFCs with other refrigerants, and in particular with natural refrigerants such as ammonia, propane and carbon dioxide. In addition to fundamental research at a small number of institute of technology departments, the Agency is financing, together with about 30 industrial companies, an applied programme of research and development, with the aim of developing and producing efficient systems with low environmental impact and at a low cost.

Lighting and ventilation which, at the beginning of the 1990s, accounted for about 70 percent of the use of electricity for building services systems[17], have become more efficient as a result of improved light sources and improved operational control and determination of necessary capacities. With a number of others, the Agency is supporting research into white LEDs for *lighting purposes*, through two parallel research projects.

In addition to the above technologically-inclined work, the Agency and ELFORSK are financing a research programme concerned with the actual use of electricity in buildings and in smaller/medium-sized industry (ELAN). The objective of the programme is to assist development in the field of electricity use/electrical applications. In addition, the Agency is financing a working programme concerned with *smart buildings*, making considerable use of IT technology in order to control various domestic processes. One of the objectives of this programme is to enhance the country's knowledge base and development within the field of smart buildings.

[17] Electricity for building services systems is that which is used for various electrical equipment (e.g. office machines), and for lighting and ventilation in office and commercial premises, as well as in public premises such as churches, schools and healthcare facilities.

Carbon balance research programmes

The Agency is running a research programme on carbon balances. Its objective is to acquire knowledge concerning carbon flows in the country's forests, thus assisting forestry to provide a useful means of reducing the atmosphere's carbon dioxide concentration. The programme is expected to provide a basis for developing strategies to maintain or increase the uptake of carbon dioxide in carbon dioxide sinks such as forestry. Particular attention is being paid to measures to which attention has been drawn in the international climate negotiations. Some of the objectives of the programme are:

- to improve knowledge of carbon uptake, carbon flows and carbon balances in forest ecosystems, based on Swedish ecological conditions, and with due allowance for Swedish forestry management practice.
- to establish Swedish competence in connection with forest carbon balances and carbon sinks, thus providing a better basis for analysis of the effects of proposals put forward as part of global climate work.
- to obtain material for appropriate, cost-efficient ways of utilising the forests to reduce atmospheric carbon dioxide. This includes reducing carbon dioxide concentrations through the use of forest fuels and using forest products in a cost-efficient manner.

The Agency's programme complements the MISTRA *Strategies to reduce greenhouse gas emissions from land use applications* research programme. The purpose of the programme is to develop integrated strategies for how changes in land use and management can contribute to optimum reduction of net emissions of greenhouse gases in Sweden.

Continued work with policies and measures

Parliament has decided that the present system of financial support for renewable energy sources and carriers will stop in 2002. Instead, a system intended to encourage electricity production from renewable energy sources will be introduced, based on a trade in certificates in combination with a requirement to include a certain proportion of electricity from renewable sources (i.e. fulfilling certain environmental requirements) in electricity supplies of the purchase of electricity. In connection with this work, the Agency has proposed a planning target for an expansion of wind power to 10 TWh/year in 10-15 years. The purpose of this target is to ensure that local and public authorities are well prepared to deal with matters relating to planning, siting etc.

Parliament has also taken a decision on the principle of greening of the taxation and to continue to transfer taxation between work and energy-related and environment-related taxes. It should be possible to transfer about SEK 30 000 million over a ten-year period. The present taxation revenues from energy-related and environment-related taxes amount to about SEK 50 000 million.[18]

Work is also in progress on other guide measures such as long-term agreements with industry, trading in emission rights and other flexible mechanisms.

Scenarios for carbon dioxide emissions from the energy sector

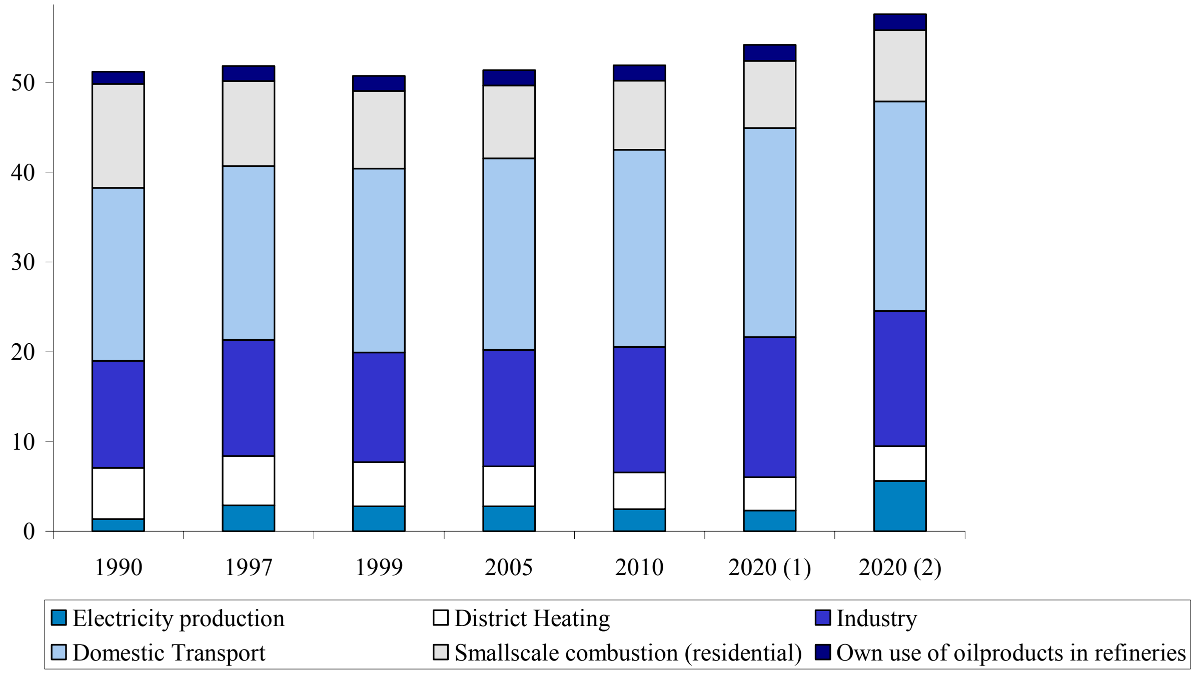
Various scenarios have been developed for forecasting carbon dioxide emission developments. The starting point for the work has been to see what development is likely to be with present-day guide measures. Carbon dioxide emissions from the energy sector are expected to increase until 2020, but with the magnitude of the increase depending on assumptions made for the Swedish nuclear power industry. Emissions between now and 2010 are expected to be virtually unchanged.

Two different scenarios have been calculated for the follow-on period from 2010 to 2020. In the first alternative (1), the starting point is the assumption that there will be continued investments in the country's nuclear power stations, and that they will continue to be operated on commercial terms. Electricity prices are expected to increase only slightly in comparison with present-day price levels. The second scenario (2) sees nuclear power being phased out after 40 years' operation, which means that the first reactors would start to be taken out of service in 2012, with all five reactors being closed during the period of the scenario. This would result in a higher price for electricity towards the end of the period.

Emission developments would differ between sub sectors. While increasing in the transport and industry sectors, they could be expected to decrease from district heating production and from small-scale residential heating applications. Emissions from electricity production would decline somewhat in the first alternative, i.e. that in which nuclear power production continues. On the other hand, emissions from electricity production could be expected to double in the scenario involving phase-out of nuclear power production after 40 years.

[18] About 3 % of GDP

Figure 3. Carbon dioxide emissions from the energy sector, 1990-1999, with scenarios of future development.



The assessment of future development of carbon dioxide emissions from the energy sector is based on what is known as a 'business as usual' scenario. This means particularly that the analysis is based on present-day energy and environmental policies, and that the assumptions in general - such as those relating to efficiency improvements - are in line with historical development. The starting point for assessments of possible technical developments and/or any technical breakthrough is that of present-day knowledge of the likely rate at which various technologies with development.

The scenarios are based on assumptions of such aspects as energy policy, economic development and technical development. Each of these areas, of course, has its own uncertainties. Several simplifications have had to be made, and so the results should therefore be interpreted with care.

Increasing emissions from the industrial sector

Industrial emissions of carbon dioxide are expected to increase by about 20 percent until 2020, or by 2.7 million tonne/year, in relation to the base year of 1997. In scenario 2 (with nuclear power starting to be phased out after 40 years), it is expected that the rate of increase would be somewhat less, due to the fact that some of the country's most electrically-intensive sectors/companies would cut their production or move it to another country. This would tend primarily to reduce the use of electricity, although it would also reduce the use of fossil fuels and district heating to some extent.

The scenario calculations foresee greater use of all forms of energy. Although the use of bio fuels is expected to increase in the pulp and paper industry at the expense of oil, this increase is likely to be less than it could be, particularly during the latter part of the scenario period. This is because it pays the forest industry to sell bio fuels (fuel from waste products) to other sectors. The incentive for this sale is to be found in the fact that manufacturing industry pays 35 percent of the country's general carbon dioxide tax. The use of oil would therefore come relatively cheaper for the industrial sector than for other sectors, apart from the electricity production sector.

Electricity use is expected to increase by almost 9 TWh/year in scenario 1 (with essentially unchanged electricity prices) or by almost 6 TWh/year in alternative 2 (with electricity prices rising in response to the phase-out of nuclear power production). The increased use of electricity is expected primarily within electrically-intensive sectors such as the pulp and paper industry, as well as in the iron, steel and other metals industries.

Changed mix of energy carriers in the residential sector

Emissions from the residential and commercial premises sector are expected to fall by 20 percent between the reference year of 1997 and 2020. This is equivalent to 2 million tonne/year of carbon dioxide. Emissions would also fall in scenario 2, although at a somewhat lower rate, by about 15 percent. In addition, emissions are expected to fall more during the first part of the scenario period, i.e. from 1997 to 2010.

Total energy use in the residential and commercial sector is expected to increase by about 5 TWh/year between 1997 and 2020. However, in the first part of this period, it is expected to grow more slowly than during the second part of the period. This greater use of energy is due primarily to a higher rate of new building and greater use of electricity for operation of appliances. The rate of new building is expected to be higher during the second part of the scenario period.

It is expected that there will be a marked change in the make-up of the various forms of energy carriers, which will affect carbon dioxide emissions. The use of electricity and district heating will increase substantially until 2010, with the use of oil declining. From then until 2020, the use of electricity and district heating will continue to increase, although not so rapidly. The use of oil will also continue to decline, but again at a less rapid rate. The use of wood fuels, and particularly the use of pellets, will increase during the second part of the period, due primarily to reduced costs for users.

The use of heat pumps will increase during the scenario period. Heat pumps produced 6.5 TWh in 1997: in 2002, it is expected that this production will have increased to 10 TWh. Heat pumps are powered almost exclusively by electricity, and generate 2-3 times as much thermal energy as is used for their immediate drive energy input. The energy in the form of heat supplied by heat pumps is not included in the figures for total energy use in this sector, although the input energy for driving the heat pumps is included.

The rising electricity prices of scenario 2 are expected to result in a reduction in the use of district heating and a greater use of oil, in comparison with scenario 1. The price of electricity heating will increase by about 10 percent, including taxes, which will result in several changes in the energy system. It is assumed that this will result in fewer heat pumps, with the use of both oil-firing and wood fuels increasing to compensate. As heat pumps provide more energy than they require for their drive energy input, and as the heating efficiency of electricity is better than that of oil or wood pellets, it is expected that total energy use will be about 1 TWh/year higher than for the corresponding case with lower electricity prices.

Continued increase in emissions from the transport sector

Emissions of carbon dioxide from the transport sector are expected to increase by 20 percent by 2020, i.e. by 3.9 million tonne of carbon dioxide. This calculation does not include emissions from international maritime transport or international air traffic, emissions from which together are expected to increase by over 60 percent by 2020, i.e. by 4 million tonne of carbon dioxide. Of this, bunkering for international maritime transport accounts for half, about 2 million tonne/year. However, this forecast is very uncertain, as actual use varies depending on the relative prices between harbours in different countries.

Today, the transport sector is reliant almost entirely on fossil fuels. Alternative motor fuels - ethanol, methanol, rape methyl ester (RME), biogas and natural gas - provide today only a marginal input in relation to total fuel use. It is felt that, with present-day guide measures, most of the use in 2020 will still be based on fossil fuels. However, there may be somewhat greater use of alternative motor fuels in certain defined sectors, such as for public transport in urban areas.

The distance covered, the type of transport, the fuels used and how efficiently they are used affect emissions of carbon dioxide in the transport sector.

The growth of passenger traffic is closely linked to economic development. In this respect, assumptions concerning disposable income, employment levels, population sizes and structure and costs of different forms of transport are particularly important. It is expected that, during the scenario period, total passenger transport will continue to increase relatively strongly, with the private car accounting for by far the greatest increase. Air traffic is also expected to increase strongly, as will rail traffic until 2010, but at a considerably slower rate between 2010 and 2020. This is based on the assumption that there will be no further new investments in rail infrastructure after those that have been started in 2001.

Freight transport depends primarily on the general development of trade and industry, which means that assumptions such as a growth of GNP, industrial production and employment are important for the scenarios. The scenarios foresee a total increase in freight transport of 25 percent by 2010, followed by a further 18 percent by 2020. Of the increased quantity, the greater proportion will be transported by road traffic.

As freight transport increases, with an increasing proportion of road transport, it is expected that the use of diesel fuel will increase relatively substantially during the scenario period. This will be particularly marked during the first part of the period, as a result of a relatively substantial increase in the number of diesel-powered private cars and a very substantial increase in the proportion of diesel-powered light trucks.

The use of aviation fuel will also increase substantially, although the use of petrol will not increase. This is partly due to the fact that the numbers of diesel-powered private cars are expected to increase, and partly due to the fact that the fuel efficiency of private cars is expected to be improved relatively rapidly.

It is assumed that the ACEA agreement will be fulfilled. This is a voluntary agreement, which has been entered into between the EC Commission and the European automotive industry concerning reduction of carbon dioxide emissions from new private cars by 25 percent by 2008, in relation to the 1995 levels. The results of this agreement have been assigned considerable weight in the scenario calculations. The annual improvement in fuel efficiency is expected to amount to 0.75 percent per annum on average until 2020, as opposed to only 0.2 percent per annum without the agreement. This is equivalent to a reduction in carbon dioxide emissions of about 2 million tonnes during the scenario period. In assessing what the rate of improvement would be without the ACEA agreement, the starting point has been that of historical development. More powerful engines, larger and heavier vehicles and more ancillary equipment, such as air-conditioning, have largely eaten up the improvements in fuel efficiency that occurred during the 1980s and 1990s.

The increase in emissions will be reduced during the second half of the period as a result of the growth in GNP being assumed to be lower than during the previous period.

Substantial increase in the use of bio fuels for district heating production

Emissions of carbon dioxide from the district heating sector will fall by about 30 percent, or by 1.8 million tonnes until 2020, despite the fact that use is expected to increase.

In total, district heating production is expected to increase by almost 20 percent between 1997 and 2020, with the greatest increase occurring during the first part of the period, and amounting to somewhat over 5 TWh/year within the residential sector.

That, despite this, emissions can be expected to decrease, is explained by a substantial increase in the use of bio fuels for district heating production. By 2020, the amount of bio fuels is expected to amount to about 40 TWh, or somewhat over 85 percent of the total fuel supply. The price relationship between the different fuels, which is affected primarily by the structure of energy and carbon dioxide taxation, makes it economic to use bio fuels. Bio fuels are untaxed, while fossil fuels carry relatively high taxes. In addition, it is expected that the price of bio fuels will remain constant, while the price of fossil fuels will increase somewhat.

In addition to continued substitution of fuels in existing plants, it is expected that there will be further expansion of bio fuelled CHP as old hot water boiler plants are taken out of service.

It is expected that the heat input from electricity boilers will decline: the price of electricity means that it is not economic to invest in new electric boilers. It is also expected that, to some extent, electric boilers will be taken out of service before the end of their economic or technical lives as their production costs are high. Heat pumps in operation now are also beginning to show their age, so that further investments will be required to extend their lives or to replace them by new capacity. However, high electricity prices affect the viability of heat pumps. Although the scenarios expect a certain amount of reinvestment and new installation of heat pumps, it is expected that the overall supply of district heating from heat pumps will decline. This applies particularly in scenario alternative 2, which expects a greater rise in the price of electricity.

Carbon dioxide emissions from the electricity production sector

Carbon dioxide emissions from electricity production are expected to decline somewhat by 2010. This will also be the case until 2020 for scenario 1, although emissions are expected to double in scenario 2.

Electricity production capacity from the country's nuclear power stations is expected to decline by about 4 TWh by 2005 as a result of the closure of Barsebäck 2. The country's other nuclear power reactors will remain in operation until 2010: with a 40-year life, the first reactor will be closed in 2012.

The scenarios have assumed a limited possible net importation of electricity. As is the case today, trade in electricity is assumed to be primarily for system balancing purposes. Some of the cross-border transmission capacity is needed in order to balance temporary surpluses or deficits in power systems. The 'commercial' flows of power will vary during the year, and from one year to another, due to the effects of temperature, precipitation and economies.

In the long term, it is expected that present-day production capacity on the deregulated and competitive electricity market will be reduced. This means that electricity production capacity in Sweden's neighbouring countries will be reduced, so that the ability to import power will be reduced in the long term. New production capacity will be built where there is a demand.

The fact that carbon dioxide emissions can be kept down, while the use of electricity is expected to increase, is due to the fact that it is expected that electricity production from renewable energy sources will become increasingly economic. It is expected that based-based CHP production and wind power will be able to benefit from the overall system of support available to electricity from renewable energy sources, which will reduce their costs. Our analyses have assumed a subsidy figure of 150 SEK/MWh. It is also assumed that imported electricity will be able to meet the additional demand for power that can arise. It is expected that the net import of electricity will amount to about 4 TWh in 2010 and 2020.

This aggregated support means that it will also be economic to carry out improvements to existing hydro power production capacity and to build small-scale hydro power stations. Taken together, these measures are expected to provide an increased hydro power production capacity of somewhat over 3 TWh during a statistically average climatic year.

Combustion-based electricity production is also expected to increase, primarily in CHP plants. Increased demand for district heating from industry and the residential sector will improve prospects for CHP production, with those plants connected to public district heating systems accounting for the greatest increase.

The use of bio fuels is expected to increase relatively considerably. In 1997, fossil fuels (oil, coal and natural gas) provided over 70 percent of the fuel input for electricity production, with bio fuels providing 28 percent. By 2010, it is expected that the proportion of fuel input provided by bio fuels will have increased to 46 percent, rising further to about 65 percent by 2020.

The significance of gas price

Just how much electricity production will be based on natural gas depends on a number of factors, including the price of the gas. The scenario calculations have assumed that the price of gas will rise relatively substantially between 2010 and 2020. If the price of gas had been lower, there would have been no opening for offshore wind power: instead, more natural gas-fuelled electricity production capacity would be installed.

The significance of electricity imports

The scenarios see a maximum of 4 TWh of electricity imported in 2020. In order to illustrate the effect that this import would have on carbon dioxide emissions, we have calculated what would happen if the net import in 2020 was zero. Instead, the 4 TWh which are assumed to have been imported, would be produced in natural gas-fired power stations, resulting in emission of a further 1.4 million tonnes of carbon dioxide in 2020.

Development after 2020 if nuclear power production is phased out after 40 years

Alternative 2 sees four reactors (over and above Barsebäck 2) being closed by 2020, with the remaining reactors being closed between 2020 and 2025. On the basis of the same assumptions as used for the scenario calculations up to 2020, the phased-out nuclear power capacity would be replaced by fossil-fuelled electricity production after 2020, thus resulting in a substantial increase in carbon dioxide emissions after 2020.

A subsidy for electricity from renewable sources

Both scenarios foresee an increase in electricity production from renewable energy sources. This development is affected by the 150 SEK/MWh subsidy that has been included in the calculations. This subsidy has been taken as a numerical approximation of the coming system of certificate trading in electricity from renewable energy sources.

Just how a system for trading in certificates for electricity from renewable energy sources might be constructed is at present being investigated. The price of the certificates (= subsidy for electricity from renewable energy sources) will depend on the requirements in respect of the aggregated proportion of electricity from renewable sources as a function of total electricity use. In addition, the price will vary with time: this applies both to short-term variations and price changes in the longer term. However, it is too complicated to attempt to allow for short-term and long-term price variations in the scenario calculations, which is why a figure of 150 SEK/MWh has been taken to apply for the entire scenario period.

A higher level of subsidy than as assumed in the calculations would not have any greater effect on the results of the scenario calculations, as there are already significant quantities of electricity from renewable energy sources. Even if the subsidy level was higher, there are circumstances that restrict just how much electricity could be supplied from renewable energy sources. The amount of wind power, for example, is restricted by what the system can handle without substantial reinforcements of the grid and complementation by more rapidly regulated production capacity. Electricity production from based-based CHP plant is limited by the size of the heat sink, while production from small-scale hydro power is limited by what would be allowed by the land and water use planners.

A reduced level of subsidy, on the other hand, would impact first on offshore wind power production, as this is the most expensive of the renewable energy alternatives. Offshore wind power production comes into the picture when electricity prices rise (scenario 2). On the basis of present-day cost assessments, a lower subsidy level would result in the construction of natural gas-fired combined cycle plant instead of offshore wind plants. The price of gas, too, would affect the balance between the two forms of power production.

The effect on the electricity system

The scenario calculations for the period up to 2020 assume that there will be changes in the installed electricity production capacity. These changes will affect the country's electricity system in several ways.

Both scenarios foresee Barsebäck 2 being closed before 2005, which means that there will be a noticeable increase in the risk of power shortages in Southern Sweden. This will place increasing reliance on the first reactor in Oskarshamn in order to maintain a power balance in the area. In the event of insufficient power production, power cuts will be the only way of maintaining system frequency.

In the 40-year reactor life scenario, it will be Barsebäck 2 and Oskarshamn 1 - the two smallest reactors - that will be closed first. Although the overall effect in terms of energy supply will not be all that great, the fact that these two reactors are both in Southern Sweden will increase the risk of a power shortage in the area. Oskarshamn 1 would be closed 2012. In order to maintain the power balance in the area, this would necessitate substantial changes in the Swedish electricity supply system, either by installing new production facilities with a high utilisation level in the southern part of the country, or by increasing grid transmission capacity.

A reactor life of 40 years means that the reactors in the central area of Sweden would start to be shut down in 2014, which would impose considerable pressure in the form of a need for new electricity production capacity. By 2025, all the reactors would have been closed down.

By 2020, both the scenarios expect natural gas-fuelled combined cycle power plants to have been built, which would result in a substantial increase in the demand for natural gas. In alternative 2, the total supply of natural gas in 2020 would amount to 24 TWh: this is, however, still within the capacity of the existing gas distribution system.

Bearing in mind the architecture of the country's present grid structure, the new power stations should be sited in the vicinity of the closed nuclear power stations. However, at present, the natural gas distribution system is concentrated in the south-west part of the country, while the Forsmark and Oskarshamn nuclear power stations are in the east.

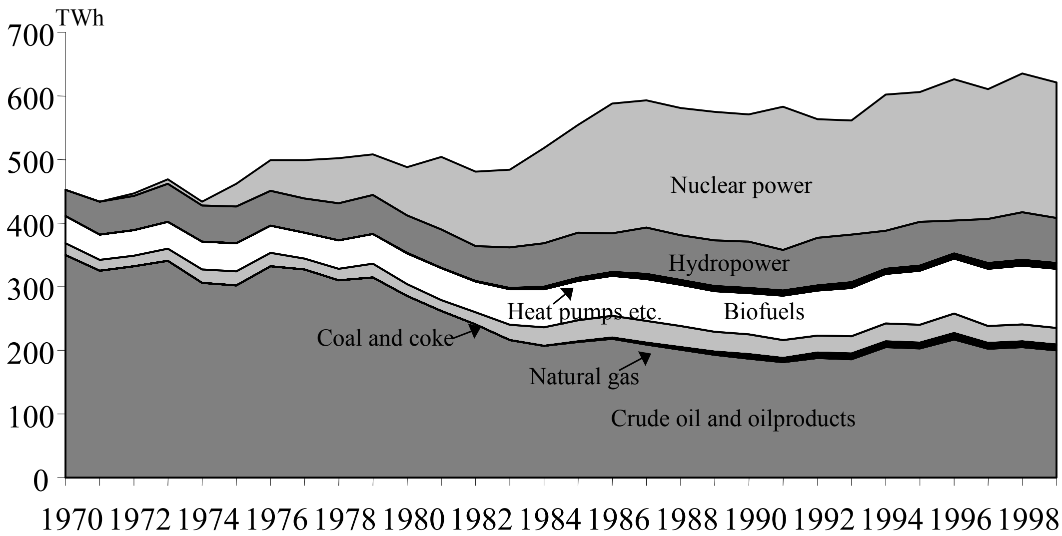
The large amount of wind energy production (over 10 TWh) in alternative 2 also imposes considerable requirements on system regulation capacity. A significant proportion of electricity production would depend on wind conditions, and could therefore vary with time.

1. Background and history

1.1 Supply and use of energy, 1970-1999

Between 1970 and 1999, Sweden's energy supply has increased by almost 150 TWh[19]. During this period, the mix of the supply has changed radically: in particular, the proportion of energy supplied by oil has fallen from 77 percent in 1970 to 33 percent in 1999. This change is partly due to an expansion of hydro power production and nuclear power production, although the use of biofuels and peat has increased at the expense of oil products, from 9 percent of total supply in 1970 to 15 percent in 1999.

Figure 1.1 Sweden's energy supply, 1970-1999, TWh/year



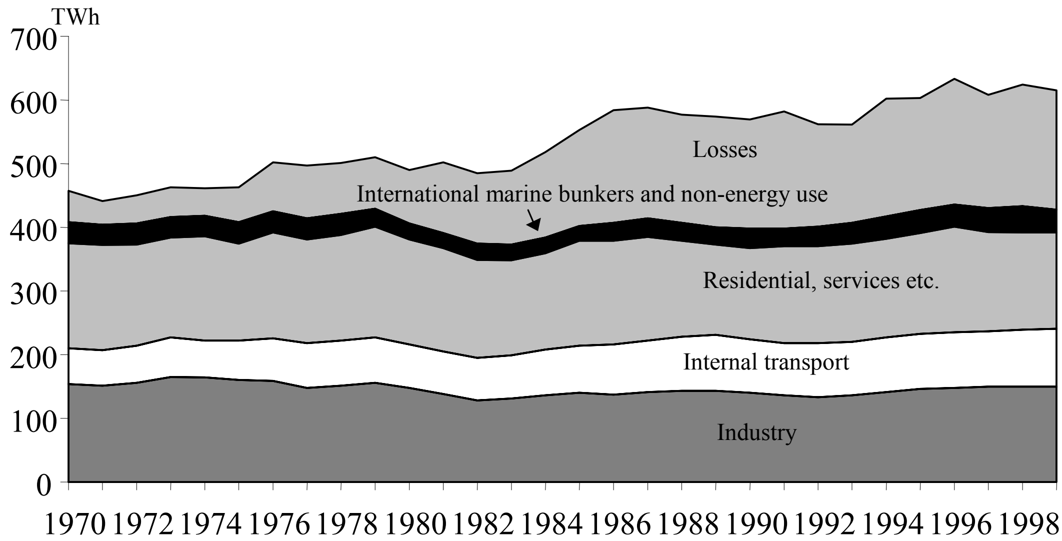
Note: Nuclear power energy quantities are expressed as the quantity of reactor heat, which is almost three times greater than the quantity of electrical energy produced.
Trade in electricity over the period has varied between a net import of 6 TWh and a net export of 11 TWh.
Source: Energy in Sweden 2000, The Swedish Energy Agency.

[19] Based on figures using the international method of accounting for nuclear power production, which considers the amount of heat supplied by the reactor, rather than the quantity of electrical energy produced. The amount of heat is almost three times as large as the amount of electricity.

Changes in the use of energy

The use of energy in the industrial and residential sectors declined somewhat over the period, although the use of energy for transport increased dramatically, by over 40 percent. It is primarily oil of which use has declined in the industrial and residential sectors, but increased in the transport sector. The use of electricity has increased substantially in the industrial and residential sectors, but rather less within the transport sector.

Figure 1.2 Sweden's energy use, 1970-1999, TWh/year



Note: In 1999, nuclear power production losses constituted 140 TWh of the total 187 TWh of conversion and distribution losses.
Source: Energy in Sweden 2000, The Swedish Energy Agency.

The use of energy in industry

Industry uses about 40 percent of the country's final energy use. Of this, 26 percent is fossil energy and 35 percent is supplied by biofuels, peat etc., with the remainder consisting of electricity and district heating.

A small number of sectors account for most of the industrial energy use in Sweden. The pulp and paper industry accounts for almost 45 percent of energy use, the iron and steel industry for 14 percent and the chemical industry for 7 percent, which means that these energy-intensive sectors account for two-thirds of industry's total energy use. However, the engineering industry - which is not regarded as an energy-intensive sector - accounts for almost 8 percent of industry's total energy use due to its large proportion of total industrial production in Sweden.

In a longer time perspective, there has been a clear redistribution between different forms of energy carriers, and particularly by a move away from oil to electricity. Despite rising industrial output, the use of oil has fallen substantially since 1970, partly through greater use of electricity and partly through general improvements in the efficiency of energy use. This development started in connection with the oil crises at the beginning of the 1970s, which resulted in both business and society as a whole starting intensive work on reducing the use of oil. Whereas, in 1970, electricity provided 20 percent of the total energy use within the sector, it has today risen to 36 percent. At the same time, industry has reduced its use of oil from 48 percent to 14 percent of its energy use. Between 1970 and 1999, the proportion of biofuels, peat etc. has risen from somewhat over 21 percent to 35 percent of total energy use.

The change from oil to electricity has meant that energy use in the sector has declined, due partly to the fact that electrical energy often has a higher efficiency than oil at the point of use, and partly to the fact that the conversion losses associated with electricity production are debited to the electricity sector, whereas they were previously debited to the industrial sector.

Energy use in the transport sector

Various oil products, such as petrol, diesel fuel and aviation fuel, meet energy use in the transport sector almost entirely. Energy use in the sector has exhibited a steadily rising trend since 1970, which is a result of a greater amount of transport work in society. Between 1970 and 1999, both passenger and goods transport increased by over 50 percent. Energy use in the transport sector fell during the oil crises at the beginning of the 1970s and 1980s, in response to substantial rises in the price of crude oil. Energy use in the transport sector (excluding bunkering for foreign maritime traffic) has increased by 60 percent over the period. The use of petrol has increased by about 45 percent, while the use of diesel fuel has doubled. The use of aviation fuel has also increased.

Energy use in the residential sector

Energy use in the residential, service and commercial sector etc. accounts for about 40 percent of Sweden's total final energy use. Of this, over 60 percent is used for space heating and domestic hot water production. This is affected by temperature conditions, which means that there are substantial random variations in energy demand from one year to another. Energy use is therefore corrected to what it would be in a statistically average climatic year in order to provide a true picture of developments.

The total temperature-corrected energy use has remained relatively stable between 1970 and 1999, although the distribution between different forms of energy carriers has changed. Oil crises, rising energy prices, changes in energy taxation and investment programmes have all affected the move away from oil to other energy carriers. The total use of oil in the residential and service sector etc. in 1999 amounted to 30 TWh, as compared with 113 TWh in 1970. There has been an opposite change in the use of electricity, which increased continuously from 1970 until the middle of the 1990s. However, in recent years, electricity use has remained around 70 TWh. The reduction in the use of oil depends largely on a change from oil to electricity and district heating for heating purposes, so that most of the heating requirements in detached houses are met by electricity, while most of those in apartment buildings and commercial premises etc. are met by district heating.

The move away from oil to electricity and district heating for heating purposes, together with the greater use of heat pumps during the 1990s, has resulted in total final energy use in the sector falling as a result of reduced conversion losses at the points of use. Other factors that have helped to counter greater energy use for heating and domestic hot water in the sector include various types of energy conservation measures, such as the installation of improved control systems, additional thermal insulation and the upgrading of windows in old buildings.

The use of domestic electricity has more than doubled during the period, from 9 TWh to 19 TWh. This can be explained by a greater number of households and wider ownership of domestic appliances.

The use of electricity for building services systems has increased substantially since the 1970s, from 8 TWh in 1970 to 22 TWh in 1999. The reasons for this include rapid growth in service activities and greater use of office machinery.

1.2 Increased use of biofuels

Biofuels, peat etc. are used in three main areas: for district heating, in the forest industry and in the detached house sector.[20] In 1999, they provided about 15 percent of Sweden's total energy supply. The greatest increase has occurred in the district heating sector, where use has increased from 2 TWh in 1980 to over 26 TWh in 1999, although the use of biofuels has also increased in industry -

[20] In 1999, the use of peat provided almost 3 TWh, while the use of refuse provided somewhat over 5 TWh. The remainder, about 85 TWh, was supplied by biofuels, of which black liquor in the pulp industry made up about 34 TWh.

primarily in the forest products industry. The forest products industry uses its by-products and waste products, i.e. losses from manufacturing processes and black liquor from wood digestion, for process heating and electricity production for economic reasons. The greater use of biofuels in the forest products industry is partly due to the fact that, in relative terms, the use of oil has become more expensive. In addition, costs are reduced by recovering the process chemicals used in pulp manufacture. In 1999, the use of biofuels in the industrial sector amounted to over 54 TWh, equivalent to almost 60 percent of the total use of biofuels.

The use of biofuels in the residential sector has remained relatively constant at 10-12 TWh since 1980. 3.6 TWh of biofuels were used for electricity production in 1999, providing over 2 percent of the country's total electricity production. Most of this biofuelled electricity production occurs in industry.

1.3 Reduced carbon dioxide emissions

Between 1970 and 1980, emissions of carbon dioxide from the energy sector - i.e. excluding industrial processes and overseas transport - have fallen by almost 15 percent, followed by over a further 30 percent reduction between 1980 and 1999.[21] This reduction is largely a result of the change from oil to electricity and other energy carriers, both on the supply side and on the use side, and as a result of improvements in the efficiency of energy use. Over the same period (1970-1990), emissions from domestic transport increased by about 35 percent.

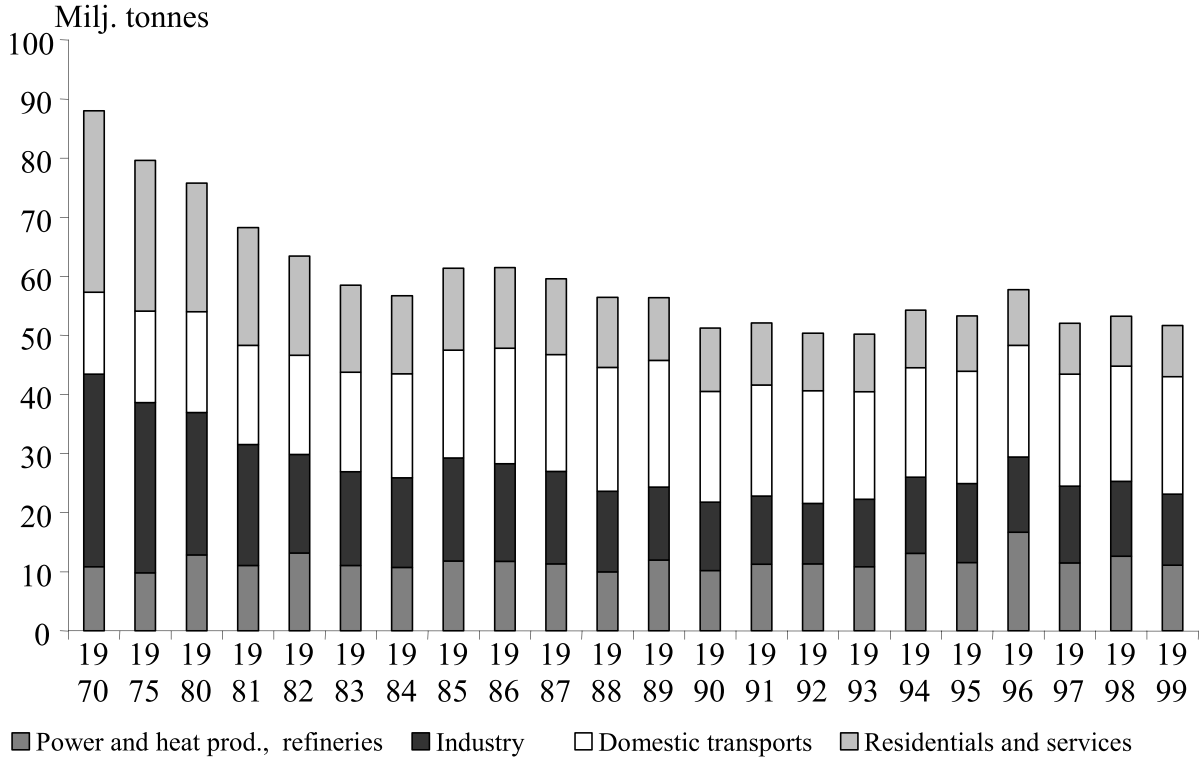
Between 1990 and 1999, emissions of carbon dioxide from the energy sector increased from 51.3 to 51.7 million tonnes, or by almost 1 percent.[22] Emissions have increased from electricity production and from the transport sector, as well as from industry, but have decreased from the district heating sector and from small-scale combustion in the residential sector.

Figure 1.3 shows carbon dioxide emissions from the energy sector in 1970, 1975 and 1980-99.

[21] Statistics Sweden, Na18, Mi18. Carbon dioxide emissions from the energy sector make up over 90 % of Sweden's total emissions of carbon dioxide, and about 80 % of Sweden's aggregated emissions of greenhouse gases.

[22] Statistics Sweden, Na18, Mi18. The energy sector includes combustion for energy purposes. The emission figures do not include diffuse emissions.

Figure 1.3 Carbon dioxide emissions between 1970, 1975 and 1980-99, million tonnes



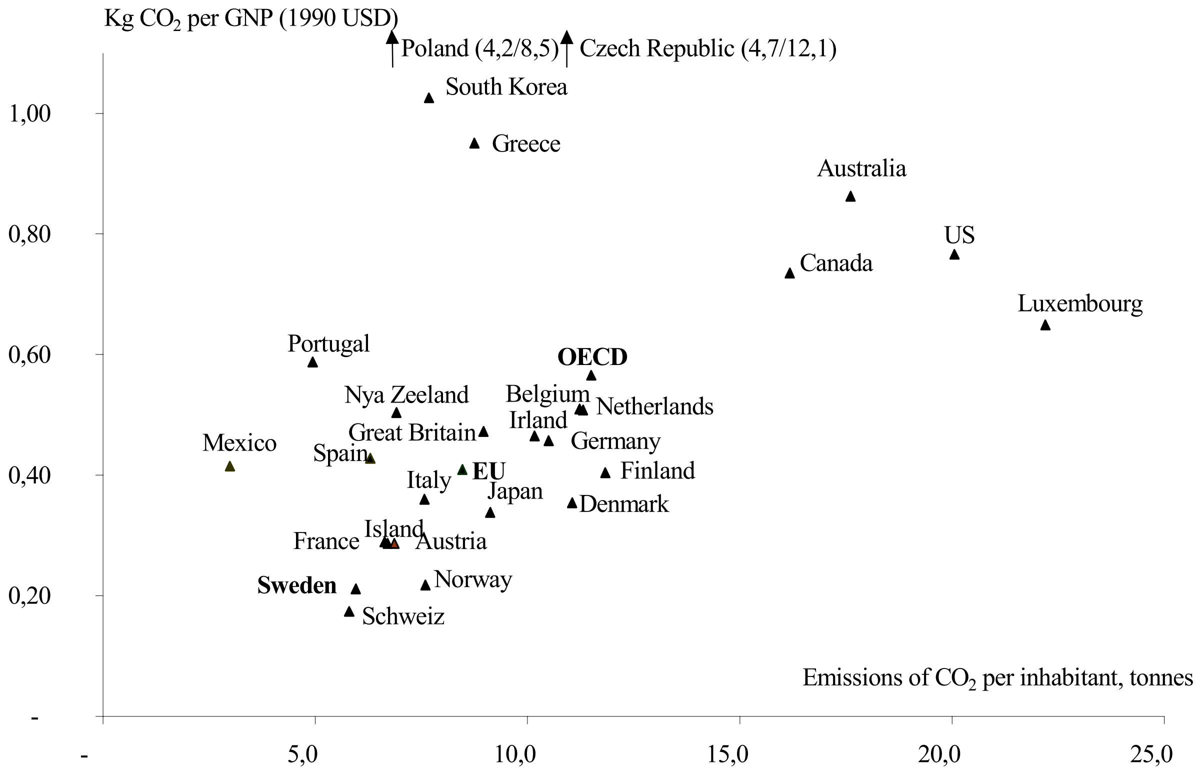
Note: Bunkering for international aviation and maritime transport is not included. Emissions from domestic transport have varied over the period between 3 and 5 million tonnes/year. In recent years, emissions from overseas transport have increased to between 6 and 7 million tonnes/year.
Source: Statistics Sweden, Na18, Mi18.

1.4 An international comparison

In comparison with other OECD countries, Sweden has a relatively high specific *per-capita* energy use. This is due to good availability of natural resources such as forests and hydro power, which in turn has resulted in a relatively high proportion of energy-intensive industries. The country's geographical position, with low mean annual temperatures and a low population density, results in a substantial need for heating and in long transport distances. However, in comparison with other industrialised countries, *per-capita* carbon dioxide emissions are relatively low, due to the fact that the proportion of fossil fuels used in the country's energy system amounts to only about 40 percent, as against a corresponding average proportion in other OECD states of about 80 percent.

Figure 1.4 shows *per-capita* carbon dioxide emissions from the energy sector for Sweden and for an average for EU and OECD states.

Figure 1.4 *Per-capita* carbon dioxide emissions from the energy sector, 1998, in Sweden, the EU and OECD, tonnes per inhabitant.



Source: UNFCCC and Energy Balances of OECD Countries 1997/1998, Edition 2000.

2. Energy policy development

The following is a description of the historical developments, in very general terms, of Swedish energy policy.

2.1 Crises and accidents

The character of Swedish energy policy has changed between 1970 and today. During the 1970s, the primary objective was to reduce the country's dependence on oil. Among the actions taken were energy conservation information campaigns and the provision of grants for energy conservation investments. Economic instruments, such as energy tax, were also employed to some extent.

The first half of the 1970s also saw the beginning of a major investment programme in nuclear power production, with the first reactor, Oskarshamn 1, being commissioned in 1972. As a result of the Three Mile Island accident in 1979, and Sweden's subsequent referendum (in 1980) on nuclear power, the Government decided that those power stations that were in process of being built should be completed and started up, but that there should be no further nuclear power development and that the power stations should, in fact, be phased out at a rate as compatible with the need for electric power in order to maintain the country's levels of employment and welfare. In addition, Parliament decided that it should be clearly stated that all nuclear power production should have been phased out by 2010.[23]

Just at this time, i.e. 1979/80, prices on the international oil market again rose substantially. The country's energy policy debate was then presented with the concept of oil replacement in order to define energy policy more exactly. This decision changed the character of the country's energy policy towards a more price-orientated and market-orientated view. A new system of energy taxation was introduced, resulting in the introduction of several taxes on energy, intended to act as guide measures.

Oil prices fell rapidly in the middle of the 1980s, which again changed the circumstances surrounding energy policy. In order to attempt to avoid a break in the trend towards reduced oil consumption, the State attempted to maintain the sale price of oil by increasing the tax on it. However, tax increases were unable to keep pace with the falling world market prices.

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[23] Bill No. 1979/80:170

1986 was the year of the Chernobyl accident, which again cast the spotlight on nuclear power. Energy policy since then has been concentrated on creating the right conditions for changing the country's energy system so that nuclear power can be phased out.

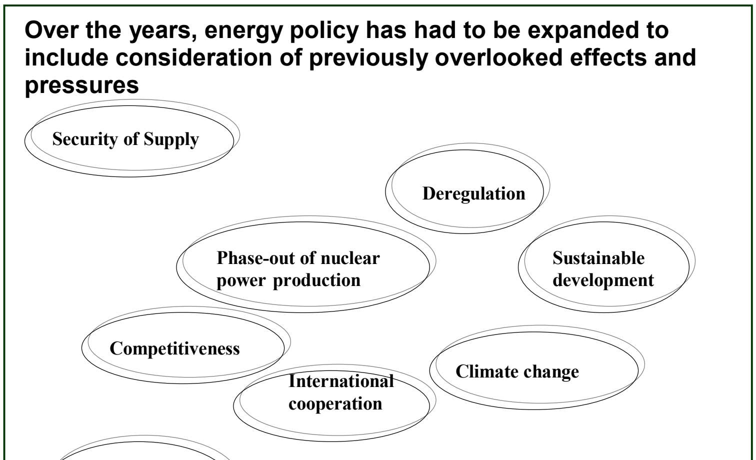
2.2 Spotlight on environmental and climate problems

The effects of the energy sector on the environment have become increasingly important in determining the thrust of energy policy. The country's large, undeveloped rivers have been protected from further hydroelectric power development, and the harm caused by combustion, in the form of acidification and eutrophication, has resulted in appropriate countermeasures. The effect of carbon dioxide emissions on world climate has also attracted increasing attention since the middle of the 1980s, to the point that dealing with it is now an important part of energy policy.

2.3 Energy policy since 1990

Changing conditions for energy policy

The circumstances surrounding Swedish energy policy have changed in several respects since 1990. Historically, day-to-day work has been characterised by the attempts to combine differing views within the energy sector. An example is given by the 1991 energy policy decision, the aims of which were to ensure a reliable supply of electricity and other forms of energy on competitive terms for Swedish industry, to fulfil the phase-out of nuclear power production and to protect the environment. Attempting to combine these conflicting interests has been - and is - a challenge in realising the decisions in the country's energy policy.



Conditions governing Swedish energy policy have changed in several respects during the 1990s. Sweden joined the European Union in 1995, which involved new methods of working. This has had significant effects on Swedish interests in energy, industrial and environmental policy, with the international element having become increasingly marked.

Energy markets have been progressively deregulated, so that trade in electrical energy across national borders is now a reality in northern Europe. This has meant that each country's requirements in terms of self-sufficiency in the production of electrical energy have declined considerably. Deregulation also means that no individual national policy can differ too much from that of other countries, in order not to distort the market. Finally, environmental considerations, and particularly the achievement of sustainable development, have come to play an increasingly important part in the countries' energy policies. In this respect, the Kyoto Protocol, intended to reduce greenhouse gas emissions, represents an important turning point in this process. The three dimensions of sustainable development -the environment, economics and social development - have become increasingly important in discussions in recent years, and now serve as a common platform within many political areas. Increasingly, specific individual areas of society now have to allow for, and apply, environmental considerations. As a result, various ministries and sector authorities have become increasingly responsible for pursuing and operating environmental matters. Three trends can therefore be said to have been important during the 1990s:

- The increase in European and global cooperation
- The increasing importance of reducing emissions of greenhouse gases
- The growing responsibility of various sectors for environmental considerations and sustainable development.

Present energy policy

Parliament adopted the new energy policy guidelines in 1997, after all-party discussions with the Government on energy policy. The discussions were concluded in February 1997 with an agreement between the Social Democrats, the Centre Party and the Socialist Party. The energy policy decision states that the aim of the policy is to facilitate changeover to an ecologically sustainable society.

The 1997 decision also confirmed that the 1980 and 1991 guidelines still applied, i.e. that nuclear power production is to be phased out at a rate compatible with meeting the need for electrical energy in order to maintain employment and welfare. However, the cut-off date of 2010, by which all reactors were to have been shut down, was no longer stated. Instead, the reactors are to be shut down at such a rate as to ensure that there are no adverse effects on the price of electricity, the availability of electricity for industry, the power balance, the environment or the climate. The 1997 decision also included closure of the two Barsebäck reactors.

Energy policy guidelines

In the short and long terms, the objective of Swedish energy policy is to ensure a supply of electricity and other energy on competitive terms. Energy policy is intended to create the right conditions for efficient use of energy and for a cost-efficient Swedish supply of energy, with low adverse effect on health, the environment or climate, and to facilitate the move towards an ecologically sustainable society. This will ensure the encouragement and maintenance of good economic and social development in Sweden.

Energy policy shall also contribute to the creation of stable conditions for industrial competitiveness, as well as for the general modernisation and development of Swedish industry. It shall also assist extension of energy, environmental and climate cooperation in the Baltic Sea region. The country's electricity supply shall be assured through an energy system based on lasting, preferably indigenous and renewable, energy sources, as well as on the efficient use of energy.

Energy shall be used as efficiently as possible, with due consideration of all resource assets. The use and development of all energy technology shall be subject to strict requirements in respect of safety, health and the environment. Nuclear power production shall be replaced by improving the efficiency of electricity use, conversion to renewable forms of energy and environmentally acceptable electricity production technology. The use of fossil fuels should be restricted to a low level. Of the fossil fuels, natural gas is preferred, and the existing natural gas distribution system should be utilised. The major national rivers, and other stretches of river that Parliament has expected from further hydroelectric power development, will continue to be protected. A reliable supply of electricity, at a reasonable price, is an important consideration in maintaining the international competitiveness of Swedish industry, and the country's energy policy shall be so designed as to ensure this. Increased production and economic activity are of decisive importance for employment, and therefore also for our future welfare. On the basis of the economic growth policy adopted by Parliament, there should be scope for greater use of electricity by industry over the coming decade. More efficient use of electricity shall be encouraged, both in industry and in other sectors of society.

Parliament subsequently passed a new Act concerning the phase-out of nuclear power production (1997:1320). It enables the Government to decide on phase-out, on the basis that each reactor should be decommissioned at a time that best serves the interests of moving the country's energy system towards sustainable development, based on the use of renewable energy sources.

The geographical siting of each reactor to be decommissioned shall also be considered, with other circumstances such as age, design and importance for the country's energy system being included in the factors governing the decision. The general structure of the framework governing the safety of nuclear power production has not been changed.

After reaching an agreement concerning compensation to the owners of the Barsebäck power station between representatives of the State, Vattenfall AB and Sydkraft AB, the first reactor at Barsebäck was shut down on 30th November 1999. Under the terms of the 1997 energy policy, the second Barsebäck reactor is to be shut down by not later than 1st July 2001. However, the Government has recently reported to Parliament[24] that the conditions for closing the second reactor have not yet been fulfilled. The Government is now of

[24] Continued restructuring of the energy system. Government Communications, 2000/01:15.

the opinion that it should be possible to close the reactor by not later than the end of 2003, by which time necessary compensatory measures will be working.

Parliament's environmental quality objectives

During 1999, Parliament agreed a new structure for work aimed at achieving environmental objectives. Fifteen national environmental quality objectives were agreed by Parliament. The Environmental Quality Objectives set out the various environmental states to be achieved, generally in a generational perspective. Interim targets shall complement the Objectives, forming the starting points for more specific definition of actions and strategies at different levels in various sectors of society. The work on drafting these interim targets is in progress, and Parliament has now passed the *Limitation on Climate Change* environmental quality objective.

The Parliamentary Climate Committee has suggested sub-objectives for the emission of greenhouse gases in Sweden[25]. For the period 2008-2012, the Committee has suggested that the emission target should be 2 percent lower than emission levels in 1990, expressed as carbon dioxide equivalents. The objective covers the six greenhouse gases set out in the Kyoto Protocol and the IPCC definitions. Measures taken outside Sweden's borders shall be supplementary, but the main emission reductions shall be effected within the country's borders.

The proposals are at present being drafted by the Cabinet Office and the Ministries.

Limitation on Climate Change:
The objective of the work of the UN Climate Convention is that the concentration of greenhouse gases in the atmosphere should be stabilised at a level less than that at which anthropogenic effects on the world's climate system become dangerous. This is to be achieved in such a way, and at such a rate, that biological diversity is maintained, that the production of foodstuffs is assured and that other objectives in respect of sustainable development are not put at risk. Together with other countries, Sweden bears a responsibility for achieving this global objective.

The environmental quality objective means:
Work is concentrated on stabilising the concentration of carbon dioxide in the atmosphere at less than 550 ppm, and on preventing the concentrations of other greenhouse gases from increasing. Achievement of this objective is very dependent on work in all countries.

Integration of environmental consideration into the sectors

[25] Proposal for a Swedish Climate Strategy, SOU 2000:23.

The objective that sustainable development and environmental considerations should be an integral part of every policy area or sector is nowadays a central plank in the work of the European Union. The Treaty of Amsterdam, which came into force on 1st May 1999, emphasises the objective of sustainable development. In addition, Clause 6 of the Treaty requires environmental considerations to be integrated with EU policy areas and activities. Sweden has been a driving force behind the work of integrating environmental consideration and sustainable development in all EU policy.

At the meeting of the European Council[26] at Cardiff in the summer of 1998, it was decided that each ministerial council should be responsible for the move towards sustainable development within its areas of jurisdiction. The intention of this is that those with the best understanding of how some particular area operates are in the best position to identify problems and shortcomings, to prepare suggestions for solutions and to ensure that they are applied. The European Council also decided that all important proposals from the European Commission must include an assessment of their environmental impacts.

The European Council has hitherto decided that the various Councils of Ministers shall draw up strategies for integrating environmental consideration with the aim of achieving sustainable development in nine different sectors. At the Summit Meeting in Helsinki, it was agreed to ask the Commission to draft a strategy for achieving economically, socially and ecologically sustainable development. The resulting strategy was adopted by the meeting of the Council of Europe in Gothenburg in June 2001. An important aspect of it is that it is to constitute a central element of the EU contribution to the UN Conference on Sustainable Development in Johannesburg in 2001, ten years after the Rio de Janeiro international conference on the environment and sustainable development.

Integration of climate and energy policies

There are close links between energy policy and climate policy. In Sweden, about 80 percent of the country's total emissions of greenhouses gases originate from energy use. A successful climate policy will therefore require substantial changes in the use of fuels, distribution systems, energy-efficient technology etc. Policies and measures to reduce emissions of greenhouse gases will result in new price relationships between energy carriers, energy production facilities and, at the next level, in changes in the relative prices of finished goods, semi-finished goods, raw materials and services. One effect of this will be problems experienced by various sectors in adjusting to the changed conditions, together with changed patterns of trade between countries. However, as with all changes, the changes will also create considerable opportunities for those correctly appreciating them. The

[26] Heads of State and of government of the European Union.

long-term objective of climate policy is to direct these processes of change. The *opportunities offered by climate policy* are to utilise them for modernisation and revitalisation of the Swedish economy. This means that there are strong links between energy policy, industrial policy and climate policy, creating an opportunity for industry to modernise its products and production processes in order to establish itself at an early stage in a new market, of which only the outlines are known.

Organisation of energy-related considerations

Changes in the organisation

In connection with the 1997 energy policy decision, the Government realised that there was a need to clarify and strengthen public authority control within the energy sector. The new energy policy agreement also imposed new, enhanced requirements on how restructuring of the energy system should be carried out. A new, central energy authority was therefore established on 1st January 1998.

The Swedish Energy Agency is responsible for implementing most of the changeover of the country's energy system and for coordinating the work. In addition, one of the Agency's central duties is to monitor developments on the energy markets and in the energy system, and to analyse their significance in terms of possible effects on the environment, technical development and economic growth. The Agency is also responsible for national measures to encourage research and development in the energy sector.

A further organisational change was carried out in connection with the 1998 change of government. A new Ministry of Industry, Employments and Communications was given responsibility for industry, energy, transport and employment, which meant that its responsibilities therefore included many different areas of policy. The object of bringing them all together within the remit of a single ministry is that integration of the various policy areas improves conditions for raising living standards and creating higher levels of employment as a result of good, substantial and sustainable growth throughout the country.

Parliament's 1998 decision to provide support to local authorities for local investment programmes for ecological sustainability represented a new duty for the Cabinet Office and the Ministries. Local investment programmes were not included in the 1997 energy policy programme, although it does have somewhat the same direction. Support for local investment programmes has two purposes: to contribute to greater employment, and substantially to increase the rate of change towards an ecologically sustainable society. Much of the money available has been spent on energy-related projects. The Ministry of the Environment is responsible for operating the programme.

Other public authority duties within the energy sector

The **Swedish Consumer Agency** is responsible for testing, marking, certification and information on energy-demanding equipment etc. The purpose of this work is to encourage development of energy-efficient technology and to assist consumers in acquiring the knowledge that they need in order to be able to reduce their own energy consumption. This is one of the five overall objectives of the work of the Agency.

The **National Board of Housing, Building and Planning** is the national authority for planning, urban development, construction and dwelling. Its duties include encouraging good energy conservation in the built environment, with particular emphasis on reducing the use of electricity for heating residential buildings and certain commercial premises. It is responsible for the country's Building Regulations, including aspects such as energy use and objectives of the energy policy programme in the form of measures intended to reduce power demand and to encourage conversion from electric heating to other forms of heating with the aim of reducing overall use of electricity.

Another important duty of the Board is to encourage sustainable development of ground and water and of the physical environment. The construction of infrastructure systems, residential areas and workplaces has a considerable effect on long-term energy use.

3. Implemented policies and measures

Sweden has taken a number of steps to limit or reduce carbon dioxide emissions from the energy sector. Of these, the most important measure is carbon dioxide and energy taxation. Other policies and measures and actions have been successively applied, although in many cases the primary objective has not only been to reduce emissions of greenhouse gases: objectives have also included:

- Improving the efficiency of energy use
- Reducing the use of electricity energy for heating purposes
- Encouraging the use of renewable forms of energy
- Improving the security of electricity supply in southern Sweden
- Encouraging sustainable development by local authorities
- Encouraging ecological construction of residential buildings
- Extending international cooperation, *and*
- Carrying out work in other countries to reduce carbon dioxide emissions.

Programmes for sustainable development by local authorities and in the residential sector have a broad approach, considering not only the environmental sector as a whole, but also the social aspects. An important part of the work of achieving sustainable development within the environmental sector is to reduce the use of fossil fuels, and so the programmes have important elements of measures intended to reduce carbon dioxide emissions.

3.1 Energy and environmental taxation

The most important instruments is that of energy and carbon dioxide taxation, which has been progressively implemented during the 1990s. Carbon dioxide tax has increased from 250 SEK/tonne CO_2 in 1991 to 530 SEK/tonne CO_2 in 2001 and over 600 SEK/tonne in 2002. There have also been changes in the structure of the taxation system during the period, as described below.

Background

During the oil crises of the 1970s, the response was concentrated on moving energy consumers away from the use of oil to the use of electricity. Environmental policy objectives entered the picture during the 1980s: for example, the taxation of petrol was modified in order to encourage the use of lead-free petrol. The importance of environmental objectives in energy taxation was boosted at the beginning of the 1990s in connection with the major taxation reform of 1990/91. Aspects of the reform that related to energy included the introduction of carbon dioxide tax, value-added tax on energy and a differentiation in a tax on oil products to distinguish between a use for heating and use as motor fuels. With the country's entry into the EU in 1995, energy taxation was harmonised with EC legislation, primarily in accordance with the Mineral Oils Directive (92/81/EEC), the objective of which is to effect harmonisation of the structures of spot taxes on mineral oils. The move towards taxation as a means of benefiting environmental aspects is continued in the country's budget for 2001 (see Section 7.4).

In addition to their function as an environment economic instrument, taxes also have a fiscal function, with the revenue from energy and environmental spot taxes making an important contribution to the national economy. Excluding value-added tax, energy taxes raised over SEK 52 000 million in 1999, or about 2.6 percent of GNP. Value-added tax then provides a further SEK 13 000 million. Certain changes were made in energy taxation in connection with Sweden's entry into the EU in order to finance the country's EU membership fees. Other increases in energy taxes have been used for such purposes as financing a wide range of measures in the education sector. *Table 3.1* shows the revenues from various environmentally-related taxes between 1990 and 1999.

Table 3.1 Revenues from certain energy and environmental taxes during the 1990s, SEK million.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Petrol tax	17 169	14 538	14 344	17 554	22 030	1 711	-[1]	-[1]	-[1]	-[1]
Total tax on energy products	15 165	18 945	18 930	18 706	17 399	38 680	45 636	46 945	49 811	50 488
Energy tax	15 165	10 489	9 546	7 875	10 239	27 456	30 371	34 212	36 900	37 573
Carbon dioxide tax	-	8 157	9 194	10 641	6 943	11 078	15 053	12 599	12 796	12 811
Sulphur tax	-	299	190	190	217	146	212	134	115	104
Special tax on electricity from nuclear power plants	130	139	117	116	137	133	974	1 478	1 537	1 553
Hydropower tax	1 018	896	1 030	1 026	817	908	1 423	194[2]	-[2]	-[2]
Special tax on acidification	57	73	63	58	63	69	64	58	58	65
Environmental tax on domestic air traffic	27	156	168	190	271	177	128	-	-	-
Energy and environment taxes	**33 566**	**34 747**	**34 652**	**37 650**	**40 717**	**41 678**	**48 223**	**48 675**	**51 406**	**52 106**

[1] The hydro power tax was converted to a higher real estate tax on 1st January 1997.
[2] Petrol tax is included in energy and environmental taxes with effect from and including 1996.
Source: The National Swedish Tax Board and the Special Tax Unit in Ludvika.

The energy taxation system is complex, with different taxes or levies on energy, refuse, carbon dioxide, sulphur and NO_x. Taxes vary depending on whether the fuel is used for heating or as a motor fuel, on whether electricity is used in northern Sweden or in the rest of the country, on whether it is used by domestic consumers, industry or by the energy sector and so on. Appendix 1 shows a summary of current taxes in the energy sector in tabular form.

Types of taxes

The legislative basis of energy taxation lies in the Energy Tax Act, SFS 1994:1776. *Energy tax* is levied on petrol, fuel oil, diesel oil, paraffin, LPG, natural gas, coal, petroleum coke and (nowadays) also on raw tall oil. The general principle is that fuels are taxable if they are used for heating or as motor fuels. The actual tax rate varies from fuel to fuel, and is independent of the energy content. Tax is also payable on the use of electricity: however, as this tax is levied at the consumer level, the actual production of electricity is exempt from tax.

Carbon dioxide tax, which was introduced in 1991, is levied on the emitted quantities (kg) of carbon dioxide from all fuels except biofuels and peat. It does not differentiate between the use of fuels for heating or as motor fuels. It was increased, on 1st January 2001, from 370 SEK/tonne to 530 SEK/tonne. A further increase to over 600 SEK/tonne from 1 st of January 2002 is decided.

Since 1st July 2000, *production of electricity in nuclear power plants* has been taxed in the form of an annual power tax on the thermal power of the reactors, at a rate of SEK 5514/MW. This is a change from the previous practice, by which nuclear power was taxed on the basis of its electricity production[27]. In addition, there is a further levy of about 10 SEK/MWh under the terms of the Act Concerning Financing of Future Charges for Disposal of Spent Nuclear Fuel (1992:1537). This levy is intended also to cover phase-out and ultimate demolition of the reactors, together with a certain monitoring and inspection. The Government determines the rate annually. There is also a further tax of 1.5 SEK/MWh to cover the costs of waste management from earlier nuclear research, carried out at the Studsvik research centre.

A *sulphur* tax was introduced in 1991, and amounts to SEK 30/kg of sulphur emissions from coal and peat, and to SEK 27/m^3 for each tenth of a percent by weight of sulphur content in oil. However, if the sulphur content of liquid or gaseous fuels does not exceed 0.1 percent by weight, no sulphur tax is charged. This applies for fuels such as petrol, diesel oil and gas oil. In addition, no sulphur tax is charged if measures to reduce sulphur emissions are applied. Fuel used for the production of lime, limestone and cement, as well as fuels used in the soda recovery boilers of the forest products industry, is exempt from sulphur tax.

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[27] Under certain operating conditions, this power tax is (and is intended to be) equivalent to the previous tax rate of 27 SEK/MWh.

An environmental levy on emissions of nitrogen oxides was introduced in 1992 (SFS 1990:613) for boilers, gas turbines and stationary combustion plant producing an annual energy output of at least 25 GWh, at the rate of SEK 40/kg of NO_x emissions. However, this levy is intended to be essentially fiscally neutral as far as the national economy is concerned, and is repaid in proportion to the respective plant's energy production, so that only those with the highest emissions are actually net payers.

Special taxation rules

Fuels that are used for *electricity production* are exempt from the energy and carbon dioxide taxes, although they are subject to the NO_x levy and sulphur tax in certain cases. 5 percent of the fuel input used for cold condensing power production and gas turbine power production is regarded as being for internal use, and is subject to energy and carbon dioxide tax.

Investment subsidies are available for wind power, biofuelled CHP and small-scale hydro power, as described in Section 3.2. There is also special support for wind power in the form of an operating subsidy, known as the *environmental bonus*, equivalent to the electricity tax of 181 SEK/MWh in southern Sweden. The obligation to accept power from small-scale electricity production sources was removed on 1st November 1999: at present, there is special support for small-scale electricity production amounting to 90 SEK/MWh.

Fuels used for *heat production* are subject to energy and carbon dioxide taxes and, in certain cases, to sulphur tax and the NO_x levy. In principle, biofuels, refuse and peat are free of tax for all energy uses, although peat is subject to sulphur tax. A tax on refuse incineration is being investigated at present.

Special rules apply for simultaneous production of heat and electricity in combined heat and power plants (CHP). For taxation purposes, the fuel input is proportioned in relation to the electricity and heat production outputs. The producer can choose which fuels are regarded as being used for electricity production and which for heat production. A full deduction of energy and carbon dioxide tax may be made for the fuel used for the production of electricity, while the fuel assigned to useful heat output is subject to full carbon dioxide tax and half energy tax.

CHP production introduces a certain degree of distortion, as it results in a conflict between the principles of electricity taxation at consumer level and fuel for heat production being taxed at producer level[28]. The present taxation system results - and not least in connection with CHP production - in relatively environmentally

[28] See, for example, 'An Evaluation of the Tax Reform Committee's Energy Taxation Model', Ds 2000:73.

disadvantageous fuels being used for electricity production, with biofuels being used for heat production.

3 percent of the fuel input to CHP plants supplying heat to district heating systems is regarded as being used for internal consumption, and is therefore taxed. In addition, a higher rate of energy tax, payable during the period from 1st November to 31st March, was introduced on 1st July 1998 for electricity used in electric boilers having an installed capacity in excess of 2 MW.

Domestic users in northern Sweden pay a lower rate of electricity tax than do domestic users in southern Sweden. In addition, the tax on the use of fuel oil for heating is lower than that for corresponding use of gas oil/diesel fuel for use as motor fuels.

No energy tax is applied for fuels used for manufacturing processes in *industry*, for horticultural purposes or, since 1st July 2000, for professional use in agriculture, forestry or fishing and associated activities, and only 35 percent of the carbon dioxide tax. The carbon dioxide tax for industry is applied at the rate of 185 SEK/tonne CO_2. Special taxation reduction rules enable 24 percent of the tax that exceeds 0.8 percent of the sales value of products to be offset and repaid. Under what is known as the 1.2 percent rule for cement, lime, limestone and the glass industries, the total tax paid by these industries does not exceed 1.2 percent of the sales value of their products. The rule should have been removed at the end of 1999, but has now been extended until the end of 2002. In addition, industry does not pay value-added tax on energy.

The rule for *transport* is that all fuels should be taxed, and that the taxes should generally be higher than if the fuel was used only for heating. Even biofuels are taxed when used as motor fuels. However, under the terms of pilot project dispensations, the Government can reduce or waive taxation on fuels used to develop more environmentally benign fuels, with such relief being provided for certain volumes of alternative motor fuels.

There are different tax levels for diesel fuel and petrol, depending on the fuel's environmental class. These taxes have resulted in use being concentrated on the best environmental classes. Energy tax, carbon dioxide tax and sulphur tax are not levied on diesel or fuel oils used for professional maritime applications or for rail traffic, and nor on aviation petrol or aviation paraffin used in aircraft.

The Taxation of Vehicles Act (SFS 1998:327) applies vehicle tax to motor cycles, private cars, buses, trucks, tractors etc., although there is a lower rate of tax for private cars in certain sparsely populated areas. An environmental classification system was introduced in 1991, with the aim of providing a means of applying different levels of sales tax and thus encouraging the introduction of vehicles producing less pollution. However, EC regulations limit the scope of such differentiation, and the system was abandoned in 1998. Sales tax on passenger cars was removed in 1996, followed in 2001 by its removal on light trucks, buses and motor cycles, with the aim of encouraging the sales of new vehicles and thus accelerating the rate of renewal of the country's vehicle stock. The average age of Sweden's vehicle stock is relatively high, and older vehicles generally have poorer exhaust cleaning and higher fuel consumption. For the same reason, the annual vehicle tax on diesel private cars of 1993 model and older has been raised to the same level as for more modern diesel-powered vehicles.

The effects of energy taxation

The use of biofuels during the 1990s has increased by 16 TWh, or about 45 percent, due to the effects of taxation. Between 1990 and 1999, their use in the district heating sector more than doubled. During the second half of the 1990s, the use of processed biofuels in the form of pellets has increased, with a new, small-scale industry developing for the production of pellets, special burners and boilers etc. Processed biofuels are used both in domestic boilers and in large pulverised fuel boilers.

The Swedish Energy Agency is responsible for monitoring and evaluating pilot project dispensations relating to the reduction of motor fuel tax for bio-based alternative motor fuels under the terms of the Energy Taxation Act (1994:1776). Table 3.2 shows the volumes of such fuels exempted from tax. Biogas is exempted from motor fuel taxation under the terms of a Section 8.4 exception (the Mineral Oils Directive), and so no pilot project dispensations have been granted.

Table 3.2 Volumes of tax-free RME and ethanol sold/used for motor fuels, 1995-2000.

	1995	1996	1997	1998	1999	2000
RME (m^3)	500	7 500	8 000	7 500	7 000	8 000
Ethanol (m^3)	6000	8000	12 000	14 000	16 000	21 000

The statistics for bio-based motor fuels are not completely reliable. The volume of fuel in question may have been accounted for by several dispensation-holders: where this is known to have occurred, allowance has been made for it in the figures above. However, it cannot be said with certainty that it has not occurred on other occasions that have not been indicated in the reports or been picked up in some other way. To some extent, the volumes listed below may be greater than those actually used. In addition, the volume for which a dispensation has been granted is also much greater than the quantity actually sold. One of the reasons for this is that a larger plant for the production of ethanol is in process of being started up.

The quantity of bio motor fuel sold in 2000 has been calculated as replacing 2000 m³ of petrol and 18 000 m³ of diesel fuel, with a resulting gross reduction in carbon dioxide emissions of about 55 000 tonnes. However, the actual reduction is less than this, as a certain quantity of fossil energy is used for producing the biofuel. Nevertheless, investigations[29] indicate that the input of fossil energy and motor fuels for the production of bio-based motor fuels plays a considerably smaller part than had previous been assumed.

Greening of the taxation system

During 2001, there has been a shift in the emphasis of taxation between higher taxes on energy and lower taxes on work. All told, this change amounts to a total of SEK 3300 million. Its objective is to make energy taxation more closely related to environmental aspects, and to use the higher taxation revenues to reduce other taxes. Within this framework, higher energy taxes are therefore balanced by a higher basic allowance of SEK 1200 for income tax and a reduction of 0.1 percentage points in employer social security charge.

Carbon dioxide tax was increased on 1st January 2001 from 370 SEK/tonne CO_2 to 530 SEK/tonne CO_2, equivalent to a rise of about 40 percent. About 25 percentage points of this increase were balanced by a reduction of 8 percentage points in the energy tax, with the result that this portion of the taxation change is revenue-neutral from a fiscal point of view. A carbon dioxide tax provides a clearer price signal concerning the external effects of carbon dioxide than does an energy tax. This means that converting the energy tax to a carbon dioxide tax increases its environmental guidance effect on users choosing between different types of fossil fuels. The effect of this is that, after about 15 percentage points have actually increased allowance for the above offset, carbon dioxide tax, as a means further of reducing Sweden's emissions of carbon dioxide. However, an effect of the higher carbon dioxide tax would have been to make electricity cheaper than other forms of energy, and so 18 SEK/MWh also increased the electricity tax.

This increase in tax affects only domestic consumers. As Sweden has an open, but small, economy, industry has been exempted from the increase in carbon dioxide tax, as have agriculture, forestry and fishing and related industries. In other words, industry pays the same rate of carbon dioxide tax as it did prior to the 2001 taxation changes, and still pays no electricity tax. Taxes on the transport sector, too, are essentially unchanged. Apart from indexing, a tax on petrol was not increased in 2001, although the tax on diesel fuel (including indexing) has increased by 117 SEK/litre. However, in order to reduce any difficulties resulting

[29] Life Cycle Assessment of Motor Fuels, KFB Notice 1997:5; Environmental effects of alternative motor fuels, Chemical Information for the Swedish Energy Agency and the Environmental Protection Board's Comparison Project; The alternative motor fuels status report 1999, Atrax Energi AB and Kemiinformation AB for the Environmental Protection Agency.

from the higher rate of diesel fuel tax on public transport or other commercial traffic, it was decided to reduce value-added tax for passenger carriage services at the same time from 12 percent to 6 percent. This reduction in value-added tax covers all forms of public transport, such as buses, underground trains, trains, taxis and domestic air services.

3.2 Support for renewable energy and improving the efficiency of energy use

An extensive programme for the introduction of an ecologically sustainable energy system was started in 1997 as a result of that year's energy policy decision. The programme includes measures intended to reduce the use of electricity and to develop new sources of electricity production, both of which are important factors in compensating for the loss of electricity production resulting from the closure of the Barsebäck nuclear power station. Under the terms of the energy policy decision, the second reactor can be closed only if that the resulting loss in electricity production capacity can be compensated for by the provision of new production capacity and a general reduction in the use of electricity. The programme also includes long-term elements such as research and development, more details of which are given in Chapter 4.

As described above, Sweden has applied energy and carbon dioxide tax to fuels and motor fuels for several years. However, electricity production is exempted in the interests of encouraging competition, and so other forms of support are needed for renewable energy in order to bring about a real change. In the same way, energy tax on electrical energy for heating purposes is not sufficient to create an incentive to change to other forms of heating, and so special targeted measures are needed in order to increase the incentive to change to other forms of heating.

The assessments of the effects are based on a report from Swedish Energy Agency[30]. In several cases, the purpose of the various measures has been to reduce the use of electrical energy. Support for renewable energy sources has also increased the production of electricity from such sources. Sweden shares a common electricity market with Norway, Finland, Germany, Denmark and Poland, with substantial power exchanges between the countries. During the winter, at times of high load, there is generally an inward flow of power to Sweden, with the opposite applying during the summer when Swedish power plants have spare capacity. It is therefore open to question as to exactly what type of electrical energy is replaced by the Swedish conservation and other measures. The Agency has calculated the effects of electrical energy replacing energy from existing coal-fired cold condensing power plants in Europe, and for another case in which the electrical energy replaces new natural gas-fired combined cycle

[30] Short-term programme for restructuring the energy system, ER 4:2001

power plants in Sweden and Europe. This means that the real emission reductions therefore actually also occurred in countries other than Sweden

Measures to reduce the use of electricity for heating

Approximately 40 percent of heating requirements in detached houses are met by electrical energy. In an international perspective, this is a high proportion, and so steps have been taken to reduce the use of electricity, particularly bearing in mind a forthcoming sometime reduction in output from nuclear power plants.

The 1997 energy policy document noted that closing the Barsebäck power station was more likely to result in a power shortage than in an energy shortage. The conservation measures were therefore structured with the aim of reducing power demand during peak load times.

Conversion to district heating and to other forms of heating, including measures intended to reduce power demand through the use of power monitors, did not work as intended. In many cases, the costs for converting heating systems are too high. In addition, district heating tariffs[31] are so high that conversion is not economically viable for individual users, despite the grants available for such conversion.

The grants were withdrawn on 20th April 1999 under the terms of the Withdrawal Ordinance[32] and, with effect from 2000, were transferred to the development and demonstration of projects for conversion and reduction in electricity use, rather than attempting to increase the amount of conversion actually carried out. The sums available, and their categories, are shown in *Table 3.3*. Following on from this change, the Agency has concentrated on work aimed at reducing the costs of conversion in buildings having direct electric heating, concentrating primarily on the application of new technology and new system designs, the coordination of technology procurement projects and encouragement of group or area heating projects. Nevertheless, these measures alone are not sufficient to make conversion viable. However, the Agency also provides support for research and development, and is conducting research in the district heating sector. In the medium/long term, the objective is to reduce costs so that district heating becomes commercially competitive with electric heating.

Table 3.3 shows the grants available to reduce the use of electricity for heating. Support for solar heating is described in Section 3.5.

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[31] District Heating in the Heating Markets', ER 19:2000, Swedish Energy Agency.

[32] Ordinance (SFS 1999:187) concerning Changes in the Ordinance (1997:635) concerning Public Grants for Certain Investments to Reduce the Use of Electricity in Residential Buildings and Certain Premises *and* the Ordinance (SFS 1997:634) cocerning Changes in the Ordinance(1997:634) cncerning Public Grants for Investment in Conversion and Connection of Electrically Heated Buildings to District Heating Systems.

Table 3.3 Grants for the reduction of electricity use for heating, 1998-2000, SEK million.

Objective	1998	1999	2000	2001	(Calculated) 2002
Extension of district heating	100	200	15	15	15
Measures intended to reduce power demand	50	95	35	0	0
Conversion to individual fuel firing	140	5	5	132	107
Conversion of electrically heated buildings to district heating		200	11	132	107
Development of projects for reduction of electricity use in residential buildings and commercial premises			25	2	2
Solar heating			10	20	20
Available to the Government			4	24	4
Total	**290**	**300**	**105**	**325**	**255**

Conversion to district heating

A quantitative target has been set, aiming to replace 1.5 TWh of electrical energy by district heating by 2001. SEK 100 million were made available in 1998 for support for such conversion. This funding was available only during 1998 and the first quarter of 1999.

The results of the district heating conversion grant are based on the information provided by applicants on the amount of electricity that they used prior to conversion. The calculated reduction in electrical energy for all the granted applications amounts to 262 GWh, with a corresponding power reduction of 144 MW. The conversions also reduced emissions of CO_2, giving a theoretical reduction in the range 88-236 ktonne/year. The spread of this range depends on whether it is assumed that the replaced electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant.

It is not felt that the objective of replacing 1.5 TWh of electricity can be achieved with the present cost picture and the grants available, as the overall economics of such conversion are disadvantageous today due to the high cost of conversion and the little or no price saving effected by district heating. There is little inclination for those in electrically heated apartment buildings or detached houses to change to other forms of heating: these two particular conversion areas have the highest specific conversion capital costs. The falling prices of electricity in Sweden between 1997 and 2000, as a result of liberalisation of the electricity market, have reduced the incentive to connect to district heating. In total, the reduction in electricity resulting from conversion to district heating is expected to be somewhat les than 0.5 TWh at the end of the five-year period. However, electricity prices have risen during 2001.

Grants for work intended to reduce electrical power demand have been withdrawn.

Conversion from electric heating to other forms of individual heating

No quantitative targets have been set for this particular form of conversion. 80 percent of the applications received have been for conversion from direct electric heating. Between 1998 and 1999, county councils provided grants to a value of SEK 113.8 million for over 7000 dwelling units.

The calculated reductions in electrical power demand and electrical energy demand for the conversions for which grants were provided amount to 47 MW and 117 GWh/year respectively. The power-reducing measures reduce carbon dioxide emissions within the range 34-81 ktonne/year, depending on whether it is assumed that the replaced electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant. These conversions have been from direct electric heating systems, despite the fact that it is considerably cheaper to convert from waterborne systems. It is felt that this is due to the fact that households with direct electric heating are more at the mercy of the price of electricity, and thus took the opportunity of obtaining a grant for conversion. Interest in the grants has declined since the start of the programme period, which is presumed to be due to the high costs of conversion and to the fact that the price of electricity has fallen during the period.

Greater use of renewable energy

Investment grants[33] are provided in order to encourage the expansion of electricity production based on renewable energy sources. Funding is also available for the procurement of new electricity production technology. A total of SEK 1000 million has been made available for the supply of new electricity production capacity over the period 1997-2002, with a production breakdown as shown in *Table 3.4*.

[33] Ordinance (1998:22) concerning Public Grants for Certain Investments in the Energy Sector.

Tabell 3.4 Brakedown of grants for support of renewable elcetric energy, 1997-2002, SEK million.

	1997	1998	1999	2000	2001	2002 calculated
Investment in biofuel-based CHP	45	90	74,8	25	130	85
Investment in wind power plant	30	60	60	60	100	70
Investment in small scale hydropower production*	5	4	0	5	47	4
Procurement of few technology for electricity production		20	0,1	5	28	9
Total	**80**	**174**	**135**	**95**	**305**	**168**

Note: this grant has been restructured since the original grant

The energy policy document states that the objectives of investments in new electricity production from renewable energy sources are to achieve a total contribution of 1.5 TWh/year within 5 years.

Investment support for biofuel-based CHP

Grants amounting to SEK 3000/installed kW of electricity production capacity are available for investments in biofuel-based CHP production, up to a maximum of 25 percent of the investment cost. The objective of this support is to increase the supply of electricity from biofuels by at least 0.75 TWh/year within a five-year period.

Over the period, the funding will amount to SEK 450 million: SEK 445 million have already been approved. Ten plants have received a grant, and all will be in operation by the end of 2002. A requirement is that all should report details of operational data, operational experience and fuel use statistics.

The ten plants represent a total production capacity of 164 MW, and should produce a total of 0.88 TWh of electricity per year. This is expected to reduce carbon dioxide emissions in the range 490-820 ktonne/year, depending on whether it is assumed that the replaced electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant.

Of all the various forms of support in the short-term energy system restructuring programme, it is that for the new or planned CHP plants that shows the best cost efficiency. The relatively low electricity prices of recent years have not constituted an obstacle in the way of a decision: instead, all those approved to receive grants have carried out the projects.

Investment support and operational subsidies for wind power plants

An investment grant, amounting to a maximum of 15 percent of the required investment, is provided for wind power plants having an electrical output of at least 200 kW. The objective of this grant is to increase the supply of electricity from wind power plants by at least 0.5 TWh/year over a five-year period.

The operational (production) subsidy for wind power production amounts at present to 270 SEK/MWh. It consists of two parts: what is known as the 'environmental bonus' that equals the energy tax on electricity (181 SEK/MWh in 2001), and a special support grant for electricity production from small-scale production plants[34]. This latter support, which amounts to 90 SEK/MWh, will be available until 31st December 2001.

The funds available amount to SEK 380 million over a five-year period: so far, SEK 235 million have been allocated. Up to the end of 2000, 269 wind power plants had received the investment grant: of them, 167 have presented final accounts and have been commissioned. It is expected that the remainder will have submitted their final accounts and have been commissioned by 30th September 2001.

Electricity production from the wind power plants that have received subsidies up to and including 2000 is expected to amount to 0.444 TWh/year, and it is expected that the overall objective will be achieved over the five-year period. The new installed capacity of commissioned wind power plants is 112 MW, which are expected to provide an annual electricity production of 0.232 TWh. The total production capacity of wind power plants for which grants have been approved is 188 MW. The marginal reduction in CO_2 emissions is expected to be in the range 170-414 ktonne/year, depending on whether it is assumed that the replaced electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant. In addition to the investment grant, the cost of this reduction must be set against the operational subsidy and the environmental bonus.

Together with the operational subsidy, the investment grant represents a good return in terms of investment in wind power plants. The operational subsidy for small-scale wind power generation capacity applies to plants with outputs up to 1500 kW, which means that it could have a retarding effect on the construction of wind power plants with higher capacities. Applications have been received, for example, for plants with a potential output capacity of 1750 kW, but which have been restricted to a maximum output of 1500 kW in order to benefit from the operational subsidy.

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[34] Ordinance (2000:614) Concerning Support for Small-scale Electricity Production.

Investment grants for small-scale hydro power plants

Investment grants amounting to a maximum of 15 percent of the investment cost are available for small-scale hydro power production plants with an output in the range 100-1500 kW. Over a five-year period, the objective of these grants is to increase the annual electricity production from such plants by at least 0.25 TWh.

The Agency has approved nine applications for such grants, which are expected to increase electricity production by 12.9 GWh. Further, if the plants for which applications have been received but not yet been approved are built, there should be a further 24.8 GWh of electricity production. The CO_2 reduction as a result of the approved applications is in the range 4-12 ktonne/year, depending on whether it is assumed that the replaced electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant.

It is not expected that the target objective of 0.25 TWh/year of electricity production from these small hydro plants will be reached. The reason for failure to construct more such plants is that it is difficult to comply at the same time with the environmental requirements.

Summing the support for renewable electrical energy

To some extent, the present support system is a continuation of the 1991 energy policy programme. Investment grants to increase the use of renewable forms of energy production such as small-scale hydro power, wind power and biofuel-based CHP complemented the guide measure effect of energy taxation, as there is no carbon dioxide tax on electricity production. A special operational support for small-scale electricity production was introduced in 2000, complementing the special environmental bonus for wind power production that was introduced in 1995. *Table 3.5* shows the total level of support for both investment grants and operational subsidies. It can be seen from the table that it is wind power that received the greatest support, amounting at present to somewhat over 300 SEK/MWh.

Table 3.5. Present governmental support for electricity production from renewable energy sources.

Electricity from:	Present support[35] SEK/MWh
Wind	
Investment support, max 15 %.	40-50
Environmental bonus	181
Small-scale electricity production, max 1500 kW, temporary support	90
Small-scale hydro power	
Investment support, max 15 %.	30-40
Small-scale electricity production, max 1500 kW. temporary support	90
Bio fuels	
Investment support, max 25 %.	50-70

Technology procurement for more efficient use of energy

The 1997 energy policy programme made SEK 100 million available for procurement of new, more energy-efficient technology over a five-year period. The objective is to encourage development and increase the market introduction of energy-efficient technology by initiating and operating technology procurement projects.

Support for procurement of energy-efficient technology was introduced in 1998, in the form of a grant amounting to a maximum of 50 percent of the development costs, or as a loan over a maximum period of five years[36]. Its objective is to reduce the economic and technical risks to the purchaser, thus encouraging the procurement of products and systems that can replace electricity and which are electrically efficient. The 1991 energy policy programme expanded this support to include improvements in the efficiency of use of all forms of energy. The 1997 energy policy decision reformulated and clarified the support system for technology procurement of energy-efficient technology. The new ordinance[37] came into force on 1st July 1999. Under it, grants of 50 percent of the additional costs involved in the technology procurement project itself are available, together with further grants of 30 percent for the additional costs in necessary investments.

Assessment on the basis of sales statistics of new products shows an indicated reduction in electricity use of about 0.4 TWh, coupled with a reduction of 0.4 TWh in the use of oil. These improvements result in a CO_2 reduction in the range 200-400 ktonne/year, depending on whether it is assumed that the replaced

[35] The calculations are based on a discount rate of 5 % and the following return of returns; wind power 15 years, CHP:s 15 years and hydro power 30 years.
[36] Ordinance (1988:806) concerning State Support for Technology Procurement.
[37] Ordinance (1999:344) concerning State Support for Technology Procurement of Energy-efficient Technology and New Energy Technology.

electrical energy would have been produced by new natural gas-fired combined cycle plant or by existing coal-fired cold condensing plant.

3.3 Information and advisory services

The Agency carries out information and communication projects with the aim of providing more structure for the vision of an economically and ecologically sustainable energy system. Other objectives of this work include encouragement of long-term approaches and thinking, and setting the general agenda for the energy debate. Further objectives include ensuring that the correct target groups receive the right knowledge and information at the right time.

This sector of the Agency's activities is divided up into:

- general energy information
- targeted information concerning more efficient use of energy and renewable energy sources
- grants for information projects
- grants for local authority energy advisory services
- information on local authority energy planning
- information on the connections between energy, the economy and the environment
- information as part of joint EU projects and in conjunction with the OPET information service.

The following description relates to work carried out within the Agency's operating area during 1998-2000. Financing comes partly from the general grant for information and training for more efficient use of energy (short-term energy policy measures), and partly from the Agency's basic operational grants and programmes. In total, the grant for energy efficiency improvement information has amounted to somewhat over SEK 30 million for the years 1998-2000. It is not possible to provide separate details for the amount spent on information activities originating from the Agency's normal funding and other programme funding. Table 3.6 shows the funds made available in the 1997 energy policy decision.

Table 3.6 Funding distribution for information, advisory and marking services, 1997-2002, SEK million.

	1997	1998	1999	2000	2001	2002 (calculated)
Information, training etc.		12	9.4	11.9	14	13
Testing, marking, certification	4	8	8	8	8	4
Local authority energy advisory services		50	43.5	45	56	55
Total	**4**	**70**	**61**	**65**	**78**	**72**

General energy information

Information is distributed to a wide target group within the energy sector, such as energy producers, distributors, users, local authorities, energy experts, architects, installation contractors, other public authorities and the mass media. Channels include the Agency's website[38] and news-sheets, publications etc., together with the annual energy conference (Energiting). The material is based on knowledge and results derived from research, development and market introduction projects and programmes that have been wholly or partly financed by the Agency. In addition, the material also provides information on the energy system, analyses and forecasts, together with information concerning changes in the regulatory and/or administrative structure. Particular attention is paid to the relationships between energy, economics and the environment. Communication via networks has become increasingly important. Constant contact is maintained with the mass media.

Targeted information, including campaigns and 'tools'

Targeted information activities are intended to deliver specific knowledge and information, on which decisions can be made, to one or more well-defined target groups. In addition to technical information, the material can include that intended to result in acceptance of, and insight into, areas such as renewable energy sources and more efficient use of energy in particular. To a very considerable extent, the material is based on knowledge acquired through the activities of the Agency and other public authorities, complemented by internationally available knowledge.

Information campaigns aimed at consumers have been extensive, providing material on various types of heating systems and different ways of saving energy.

[38] www.stem.se

A travelling exhibition has toured the country for the last three years, in the form of two trailers containing demonstration equipment of alternative energy systems for heating residential buildings, such as pellets, heat pumps and district heating. During this period, the exhibition has visited about 300 places, attracting 200-300 visitors on each occasion.

A wind power tour was carried out in 2000, with the aim of bringing local and regional authorities and local authority energy advisers up to date on research, development and implementation of wind power in Sweden.

An annual prize (the Eko-energi Award) has been awarded each year to the industrial company that has best improved its efficiency of energy use as a result of continuous improvement work.

The Agency is also involved in several networks with other public authorities and interest groups. Knowledge acquired in a research programme has, for example, resulted in the National Forestry Board producing a set of regulations concerning methods of removing forest fuels in an environmentally responsible manner.

Voluntary agreements were entered into with about a dozen Swedish local authorities in 2001, concerning restructuring of the energy system and improvements in the efficiency of energy use in order to help reduce CO_2 emissions to 1990 levels. The local authorities concerned have also been offered training as needed.

As part of the work of technology procurement projects, the Agency distributes information intended to assist market introduction of the winning products. This information is distributed in such ways as through brochures or fact sheets in popular form, aimed at residents' associations, consumer advisers, local authority energy advisers, property administrators, architects, developers and energy utilities.

During 1998-2000, the Agency has provided funding for special information and training measures with the aim of improving knowledge concerning more efficient use of energy. This funding has gone primarily to regional energy offices, trade associations and other organisations.

Public funding for local authorities' energy advisory services was made available for the first time in the period 1977-1986, and was reintroduced in 1998-2002. Its objective is to channel information on environmentally responsible energy supply and more efficient use of energy to the general public, companies and local organisations through local authorities. The grant can be used by the authorities to finance the provision of energy advisers in their own area, or for energy advisory services in conjunction with other local authorities. It amounts to SEK 150 000/year, with an additional amount available that depends on the population of the area.

Information in connection with EC marking of domestic appliances and other EC directives

The '**Stop the electricity guzzlers - think low-energy**' domestic appliances campaign was run by the Agency during 1998-2001, with additional funding provided by the industry. The objective has been to persuade consumers to use appliances with the lowest electrical energy demand when replacing their old appliances. This work is a complement to the EC-wide energy marking scheme for refrigerators, freezers, dishwashers, washing machines and driers.

Information campaigns are also carried out with the aim of encouraging the measures set out in EC Directive EEC/93/76, for individual metering and billing of heat and domestic hot water, boiler inspections, insulation of buildings and what is known as third-party financing.

Two Swedish offices for OPET (Organisation for the Promotion of Energy Technology)

OPET's main duty, operating as part of an EU network, is to assist in disseminating the results of research into new energy technology. Sweden has two offices: OPET Sweden (operated by the Swedish Energy Agency) and OPET Arctic. Work started in 1997: a total of SEK 2.5 million had been made available by 2000. The objective of the work is to encourage energy technology by accelerating the market introduction of new and innovative technologies. The overall objective is to contribute to the creation of a long-term economically and ecologically sustainable energy system.

OPET disseminates results from successful demonstration projects in EU energy programmes or from national demonstration programmes. It does this by arranging seminars, workshops, study trips and technology transfer meetings, as well as by producing brochures, lists of suppliers and so on. OPET Sweden covers a wide range of work within the following areas: bio-energy, solar heating, small-scale hydro power production, wind power, transport, improving the efficiency of energy use in buildings and natural gas. During 2000, in conjunction with various parties in the market, OPET Sweden arranged a series of seminars at seven places in Sweden, on the theme of financing energy-efficient lighting. The Sundsvall City Council was inspired to replace 16 000 street lights. OPET Sweden has also worked with the Stockholm City Council, arranging green vehicle demonstration days for Swedish and international parties. It is also involved in nine international activities in the bio-energy sector.

Assessing the results of programmes

The purpose of the Agency's information activities is to increase levels of knowledge. This knowledge is intended, in turn, to result in action contributing to the more efficient use of energy and greater utilisation of renewable energy sources. Monitoring is concentrated on measuring to what extent target groups' knowledge has increased, and to what extent this has resulted in action. However, this monitoring is expensive, and measurements of effects have been concentrated on the larger activities such as specific campaigns.

Over 23 percent of consumers have seen the domestic white goods campaign during 1998-2000. 50-54 percent of consumers say that energy efficiency is an important factor for them when purchasing refrigerators/freezers or washing machines/driers. Domestic appliance retailers state that, increasingly, customers are tending to ask for the energy-efficient products. A comparison of sales statistics between 1997 and 2000 (i.e. over the period of the campaign), shows a substantial swing from less electrically-efficient appliances to the electrically-efficient Class A and Class B appliances. Calculations indicate that this increase in the sales of such products can have produced a saving of over 120 GWh.

About 40 percent of domestic consumers have noted the campaign for low-energy lamps. During 1998-1999, the increase in the sales of such lamps is calculated as having reduced energy consumption by about 5 GWh.

According to heating system installation contractors, the effect of the 'Water Heats Better' campaign tour has been considerable, with orders being received after the visit to each place. The number of installations of heat pumps and pellets burners has increased. Based on reports from companies, the effects of the eco-energy project in industry up to 2000 amounts so far to an energy saving of 33 GWh, of which over 10 GWh are in the form of electricity.

Information on new technology that had been the subject of technology procurement programmes is regarded as having made a substantial contribution to the introduction of the 17 products targeted during the period 1998-2000. However, it is not possible to distinguish the effects of information campaigns and the effects of technology development projects. New technology for heat pumps has spread particularly well, with heat pumps replacing both oil firing and electric heating. A very rough estimate of the effects of new heat pumps is a reduction of 0.4 TWh in the use of oil and of 0.13 TWh in the use of electric heating.

Bringing together the results of all types of energy efficiency improvement projects, it is estimated that savings in the form of reduced energy use amount to about 0.4 TWh of electricity and 0.4 TWh of fuel oil. This calculation is based on sales statistics: other methods of calculation could give other results.

It is particularly difficult to monitor the effect of the grants for local authority energy advisory services, and almost impossible to turn them into kWh savings or carbon dioxide emission reductions. However, a number of evaluations have been carried out. Despite the fact that, in terms of absolute numbers, energy advisers receive relatively few enquiries each day, about 40 percent of them feel that their services have contributed to greater energy awareness on the part of the public. Interviews with over 200 consumers who have made use of the services show that nearly all of them live in detached houses and either want general energy conservation advice or have questions concerning modification of their heating systems, e.g. concerning heat pumps or pellets. 86 percent of them thought that the information that they received was very or quite applicable. After receipt of energy advice, about half of the consumers have invested in new equipment etc. or modified their living patterns, while the remainder plan some form of energy efficiency use improvement.

3.4 Local authority energy planning and dissemination of knowledge on the relationships between energy, economics and the environment

In accordance with the Act (1977:439) Concerning Local Authority Energy Planning, local authorities are required to prepare and maintain plans for the supply, distribution and use of energy in their area. In their planning, they are also required to investigate the conditions for joint working with other local authorities or with significant major interest parties in the energy sector in their area.

The Swedish Energy Agency provides assistance to local authorities to help their energy planning, aimed at the introduction of local economically and ecologically sustainable energy systems. This is done by commenting on proposals for local authority energy plans, and through the provision of information and dissemination of knowledge concerning relationships between energy, economics and the environment. Several publications have been produced in conjunction with the Environmental Protection Agency. The publication, '**20 degrees - but how?**', was published in 1996, and includes comparisons of cost efficiency, environmental impact and energy efficiency of various types of heating systems for use in detached houses, apartment buildings, office buildings and schools. Target groups are property-owners, operating personnel, HVAC contractors, staff with local councils and energy utilities, local Agenda 21 groups and education institutions, including institutes of technology, universities and vocational training providers in the fields of HVAC and electrical installation.

Several publications on the same theme have followed, such as '**Economics, energy and the environment at local level**', which discusses the links between energy, the environment and economics at local and regional level in a new, methodical manner. In addition, it gives examples of measures or projects that are cost-efficient and profitable, while at the same time reducing energy use and environmental impact. Target groups include local and regional parties. '**Local Heating Strategies**' provides ideas for local level changes to heating systems, e.g. the introduction of district heating in part of a town or project proposals for group heating based on biofuels. The '**Examples of environmentally compatible local energy plans**' publication complements the above by describing good examples of environmentally responsible local authority energy plans, such as planning processes, objectives, strategies, environmental impact descriptions and suggestions for concrete projects. Another publication describes the rules for local energy systems.

3.5 Local investment programmes for ecological sustainability

Support for local investment programmes for ecological sustainability was introduced in 1998, with total grants expected to amount to SEK 7200 million over the period 1998-2003. Under the terms of the ordinance (1998:23) concerning Public Grants for Local Investment Programmes Intended to Increase Ecological Sustainability in Society, the Government can provide grants for programmes that fulfil certain criteria. These grants are intended to go to local authorities whose investment programmes best contribute to ecological changeover. The grants are approved by the Government and administered by the Ministry of the Environment, under the following criteria:

- to reduce environmental impact
- to improve the efficiency of energy use and of natural resources
- to encourage the use of renewable raw materials
- to increase recovery, reuse and recycling
- to contribute to maintenance and reinforcement of biological diversity, *and*
- to preserve cultural/environmental values, or to contribute to improving the circulation of plant nutrients in a closed cycle.

The various programmes are also intended to contribute to increased employment: in addition, local authorities can receive assistance with the funding of information and general training programmes associated with the programme.

In total, almost half of the country's local authorities have received grants under the programme. The climate-related grants paid out or approved up to February 2001 are calculated as amounting to SEK 2629 million[39], or almost half of the total funding granted.

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39 Total investments in local authorities amount to about SEK 9700 million.

Grants for investments in climate-related and energy-related sectors have been mainly for the following types of work:

Energy conservation in residential buildings and other properties
The use of waste heat in district heating systems
Expansion of district heating and group heating schemes, mainly for use of biofuels
Conversion of oil-fired boilers in individual buildings to renewable energy
Recovery of methane for heating or for use as motor fuels from digestion of sewage sludge or domestic refuse
Renewable motor fuels and vehicles for passenger and goods transport
The construction of cycle path networks
Marginal measures in connection with solar energy, wind power and hydro power.

Most of the works to which the investments apply is in progress, and only a few programmes have, as yet, published final reports. However, the material that the local authorities have provided in connection with their applications, together with a questionnaire to them on behalf of the Agency, can provide an indication of the extent of the environmental effects of the grants hitherto approved.

According to the material submitted in the applications, the results should provide a reduction in carbon dioxide emissions of 1.6 million tonnes/year, as shown in *Table 3.7*.

Table 3.7 Climate-related projects in the investment programme

Action	Investment grant SEK million	Estimated emission reduction, ktonne CO_2-equivalent per year
Changing to the use of renewable energy	1278	951
Measures in the transport sector	507	108
Improving the efficiency of energy use	496	470
Biogas plants and refuse processing	347	43
Total	**2628**	**1572**

Source: Ministry of the Environment

The projects include work on recovering biogas from refuse, or digesting refuse to produce biogas, and using the gas for energy purposes or as a motor fuel. Since this work was completed, an investigation has been planned into how biogas projects are divided between the collection of methane that would otherwise simply leak away from landfill and the deliberate production of methane. At present, information on which to make a quantitative determination is altogether too unreliable. The table above therefore does not include the effect of reduced methane emission.

According to a questionnaire sent to the local authorities, investments that have been carried out up to and including 2000 are expected to result in a reduction of 0.7 million tonnes/year of carbon dioxide emissions, together with a saving of about 390 GWh in electrical energy[40]. If the electrical energy is assumed to replace existing coal-fired cold condensing plant or new natural gas-fuelled combined cycle plant, there will be further savings of about 0.1-0.3 million tonnes CO_2 per year respectively.

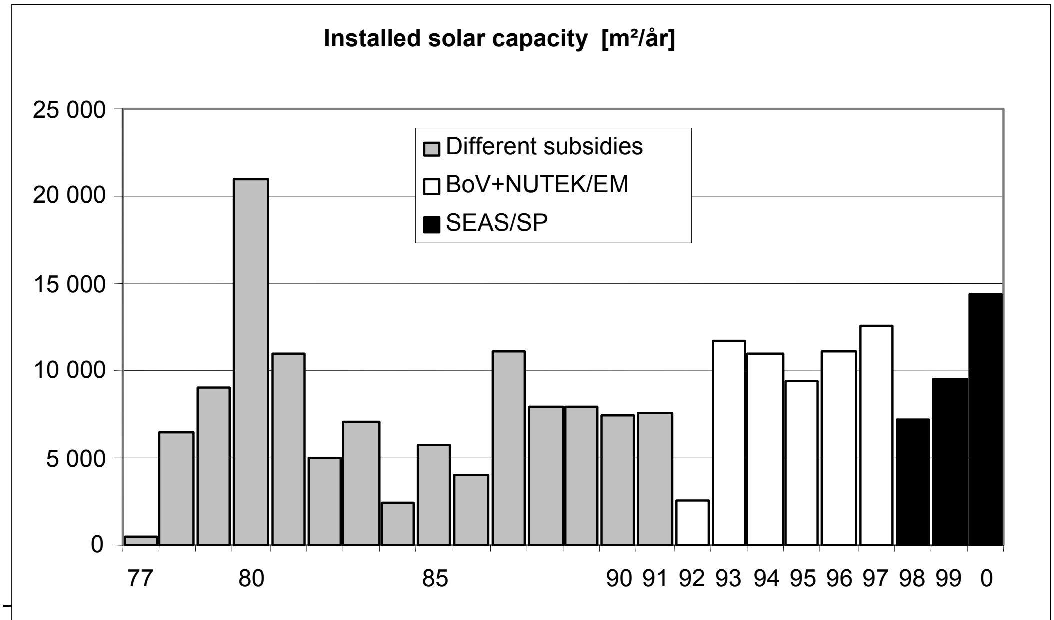
3.6 Measures in residential buildings and commercial premises

In addition to the measures relating to residential buildings and commercial premises as described above, such as support for connection to district heating systems, conversion from electric heating to other heat sources or technology procurement projects, some further measures can be named.

Support for solar heating

Various grants have been available, over relatively short periods, since the end of the 1970s. They have been administered by various bodies, had different structures and have been available only for limited periods. This has resulted in wide variations in interest in solar heating, which have not always encouraged development as far as the manufacturing industry is concerned. Figure 3.1 illustrates the installed capacity of solar collectors between 1977 and 2000.

Figure 3.1 Installed solar collector capacity, 1977-2000



40 Monitoring of energy projects in the 1998, 1999 and 2000 local investment programmes (Ångpanneföreningen, November 2000).

Acting through a special development programme for solar heating, the Agency has attempted to assist the sector by offering support for the development of more economic solar heating technology. New technology has subsequently been demonstrated, supported by grants from the Agency, and resulting in the installation of about 5600 m² of solar collector area in medium-sized installations (ranging from a few hundred to somewhat over 1000 m² per system), and equivalent to about half a year's sales of solar collectors in Sweden during the period concerned. In addition to demonstrating the new, improved technology, the demonstrations have also helped the manufacturers to maintain higher sales volumes than would otherwise have been the case.

SEK 10 million and SEK 20 million have been assigned to assist solar heating during 2000 and 2001 respectively[41]. The grant is available for solar heating installations on buildings for permanent occupation and for premises not used for commercial or industrial purposes. Funds are administered by County Agencies and the National Board for Housing, Building and Planning, although some funding has gone to the Swedish Energy Agency for information on the solar heating grants. The actual size of each grant depends on the expected annual heat production of the collectors concerned, and is paid at the rate of SEK 2:50 per annual kWh, with a maximum of SEK 7500 for detached houses, SEK 5000 per apartment in apartment buildings and SEK 5000 for other premises unit connected to a dwelling unit (200 m² of premises area are regarded as equivalent to one apartment).

In the case of solar heating installations for apartment buildings or for premises connected to residential buildings, the grant is maximised to 25 percent of the investment cost, and also to a maximum of SEK 250 000 per building.

On the basis of the grants so far approved, it is expected that the total funding should reduce energy use by 13.5 GWh[42], which should result in a reduction of between 3000-5000 tonnes/year of carbon dioxide emissions.

Split incentive

An obstacle in the way of introduction of energy-efficient systems is that information on these systems themselves, or on incentives for creating such systems, is not available at the right place in an organisation or company. A typical example of this is what is known as '*split incentive*', where the person or department responsible for investment (first cost) in a facility is not responsible for financing its operation. A simple example is that of a property developer

[41] Ordinance (2000:287) Concerning Government Grants for Investments in Solar Heating.
[42] Report of Experience from the Government Grant for Investments in Solar Heating (SFS 2000:287), Swedish Energy Agency, 2001-05-28.

buying domestic white goods on the basis of their purchasing cost, while it is the occupants of the building who then have to pay the running costs.

The Energy Agency is trying to overcome these gaps in information and to develop a tool that facilitates the application of energy-efficient solutions in the fields of procurement, Agency and use, where split incentives are barriers that must be tackled. The long-term objective is that all purchasers should use a procurement procedure, of which the best possible energy reduction forms an obvious part, i.e. that it should be the life cycle cost that determines the choice of equipment. The strategy aims at developing support or tools that can be used in connection with procurement, imposing requirements on energy use with the aim of achieving the best possible energy reduction in relation to present-day regulations and energy use levels. An important part of the work will be to persuade all parties to use life cycle costs. This will involve coordination with many parties, including the National Board of Housing, Building and Planning and Formas. In addition, the Agency is encouraging the greater use of voluntary environmental agreements, including energy efficiency improvement requirements with industry and local authorities. Other activities include third party financing and performance contracting, by which incentives to arrive at a low life cycle cost are transferred primarily to a third party who invests in the more expensive energy-efficient equipment, while the savings from lower running costs can be split between investors and users.

Grants for ecological construction

The Government has earmarked SEK 635 million to be available for grants for ecologically sustainable building construction over the period 2001-2004. The effect of the grants will be evaluated at the end of the period. They will be available for all forms of ecological building, of which improvements in the efficiency of energy use and of other natural resources will constitute a criterion.

The grants are available up to a maximum of SEK 2000/m² of heated occupied area, with a maximum of 35 m² per residential apartment. The Ministry of Finance will be responsible for paying the grants, after processing and approval of the applications by the National Board of Housing, Building and Planning.

3.7 DESS, Delegation for Energy Supply in Southern Sweden

Special steps have been taken to develop energy supply in southern Sweden, in order to compensate for the loss of electricity production resulting from the closure of the Barsebäck nuclear power station. A specific public authority, the Delegation for Energy Supply in Southern Sweden (DESS), has been set up under the Ministry of Industry and Commerce. Its purpose is to provide short-term improvements in the security of electricity and heat supply in southern Sweden through:

- investigating the energy situation in the area
- providing economic support for projects, *and*
- initiating appropriate measures.

The Delegation does this by supporting research, training, information, projects and investigations, as well as by performing feasibility studies and providing investment grants. During 1998 and 1999, it has provided a total of SEK 400 million in assistance. Work is still is progress.

It is estimated that the projects that have received investment support will make a positive contribution of about 0.9 TWh to the energy balance in southern Sweden. Projects also include information, training and the provision of advisory services. The total effect in terms of reduction in CO_2 emissions is estimated as amounting to about 70 000 tonne/year.

3.8 Local initiatives

In addition to the central, State investments in, and work on, energy and climate, initiatives are also carried out at regional and local levels. It is more difficult to summarise this work in a comprehensive manner, but the following describes the work in five local communities.

Twelve regional energy offices

Twelve regional energy offices have been established in Sweden, with financial assistance from the EU SAVE programme. The organisers and partial financers are generally local authorities, local authority associations and/or county councils or county administrative boards. The first offices were opened in 1996. Local financing is estimated as amounting to a total of not less than SEK 14 million, with the EU providing approximately the same amount. The main duties of the regional energy offices are to ensure that energy matters are properly considered in each region. The services of the offices include:

- energy supply, including renewable energy
- energy recovery from refuse
- energy conservation by local authorities, private companies, cooperative organisations and at the individual level
- small and medium-sized companies, including building contractors and building services systems companies

- the creation of regional systems of local resources (wood, small-scale hydro power and solar energy)
- the public and private service sectors
- development and regional and urban planning
- local authority and regional infrastructures: buildings, public lighting, vehicle and bus parks, water and sewage systems
- the provision of independent energy advice.

The Challenge Towns

In 1998, the Swedish Society for Conservation of Nature started a project under the name of the 'Challenge Towns'. Five local authorities areas in the country have taken part in the project, the objective of which is that they should, in the longer term, phase out the use of fossil fuels. This will be done in a number of ways, including more efficient use of energy, reduced transport requirements and less use of fossil fuels for heating and transport. It is the intention that the work should be carried out on the basis of each particular area's local conditions, and that it should form a model for other areas. *Table 3.8* shows the targets of the five areas.

Table 3.8 The Challenge Areas' targets for reduction of carbon dioxide emissions.

Town	Base year	Target year	Objective
Lund	1995	2005 2050	25 % reduction from road traffic 75 % reduction
Säffle	1995	2025	75 % reduction
Växjö	1993	2025	50 % reduction
Uppsala	1990	2010	25 % reduction from traffic
Övertorneå	1990	2020	50 % reduction

4. Applied research and development

4.1 Introduction

Climate change is an environmental problem that will continue to unfold over many years into the future. Action is needed now in order to reduce emissions of greenhouse gases, but this must be complemented by further technical development in order to solve the problems in the long term. Research, development and demonstration therefore form the bases of Swedish strategy to arrive at a sustainable energy system with limited effect on the climate. An overall objective of Swedish energy research and energy technology support is that such work and support should reduce the costs of renewable forms of energy, to the point where they become economically viable alternatives to nuclear power and fossil fuels. The amount of electricity and heat production based on renewable energy sources must be substantially increased over the next 10-15 years: this will require new technology to be developed to the point where it is commercially available and economically viable. Research areas to which particular priority must be given are:

- biofuel-based CHP
- supplies of biofuel, with associated ash-handling systems
- new processes for the production of ethanol from cellulose-rich raw materials
- alternative motor fuels
- new technology for large-scale utilisation of wind power and offshore wind power
- solar cells
- research and development for improving the efficiency of energy use in the built environment, in industry and in transport.

In 1997, Parliament made available about SEK 5000 million, over a seven-year period starting in 1998, for research and development of energy technology[43]: the table below shows a breakdown of the funding in various sectors. The funds are channelled through various public authorities, although the Swedish Energy Agency is responsible for their coordination. Appendix 2 provides a detailed list of 1998-2000 programme working areas.

[43] Bill on Sustainable Energy Supply (Bill No. 1996/97:84).

Table 4.1 Approved and expected research and development funding, 1998-2004, SEK million.

Working area	1998	1999	2000	2001	Expected 2002	Expected 2003	Expected 2004	Total
Energy research, total[44]	320	335	402	431	461	426	426	2801
Energy technology support	90	130	130	130	130	130	130	870
Introduction of new energy technology	160	230	230	230	230	230	300	1610
Total	**570**	**695**	**762**	**791**	**821**	**786**	**856**	**5281**

4.2 Implementation of research and development

The Swedish Energy Agency finances both research and development programmes. Research programmes are financed entirely by the Agency, but development programmes are jointly financed with industry. The rules for development work are set out in the Ordinance (1998:653) Concerning State Support for Energy Technology and in the Ordinance (1998:654) Concerning Energy Technology Grants.

Identification of areas in which research is needed, and the drafting of programmes, is often carried out in conjunction with other parties such as scientists, industry or other public authorities. The programmes are then advertised, inviting applications for grants for research or development projects. Programmes that are concerned primarily with fundamental research are aimed at institutes of technology, universities or research institutes, while applied programmes or projects involve manufacturing industry, energy utilities and sector organisations in various ways. Programmes usually run for about 2-4 years, but may be followed by further stages in order to achieve better continuity of research. Annual programme conferences are held, at which results are presented and information exchanged, not only between projects and management groups, but also with various potential users of the results.

Competence Centre, financed jointly by institutes of technology, companies and the Agency, provide an alternative to specific research programmes. They usually provide a means of ensuring that research is carried out across school or department boundaries within the institutes of technology or universities.

Knowledge generated by the programmes is applied in various ways. The results of work in more 'diffuse' areas can provide a decision-making basis for public

[44] About 80 % of the funding is routed via the Swedish Energy Agency, with the rest via Vinnova, Formas and the Science Council.

authorities and decision-makers, finding expression in various regulations or guide measures. Either directly or in the longer term, technical research and development results in the performance of physical and/or technical components in energy systems being improved.

4.3 Hydro power

- Hydropower is a renewable and controllable source of energy that constitutes the basis of the Swedish energy system.
- Research in the sector is important, as personnel and skills have been lost in recent years.
- The environmental impact of hydropower production, on and around the rivers, is the greatest obstacle in its way.

The knowledge pool and commercial maturity[45]

For centuries, Swedish industry and business have benefited from using flowing water as a power source. The first hydro power plants for the production of electricity were commissioned about a hundred years ago. Expansion then continued rapidly until the end of the 1960s, since when only a few further hydro power stations have been built. There are at present over 700 hydro power stations with outputs exceeding 1.5 MW, and about 1200 with outputs of less than 1.5 MW. Together, these smaller power plants produce about 1.5 TWh of electricity, out of a total of about 65 TWh.

Barriers in the way of more widespread use

In the middle of the 1900s, when new hydro power stations were being built at a rapid rate, extensive research and development work was also being carried out at various institutes of technology around the country. When further hydro power construction stopped, it had a knock-on effect in that sector research and development at the institutes of technology declined, so that relatively little work is today being done in this field. This can retard renovation and upgrading of hydro power production facilities, which are constantly needed, both in terms of technology and of environmental impact. The need to renovate older hydro power plants in Sweden will become pressing within the next decade. In the case of

[45] We define commercial maturity as being the stage when products based on new technology, or new knowledge within the framework of the particular development area, start to find their way on to the market on a large scale in competition with other products. Markets are also regarded as mature and ready to accept the new product. Economic and other guide measures can result in market growth starting earlier than would otherwise be the case.

smaller power plants, there is a risk that they will be shut down instead of being renovated. The cost of modernising the power plants is high, as are the operating and maintenance costs, which means that it is difficult to make investment pay.

The economics can be improved by research into, and development of, simpler, cheaper and more maintenance-free equipment. However, with the present low price of electricity, it is difficult to get any extensive development started. The market, too, is uncertain at present, which contributes to a disinclination to invest. There is only limited potential for building new hydro power stations, which has an adverse effect on the readiness to invest resources in developing the technology.

Other barriers lie in hydropower's environmental impact and the general attitude to hydropower. At the local level, it affects the environment, but is an excellent power source in a global perspective as it is constantly renewed and produces no emissions. In many cases, the negative attitude to hydropower in Sweden is due to the rapid exploitation of Sweden's major rivers about 40 years ago, when many of the hydro power stations were built. At that time, environmental awareness was less than it is today, and there was little knowledge of how power stations should be built to have the least possible environmental impact.

Current research and development

Some research is being carried out into water turbine technology in Sweden, financed jointly by the State, the power industry and turbine manufacturers. Research into environmental aspects of hydro power production is financed by the State and by the power industry.

The Agency is financing research through two programmes: *Water turbine technology* and *Hydro power - environmental effects, measures and costs for already developed rivers*. The objectives of the first programme include the development of water turbines with high efficiencies and good part-load characteristics, enabling their outputs to be varied while maintaining good efficiency. The second programme considers the various rivers individually, to provide a technical and economic evaluation of various ways in which desirable objectives in respect of the natural environment can be achieved.

The initiative to the hydro power turbines programme was taken by the power industry some years ago, acting through ELFORSK[46]. The Swedish Energy Agency (in its earlier conception as the National Board for Industrial and Technical Development, NUTEK) prepared a draft for a research programme in conjunction with the other parties. The first stage was started in 1996, with a total budget of SEK 14.5 million. The work was extended in the summer of 1999, with

[46] The joint research body of the Swedish power industry.

a total budget of SEK 20.5 million and a planned conclusion date at the end of 2002. The strategy is to finance the training of PhD candidates, to ensure the maintenance of fundamental and higher education in the field of water turbine technology at the institutes of technology. The overall objectives of the programme are to:

- ensure that it will be possible further to develop the use of hydro power production as a renewable energy source, and to meet future requirements in respect of environmental impact and general efficacy, *and*
- to ensure that, in the long term, both the power utilities and the manufacturing industries can obtain the personnel that they need with skills in the water turbine field.

An important part of the work is practical verification of theoretical work and models in experimental and pilot plants. As numerical simulation is regarded as being an important future tool in the field of flow mechanics, long-term work is concentrated on developing suitable numerical methods of doing this. The *Hydro power - environmental effects, measures and costs for already developed rivers* joint research programme, which is at present in its first stage, is financed jointly by the Swedish Energy Agency, the National Board of Fisheries and ELFORSK, with participation by the Environmental Protection Agency. The overall objectives of the programme are:

- to develop a common scientific basis for assessing the environmental impact of hydro power production, *and*
- to ensure that it will still be possible to operate hydro power production effectively after meeting national environmental quality objectives and directives in respect of water quality, fishing, ecological function, biological diversity and genetic variation.

The work involves testing hypotheses and theoretical work in experimental and pilot installations, as well as in natural waters. It is also important to increase the expertise of the research institutions, and to encourage cooperation between research institutions, companies and groups of scientists, both nationally and internationally. To this end, a network of research groups involved will be established.

4.4 Wind power

The knowledge pool and commercial maturity

- Wind power is the energy source that, in the short term, is forecast to increase the most rapidly in Sweden.
- The new Swedish 'Windformer' generator design is expected to have a considerable effect on the wind power industry.
- The major barriers in the way of further wind power development in Sweden are cost, the country's power balance and matters relating to planning and siting permission. Technical developments in recent years have reduced costs.

The national and international markets are expanding rapidly, and are regarded as continuing to do so, partly due to the need to meet climate objectives. However, a decisive factor in future development is the extent to which costs can be reduced. The technical potential for wind power production in Sweden is considerable: the Agency has recently suggested 10 TWh over a period of 10-15 years (see also Section 7.2) as a planning objective.

Expertise in wind power exists at a number of departments in institutes of technology and universities, in companies in the wind power manufacturing industry and in wind power development companies. Swedish technology in this field is among the most advanced in the world. The country is also among the leaders in offshore wind power technology, with the world's first offshore wind power unit in production.

Important research results include development, through aerodynamic research, of blade profiles now used by commercial manufacturers of wind power units. The unique Swedish design concept of light, structurally flexible units has been developed as a result of intensive cooperation between Swedish research groups.

Wind power production is becoming increasingly large-scale, both in terms of individual power units and of entire wind farms. While other countries previously concentrated on small-scale wind power units, Sweden concentrated instead on the development of large units with outputs of 1 MW and up, although this has not yet resulted in any commercial products. However, the work has resulted in a substantial accumulation of knowledge over a long period of time, which may well be decisive when large-scale technology is commercially introduced.

The investment costs of wind power are still far too high for the technology to make a breakthrough in its own rights in any EU country, and so some form of support is essential. This can be provided in the form of tax relief, investment grants or operating subsidies, or as market-based guide measures such as green certificates (see Section 7.1).

Barriers in the way of more widespread use

Conventional electricity production needs to be replaced by production from renewable sources with less environmental impact. However, there is little economic incentive at present for building new electricity production capacity in Sweden. The economic support system is currently under review: uncertainties concerning the future economic situation constitute a real obstacle to investment.

Another obstacle is presented by the general question of acceptance of such plant, and thus also of planning and siting permission. Even though in favour of wind power as a principle, individuals tend to be opposed to the siting of actual plants close to their homes. Wind power farms occupy considerable areas, although the land between the individual units can be used for some purposes. Conflicting interests, such as recreational objectives in coastal areas, can stand in the way of wind power expansion.

Planning and siting considerations are extremely important for those attempting to establish wind power plants. Costs in this connection, such as property tax and fees associated with the planning application, can also constitute barriers. Nevertheless, contacts between those involved in wind power and the authorities granting permission for its construction and operation are essential as part of the planning process, and so a functional network between the wind power sector and the authorities should be aimed at. At present, the general impression is that the industry and the authorities are not talking the same language.

The biggest technical barriers in the way of large-scale wind power production are the country's grid and the power balance. The grid is often weak in areas where wind conditions are most favourable for wind power plants, i.e. along the coasts and offshore. Developing a large wind farm may require the grid in the area to be reinforced or extended. There is also uncertainty as to how much wind power the Swedish system can absorb without running the risk of power shortage at times.

Current research and development

Swedish work has recently resulted in a technical advance in design, known as the Windformer™, which is expected to have a considerable impact. It enables the output from wind power generators to be connected directly to the high-voltage grid, without the need for a generator transformer. This reduces costs and increases efficiency.

Research for the wind power programme is of fundamental character, and is entirely financed by the Agency, although some sub-projects are partly financed by companies and by EU funding.

Working primarily with the power industry and the wind power industry, the Agency is also jointly financing a number of research and demonstration projects aimed at facilitating the establishment of wind power production. This is of importance for the power industry in order to assist it in dealing with future investments in wind power. The demonstration projects are being partly financed (to varying extents) by the Agency, depending on the development content of the various projects. However, the proportion of the costs of demonstration projects met by such grants is generally 25 percent.

4.5 Solar cells

Solar cells present major environmental benefits, as they use only sunlight as their energy input and produce no emissions at all. With no moving parts, they are also completely silent. Long life, with low maintenance costs, are other benefits associated with the use of solar cells for electricity production.

- Today, the energy contribution of solar cells to Sweden's electricity production is insignificant, but the market for them is growing steadily.
- The Ångström Solar Centre at Uppsala is a successful centre of research into solar cells. The Centre holds the world record for the efficiency of a CIGS solar cell module[1].
- Cost is at present the major obstacle in the way of a breakthrough for solar electricity, apart from applications in areas where conventional electricity supply is impractical.

The knowledge pool and commercial maturity

Today, the energy contribution of solar cells to Sweden's electricity production is insignificant, but the market for them is growing steadily. World solar cell production in 1999 amount to a total peak output power of 168 MW, as compared to 126 MW in 1998.

Sweden has a small but growing market for standalone solar electricity systems, such as for beacons, on boats and in caravans, i.e. where energy supply by more conventional technology is infeasible for practical or economic reasons. So far, almost all the solar cell systems in the country are of standalone type, i.e. not connected to the normal electricity supply system in any way. The technical potential for solar electricity in Sweden is 5-10 TWh/year, without extra costs for energy storage, as hydro power would be used as the buffer.

The market is waiting for thin-film solar cells to become cheaper and more effective, and to have higher efficiencies than those of the conventional silicon solar cells, which are the type mainly used today. Sweden has a sound core of knowledge, with its practitioners linked by an excellent network, thus facilitating the prospects for future commercialisation of solar cells. Research into the subject is at a number of levels: that into nanocrystalline solar cells is at present at the fundamental stage, while research into thin-film solar cells is approaching the stage of developing manufacturing processes and commercialisation. Researchers at the Ångström Solar Centre at Uppsala at present hold the world record in terms of efficiency of a thin-film module using CIGS cells.

It is unlikely that solar cells will account for any larger proportion of Swedish energy supply in future, although they will, in conjunction with wind power and hydro power, form a low-environmental-impact alternative for which there is an increasing demand.

Barriers in the way of more widespread use

By far the greatest obstacle in the way of the introduction of solar cells at present is cost. Costs would have to be reduced by a factor of ten before solar electricity even begins to become competitive with other energy sources.

Solar cells require large areas in order to generate useful quantities of electricity. As far as Sweden is concerned, this is not a particularly serious limitation, as cells could be integrated into existing buildings. The advantage of such cells, as opposed to wind and hydro power, is that they can be mounted on or integrated into existing or new buildings, thus bringing them close to the point of use of their electricity. Research includes work aimed at finding effective applications for the utilisation of the cells' features.

Greater cooperation is needed between installers, building contractors and architects in order to facilitate the introduction of solar cells and improve awareness of them for application in buildings.

Current research and development

Solar cell technology as such is proven and reliable: research is now concentrated on finding materials and methods that can open the way to large-scale economically competitive production.

Swedish research into solar electricity is today concentrated in two large research programmes. *SolEl 00-02*, which is a three-year research programme, is investigating the feasibility of using solar cells in the existing electricity system on reasonable economic terms. In addition, work is in progress aimed at determining what development is needed in order to improve the prospects for solar cells to play a part in Swedish electricity production. The work includes analysis of the environmental impacts of various solar cell technologies, looking at the processes of obtaining the raw materials, transport, production technology, recycling and disposal. A number of experiments are also in progress concerning cathodic corrosion protection of power line pylons, with the necessary current being supplied by solar cells. The *Solar Cells in Buildings* working area is concentrated on competence development and information dissemination to the building industry and architects. As far as installation is concerned, the use of reflectors is an interesting approach to increasing installation per unit of solar cell area, and thus reducing the total energy production cost. The Swedish programmes include international cooperation via the International Energy Agency (IEA).

Work at the Ångström Solar Centre in Uppsala includes research into thin-film solar cells, nanocrystalline solar cells and 'smart windows'. The Ångström Solar Centre is a research organisation that is financed in equal parts by the Swedish Energy Agency and by MISTRA[47], and is now in its second period of research, which will continue until the end of 2004.

As far as thin-film technology is concerned, the emphasis is on developing processes for large-scale manufacture of cheap thin-film-based solar cells. This includes research and development of CIGS thin-film solar cells. These are cells having a high efficiency, but for which the technology of large-scale manufacture is still not known. The objective is to develop a production technology that can produce cells at a cost not exceeding SEK 700/m². With a 14 percent efficiency, this would mean that the specific cost of the cells would be SEK 5 per watt, which is about 5-6 times lower than the cost of electricity from present-day silicon cells. It is felt that it should be possible to achieve this objective within a ten-year period.

As far as nanocrystalline solar cells (NSC) are concerned, research is mainly at the fundamental stage. These cells can be manufactured very simply in the laboratory, which indicates that prospects should be good for future large-scale production of cheap solar cells. Research into NSC started about ten years ago, when it was found that certain metal oxide films became good electrical conductors when in contact with an electrolyte. The performance of the metal oxide as a solar cell can be improved by applying a colour film to the surface to improve absorption of sunlight.

Work on 'smart windows' at present involves windows of which the transparency can be varied by application of an electric voltage. The objective of the work is to develop windows with excellent optical properties and good long-term stability.

[47] The Swedish Foundation for Strategic Environmental Research.

It is important that the application and integration of solar cells should be demonstrated in connection with new building and renovation work in order to win acceptance for them and to create a demand.

4.6 Fuel-based electricity and heat production

Today, energy industries[48] accounts for about 19 percent of Sweden's energy use and about 21 percent of its carbon dioxide emissions. Greater use of biofuels is an important element of the country's climate work. Such fuels are already used for small-scale heating, district heating, CHP and in industry, primarily for process requirements in the forest products industry. Research and development of hydrogen-based systems is a complementary strategy for future climate work.

- Biofuels, peat etc. provide 93 TWh, or about 15 %, of Sweden's energy supply (or nearly 20 % if the heat losses in the country's nuclear power stations are not considered in the equation).
- Within 20 years, about 130 - 150 TWh can be a realistic biofuel potential.
- No value is today credited for the carbon dioxide neutrality of electricity production from biofuels, which acts as a brake on expansion of their use.

The knowledge pool and commercial maturity

Biofuels have been available on the market for a long time, although systems have been greatly developed and improved over the last 20 years or so. They are used primarily for heating purposes and in the forest products industry. In the latter, it is the use of by-products from sawmills and the pulp and paper industry that dominate, although the use of felling residues and thinnings from forestry is increasing. There is a considerable technically and ecologically available, but unused, potential in primary forest fuels at a reasonable cost. The supply of about 130-150 TWh from biofuels within 20 years is a realistic potential[49], which would represent an increase of about 50 percent over the present-day level. In the longer-term, intensive cultivation of forests could provide further fuel. The technology of packaging felling residues into large bales reduces requirements for load transfer during transport and cuts costs: the method is close to market establishment. Cultivated biofuels, primarily from *Salix* energy forests, are in process of market introduction. The country possesses fundamental knowledge of the cultivation of energy crops and for extracting forest fuels in an environmentally responsible manner. Ecologically sustainable abstraction of felling residues requires that appropriate nutrients, e.g. ash, should be returned to

[48] Power production, CHP´s and refineries.
[49] Statistics from Swedish Energy Agency to the Swedish Climate Strategy Commission, SOU 2000:23.

the forest. Methods of returning the ash have been demonstrated, but cannot yet be regarded as routine.

Combustion of refuse is expected to increase, as combustible refuse may not be disposed of in landfill after 2002, with a corresponding ban on the disposal of organic refuse after 2005. Refuse consists largely of biomass, which means that its use as a fuel results in a low net emission of carbon dioxide, but its incineration can have other undesirable environmental effects. Refuse incineration presents a potential of about 16 TWh, complemented by about 5-6 TWh for the production of biogas. This gas is suitable for use as a motor fuel.

Transport costs make up a significant proportion of the total costs of biofuels. New methods of handling and transporting felling residues can radically reduce reloading and transport costs.

Sweden is well to the fore in the use of CHP. Steam and gas turbines are the main prime movers, with the steam turbines fuelled by biofuels, refuse and coal, and the gas turbines fuelled by natural gas. Boiler technologies for the steam turbines are circulating fluidised beds (CFB), bubbling fluidised beds (BFB) and grate boilers.

The following are the main technologies that can be expected to be commercialised by 2010:

Evaporative gas turbines. The mechanical output of gas turbines (and thus the amount of electricity produced by the generator driven by the turbine) can be increased by raising the humidity of the combustion air and then recovering energy from the hot exhaust gases, which also has the beneficial effect of reducing NO_x emissions. Sweden has an experimental pilot installation of such a turbine (600 kW) in Lund, fuelled by natural gas, and has come a long way in development of the process. In the longer term, it should be possible to use biofuels, mainly with indirectly fired gas turbines.
Bio-integrated gas turbine combined cycle with gasification (Bio-IGCC). The output efficiency of a combined cycle can be increased, relative to that of conventional technology, by using thermally gasified biofuel. Sweden and Finland are leading countries in the development of biofuel gasification. A unique gasification plant, with an output of 6 MW_e, is operating in Värnamo.
Indirectly fired gas turbines and Sterling engines. Solid fuels are burnt in a solid fuel boiler, with the heat being transferred to the gas turbine's (or the Sterling engine's) working medium through a heat exchanger. External firing reduces the risk of pollution or particles from the fuel damaging the turbine, which is otherwise a problem with solid fuels. Indirect firing using biofuels can become an interesting application area in Sweden. The process requires development of high-temperature heat exchangers.

Microturbines are gas turbines with outputs in the 30-200 kW_e range, for embedded electricity production[50] and small-scale CHP. The technology has been demonstrated in Gothenburg for CHP, using natural gas as a fuel. As gas turbines of this size are also of interest to the automotive industry, it is expected that such turbines will have been developed and be commercially available for small-scale CHP production by 2010. This is an area in which Sweden is well to the fore, although development will be dependent on extension of the country's natural gas distribution system. Further development for firing of such turbines by biofuels is of interest.

If hydrogen can be produced by artificial photosynthesis in a renewable and competitive manner, it will have an extremely large potential market, e.g. for use in fuel cells. It is estimated that demonstration plants should have been built in about 15-20 years, followed by market establishment in about 20-25 years.

Stationary fuel cells have important environmental advantages, and development of them is proceeding rapidly. The international market in fuel cells is expected to grow over the next few years, in step with falling costs. Although there are demonstration installations in many countries, actual operating experience is limited. It is expected that the costs of fuel cells based on polymer electrolytes should be about SEK 22 000/kW in 2010, producing energy for a cost of about 450-600 SEK/MWh. It is expected that, by 2020, the costs should have fallen to about SEK 2000/kW.

Barriers in the way of more widespread use

Much of the costs for collecting biofuels from felling residues is made up of the costs for gathering the fuel, chipping it and transporting it. Biofuels also have a lower energy density than have fossil fuels, which makes them bulky. Indigenous biofuels face competition from imported wood fuels and recovered wood. Competition between biofuels from one region to another can also constitute an obstacle to wider use.

Barriers in the way of more widespread use of bioenergy include its poor competitiveness in a deregulated electricity market, a lack of harmonisation of taxation and environmental levies within the EU and the fact that the environmental effects of various fuels are not fully reflected in their prices. No value, for example, is attached to the fact that electricity production from such fuels is carbon dioxide-neutral, which is an obstacle in the way of its expansion. Uncertainty concerning future taxation regulations hampers the will to invest in capital-intensive plant.

[50] Embedded electricity production refers to siting close to the load, with only short distances between producers and consumers.

Barriers in the way of small-scale bioenergy include insufficient development of reliable systems providing high levels of comfort for small users. The sector consists of small manufacturers, with only limited economic resources to invest in development. There is no developed infrastructure for supplying fuel to somewhat larger plants, with outputs of a few hundred kW, which also constitutes a brake on their introduction. Older small-scale biofuelled boilers often have high emissions of health-hazardous substances such as particles and VOCs etc., which has resulted in restriction on log firing in a number of urban areas.

In the case of fuel cells, it is high costs that are at present preventing larger-scale production.

Current research and development

Research in progress at present is aimed at improving the entire biofuel chain, from production, ecology, handling, transport and possible upgrade processing, to energy conversion and the most efficient utilisation of the energy. Research into the ecological, economic and technical factors associated with the production of forest fuels, including the return of ash, energy forests and energy plantations, as well as intensively cultivated forests, is intended to quantify the practical potential of biofuels. Long-term effects are being monitored, and methods of harvesting, transport, preparation and processing of the fuels are steadily being developed. New technologies, aimed at improving the environmental conditions and costs in the refuse incineration and biogas sector need to be developed and demonstrated.

We need a better understanding of how to make optimum use of bioenergy, including refuse, in terms of its cost and resource efficiency, when set against society's need of alternative forms of energy. This requires system analyses and life cycle assessments.

The Agency is operating several research and development programmes aimed at developing biofuel technologies for electricity and heat production, with higher efficiencies, reduced environmental impact and, in the long term, at competitive cost levels. Special effort is being devoted to reducing emissions of health-hazardous substances from small-scale combustion. Materials and systems are being developed for boilers for steam turbines, aimed at reducing superheater corrosion and raising steam data in order to improve overall process efficiency. In the field of power production from natural gas, it is gas turbines that are at the centre of research attention.

Sweden is conducting fundamental research into a process for producing hydrogen by artificial photosynthesis, with the aim of being able to produce hydrogen from water and sunlight. The basic idea is to produce a molecular complex, coupled to an electron acceptor, which can 'crack' water under the influence of light and which, when connected to a platinum-based system, can produce hydrogen. Light-induced electron transport has now been demonstrated. Swedish research in this area is at the leading edge of international work, and is expected to move on to the applied phase in 5-10 years.

Research into stationary fuel cells, aiming at commercial applications such as operational optimisation, the properties of materials, improved performance, operating characteristics for varying conditions, different types of fuels, application areas, reliability etc. is being conducted in close conjunction with industry. Research into solid oxide fuel cells, for use in larger stationary installations, is concentrating on the feasibility of linking the cells to a gas turbine, thus increasing efficiency, and on other ways of obtaining more energy. Research into molten carbonate fuel cells, for use in smaller installations, is concentrated on materials aspects in order to improve performance and extend life. The emphasis of research into fuel cells based on polymer electrolytes (PEFC) is on small-scale CHP production.

Relationship between carbon sinks and biofuels in climate work

Forests, forest biomass and forest management can contribute to climate work in three different ways:

Sustainable use of biofuels for **replacing fossil fuels**. In principle, systems involving the replacement of fossil fuels by biofuels are climate-neutral. A limiting factor on this particular sustainable system is the capacity of annual biofuel production.

Carbon storage can take place in biomass and in organic materials in the ground. At present, changing land use patterns, particularly in tropical forests, is resulting in a net emission of carbon dioxide to the atmosphere. On the other hand, the boreal forests are producing a net binding of carbon, thus acting as a global carbon sink. The high net uptake of carbon in the boreal forests is due not only to good forest management but also to indirect effects such as nutrient supplies in the form of elevated deposition of nitrogen from the atmosphere and to the fact that the higher atmospheric carbon dioxide concentration increases photosynthesis. Although the sink capacity for carbon in forests is substantial, decisive factors for how long such storage of carbon can continue depend on elements such as ground treatment, forest management and other aspects. However, it seems likely that carbon can continue to accumulate in forests for about 100 years, and for considerably longer in the ground. There is therefore reason to care properly for these carbon sinks and, if possible, to increase their rate of uptake. On the other hand, unsuitable use of land, or unsuitable forest management, can result in the release of absorbed carbon as carbon dioxide or other greenhouse gases.

Avoiding usages that increase emissions of greenhouse gases. It is important to understand what processes control the accumulation and breakdown of the large quantities of carbon stored in various forms in the ground. Scarification and ditching are examples of activities that encourage the breakdown of organic materials and the production of carbon dioxide. Under certain conditions, nitrogen chemistry processes in the ground can result in the production of nitrous oxide, while saturated ground can produce methane.

Chapter 5 describes research into the carbon cycle of forests. There are differences in principle between carbon sinks and the replacement of fossil fuels. A combination of measures, resulting in the replacement of fossil fuels by biomass, and accompanied at the same time by an increase in the amount of carbon stored in biological sinks, seems to be optimum. An example of such a strategy is that of forest management, intended to increase the amount of carbon absorbed in biomass and in the ground, coupled with simultaneous use of felling residues to replace fossil fuels. However, it will not be possible indefinitely to increase the amount of carbon stored in biological materials.

The high net uptake of carbon dioxide in Swedish forests is probably due partly to good forest management and to a high nutrient input, primarily in the form of NO_x precipitation. Looking after and, if possible, increasing the uptake of carbon in Swedish forests is a complement to other Swedish strategy in the climate field, aimed at reducing the use of fossil fuels. It is just as important to take all effective steps that can contribute to the reduction of the carbon dioxide concentration in the atmosphere.

4.7 Industry

Today, Swedish manufacturing industry accounts for about 31 percent of the country's energy use and about 23 percent of its carbon dioxide emissions (disregarding process emissions in industry). Process industries - i.e. the pulp and paper industry, the iron and steel industry and the chemical industry - use about two-thirds of industry's total energy use. The consumption of coal and oil has decreased, but the use of electricity has increased. Improving the efficiency of energy use in
industry is a continuous process, advancing by a multiplicity of small steps. Technical development to reduce the effects on climate is an important task. Swedish efforts cover the entire range of work, from purely fundamental research

- Research cooperation between industry and academia is assisted by prototype and demonstration projects.
- The greatest obstacle in the way of the introduction of new technology in industry is industry's fear of economic loss in the event of a loss of production.

to ultimate market introduction, via development work at institutes of technology, universities and within companies.

Unit processes in industry

Industrial unit processes consist of the strategically important and energy-demanding process steps within various manufacturing processes, such as blast furnaces in the steel industry and digesters in the pulp industry. Apart from industry itself, the Swedish Energy Agency is the single largest financer of energy-related development in industry. An important part of the Agency's work is to identify important process stages and/or unit processes for future efficiency improvements.

The knowledge pool and commercial maturity

With its highly developed process and environmental technologies, the Swedish pulp and paper industry is among the leading industries in this sector in the world. Black liquor gasification is a new, interesting technology in sulphate pulp production, with the first commercial installation estimated to be on-line in 2010. As far as process integration is concerned, various optimisation tools for energy efficiency improvements are being developed, and it is estimated that process integration will be partly integrated in industry by 2020.

Development of the membrane method for chlorine production for bleaching is driven mainly by environmental pressure: an international agreement has set 2010 as the date by which the mercury method must have been replaced by less environmentally harmful production. The membrane filter method is regarded as having replaced the mercury method by 2010.

A method of high-temperature combustion for more energy-efficient furnaces is being tested at present in an experimental furnace at the Royal Institute of Technology in Stockholm. The technology is aimed mainly at the iron and steel industry, but can also be of value to other industry sectors. The process is already in use in a large number of soaking furnaces in the Japanese iron and steel industry.

The Swedish Foundry Association is operating a group of projects aimed at spreading awareness of energy-efficient casting methods. It is estimated that these methods will be more widely applied by 2010, and have become relatively common in Sweden by 2020.

Barriers in the way of more widespread use

Although there is increasing pressure within the industry for short-term profitability, it is difficult to develop and test new technologies in the sensitive manufacturing processes. Apart from black liquor gasification, this means that it is unlikely that any new major technology breakthroughs can be expected.

Current research and development

The joint industry-specific research and development work carried out in universities and institutes of technology, as well as by the various industry research associations, plays an important part in the joint work. IEA provides an important network enabling the Agency to monitor international developments.

Impulse drying to reduce the amount of energy used in making paper is an important area of development in the energy-intensive paper industry. The lead in developing energy-efficient knowledge for the foundry industry is taken by Japan: Europe lacks specialised sector knowledge of these casting technologies.

Much joint work is being carried out between the Scandinavian countries in both the cellulose and the steel industries. MISTRA's *Closed-cycle Pulp Mill* and *Closed-cycle Process Flows* programmes constitute an area of particular interest in the pulp and paper industry. The Swedish Steel Producers' Association occupies a special position in the steel industry in terms of coordination of research.

The Agency is operating the *Process Integration* research programme, aimed at developing methods for the design and modification of industrial processes in order to reduce their investment and running costs. The provision of support for pilot projects operated by sector research institutes is important in order to support technical development in heavy industry. Support is provided for research and development through cooperation with organisations such as the Forest Industry Technical Research Institute (STFI) and the Metallurgical Research Foundation (MEFOS). The Agency also supports the Swedish Steel Producers' Association in its research and development work for the iron and steel industry. Working with the Agency, the Swedish Foundry Association has developed a package of programmes for energy-related research and development. The chlorine/alkali production process using membrane technology is an example of development in the chemical industry: today, it is the mercury method that is most widely used in Europe.

Industrial ancillary systems

Major energy savings can be made in industrial ancillary systems: it is estimated that at least two-thirds of the electrical energy used in industry in Sweden is for powering ancillary systems such as fans, pumps, air compressors and lighting. In addition to carrying out research and development work to refine knowledge of products and systems, the strategy includes creating a demand for more energy-efficient ancillary systems. Information on newly developed technology in this sector is important, as there is such a large number of user groups. Supporting development of EU marking and classification systems is also important, in order to help purchasers to appreciate the value of energy efficiency.

The knowledge pool and commercial maturity

Knowledge levels in Sweden relating to industrial ancillary systems are relatively high in the technical universities and institutes of technology. There are also a number of Swedish industrial companies, such as ABB Motors and Atlas Copco, that compete on the international market with their energy-efficient products. However, the costs of metering energy demand and identifying weak points are still high, although developments within the IT sector are helping to bring down costs of metering energy use.

Barriers in the way of more widespread use

Most industrial ancillary systems can be regarded as mature technology. Although awareness of the importance of energy efficiency within industrial companies is generally good, there are some parts of industry that lack the necessary knowledge. Perhaps the most important barrier to more efficient energy use is industry's concentration on production and fear of upsetting working processes. In addition, ancillary processes and systems are not regarded as mainstream elements of industry, which reduces the motivation to invest in new technology. Further, as the user group is so large and heterogeneous, it is also difficult to reach out into every corner and disseminate information on new technology. It can also be difficult and expensive to determine exactly where efficiency improvements can best be set in, e.g. in pumping systems with poor energy efficiency. However, new IT technology can substantially reduce the costs of the necessary measurements.

Current research and development

IEA and the European Union are driving forces behind the technical development of ancillary systems and spreading awareness of the developments. New technology is very close to commercial market introduction, with most development being close to introduction. Industry replaces equipment continuously, and it is felt that much of it should have been replaced by 2010-2020.

4.8 Transport

In 1999, domestic transport accounted for about 20 percent of the country's energy use, but produced about 38 percent of its carbon dioxide emissions. Developments in electric and hybrid electric vehicles are expected to result in higher efficiencies and reduce emissions. Such vehicles will make it possible to use power sources such as fuel cells, the fuel for which can be either fossil or bio-based. As far as reducing emissions from long-distance road transport, development of bio motor fuels is the best way forward. The Agency also provides grants for demonstration projects aimed at improving the energy efficiency of goods transport by rail and water in order to reduce the country's carbon dioxide emissions from road transport.

- Research is concentrated on developing biobased motor fuels to the point that they can make a significant contribution to the supply of such fuels.
- To achieve a meaningful reduction in carbon dioxide emissions will require a substantial improvement in the energy efficiency of vehicles, and greater use of electric and hybrid vehicle technologies.
- The greatest obstacles in the way of wider use of motor fuels made from cellulose raw materials are the present production costs of such fuels and the high-energy losses in converting the cellulose raw materials into motor fuels.

Production of bio-based motor fuels

The knowledge pool and commercial maturity

In the field of ethanol production, research and development in Sweden is spread among about a dozen institutions, with much of the work being carried out by the Lund Institute of Technology. There is only little research and development in the field of gasification and production of methanol, dimethylether, bioparaffin and bioalkylate. Biogas is already used to some extent as a motor fuel, mainly for goods and passenger transport[51] in central and southern Sweden.

A first pilot plant for ethanol production may soon be built in Örnsköldsvik, based on the production of ethanol from cellulose, and followed by a demonstration facility a few years later. There are plans to build a facility for the production of bio-based methanol, or a pilot plant for dimethylether (DME): manufacturing facilities for RME already exist. It is forecast that the demand for liquid bio-based motor fuels will increase over the next ten years: the demand for methanol is also expected to increase in parallel with an increase in the use of fuel

[51] See also the section on fuel-based energy production.

cells. DME can replace diesel fuel, although some further development is still needed.

Barriers in the way of more widespread use

The main obstacle in the way of more widespread use of bio-based motor fuels is their high cost of production. Other barriers are presented by the lack of interested industrial parties and the lack of, or competition for, appropriate input raw materials. Another obstacle at present is presented by the high energy losses in converting cellulose to a motor fuel: the unavoidable use of an energy input from fossil sources reduces the overall efficiency. Higher process yields and lower prices would permit raw materials to be provided from a wider area, which would in turn increase the raw material potential.

Current research and development

The Agency has started a working programme with the objective of constructing a pilot installation for gasification of forest raw materials and associated production of bio-based motor fuels. There are at present no direct platforms for joint work on gasification aimed at the production of motor fuels such as methanol, dimethylether, bioparaffin or bioalkylate.

Extensive research activities have been carried out over many years within the framework of IEA and other parties. There are joint projects in areas such as the production of ethanol from lignocellulose, the introduction of liquid bio-based motor fuels, the use of bio-based diesel fuel, oxygenates for diesel fuel, the production and use of DME, bio-based lubricants and the production of biogas for powering vehicles. A joint Swedish project with the Department of Energy/ National Renewable Energy Laboratory (NREL) in the USA has also been established within IEA.

Combustion engines

The Agency provides research grants to assist the postgraduate training of PhD students and to develop knowledge in the field of combustion engines through its existing *Energy Systems in Road Vehicles* programme. Much of the programme budget for the 'Green Vehicle' project will be applied to research and development of more energy-efficient combustion engines.

The knowledge pool and commercial maturity

Sweden at present possesses good expertise in the fields of supercharged engines (turbocharged, variable compression) and in the diesel sector. The EU Fifth Framework Programme includes development of combustion engines. Sweden is also a member of the IEA *Energy Conservation and Emissions Reduction in Combustion* implementing agreement, relating to combustion engines in both stationary and traction applications.

Industry and the institutes of technology are carrying out joint research at centres of excellence for combustion technology, catalysts and high-temperature corrosion at Chalmers University of Technology, and in the field of combustion processes at the University of Lund.

Barriers in the way of more widespread use

There are no coordinated national or international guide measures to reduce carbon dioxide emissions from road traffic. Fuel cells are regarded as being more energy-efficient than present combustion engines, which is sometimes cited as a reason for not concentrating on development of combustion engines, although this in turn would harm the long-term recruitment of university students in the subject. In addition, uncertainties as to which alternative fuels might make a breakthrough make it difficult for the vehicle manufacturers to concentrate development on suitable engines.

Current research and development

Present levels of expertise in Sweden on combustion engines can be regarded as high. The automotive industry in Sweden is a leader in the research and development of diesel and Otto cycle engines, and is thus in a good position to influence global development. In future, an important area of new technology will be to bring together combustion engine and electrical technology into the design of hybrid vehicles.

In new, conventional vehicles, powered only by combustion engines, fuel consumption over a given distance is forecast as falling by 20-30 percent over the next ten years. It is forecast that, in a later stage, research will be concentrated on various types of hybrid vehicles (i.e. having combustion engines and electric motors), the fuel consumption of which should be reduced by 30-50 percent over a ten-year period. New types of combustion engines made for use in hybrid vehicles may appear within 20 years. The total potential for fuel saving is estimated as about 60-70 percent: it should also be possible to achieve this saving for fuel cell vehicles.

The 'Green Vehicle' project is a recently started joint programme between the Swedish automotive industry and the State. Running for six years, and with a total budget of SEK 1800 million, it will support the development of vehicles with reduced environmental impact. The State is providing SEK 500 million, and the automotive industry is providing the rest. In addition to the vehicle manufacturers, the other parties in the programme are the Swedish Energy Agency, the Strategic Research Foundation (SSF) and the Technology and

Natural Science Research Council [52]. The objective of the programme is not only to develop vehicles with less environmental impact, but also to improve the competitiveness of the Swedish automotive industry. Priority areas within the programme include the development of more fuel-efficient engines, engines for use with new fuels and hybrid operation, and other measures intended to reduce the fuel consumption of vehicles.

Electrical drive systems

The Agency's input in this field is important for the development and expertise enhancement of the Swedish industry. There are a number of larger joint research and development projects being carried out between industry, universities and the State for demonstration of electrical transmission technology. The Agency's concluded *Electrical and Hybrid Vehicle Technology* programme, together with the current *Energy Systems in Road Vehicles* programme, has assisted the consolidation of expertise in Sweden. The *Energy Systems in Road Vehicles* programme includes working areas such as electrical, hybrid and fuel cell technology, as well as vehicle ancillary systems.

The knowledge pool and commercial maturity

Today, knowledge of electrical and hybrid vehicles is poor, and the market requires major information campaigns. The Agency has pushed the development of electric vehicles forward through such means as its technology procurement projects for electric vehicles. At present, work on improving knowledge of electrical vehicle transmission technologies is being carried out mainly outside Sweden.

The market would like to see both lighter and heavier hybrid vehicles for urban distribution duties. In the case of hybrid passenger cars, the market introduction can be managed by normal fully commercial methods. It is forecast that hybrid vehicle technology will be familiar on the market by 2010, with 2020 being the date for market establishment of heavy hybrid vehicles (i.e. buses and trucks etc.).

Barriers in the way of more widespread use

Research and development work should be concentrated on finding new niche applications for Swedish automotive-related industries. More demonstration projects are needed in order to bring down system and component costs, particularly for electric vehicles. Work on such areas as battery technology,

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[52] The above parties were those involved prior to the 2001 reorganisation of research bodies in Sweden.

together with the establishment of an infrastructure for rapid charging of batteries, will increase application areas for such vehicles.

Current research and development

Automotive development is highly internationalised, with Japanese vehicle manufacturers being in the lead of development of lightweight hybrid vehicles. The European automotive industry is today investing considerable sums in the development of hybrid and fuel cell technologies, based on the use of hydrogen as the energy carrier. Fuel cells of the proton exchange membrane (PEM) type are the main areas of development, although work has also been carried out on direct methanol fuel cells, using methanol as their energy source. It is forecast that commercially available vehicles should be on the market by 2003-2004.

Sweden should invest more resources in building up system expertise through practical application of research results from various demonstration projects. A number of demonstration bus fleets should be in operation in several towns and cities by 2010.

4.9 Buildings

The built environment accounts for over 40 percent of Swedish energy use and 50 percent of its electricity use. In 1999, individual space heating of residential buildings and commercial premises (including energy use for domestic hot water production) accounted for 17 percent of Sweden's carbon dioxide emissions. At the same time, building stock represents the country's largest real capital investment, with a replacement value for properties and plant of about SEK 6000 x 10^9. Statistics from 1995 show that there were about 2.3 million apartments in apartment buildings (150 million m^2), and about 1.9 million dwelling units in detached houses (230 million m^2). To this must be added about 70 million m^2 of commercial premises, 85 million m^2 of public buildings and about 115 million m^2 of industrial premises. In terms of occupation density, Sweden is among the lowest in Europe with about 2.1 persons per dwelling unit.

The construction market reached a peak in the 1960s, when more than 100 000 apartments per year were bring built as part of the Million New Homes project. Investment in construction has declined since then, so that it accounted for about 7 percent of GNP in 1996, as against 18 percent in 1967.

Unfortunately, due to the present low rate of new construction work, energy efficiency improvement and energy conservation measures in new buildings are having very little effect. Energy conservation work in connection with renovation and rebuilding is therefore important, but as this, too, is at present at a low level, the efficiency improvement measures must be such as can be applied in connection with normal maintenance work.

New commercial technology in the sector has considerable potential, e.g. newly built houses that use only 8000 kWh/year, as compared with the current 14 000 kWh/year, which is an average figure for today's typical houses. However, there is low turnover in terms of replacing old houses with new ones. Further opportunities are available in many sectors, with research and development in progress.

Lighting and ventilation, which at the beginning of the 1990s accounted for about 70 percent of the electricity used in building services systems, have become more efficient through the development of improved light sources, more accurately designed systems in terms of capacities and improved operational control. However, it is felt that there is still considerable scope for further improvement: using present-day technology, it should be possible to reduce the amount of energy used for ventilation to half, i.e. to 5 TWh/year. Current development of new technology has the potential further to reduce consumption, to a level of about 3-4 TWh/year.

Light sources today use about 14 TWh/year of electricity, offering considerable potential for efficiency improvement, e.g. through the use of light-emitting diodes (LEDs). However, this is still a young technology, with the potential depending on possible technical breakthroughs and on prices.

Heating, cooling and climate screens

The knowledge pool and commercial maturity

The State supports research and development in the field of **improving the efficiency of energy use**, primarily by further development of known and proven building systems and building services systems, together with the development of new materials, components, methods and systems. Increasing importance is being attached to the needs of users when designing energy efficiency features in a building.

Long-term support for research and development of energy use in buildings covers a wide area, such as solar heating, district heating, heat pumps and small-scale biofuel applications.

Backed by many years' experience of **solar heating**, Sweden possesses excellent knowledge and experience in this field. There is also sound knowledge of associated heat storage technologies. Every year, a normal detached house receives about ten times as much energy from the sun as is needed for space heating and domestic hot water production. Future prospects for **solar energy** are therefore good. In terms of performance, solar heating systems operate well today, but investment costs must be brought down and system efficiencies improved if they are to become competitive with other forms of energy supply.

There are only a few **solar cell systems** in the built environment in Sweden. This is due to the present low price of electricity, the extensive electricity distribution network and the high costs of the technology. In several European countries with domestic production of solar cells (Germany, Holland and Italy), relatively large numbers of solar cells are being installed with substantial state subsidies.

Sweden's knowledge in respect of the use of **heat pumps** is at the international front line. In addition to Sweden, this sector is dominated by countries such as the USA, Japan, Germany, Holland, Canada etc. Swedish-manufactured heat pumps have an excellent reputation, of a level with those of the USA and Japan. Sweden occupies a leading position in replacing environmentally hazardous CFCs by other refrigerants, and in particular by natural refrigerants such as ammonia, propane and carbon dioxide. Research in Sweden is concentrated on energy-efficient systems, using refrigerants having as little environmental impact as possible.

The bottom fell out of the market in 1985 as a result of substantial drops in the price of oil, coupled with removal of state subsidies intended to stimulate the market. However, a few companies survived, managing to maintain a certain level of production and sales. Today, the country has about 350 000 heat pumps in use in commercial premises, giving the country by far the highest density of heat pumps in Europe, and probably in the world. In terms of numbers, Swedish sales of heat pumps for heating purposes, amounting to about 25 000 per year, makes up half the total European sales. The USA and Japan are also major exporters of heat pumps. Swedish sales today are dominated by rock and surface earth heat pumps, which are capable of meeting about 80-95 percent of the heating energy requirements of a house.

District heating is very flexible in respect of production and type of fuel. It has low environmental impact, and can be combined with electricity production (CHP). Although district heating already has a substantial market share, there is still very considerable scope for expansion.

There are several ways of using **district cooling**: many Swedish district heating utilities, for example, use waste heat from industries to produce district heating via heat pumps. This particular arrangement means that for every three energy units of district heating, the heat pumps also produce two energy units of cold water for district cooling. Large district heating heat pumps nowadays use less hazardous refrigerants. Another way of producing district cooling is to install a number of absorption cooling pumps, actually powered by district heat and using a salt solution as the refrigerant. Alternatively, cold bottom water from the sea or a lake can also be used (free cooling), without requiring the use of a heat pump.

District cooling systems are expanding rapidly in Sweden: in total, there were 16 such systems in operation in the country at the end of 1998. 180 GWh of district cooling was supplied in 1998: it is expected that, within 5-10 years, the supply will have risen to about 500 GWh, provided by 25 systems.

Knowledge levels of **small-scale biofuel applications** are very high in North America, Austria, Italy, Switzerland, Germany and Scandinavia. The leading research groups in the bioenergy field in Sweden are spread throughout the country. In recent years, wood firing and the use of biomass as fuel have been developed into more user-friendly systems with less pollution. Processed products such as pellets and briquettes are being increasingly used. In countries where there is a greater difference in the prices of heat and electricity, such as Denmark and Austria, the use of biomass for local heating, group heating and small-scale CHP is growing rapidly.

Barriers in the way of more widespread use

Costs for the application of new technologies constitute an obstacle to their wider application, although a further important aspect in determining market penetration is that of reliability and convenience. Today, environmentally benign alternatives have difficulty in competing with other, more established, technologies in terms of price, availability and convenience when considered in the **short term**.

Falling prices of electricity severely complicate the work of development, so that the guide measures and incentives that are at present used need to be further refined. In addition, virtually all projects need to include aspects other than solely energy economics. This will provide a means by which non-energy benefits, such as environmental considerations, productivity and indoor climate, can assist the introduction of new technologies as a step along the path to a sustainable energy system.

The main problem of introducing biofuels for heating to replace electricity or oil-fired systems depends on two factors; security of supply and critical mass. Security of supply covers the entire chain from the supplier of the raw material, fuel suppliers, equipment suppliers, service and maintenance. A domestic heating system has a life of at least 20 years: customers want to be sure that a system will operate reliably, with good economics, throughout this period.

Solar collectors are today manufactured more or less manually, and with small volumes. Manufacture must move more towards mass production if costs are to be brought down.

Regulations regarding the use of natural, but flammable, refrigerants in heat pumps are unclear. International work on standardisation s in progress, but is proceeding only slowly as views on flammable media differ considerably between (primarily) the USA and Japan on one hand and Northern Europe on the other.

Current research and development

As far as *thermal solar heating* is concerned, research, development and demonstration activities are carried out within the framework of an integrated programme, bringing together participants from research institutions, manufacturing industry and purchaser groups. The aim is to increase the use of solar heating during the summer in the shorter time perspective, and to use seasonal heat storage to make solar heating into an attractive method of heat supply for heating throughout the year.

In addition to basic research into **heat pumps** by a number of institute of technology departments, the Agency is operating an applied programme of research and development with about 30 Swedish companies, with the aim of developing and producing efficient systems at a low cost and with little environmental impact.

Since 1998, the Agency has been financing a research and development programme for hot water technology together with the Swedish District Heating Association, covering distribution, consumer service units, control and metering. The objective is to develop energy-efficient, low environmental impact district heating systems. The purpose of the programme is to create a field for the training of research scientists, with the project work resulting in long-term accumulation of knowledge within the institutes of technology, founded on links with the district heating sector.

Components and ancillary systems

The knowledge pool and commercial maturity

In comparison with other countries, Sweden is well advanced in terms of setting **insulation standards** in the built environment. Despite significant differences in the climate, the average heating requirement for buildings is the same in southern, central and northern Europe. Sweden differs from most countries in the high proportion of electricity used for heating.

It is not expected that LEDs will be used for light sources until they have achieved at least the same performance as that of present-day CFLs. It is expected that, over the next 5-10 years, light output from LEDs will have risen to about 7-8 times as much as that from an incandescent lamp. Some international research is being carried out into white LEDs, based primarily in universities/institutes of technology and among the manufacturers of traditional light sources.

National knowledge levels in the **domestic white goods sector** are relatively high, thanks to the fact that one of the world's leading manufacturers has its headquarters in Sweden, together with a certain amount of manufacturing production. On the other hand, almost all domestic electronic equipment and office equipment is manufactured outside Sweden. However, national labelling schemes, such as the TCO marking scheme for IT and communication equipment, have achieved international recognition and application in respect of energy, ergonomics and environmental choice of materials.

Barriers in the way of more widespread use

Technology for the use of **LEDs** for lighting purposes is not yet mature. Possible barriers are presented by the initial price and acceptance of replacing incandescent lamps and CFLs by LEDs. New networks will be needed, e.g. between manufacturers of domestic lighting fittings and the manufacturers of new light sources, if the technology is to become commercially available within all sectors. An obstacle in the way of greater use of **daylight** is that it requires more technologies/components to be integrated in the building system, and the present building market is not capable of accommodating the necessary holistic approach. A further obstacle in the way of greater use of daylight is the lack of physical data suited to Swedish geographical conditions.

Current research and development

The Agency is one of a number of parties supporting two parallel research projects for research into white LEDs for **lighting purposes**. The objective of the first project is to investigate the market structure for white LEDs, what parties are involved, technical development and the potential markets, and also to determine the forces behind development. The second is concentrating on technical development of white LEDs by investigating the potential for substantial improvements in performance. The former Technical Science Research Council (TFR) is also supporting research into the use of white LEDs for general lighting purposes.

The Agency's support for research into **daylight systems** is concentrated primarily on measuring passive daylight systems (screening out heat, using daylight and retaining outward visibility).

Together with the Swedish Association of Electrical Utilities (ELFORSK), and in addition to the above technology-related work, the Agency is financing a research programme aimed at the use of electricity in buildings and in smaller/medium-sized industry (ELAN). Its objective is to strengthen development within the field of electricity use/electricity applications through the establishment and consolidation of good research environments at the country's institutes of technology, and by increasing the accumulation of knowledge and expertise by and among the electricity industry, electricity users, manufacturers of electrical products and communications systems, network operators and scientists. In addition, the Agency is financing a **Smart Building** programme, i.e. concerned with the development of buildings making extensive use of IT technology. The objectives of this programme include improving general knowledge levels and development relating to Smart Buildings, ensuring that administrative and legal barriers are identified and, if possible, removed, investigating matters relating to integrity encroachments, creating technical platforms and possibly initiating continued joint research within the field.

5. Other climate-related research

Chapter 4 described the country's applied research and development: this chapter describes some of the more important programmes in the energy sector that are linked to climate considerations.

5.1 Carbon flows in forest areas

Forestry is of considerable importance in reducing the net emissions of greenhouse gases. 52 percent of Sweden's land area is covered by forests. Each year, Swedish forests absorb 6-9 million tonnes of carbon in biomass and 2-5 million tonnes in the ground, equivalent to 50-85 percent of the country's carbon dioxide emissions from fossil fuels. In addition, the forests provide fuels that replace oil equivalent to a further 6-7 million tonnes/year of carbon. Greenhouse gases can be significantly reduced through strategic utilisation of forestry and land use. Sweden has two main research institutions that finance research in this sector: the Swedish Energy Agency and MISTRA (the Foundation for Environmentally Strategic Research).

The Swedish Energy Agency's carbon balances research programme

The Swedish Energy Agency is running a research programme into carbon balances, the objective of which is to provide knowledge concerning carbon flows in forests, thus enabling forestry to be employed as an efficient means of reducing carbon dioxide concentrations in the atmosphere. The programme is expected to provide material for decisions on strategies for maintaining or increasing the uptake of carbon dioxide in carbon dioxide sinks as a part of silviculture. Particular attention is being paid to measures on which the international climate negotiations have concentrated. Sub-objectives of the programme are:

- improving our knowledge of carbon take-up, carbon flows and carbon balances in forest ecosystems, based on Swedish ecological conditions, and with consideration of Swedish silvicultural practice.
- establishing Swedish expertise in respect of carbon balances and carbon sinks in forests, thus enabling (for example) analysis of the consequences of proposals put forward in global climate work.
- preparing a basis for forestry that can reduce the carbon dioxide concentration in the atmosphere by tending and increasing carbon sinks in a cost-efficient manner.

This includes measures to reduce atmospheric carbon dioxide concentrations through the use of forest fuels and of forest products in a cost-efficient manner.

Current projects are concerned with the following questions and working areas:

- Accumulation of organic materials in forest soils and in different ages of forests on agricultural land. This work is concentrated on being able to identify the two carbon dioxide flows in land use processes, namely root respiration and the breakdown of organic materials.
- The effects of elevated carbon dioxide concentration and air temperatures on the growth and carbon balance of individual trees.
- Modelling and data acquisition across a broad base to quantify a Swedish carbon balance for the forest ecosystems, and how it changes as a result of climate changes, silviculture, forestry strategies etc.
- Measurement and modelling of emissions of carbon dioxide, methane and nitrous oxide from drained forest land. Calculation of annual emissions from various ground types. This project is investigating to see whether the emissions can be reduced by raising groundwater levels.
- Dynamic modelling of various forestry systems in respect of their carbon balances. We need to be able to make long-term (>100 years) and integrated analyses of factors such as carbon balances, availability of wood fuels etc.
- Information for assessing the cost efficiency of various forestry strategies as part of the work of countering higher atmospheric carbon dioxide concentrations.
- Calculation of carbon storage in forest products for the entire forest industry sector.

MISTRA's research programme - Strategies to reduce greenhouse gas emissions from ground use applications

MISTRA finances the *Land Use Strategies for Reducing Net Greenhouse Gas Emissions* (LUSTRA) research programme, the purpose of which is to develop integrated strategies for how changes in the pattern of land use and care can contribute to optimum reduction of net emissions of greenhouse gases in Sweden during the periods 2000-2030, 2000-2100 and 2000-2500. Various possibilities are being evaluated in terms of their potential effects on greenhouse gas emissions, measured as carbon dioxide equivalents. The significance of variations in site conditions and large-scale environmental changes will be investigated. Proposed forestry systems will be evaluated in 10, 30 and 100-year perspectives in order to determine:

- The quantitative effects on greenhouse gas emissions and bound carbon in the short and long terms.
- Short-term and long-term costs to commercial organisations and to society.

- Stability as affected by changing conditions such as climate, nitrogen deposition, economic conditions of the forest products industry etc.
- Flexibility in land use systems in order to accommodate a change in the pattern of demand for products.
- Strategies that are thought to have unduly adverse environmental effects will not be considered.

5.2 System research

The objective of the programme is to improve the material available for energy policy decisions by describing and explaining relationships between energy, the environment, technical development and economic growth. A further objective is to develop and improve methods and models of forecasting and evaluation. The Swedish Energy Agency is financing research aimed at describing and explaining system relationships in the energy system, as well as at the development of working methods and models.

Research into energy systems

Research into energy systems is important if we are to be able to change the country's energy system and achieve sustainable development. Research attempts to describe and explain how the energy system works, and how it affects and is affected by persons, society, technology and the environment. Another task is to develop tools in the form of planning instruments for local, regional or national use, generally in the form of technical or economic computer models. Using the technical models can, for example, enable the most cost-efficient alternative to be selected when, for example, a district council needs to make an investment decision. The consequences of various economic guide measures or incentives on carbon dioxide emissions can also be analysed, or descriptions produced of how the energy markets would operate in various situations.

A special national and international network of scientists and developers of methods and models exists, which helps to evaluate the results of new research. The work of disseminating such knowledge has been increased. The following is a description of the main components of the programme:

R&D activities in energy systems technologies. This project has two main objectives. One is technical system analysis, which involves the development of models and methods for investigating the roles played by various technologies in physical systems involving the production/turnover of energy and materials. The second objective involves the development of methodologies to enable models and methods to be used as tools in real decision situations.

Development of numerical models for energy market analysis. The objective of this sub-project is to develop a new model of the electricity market in the Nordic countries, and possibly also in northern Europe. An important part of the work is to achieve understanding of the relationships between the electricity, gas and district heating markets. Another part of the work is concerned with the relationships between the energy sector and the public economy as a whole, and how various energy and environmental policy guide measures affect the extent and geographical distribution of energy production and energy use.
The effect of external costs on physical energy systems. The objective of this project is to analyse the external costs of a local energy system, and to evaluate them in monetary terms. The results will show the benefits in terms of living quality of including the external costs right from the decision stage.
Regional energy system optimisation. The purpose of this project is to apply an overall system approach to identify the opportunities and potentials for optimisation of the energy system as a whole, and to propose improvements for a region in Central Sweden.

Behavioural and acceptance research

More attention is being paid to behavioural considerations, particularly in order to attempt to understand how individuals and organisations react to change, e.g. when expanding the use of renewable energy. Other questions relate to understanding the driving forces behind development of a new technology into new commercial products, while other products disappear at an early stage of the process. The following is a brief description of the contents of these programmes:

Energy management in industrial companies. The purpose of this project is to develop the energy management role in Swedish industrial companies, so that it becomes more efficient and therefore benefits both industry and the environment. Industry needs not only information on technology, but also information on how best to apply the knowledge of a technology that already exists.
Networks for social science and humanistic environmental research. The objective of this programme is to acquire knowledge of humanistic and social science research factors that are of importance for sustainable development within the environmental sector, of which the energy sector forms a part. Humanistic and social science research has hitherto been under-represented in the environmental and energy sector.
Energy opinion in Sweden. This involves ongoing surveys of the attitudes of the Swedish population to energy matters, e.g. renewable energy sources.

5.3 Life cycle assessments as a tool for climate work

An important starting point in planning a sustainable and climate-friendly energy system is that of consideration of the entire use of resources and of the total environmental and climate impact of the entire chain from obtaining the energy raw material through to the finished energy service, i.e. work, light, heat and transport. Important tools in making such assessments are Life Cycle Assessment (LCA) and energy system analyses.

LCA is a tool which, in a standardised manner, quantifies the entire environmental impact of a product or a service from cradle to grave. The environmental impact is expressed as the total effect within special environmental impact categories[53] per 'functional unit' of a product or service[54]. The analysis includes obtaining the raw materials, construction of processing plants and production systems, ancillary systems such as transport, production and delivery of the product/service, together with final disposal or other treatment of any residues, and demolition of the various plants. In the case of an energy facility, the direct environmental and climate impact of operation forms only a part of the total LCA.

When analysing various energy systems, the emphasis is on factors such as how efficiently the total energy input (including both the energy raw material and the energy inputs to various ancillary systems) can be utilised in various energy chains from the fuel source right through to the final, delivered energy service. We talk of system efficiencies for various forms of energy and applications: corresponding analyses can also be made of the economic factors. Particular importance is attached to investigating the consequences of various energy applications for the rest of the energy system, e.g. in terms of resource consumption and climate effects.

Using these methods -preferably in combination - makes it possible to investigate which energy systems (fuels, conversion processes, types of transport and also energy carriers) have the least environmental and climate impact on their way to the final energy service. Both LCA and energy system analyses are very sensitive to input data assumptions, limitations and, not least, to the choice of alternative systems used as reference systems.

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[53] Acidification, climate effects, land use etc.

[54] e.g. per kilogram of paper, kWh of heat etc.

5.4 Research into climate policy areas

Two research programmes are in progress within the framework of international climate work: a national programme, concentrated on climate policy areas, and a bilateral programme of joint research in the energy sector with the Baltic States.

Since last year, as part of the work of the national programme, the Agency has supported a research programme being run by the University of Stockholm into trade in emission rights. During the spring, and still within the framework of the national programme, a project was started by which a group of scientists at Chalmers University of Technology are investigating the flexible mechanisms, with particular emphasis on the use of carbon sinks within the framework of the Clean Development Mechanism, one of the Kyotoprotocol mechanisms.

Within the bilateral programme, work was started in June on a project intended to develop methods to simplify verification of climate projects carried out under the Joint Implementation flexible mechanism. The work is being carried out by Det Norske Veritas in conjunction with Baltic experts in the area. Work by scientists at the Stockholm Environment Institute, developing methods for sector-based reference scenarios for the district heating sector in Estonia, and forming part of the bilateral programme, was concluded.

6. The Climate Convention's pilot programme for joint implementation, and other international cooperation in the energy field

6.1 Introduction

The United Nations' Framework Convention on Climate Change was signed by over 150 states in June 1992. It forms the basis for international work on climate matters, with progress being reported to the regular Conference of Parties. These conferences have the authority to make decisions, and bring together the states that have ratified the framework convention.

Sweden's parliament approved the Framework Convention on Climate Change in 1993. At the same time, it decided to draft a programme with the aim of assisting the Baltic states and Eastern European countries in their energy efficiency improvement work and in greater utilisation of renewable forms of energy, known as the *Environmentally Adapted Energy System* programme (EAES).

At the first Conference of the Parties in Berlin in 1995, the member states decided to introduce a trial period (a pilot phase) of *Activities Implemented Jointly* (AIJ). As emission reductions are expensive for many industrial states, as they have already developed advanced methods of emission control, and as energy efficiencies are high in these countries' industries, the AIJ programme provides a means by which these countries can invest in other states where costs of reducing GHG-emissions are lower. The objective of the pilot phase was to find out whether such projects could be carried out in a cost-efficient manner and can contribute to sustainable development. It was also decided that projects carried out as part of the work of the pilot phase could not be credited in respect of emission reductions. A condition for projects being eligible for inclusion in the trial period is that financing should not be part of the industrialised states' normal aid programmes (ODA).

The third conference in Kyoto in 1997 drew up a protocol as an appendix to the main Convention, under which the parties agreed on levels of emission reductions to be effected over the period 2008-2012. Details of how joint cooperation could be carried out were defined in the Kyoto Protocol, with three types of mechanisms being determined. These mechanisms are *Joint Implementation* (JI), the *Clean Development Mechanism* (CDM) and *Emissions Trading* (ET). They are referred to as flexible mechanisms, as they provide different ways by which an industrialised state can reduce emissions. However, they are supposed to be supplemental to national measures within the country concerned.

JI and CDM are project-based mechanisms. JI means that an industrialised country invests in measures intended to reduce emissions in another industrialised country, with the aim of partly or wholly being able to credit the resulting emissions reduction. CDM means that an industrialised country invests in emission-reducing measures in a developing country. The key difference between CDM and JI is that CDM involves a developing country, i.e. a party not having any quantitative commitment in the Kyoto-protocol.

Trade in emission permits has made it possible for parties concerned, whether entire states or individual companies, to purchase the right to emit greenhouse gases. Emission permits are not project-based, but are assigned or auctioned to parties in the market. JI and CDM, on the other hand, provide a means by which parties can purchase approved, credited emission reductions achieved as the result of specific projects. As opposed to projects carried out during the pilot phase, JI and CDM projects do permit the resulting reduction emissions to be credited to the originating countries.

In its 1997 energy policy decision[55] Sweden set out guidelines for a Swedish climate policy within the energy sector. These guidelines say that, as a member of the European Union, Sweden should work to ensure and apply a common climate policy, and should also be a driving force behind international climate work. In addition, it was stated that Sweden should cooperate with other countries, in accordance with the aims of the climate convention, through the work of joint implementation. The policy also states that the widely varying costs for improvement measures, whether within or between countries, mean that cost efficiency must be seen as an important element in order to ensure that the climate policy remains credible in a long-term perspective.

6.2 Measures performed in the Baltic states and Eastern Europe

Introduction

Sweden contributes to projects aimed at reducing the emission of greenhouse gases in a number of different ways, working in conjunction with various sources of financing and with various operating agencies or institutions. As previously mentioned, the Swedish Energy Agency is responsible for the Environmentally Adapted Energy System (EAES) pilot programme of climate-related energy

[55] Bill on Sustainable Energy Supply 1996/97:84.

projects in the Baltic states, Poland and Russia. The programme consists of projects that can have four different thrusts: boiler conversions, modernisation of district heating distribution systems, the improvement of efficiency of energy use in buildings, or combined projects involving two or more of the above project types. It assists the recipient countries in investing in projects intended to improve the environment and/or the efficiency of energy use. In addition, Sweden is involved in the work of the World Bank *Prototype Carbon Fund* (PCF). The PCF programme recently became operative as a result of undertakings by a critical mass of sponsors, companies and states. CDM-Assist is a new programme. Some of the programmes being carried out within the framework of *the Baltic Billion-investment programme* are related to the climate programme, as are parts of SIDA's development work with Central and Eastern Europe.

The Swedish Energy Agency's investment programme

The purpose of the programme is to reduce emissions of carbon dioxide and other environmentally harmful substances, to improve the efficiency of the Baltic states' energy systems and to introduce renewable energy sources . To date, over 70 projects have been initiated by the Agency (and by its forerunner, NUTEK), of which 52 have been reported to the UN Climate Secretariat. Projects have been carried out in the *district heating sector* in the Baltic states, and in St Petersburg and the Kaliningrad areas of Russia. A biogas project has been started in Poland. *Boiler conversion projects* are concerned primarily with conversion of district heating boilers in the 3-10 MW range, so that fossil fuels such as heavy fuel oil or coal can be replaced by biofuels such as wood chips, forest waste and waste products from wood-based industries. *Distribution projects* are concerned with the upgrading of district heating distribution systems by replacement or re-insulation of piping systems, water treatment to extend system life and installation of consumer service units and control equipment etc. *Efficiency improvement projects* in buildings cover measures such as conversion or re-insulation of roofs, installation of district heating consumer service units, heat exchangers, metering and control equipment, balancing of systems, weatherstripping of windows and doors etc.

Projects are financed by loans to the recipient countries on beneficial terms, with the Agency paying the costs of consultants, e.g. for feasibility studies. Loans to plant owners or equivalent bodies generally run for ten years, with the first two years being repayment-free. Interest rates are as published by STIBOR[56], or in one case 0.5 percent higher. The ambition of the projects is that they should have a payback time that is shorter than the term of the loan. The payback time of boiler conversion projects averages out at about five years, while that of distribution projects varies between about two and twelve years, depending on to what extent new pre-insulated district heating pipes are needed. As far as the

[56] Stockholm Inter-Bank Official Rate.

building projects are concerned, those intended solely to improve the efficiency of energy use have a payback time of 7-9 years, while renovations in the building stock that are regarded as essential for efficient energy use have a payback time of 16-20 years.

6.3 Results

Emission reductions and costs

Table 6.1 shows the results of projects that have been completed, divided up into boiler conversions, renovation of district heating distribution systems and energy efficiency improvements in buildings, showing the emission reductions in which the projects have resulted for each country. *Table 6.2* shows the specific costs expressed in Swedish crowns per tonne reduction of emissions (during the life of the project), expressed as an average of the results for all countries in the particular group of projects.

The costs have been divided up into investment costs and transaction costs[57]. In this case, the investment costs are in the form of low-interest loans to the plant-owners, and to others in the Baltic countries and Russia, which are to be repaid to Sweden. The transaction costs consist of consultancy support and administration, and in certain cases of write-off of loans or interest claims. The projects have been carried out within the framework of the Climate Convention's AIJ programme. The question of how costs and crediting of the emission reductions achieved are to be proportioned between the countries in the case of true JI projects is a matter for negotiation between the parties.

The total cost of projects amounts to SEK 271 million, of which SEK 197 million is met by the investment country (the recipient country), and SEK 74 million is met by Sweden. The total reduction in CO_2 emissions is estimated as 4 003 000 tonnes (about 1 million tonnes up to and including 2000).

[57] These costs are reported annually to the Climate Convention's Secretariat.

Table 6.1 Results of completed projects

Conversion projects

Country	Number of projects	Investment cost, SEK million	Transaction cost, SEK million	Total cost, SEK million	CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, Project life, tonnes
Estonia	9	47.1	9.4	56.5	82 700	384 000	1 311 000
Latvia	14	44.7	14.1	58.8	68 400	350 000	1 230 000
Lithuania	8	39.0	15.2	54.2	30 300	126 000	625 000
Russia	8	27.5	13.8	41.3	21 300	77 700	509 000
Total	**39**	**158.3**	**52.5**	**210.8**	**202 700**	**937 000**	**3 675 000**

Note: Annual energy production based on biofuels instead of on fossil fuels is estimated as amounting to 0.65 TWh. In a few individual cases, the projects also include distribution measures.

District heating distribution renovation projects

Country	Number of projects	Investment cost, SEK million	Transaction cost, SEK million	Total cost, SEK million	CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, Project life, tonnes
Estonia	8	9.5	7.0	16.5	11 500	41 600	190 400
Latvia	5	10.7	3.6	14.3	3 100	18 400	70 600
Lithuania	1	0.8	0.7	1.5	220	1 100	4 000
Total	**14**	**21.0**	**11.3**	**32.3**	**14 800**	**61 100**	**265 000**

Note: These projects are expected to produce an annual energy saving of 0.12 TWh.

Energy efficiency improvement measures in buildings

Country	Number of projects	Investment cost, SEK million	Transaction cost, SEK million	Total cost, SEK million	CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, 2000, tonnes	Accumulated CO_2 reduction, Project life, tonnes
Estonia	4	11.0	4.3	15.3	1 950	7 900	29 100
Latvia	3	3.9	2.1	6.0	390	1 600	5 090
Russia	4	2.1	3.5	5.6	1 500	3 800	28 600
Total	**11**	**17.0**	**9.9**	**26.9**	**3 480**	**13 300**	**62 800**

Note: These projects have reduced energy use by 0.05 TWh/year.

The projects that have been carried out within the framework of the pilot phase of the Climate Convention for Activities Implemented Jointly (AIJ) show that it is possible to do so in accordance with the flexible mechanisms criteria, i.e. that they should be cost-efficient and achieve substantial emission reductions with relatively modest means. *Table 6.2* shows investment and transaction costs in SEK/tonne for carbon dioxide emission reductions. The figures shown relate to the total cost over the life of the project, which varies between 10-25 years. The costs for the investing and recipient countries in a future JI system will depend on the proportions of the emission reductions that can be credited to each country. This is something that will be decided by negotiations between the two parties.

Table 6.2 Investment and transaction SEK per tonne of carbon dioxide reduced

Type of project	Investment cost, SEK/tonne of carbon dioxide reduced	Transaction cost, SEK/tonne of carbon dioxide reduced	Total, SEK/tonne of carbon dioxide reduced
Conversion projects	42	14	57
District heating projects	79	43	122
Energy efficiency improvement projects	270	160	430
Total	**49**	**18**	**67**

Table 6.2 does not include revenue for the recipient country in the form of reduced costs for fuels resulting from conversion to other forms of energy or from energy conservation measures. Nevertheless, the table shows that the projects are cost-efficient in comparison with costs in Sweden, where the marginal cost of reducing carbon dioxide emissions generally exceeds 500 SEK/tonne.
The costs are based on an estimate of carbon dioxide emissions over the lifetime of the project, on investment cost as a once-off sum and on transaction costs from and including 2000. Further transaction costs for reporting and follow-up may arise, thus increasing the costs slightly.

At present, conditions are not right for further AIJ projects, as new projects must be carried out in a form that qualifies for credits in accordance with a coming national climate investment programme within the framework of the JI and CDM flexible mechanisms. However, the Agency is concluding AIJ projects that were authorised prior to 1999 but which, for various reasons, could not be started until later.

Other effects of the investment programme

The programme has been continuously evaluated by local experts and by independent consultants, and has attracted international attention due to its cost efficiency and efficient implementation. It has attracted attention not only as a result of its greenhouse gas reductions, but also because of other positive effects, both in recipient countries and Sweden. It has had a positive effect on attitudes towards environmentally aware energy supply and energy use on the parts of those in the recipient countries who have been involved or who have been in contact with the programme. Attitudes have been changed, and awareness (e.g. of the UN Framework Convention on Climate Change) has been improved. The programme has also had a beneficial effect on the formation of local markets for biofuels and boilers for burning them. In addition, it has contributed to the establishment of long-term cooperation between Swedish companies and companies in the recipient states, including cooperation on third party markets. Finally, it has contributed to good relations between the Baltic states' energy and environment ministries and departments, thus helping to establish long-term reliable cooperation with Sweden, as represented by the Swedish Energy Agency.

Other international climate policy programmes

The Swedish Energy Agency and the Ministry of Industry, Employment and Communications are working with the World Bank on two programmes. One of these is the World Bank's *Prototype Carbon Fund* (PCF) programme, to which Sweden is contributing a total of USD 10 million. The purpose of the fund is to develop Joint Implementation projects. The other programme is CDM-Assist, the purpose of which is to expand the use of CDM (Section 8.3).

The Agency has SEK 33 million available for investment projects in Lithuania within the framework of the Baltic Billion Fund (see below), and for expansion of capacities in connection with these projects, with SEK 8 million available for capacity expansion projects in Russia in connection with bilateral agreements on energy and climate cooperation.

Other energy projects with possible climate effects

SIDA is financing energy-related projects within the framework of its development cooperation with Central and Eastern European countries. This applies primarily to aid in respect of consultancy fees, feasibility studies, seminars etc. Over SEK 18 million, for example, were invested in such work for the district heating sectors in Latvia, Lithuania and Russia in 1998 and 1999. Almost

SEK 8 million have been spent on energy efficiency improvement work in Poland, Russia and the Ukraine.

Both SIDA and the Swedish Energy Agency operate projects financed by the Baltic Billion Fund. The purpose of the Fund is to encourage commerce and industry in, and trade with, the countries around the Baltic, in accordance with Swedish interests. The first SEK 1000 million was used to finance energy projects, such as district heating projects sponsored by SIDA, sulphur treatment in Poland as sponsored by NUTEK, projects operated by the Ministry of Industry, Employment and Communications, projects for which various groupings within the energy industry had been responsible and energy efficiency improvement and other energy projects operated by the Swedish Energy Agency. Parliament approved the second Baltic Billion Fund in the autumn of 1998, for economic development in the Baltic region over a five-year period (1999-203). In a joint project with the World Bank, in connection with preparations to improve heat supplies in Riga, SIDA is contributing about SEK 40 million for investments intended to improve the efficiency of heat supply, extending availability and improving the service for almost 80 percent of the city's inhabitants. The programme will provide a total of about USD 140 million, which is the cost of the entire World Bank project. Another example concerns preparations to improve district heating in Vilnius. Here, the work is intended to result in more efficient utilisation of existing resources, coupled with a transfer to less polluting forms of energy.

The grants for the investment portions of the projects in Riga and Vilnius are financed with money from the First Baltic Billion Fund in accordance with a special Government decision, i.e. it is the Government that provides the money but SIDA that carries out the project using financing from the Baltic Billion Funds. Consultants' costs and seminars etc. are met by SIDA from its ordinary development budget. The First Baltic Billion Fund also includes a district heating project in Gattjina in Russia, to which SIDA is contributing SEK 40 million. In other words, in virtually all the energy projects, SIDA is using its normal Eastern European funding for financing consultants' fees for feasibility studies etc.

The Second Baltic Billion Fund will be used to carry out the assistance projects recommended by the Baltic Committee in order to meet economic requirements. Public authorities and State-supported bodies on behalf of the Government will carry out the actual measures. The Second Baltic Billion Fund will also finance NUTEK's economic development programme in the Baltic region. This programme has seven theme areas, of which environmental technology and environmentally-powered growth is one: SEK 14.5 million of the Second Baltic Billion Fund has been earmarked for this working area. A decision has recently been taken, for example, concerning a district heating project in Archangel for a total of SEK 27 million.

Some of SIDA's development work is carried out in conjunction with the World Bank, and these projects are described below in connection with the Baltic Billion Funds. Together with the World Bank and other Swedish parties, SIDA has contributed to investments in improving district heating systems in Tallinn, Tartu and Pärnu, the three largest cities in Estonia, together with assistance for conversion of smaller boiler plants. The programme had a budget of USD 60 million, of which Sweden contributed with a credit of USD 10 million and support for consultants' fees and institutional development. These projects formed part of the World Bank's normal work in Eastern Europe from 1991 to about 1998.

Table 6.3 shows the costs of the various energy-related programmes that are relevant to the climate problem and which have been financed by Sweden. Note that some of the figures apply for long programme periods and others for shorter periods.

Table 6.3 Energy-related programmes in the Baltic region

Programme	Financing via:	Time period	Cost
The AIJ programme	Ministry of Industry, Employment & Communications	1993-2000	SEK 270 million
World Bank Carbon Fund	Ministry of Industry, Employment & Communications	2000-	SEK 100 million (USD 10 million)
World Bank CDM-Assist	Ministry of Industry, Employment & Communications		
First Baltic Billion Fund	Ministry for Foreign Affairs	1996-	About SEK 170 million for energy projects (district heating)
Second Baltic Billion Fund	Ministry for Foreign Affairs	1998-	About SEK 47 million to date
Development cooperation (SIDA)	Ministry for Foreign Affairs	1998-1999	About SEK 26 million of a total of about SEK 150 million for environmental cooperation[58] in total (Grant Item 7b)

6.4 Methodology development

The Swedish Energy Agency has provided constant support for method development, i.e. development of how various types of AIJ and JI projects can be evaluated, primarily in respect of their environmental effects. In the autumn of 1999, the Agency established a joint project with Det Norske Veritas (DNV),

[58] Over the period 1995/96-1998, about SEK 395 million was spent on the environmental sector within the framework of development cooperation with Central and Eastern Europe.

aimed at developing methods of following up climate projects in the Baltic area. This work continued during 2000 in the form of a method project aimed at simplifying verification of similar JI/CDM projects. The work has resulted in several reports, including a larger report on verification of small projects.[59]

The data reported to the UNFCCC Secretariat has been in accordance with the framework and regulations for AIJ projects as decided by the Climate Convention. The assessments of the efficacy of projects is based on the *status quo* reference performance, i.e. on the assumption that there would be no changes in energy use unless the project had been carried out. For certain projects, values based on sector-specific dynamic reference performances have been reported. The DNV report confirms that the Swedish programme fulfils the requirements in respect of AIJ projects as set out by the Climate Convention.

Other requirements may be imposed on projects when Joint Implementation schemes are brought into climate work: for example, the question of baselines will become of key importance for evaluation of such projects. DNV's work has resulted in valuable knowledge, and the question of reference performances requires continued attention in international climate work.

[59] Multi-Project Verification of Swedish AIJ Project Methodology and Lessons Learned, ER 9:2001; Multi-Project Verification of Swedish AIJ Projects Verification Results and Documentation, ER 10:2001.

7. Confirmed but not implemented actions, guide measures and incentives

The instruction guidelines from the UNFCCC specify that countries must distinguish clearly between measures that have been implemented, those that have been decided upon, but which have not yet been implemented, and those that are still at a planning stage. This chapter describes policies and measures that the Swedish Parliament or Government has decided to implement, but for which the necessary legislation has not yet been passed, or for which the detailed planning required for implementation has not yet been completed.

7.1 Green certificates, combined with a quota system for encouraging electricity production from renewable energy sources.

As described earlier in this report, Sweden has introduced several different economic instruments in order to encourage the production of electricity from renewable energy sources. Over a period of time, the conditions relating to these various forms of support have changed in several respects. Sweden has, for example, liberalised its electricity market, in order to create competition between suppliers, and this has also changed the conditions relating to the guide measures or incentives. Since the introduction of the liberalised electricity market in 1996, electricity prices to end users have fallen (see also Section 9.2), which has resulted in reduced revenues per kWh for electricity producers and suppliers. This has meant, in turn, that the need for economic support for small-scale and often 'green' electricity production has, in many cases, increased despite cost reductions. However, electricity prices have started to move upwards again during 2001.

The Kyoto Protocol has concentrated interest on measures intended to support renewable forms of energy, and thus reduce power production from fossil energy sources. The EU has recently published a new directive for encouraging the use of renewable energy sources on the single market, based on its White Book on renewable energy sources, setting out the aim of having 12 percent of EU energy supplied from renewable sources by 2010, as against only about 6 percent today.

Against this background, Parliament decided in 2000 to introduce a new system for encouraging the production of electricity from renewable sources.[60] The new

[60] See the report of the Standing Committee on Economic Affairs, 2000/01:NU3.

system, which is to come into force on 1st January 2003, will be based on trading in green certificates, in combination with an obligation for electricity suppliers to include a certain proportion of electricity from renewable sources that fulfils certain defined environmental characteristics.

Trading in certificates, in combination with quotas, requires a system of support that is internally financed from within the market, which will provide a more long-term approach to the support system. In addition, it creates business opportunities for the parties involved, together with a market dynamic which should improve cost efficiency and technical development without causing market problems. The Government feels that this will provide important objectives for a future support system, as follows:

- to encourage the provision of new facilities for the production of electrical energy from renewable energy sources with certain defined environmental characteristics,
- to encourage technical development and cost efficiency,
- to create reasonable terms for existing production facilities,
- to avoid interfering with the operation of the electricity market,
- to create stable rules of play, regardless of State finances, *and*
- to facilitate international harmonisation.

A commission has been appointed to investigate the technical aspects and to suggest necessary changes in legislation (Dir 2000:56). Approval for a new system is expected to be presented in March 2002.

7.2 Planning objectives for wind power production

In its spring 2000 Budget Bill (Bill no. 1999/2000:100), the Government has undertaken to submit proposals for a suitable planning objective for the development of wind power production to Parliament. An important element of the move towards a sustainable energy system is that the right economic conditions should be created for the production of electricity from renewable sources. Wind power plays a key role in this context, and can also contribute to fulfilling several of the national environmental quality objectives decided by Parliament in 1999[61]. Appropriate readiness for continued expansion of wind power production is therefore of strategic importance. The Government is of the opinion that planning objectives for wind power can be a suitable means of encouraging this development.

The Government has asked the Swedish Energy Agency to identify areas on land and at sea where conditions are particularly favourable for wind power

[61] Swedish Environmental Objectives, Bill no. 1998/99:145.

production, and to prepare and put forward a draft planning objective for wind power production. In addition, the Government has decided to appoint a working party to investigate the general factors governing the siting of wind farms at sea and in the mountains.

In its report, the Swedish Energy Agency suggests that the planning objective for the expansion of wind power production should be 10 TWh/year within the next 10-15 years. This is defined as being the annual energy production quantity to be aimed at, and for which the necessary associated and ancillary facilities and conditions should be planned. A national planning objective should then be broken down to regional level, so that the county councils and district councils can apply it in their wind power production planning. It is particularly important that wind power production should be systematically included as part of the general strategic planning of local authorities.

It is the intention that onshore and offshore wind farms, in areas with suitable wind conditions, shall be developed, primarily along the coasts. If sufficient production capacity for wind power is to be achieved, it will be necessary to establish larger wind farms offshore. This is because large-scale siting of wind power in mountain areas, and in other parts of northern Sweden, would be restricted by the need to make expensive investments in increasing the capacity of the country's grid in these areas.

7.3 Public procurement in the energy sector

Total public procurement in Sweden amounts to about SEK 300 x 10^9 per year, of which about SEK 100 x 10^9 is for material items, while SEK 200 x 10^9 is for services and work. One of the working objectives of the Delegation for Ecologically Sustainable Procurement (M 1998:01) is to develop a common internet-based tool that can be used by the entire public sector and serve as a model for ecologically sustainable procurement. The Delegation's terms of reference include:

The tool shall be an aid/guide for specifying environmental requirements in connection with public procurement. The level of these requirements shall be high, with the tool being designed to comply with current legislative requirements.

Although the public organisations will decide what environmental requirements are to be included, manufacturers, suppliers and environmental organisation shall be given the opportunity to comment on relevant and important aspects concerning the contents of the tool and/or changes to it.
The environmental requirements expressed in the tool shall be of a high standard and shall keep up with advances within the environmental sector. The Delegation

therefore proposes that a scientific panel should be established for quality assurance of the environmental requirements in the tool.

A criterion in connection with procurement is that of specifying requirements in respect of energy efficiency or of improvements in energy efficiency. A working party has investigated the effects of including such requirements in public procurement procedures. As part of the working party, the Swedish Energy Agency has prepared a set of guidelines for the procurement of energy intensive equipment, which consider aspects such as quality requirements, the work environment, operation and economics. These guidelines have so far been produced in specific versions for pumps, fans, lighting, ventilation, refrigeration compressors and air compressors. They are intended to assist purchasers, and are based on such aspects as life cycle energy cost calculations. It has been calculated that the effects of greater awareness of energy efficiency should reduce the country's electrical energy demand by 2 TWh/year within ten years, accompanied by a corresponding reduction in carbon dioxide emissions of 0.7-1.7 million tonnes/year from 2010.

7.4 Continued greening of the tax system

The report of the Tax Transfer Committee (SOU 1997:11) concluded that there was scope, over the next 15 years, for further greening of the taxation system in the same order as that which was effected during the 1980s and 1990s. Since then, there has been a lively debate on tax transfer within the political parties and in sector organisations affected by it. In the spring of 2000, the Government decided that a total of about SEK 30 x 10^9 of taxation should be transferred to energy and environmental related taxes over the period 2000-2010.

In order to implement this strategy, a number of areas, including taxation relief rules for specially energy-intensive and internationally competitive industries, as well as traffic taxation policy, need to be further investigated. Two parallel investigations are looking into these aspects: the Industrial Taxation Relief Committee (Dir 2001:29) and the Review of Road Traffic Taxation Investigation (Dir 2001:12). As far as traffic taxation is concerned, it is the objective that it should have a greater effect in controlling the environmental impact of traffic. In addition, the Government has decided that certain matters relating to the taxation of refuse shall be investigated (dir 2001:13).[62]

[62] Council Resolution (90/C122/02) on refuse policy states that the creation of refuse should preferably be avoided. If not, it should be recycled or used for energy production, and only sent to landfill as a final resort. Today, considerable quantities of refuse are disposed of in landfill, and it is the intention that this should be phased out in the long term. A landfill tax of SEK 250/tonne was introduced in 2001: from 2002, combustible refuse must be removed and may not be disposed of in landfill. Further restrictions come into force in 2005, banning the landfill disposal of organic waste. However, there is a risk that these measures will result in more

8. Planned measures

The guidelines from the UNFCCC state that countries shall provide information on planned measures, guide measures or incentives for the reduction of greenhouse gas emissions. In recent years, several investigations have been carried out into the various ways in which emissions of greenhouse gases could be reduced. This chapter discusses measures that the Government has decided upon, either in formal decisions or as announcements of policy. It does not, however, include measures put forward by committees, public authorities or organisations and which have not yet been considered.

8.1 Long-term agreements with industry

Energy efficiency improvements within industry

It has become increasingly common over the last decade, both in Sweden and in other countries, for companies or sector organisations to enter into some form of environmental agreement with the State with the aim of reducing environmental impact. These agreements are usually combined with some form of sanction that will come into force if the undertakings are not fulfilled, e.g. such as legislation within the sector, higher taxes or environmental levies. Several projects are at present being operated by a number of public authorities, who are investigating the scope for using environmental agreements between the State and industry as a way of reducing industry's environmental impact.

The Government has decided to appoint a special negotiator, whose duties will be to negotiate and investigate the opportunities for applying long-term agreements to achieve energy efficiency improvements in industry. Close cooperation with energy-intensive industries has recently been started, with the aim at arriving at specific agreements.

It is the objective that the draft programme for long-term energy efficiency improvement agreements between the State and industry should have been prepared and notified to the EC-Commission before the end of 2001. If then appropriate, the negotiator will start negotiations for an agreement with industrial representatives. The negotiator should strive to establish close contact with the industry concerned when drawing up the agreement. The purpose of these

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incineration of unsorted refuse, instead of first sorting and recycling it. This may mean that the combustion of refuse may also be taxed.

long-term agreements is to encourage industry to implement cost-efficient measures to reduce overall energy use and greenhouse gas emissions.

A dialogue with industry and commerce

The Standing Committee on the Environment (Jo 1968:A) is responsible for developing strategies for the development of ecologically sustainable industry by initiating dialogues with appropriate parts of industry. The Committee has initiated dialogues with a number of companies in two main sectors: construction/housing and future commerce. The objective is that companies should voluntarily undertake certain development steps, and also put forward suggestions to the Government for facilitating these particular developments.

The results of these dialogues were presented to the Government in December 2000.[63] The dialogue represents a common vision for a sustainable construction and property sector, objectives for further work and a strategy for achieving the vision and objectives. This vision is not a forecast of what future development might be, but should be seen as what those involved in the dialogue see as a desirable future for 2025. Priority areas are for improving the efficiency of use of energy and resources, the indoor environment and a proper (i.e. healthy) choice of materials. They include the target of eliminating the use of fossil fuels within the sector by 2025, and of reducing energy use by at least 30 percent over the same period. Analysis of possible obstacles and potentials along the road to sustainable development has identified seven priority action areas. as follows:

- A sustainable society
- The application of best technology and development of new technology
- Procurement based on life cycle perspectives and a holistic approach
- Coordination of the construction and subsequent management processes
- Classification of commercial premises and residential buildings
- Concentration on research and development
- Marketing of environmental solutions.

Work is continuing in working parties, concentrating on essentially the above directions, and with the aim of reaching agreements by the start of 2002 on concrete measures between the State and the companies involved.

8.2 Emission trading

The Government has appointed a special investigator to look into the scope for introducing a system of trading emission rights in Sweden (SOU 2000:45). This

[63] Think New, Think Sustainable - Building and Management for the Future. The Standing Committee on the Environment 2000, http://www.sou.gov.se/mvb/

work has also included analysis of questions put forward in a Green Paper published by the EC Commission, and containing proposals for an EC-wide system of trading by CHP companies and energy-intensive industries in emission rights. The Commission is at present continuing its work on an EU-based system. Sweden supports this process: the Government has recently appointed a Parliamentary Committee to investigate outstanding points relating to trading in emission rights and other flexible mechanisms.[64]

8.3 Project-based mechanisms in the Kyoto Protocol

Funding was included in the 1997 energy policy decision for climate policy improvement work carried out in other countries. This funding has hitherto been applied to projects forming part of the UNFCCC's activities implemented jointly pilot programme. The Government now plans that the remaining funding shall be applied to project-based mechanisms within the Kyoto Protocol.

The Swedish Energy Agency shall assist the negotiator whom the Government intends to appoint for reaching agreements between Sweden and suitable candidate countries for joint implementation work. This means that the work of the Agency will include preparing an analysis of appropriate working partners, and of the potential for appropriate cooperation in various countries. This work is being carried out by the Agency.

Working with the World Bank, and in conjunction with SIDA, the Agency will plan investment projects suitable for treatment as Clean Development Mechanisms under the terms of the Kyoto Protocol. As far as the work with the World Bank is concerned, the primary objective is to identify possible CDM projects within the framework of the Bank's CDM Assist programme for Africa, which also includes concentration on work intended to develop capacity.

8.4 Energy declarations for residential buildings

Several different *energy declaration projects* are at present being started up. The Swedish Energy Agency is playing an active part in the work of arriving at a common system. Together with the National Board of Housing, Building and Planning, it will investigate and put forward a proposal for energy declarations for residential buildings. Looking further ahead, the Agency will participate in the current SAVE project for energy marking of windows. At present, there is no

[64] N 2001:08 - Investigation of a system and regulatory structure for the Kyoto Protocol's flexible mechanisms.

means for building developers accurately to be able to forecast the energy efficiency of a building. The Agency therefore intends to participate, through such means as technology procurements, in projects aimed at developing improved and more accurate energy declaration calculation programmes.

9. Policies and measures and incentives that have an indirect effect on greenhouse gas emissions

9.1 The Environmental Code and the Planning and Building Act

The Environmental Code

In principle, the underlying rules in The Environmental Code (SFS 1998:808) are applicable to all human activities that can harm the environment. The most central elements are the general rules of consideration, from which follow that all activities shall be carried out, and actions taken, in such a way as to avoid harm, damage or injury to human health or the environment. At the same time, proper husbandry and management of the ground, water and other resources shall be encouraged. Unless otherwise stated, the requirements of The Environmental Code apply to all activities and all actions that can affect the environment: it makes no difference whether they are carried out as part of a business or by a private person.

The Environmental Code applies, in other words, to everything from major projects such as building and operating hydro power stations or motorways to small individual tasks such as washing a car with detergent or composting domestic waste. As the purpose of The Environmental Code is to encourage sustainable development, it has considerably more powers in terms of specifying conditions than have the regulations in the Environment Protection Act.

The provisions of The Environmental Code can have considerable power, not only through the comprehensive environmental assessments enabled by it, but also through the specific effects of the various regulations. Chapter 2, 3§ states that it is the duty of one and all to apply all protective measures needed to prevent, oppose or counteract any harm, damage or inconvenience to human health or the environment. Protection for human health or the environment refers not only to traditional health and environment protection, but also to everything that is of importance in respect of the overall objective of encouraging sustainable development. The mere risk of any such effects is sufficient to introduce a requirement to take all necessary care.

Examples of protective measures of importance for effects on the climate are the use of energy-efficient processes, the choice of energy carrier and the choice of means of transport.

The concept of general consideration is described in the introduction to The Environmental Code. All, regardless of whether or not there is any specific direct action or instruction from a public authority, shall comply with these rules. The same rules apply to all: it makes no difference whether the actions are taken as part of the work of a business or not. Nor is there any difference whether the activity requires permission or not. Complying with the general consideration rules is particularly important in connection with the emission of greenhouse gases.

The **Resource management and the eco-cycle principles** states that, where possible, materials shall be reused and/or recycled, and that renewable forms of energy shall be used. The primary purpose of this rule is to conserve raw materials and energy. The **Product Choice Principle** states that chemical products or biotechnical organisms shall be selected on the basis of presenting the least risk to human health or the environment. The best technical principle for commercial activities means that the best possible technology shall be used in order to avoid harm: technically and economically, it shall be possible to use the technology on an industrial basis in the sector concerned. The **Reasonableness Rule** means that requirements in respect of taking appropriate steps, as described above, apply to the extent that it cannot be regarded as unreasonable to fulfil them. In making any necessary assessment, the value or benefit of the degree of care taken shall be compared with the costs of taking the measures, but must not result in setting aside any environmental quality standard. It is incumbent on the person performing the activity to show that the cost of some measure is not environmentally justified, or that it is unreasonably burdensome.

In addition to the general consideration rules, there are additional rules for certain types of activities. Examples of such activities that are relevant in connection with limiting effects on climate are:

- extractive activities (e.g. peat)
- agriculture
- properties of fuels
- handling of chemical products
- refuse.

Regulations issued under The Environmental Code can also be used to assist the achieving of climate objectives. As far as environmentally detrimental activities are concerned, general regulations can be published as needed, for example, to reduce climate effects from an entire sector or to regulate some problem that cuts across several sectors. However, to date, this power has not been used.

As in the Environment Protection Act (1968:387), the authority responsible for granting permission to operate some environmentally detrimental activity can make the permission conditional upon fulfilling certain measures. However, such measures within the climate sector are rare, partly due to the fact that there is already specific legislation aimed at preventing the emission of greenhouse gases. Conditions relating to emission of methane, nitrous oxide and the use of fossil fuels (i.e. concerned with greenhouse gas emissions) are in force for a number of individual airports, combustion plants, waste sites and iron, steel and metal works.

No evaluation of the effects of The Environmental Code (or of the Environment Protection Act or the Nature Conservation Act) in respect of emissions of greenhouse gases has been carried out. Although the legislation permits the publication of regulations and setting conditions concerning greenhouse gas emissions, this has been utilised to only a limited extent by the authorities concerned. Bearing in mind the limited number of cases in which special conditions have been specified, it is felt that The Environmental Code has so far had only a limited effect in comparison with other guide measures.

The Planning and Building Act

Physical planning involves the location and design of traffic facilities, together with district councils' land use planning and detailed planning in accordance with the requirements of the Planning and Building Act. Physical planning is one of the most long-term forms of planning that is employed, which makes it particularly interesting from the point of view of climate and energy policy, especially in the residential and service sector. Appropriate planning, with energy conservation in mind, can create savings in terms of reductions in energy use and reduced emissions from the combustion of fossil fuels. A central element of future climate policy is how commercial and similar premises are to be built and where they are to be sited in relation to infrastructural services and other aspects.

Since the 1960s, the planning tendency in Swedish urban areas has been towards increased thinning-out of the urban areas. There are towns which, despite a falling population, have increased their land area. In several cases, there are strong links between the local council, interest associations and companies that have created driving forces for this development.

There is no in-depth research into connections between energy efficiency and urban structures. However, energy use for transport, and emissions from traffic, in low-density towns are several times higher than in high-density towns of similar population sizes.[65] This demonstrates a significant environmental drawback of excessively thinly populated urban structures. The tendency towards urban sprawl, with residential areas, working areas and shopping areas being separated, has increased the use of cars, which has in turn increased energy use and emissions. This structure also affects the viability of public transport.

[65] The National Board of Housing, Building and Planning's Report on environmental objectives, environmental quality objectives 11 A Good Urban Environment, 1999.

> **The environmental Quality Objective – A good Urban Environment**
>
> Towns, urban areas and other built environments must provide a sound, healthy living environment, as well as contributing to good regional and global environmental conditions. The natural environment and cultural values must be recognised and tended. Buildings and infrastructure must be designed and sited sensitively and in such a way as to further sustainable, responsible use and conservation of the ground, water and other resources.

Concentrating shopping areas along main traffic routes means that non-car-owning households can find it difficult to meet their daily needs. It is also difficult, in lightly populated areas, to justify expansion of district heating, which can play a part in reducing the environmental impact of energy use, particularly in older built environments.

The importance of rethinking local authorities' physical planning has attracted increasing attention in recent times. In its work on environmental objectives, Parliament has set a special environmental quality objective for the built environment. In addition, energy, water and other natural resources shall be used in an efficient manner, conserving resources and reducing environmental impact. Energy sources should also preferably be renewable. These environmental quality objectives will be regularly monitored. In the Swedish Environmental Objectives - Stage Objectives and Action Strategies Bill (Bill no. 2000/01:130), the Government has recently put forward stage objectives for all environmental quality objectives, including those for the built environment.

In conjunction with the Environmental Protection Agency, the National Board of Housing, Building and Planning has been operating the Town and Country Planning with Environmental Objectives in Sweden project, which is intended to assist local authorities with incorporating environmental considerations into their planning processes.

9.2 Liberalisation of the electricity market

The electricity market in Sweden was reformed in 1996. Electricity legislation had been changed in Finland in 1995, while Norway had opened its electricity market to competition as long ago as 1991. This means that, since 1996, Finland, Norway and Sweden have had a common electricity market. Denmark joined the Nordic electricity exchange in 2000, and the Danish electricity market will be open to competition for domestic supplies in 2003.

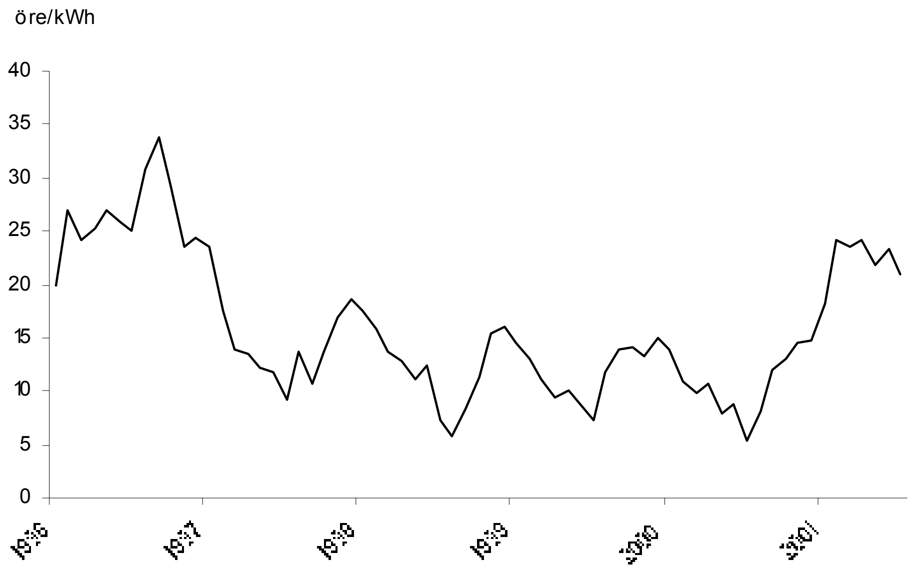
The electricity market was liberalised for economic reasons. Economic incentives would increase competition and make better use of resources, resulting in savings for society as a whole and for consumers in the form of lower electricity prices. How has this turned out in practice?

Before the reform, each of the Nordic countries attempted to be self-sufficient in terms of electricity supply, although there was some trading of electricity under the terms of bilateral agreements between the large electricity producers. However, with liberalisation, self-sufficiency lost some of its importance. Today, electricity is simply an energy raw material that can be traded and supplied across national borders. Pricing has become more efficient, through access to a common trading arena, NordPool. Border tariffs between Norway, Sweden and Finland have been removed, which has also helped to make trading more efficient. In total, traded flows of electricity between the Nordic countries have increased.

The power industry is in process of extensive restructuring, with the power utilities developing into steadily larger and more integrated energy utilities, operating in several countries. Swedish companies are looking for new markets and increasing their holdings in the neighbouring countries: in the same way, companies from other countries are increasing their holdings in Sweden.

Since 1996, there has been a clear trend towards falling electricity prices on the Nordic spot market, which continued until the end of 2000, as shown in Figure 9.2. One explanation for the falling prices is to be found in the greater competition in the shared market, although the decisive factor has been good availability of cheap hydro power during 1997-2000. However, at the beginning of 2001, prices rose sharply as a result of poor precipitation, primarily in Norway. In the same way, the rising prices in 1996 were caused by unusually low precipitation in the Nordic countries.

Figure 9.1 System price of electricity on the Nordic power exchange (NordPool), 1996-2001, öre[66]/kWh.



The price of electrical energy for end-users (excluding fees and taxes) has also fallen between 1996 and 2000. Over the same period, electricity tax has increased, which has resulted in the final price of electricity increasing for many customers. This does not apply to industry in Sweden, which is exempted from the electricity tax, and thus pays less for its electricity. However, from 2001, prices have started to move upwards again, as a result of increases in the spot market prices.

It is still difficult to ascertain the effect of falling electricity prices on industrial investment decisions, although it is clear that there is less potential for profitable energy efficiency improvement measures. We can see that the use of electricity in industry has increased substantially in recent years, but this is probably primarily an effect of rising output. Another important factor is the high price of oil, which has resulted in companies replacing oil by electricity where possible. The low prices of electricity, and the high prices of oil, in the residential sector has resulted in a change from oil to electricity for heating, which conflicts with the energy policy objective of reducing the use of electric heating in Sweden.

The low prices of electricity on the market have also affected Sweden's trade in electricity. During 2000, Sweden changed from being a net exporter to a net importer, despite plentiful supplies of water for hydro power production and high availability of the nuclear power stations. This was due to the fact that the power

[66] 1 SEK=100 öre

companies have started to adjust their production to the price of electricity. During the spring of 2000, the price of electricity on NordPool was so low that it fell below the production costs for most forms of production. Several of the nuclear power stations reduced output during the year, with Sweden importing power, mainly from Norway.

Another effect of low electricity prices and more competition is that Sweden's installed capacity has been cut back. As part of the reform of the electricity system, the previous requirement that the major electricity producers must have a certain amount of reserve capacity was done away with. In a competitive market, the effect of this was that the utilities could not afford to maintain reserve capacity in the form of gas turbines or oil-fired cold condensing plant. The availability of cheap power from coal-fired cold condensing plant in Denmark and Finland has meant that the Swedish oil-fired cold condensing plants could not longer compete, with the result that most of them have been decommissioned. In any case, little use was previously made of such production capacity: it was really used more or less only during dry years, which means that the effect of its decommissioning on total carbon dioxide emissions has been limited.

As far as investments in capital-intensive production technologies such as CHP and renewable energy are concerned, the effect of liberalisation of the electricity market has been, in the short term, to reduce utilities' willingness to invest. This is because they can no longer recover the higher marginal production costs of these forms of power generation from higher electricity prices, as was previously the case. However, in the longer term, when new power production capacity is required, it is expected that the prices of electricity will rise to the long-term marginal cost of new production capacity. There is a need for new types of guide measures and incentives, compatible with the changed conditions of a liberalised electricity market, in order to encourage utilities to invest in renewable energy and CHP. Work is at present in progress, for example, on drafting a system for trading in certificates for electricity from renewable sources, in order to create a market for renewable energy in Sweden. Other possible guide measures include carbon dioxide taxation and emission trading. All the Nordic countries have a carbon dioxide tax, although electricity production is exempt from it in Finland, Sweden and Denmark. Denmark started trading emission rights in January 2001, covering all the electricity producers in the country. However, in order to ensure a smoothly operating open electricity market, it is important that the conditions and regulations in all countries should be harmonised.

Overall, the effects of the liberalisation on the environment are regarded as negative in the short term. Although carbon dioxide emissions in Sweden have probably not been significantly affected, the low prices of electricity have reduced the potential for energy efficiency improvements and resulted in a more hostile climate for investment in renewable energy and CHP. It is also felt to have resulted in postponement of the construction of gas-fired power production capacity in Norway, with Norway instead increasing its imports of electricity from

Denmark and Finland. An evaluation of the effects of the reform across the Nordic market has estimated that carbon dioxide emissions have increased by 8 million tonnes/year, which is equivalent to about 20 percent of Nordic emissions in the power sector[67]. This figure is based on a comparison between the current situation and a simulated development of what it would have been if the Nordic electricity market had not been liberalised. However, it is felt that the effect of the liberalisation on the environment will not be negative in the long term. The price of electricity on an open market is expected to rise to the long-term marginal production cost, resulting in higher prices than would have been the case on a regulated electricity market, accompanied by a cutback in use and, therefore, in electricity production. At the same time, it is expected that the use of coal will be phased out, to be replaced by gas for electricity production. In addition, production resources will be better utilised on an open electricity market.

9.3 The Act Concerning Phase-out of Nuclear Power Production

As part of its 1997 energy policy, Parliament decided that the two Barsebäck reactors should be shut down, and this was followed, in due course, by a new Act Concerning the Phase-out of Nuclear Power.[68] The Act empowers the Government to decide on shutdown of each reactor at a time that best serves the objective of moving the country's energy system towards sustainability. In addition, other considerations are to be weighed into the decision, including the geographical siting of the reactor, its age, design and general importance for the country's energy system.

The first reactor was closed in November 1999.

Parliament's 1997 energy policy, which was subsequently confirmed in the spring of 2001, stated that one condition for closure of the second Barsebäck reactor is that the resulting loss of electricity production capacity can be compensated by a supply from new production and reduced demand for electricity. In addition, closure must not have any negative effects in respect of the price of electricity, the availability of electricity for industry, the country's power balance, the environment or climate. It is Parliament that will determine whether the various conditions have been met, prior to shutting down the second Barsebäck reactor.[69] The Government is of the opinion that the necessary conditions can be fulfilled before the end of 2003.[70]

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[67] Working paper 3/99: The Nordic electricity reform: Economic and environmental consequences, ECON and an article in Nordisk Kraft [Nordic Power], 2001.
[68] SFS 1997:1320.
[69] Report from the Standing Committee on Economic Affairs, NU 2000/01:NU3.
[70] Government document: Continued restructuring of the energy system etc., Skr 2001:15.

Closure of both the Barsebäck power stations will result in a direct production loss of about 8 TWh/year of electrical energy, with half being from November 1999 and the remainder from the sometime closure of Barsebäck II. The knock-on effects of the loss of electricity production will depend on the demand for electrical energy, expansion of renewable production capacity, energy conservation measures and the availability of imported electricity. The model calculations of the effect of closing the second reactor indicate that its production loss will be met by increased import of electricity and expansion of renewable power production.[71] Expansion of production capacity from renewable sources depends upon the subsidies or support available for small-scale hydro power production, improvements in the efficiency of existing hydro power plant, wind power plants and biofuelled CHP plant. Under these conditions, carbon dioxide emissions in Sweden will increase by only about 100 ktonne/year.

It is difficult to calculate the emissions resulting from a greater importation of electrical energy. The amount of power available varies considerably during the year, and there is also a significant variation from year to year, depending on the availability of hydro power in the Nordic electricity production system. Elsewhere in this report, we have assumed that changes in electricity use in Sweden affect emissions from the type of power production that is meeting the marginal demand. At present, it is assumed that marginal production capacity in the northern European electricity system is provided by coal-fired cold condensing plant, but is felt that this will gradually change to natural gas-fired plant in the future. Under these conditions, emission increases outside Sweden's borders will be in the range 700-1600 ktonne/year. If, instead, we apply an average figure for the northern European electricity system, the emission increase amounts to about 800 ktonne/year.

9.4 Some aspects of taxation etc.

The property tax

Sweden has a system for property (real estate) taxation that is based on a calculation of the property's market value. Each year, the property-owner is required to give details of several aspects of the standard of the property. A taxable value is then calculated, on the basis of this declaration and of the general price development for residential buildings. The tax is levied as a certain percentage of the taxable value. Under the present system of property taxation, the taxable value of a detached house is affected by the increase in its market

[71] Report ER 8:2001, Scenarios for electricity supply with and without Barsebäck 2, Swedish Energy Agency.

value as a result of an environmental improvement. The use of heat pumps or high-performance windows, for example, affects the taxable value and thus the amount of tax charged. The tax has increased during the 1990s in step with price rises in the property market. This has also meant that investments that increase the value of a property have had a greater effect on the taxable value than was previously the case, which has affected the willingness of property-owners to invest in new, low-energy technology. There are examples of property-owners electing not to invest in new energy-efficient technology in buildings due to the resulting effect that such investments would have on the amount of tax.

The Property Tax Review Committee (SOU 2000:34) has proposed changes to the present system. For certain types of environmental investments, the resulting increase in the taxable value of the property will not affect the amount of tax charged during the first ten years after making the investment. The proposal is at present being considered by the Cabinet Office and the Ministries.

Energy taxation

Different rules and rates govern energy taxation, depending on the fuel concerned and on the user. The present taxation system is not ideal, whether seen from an environmental or from a fiscal point of view. The rules vary between, on the one hand, electricity and heat production and, on the other hand, between manufacturing industry, district heating and domestic users. Instead of achieving the intended objectives of rational energy use, or development of improved technology, the system is tending to encourage operators to move fuels between sectors or application areas. The fact that industry, horticulture and agriculture pay lower rates of energy and carbon dioxide tax must be seen against the background of a desire to stop the energy-intensive Swedish industries from suffering from competition from companies in other countries that do not charge equally high rates of energy tax. However, this means that the environmental cost is not fully reflected in the price of the energy.

Sweden is pressing for international taxation of carbon dioxide emissions. A parliamentary committee has been asked to propose a new tax relief system for industry, partly against a background of continued greening of the taxation system and the national subsidy rules of the EC Commission.

9.5 CFC/HCFC versus energy conservation in refrigeration and cooling plant

Over the last few decades, the working medium (the refrigerant) in a heat pump or refrigeration/cooling plant has almost always been some form of halogenated hydrocarbon, usually referred to as a CFC, an HCFC or an HFC, depending on the particular chemical composition. CFC and HCFC compounds attack the ozone layer in the atmosphere, and are therefore strictly controlled in national regulations and international agreements, aimed at phasing them out. Sweden, for example, has banned the installation of new heat pumps using CFCs from 1st January 1995, and of those using HCFC from 1st January 1998. Topping-up of CFCs in existing equipment was forbidden with effect from 1st January 1998, and a total ban on its use came into force on 1st January 2000. Systems using HCFCs will no longer be able to be topped up after 1st January 2002: as yet, no date has been set for a subsequent outright ban on their use. There are, however, certain exceptions from these rules.

HFC compounds have no chlorine atom, and thus lack the effect on the ozone layer that CFCs and HCFCs have. Their use has been permitted as replacements for CFCs and HCFCs in most plants, whether existing or new. However, HFCs are strong greenhouse gases, as are CFCs and HCFCs, and are therefore subject to regulation, in such ways as through special requirements applicable to their manufacture, service, risk of leakage, disposal etc.

There are further alternative substances that can be used as refrigerants instead of HFCs, such as hydrocarbons, carbon dioxide, ammonia etc. However, they usually have other drawbacks, such as flammability, local toxicity or high system pressures. New plant can, of course, be designed for new types of refrigerants. However, conversion of existing plants usually results in considerable problems, and can normally be done only from CFC or HCFC to HFC.

Changing the refrigerant can also result in a reduction in the energy efficiency of the equipment. This applies particularly to existing plant, where conversion usually results not only in reduced heating or cooling power, but also in reduced efficiency (heating or cooling factor). In other words, changing the refrigerant can result in a greater primary energy input in order to maintain the same performance. It is not easy to find a balance between reducing the direct greenhouse impact by replacing the refrigerant and the associated higher use of primary energy. Attempting to find this balance is also further complicated by economic factors.

A better way of assessing the greenhouse effect of refrigerants would probably be to assess the total emissions of greenhouse gases from the plant during its lifetime. The concept of Total Equivalent Warming Impact (TEWI) has been developed to facilitate this. A TEWI value can be obtained by adding the direct greenhouse effect resulting from such causes as leakage of refrigerant, to the indirect effect resulting from the total use of energy during the lifetime of the plant. However, the problem with TEWI is that the value is very dependent on the values of annual leakage quantities, electricity production mix, length of life etc. Nevertheless, the importance of attempting to put a value on the total effect is clear, as the direct effect of the refrigerant is usually less than one-tenth of the total effect.

Research and development work aimed at produced energy-efficient and low-leakage systems, requiring little topping-up of refrigerants, benefit all types of systems, whether they have natural refrigerants or anthropogenic HFC refrigerants.

9.6 Subsidies that harm the environment

Housing grants

In 1993, SEK 35 x 10^9 were paid out in the form of housing grants. The grants reduced the interest charges on loans, and were based on a standard building cost, related to the total floor area of the property (SFS 1992:986). No grants were paid for dwelling units over 120 m^2. The grants were heavily cut between 1993 and 1998, and have now been withdrawn for owner-occupied homes.

One result of the grants was that residential buildings could have been larger than necessary, consuming more materials and energy. Today, there are no energy or environmental requirements that must be fulfilled for a building project to be entitled to State support.

Transport grant

The transport grant is paid to companies in a number of sectors in certain parts of the country, in order to subsidise the costs incurred by the companies for obtaining fully-finished or semi-finished parts and materials. In a report from 1998, the National Audit Bureau notes that earlier analyses of the effects of the grant are divided as to whether the grant has had any positive effects.[72] In general, it can be said that any subsidies to transport have the effect of increasing the amount of transport. A review of the grant, and possible subsequent changes to it, would help to make the transportation of goods more efficient and transfer a greater proportion to rail or ship.

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[72] National Audit Bureau, The effects of subsidies on ecologically sustainable development, RRV ref. no. 20-97-1637.

10. Scenarios of carbon dioxide emissions from the energy sector

10.1 Introduction

Carbon dioxide emissions from the energy sector[73] account for about 80 percent of Sweden's total emissions of greenhouse gases. They have declined by about 40 percent between 1970 and today, primarily due to a change away from oil to electricity and other energy carriers. Emissions during the 1990s increased by somewhat less than 1 percent.

The development of future emissions depends on several factors: economic growth, fuel price developments, at what rate (and how) technology develops and on the overall political framework. Developments on the electricity market will be significant for Sweden. Emissions will also be affected by the rate at which nuclear power production is phased out, and by how it is replaced.

Sweden's third report to the Climate Convention presents scenarios of possible emission developments as seen over a relatively long period, getting on for twenty years. The assessment of future development of carbon dioxide emissions from the energy sector is based on a 'business as usual' scenario. This means primarily that the analysis is based on present-day energy and environmental policy frameworks, and that the other assumptions, such as those concerned with efficiency improvements, are assumed to be a continuation of historical development. The starting point for assessments of technical development and possible technical breakthroughs is that of our present knowledge of the rate at which various technologies may develop. This includes such elements as cost assessments and any market obstacles.

Bearing in mind the uncertainty as to the rate at which nuclear power may be phased out, two different alternatives have been used for the period from 2010 to 2020. The one case sees nuclear power production being phased out after 40 years' operation, while the other sees it as continuing in operation as long as it is viable. This second scenario has therefore attempted to assess the reinvestment costs necessary to enable operation to continue, which affects both the composition of the country's electricity production system and electricity price levels.

[73] Emissions from the energy sector include those from combustion in CHP and district heating plants, industry, domestic combustion for heating purposes, and transport.

In addition to the base scenario, we have analysed the effect of the various economic guide measures from 1990 up to today, in terms of how they have affected emission developments.

Calculations using the MARKAL model have formed an important element of the work.

The scenarios presented in this report are based on many different assumptions, each of which has its own element of uncertainty. It has been necessary to make several simplifications, and so the results should be interpreted with care.

10.2 Conditions

Future energy use is very dependent on general economic conditions. Up to now, increased economic activity has resulted in an increase in the demand for energy. However, whether this will continue to apply in future depends primarily on how well the efforts to improve the efficiency of energy use succeed, and on the structural changes that occur in the economy as it develops. Energy use is also sensitive to the price of energy: a high price usually results in less use. The price relationships between different energy carriers affect the composition of this use.

The energy market framework is largely determined by political decisions, which affect the future developments of energy use and energy production. In our scenarios, we have started from the decisions made by Parliament and the Government within the framework of present energy and environmental policy.

The political framework

A political process is at present in progress in Sweden, and is expected to result in a unified Swedish strategy and action programme to limit and reduce emissions of carbon dioxide and other greenhouse gases. The Government presented a bill to the Parliament in November 2001 (prop 2001/02:55). Our scenarios do not include any political actions that may accompany a new climate strategy.

The most recent energy policy guidelines were set in 1997, and resulted in the establishment of a programme to achieve an ecologically and economically sustainable energy system. The programme has two parts: a short-term element, with the aim of replacing the loss of electricity production from the two Barsebäck reactors by reducing the use of electricity for heating, making more efficient use of the existing electricity system and increasing the supply of electricity and heat from renewable energy sources. The second part of the programme is long-term, and consists of continued research and technical and technological development.

Among the features of the energy policy programme are measures to encourage the use of renewable forms of energy over a five-year period. This support provides investment subsidies for biofuel-based CHP, for wind power and for small-scale hydro power. In addition, there is financial operational support for wind power and small-scale hydro power, together with reduced taxation for wind power. All these forms of support will be terminated at the end of 2002, being replaced with effect from 2003 by a system of trading in certificates for electricity from renewable sources. The scenarios include an operating subsidy for electricity from renewable energy sources, amounting to 150 SEK/MWh, which is felt to be a good approximation of the results of the future support system.

According to the current energy policy, 2010 is no longer seen as the final date by which Swedish nuclear power production must be phased out: instead, production is to be phased out in an economically and environmentally sustainable manner. Legislation concerning the phase-out of nuclear power was passed in 1997, giving the Government the right to set specific dates terminating the operating concessions of each individual reactor. In this way, Barsebäck 1 was closed down on 30th November 1999, reducing the country's generating capacity by 600 MW. The rest of Swedish nuclear power production will be progressively phased out, provided that the loss of production can be compensated for by new electricity production capacity and a general reduction in the use of electricity. The Government believes that it will be possible to shut down the second Barsebäck reactor by not later than the end of 2003[74]. We have therefore assumed in the scenarios that the second Barsebäck reactor will be closed before 2005.

With a time perspective of 20 years, and in the current political climate, it is difficult to say when, and by how much, nuclear power production will be reduced or phased out. When will the necessary conditions for closing the reactors be fulfilled, i.e. at what rate will nuclear power production be phased out?

We have therefore presented two different possible development paths for the Swedish system between 2010 and 2020. In the one alternative, the reactors are operated until they have achieved a life of 40 years, and it is this on which the assessments produced in the last ten years have been based. However, the circumstances surrounding operation of the reactors have changed in connection with liberalisation of the electricity market, so that now it seems as if the reactors may continue in operation after 40 years, provided that their operation is still economically viable. This is illustrated in the scenarios by a second alternative, assessing the necessary reinvestment costs in order to enable operation to continue. In this case, nuclear power production will continue as long as it is

[74] Government communications, 2000/01:15.

economically viable. Calculations using the MARKAL model have provided the basis for the various 2010-2020 scenarios[75].

Other starting points

It is assumed that the single European electricity market will have been fully implemented. Present-day energy and environmental policies continue to apply in the Nordic countries, together with present-day taxes, levies and other regulations. Interconnections between Sweden and neighbouring countries in 2020 are those as exist at present, which means that the cross-border transmission capacity is unchanged[76]. It is assumed that the possible net import of electric power over the existing cross-border links during a normal year will decline during the period. There is at present a substantial production capacity in the northern European electricity market, e.g. in Denmark and Germany. However, since these countries' electricity markets have been liberalised, the power utilities have started to reduce this production capacity. The utilities have also reduced production capacity in Sweden. Over a 20-year perspective, it is reasonable to assume that the northern European electricity market will reach a balance, i.e. with production capacity matching demand.

In general, there is insufficient data concerning costs and the likely dates when possible new technologies or substantial changes to systems will be introduced, and so they have not been included in the calculations. As the time perspective is 20 years, the scenario calculations have been complemented by a description of the present state of knowledge with respect to a number of technologies that might approach market introduction during the period, such as various means of small-scale electricity and heat production and alternative motor fuels for use in the transport sector. Finally, the report describes the possibility of separating and storing carbon dioxide.

Other measures that affect the scenario calculations are described under the respective sectors.

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[75] See the description of the method in Appendix 4. A separate description of the MARKAL calculations can be found in the Agency's ER 15:2001 Report, describing the material on which the scenarios are based.

[76] A total of about 7500 MW transmission capacity to Sweden.

Economic development

The following tables present forecasts of GNP, industrial output, private consumption, public consumption and exports. The assessments of future rates of development are also shown in relation to historical development.

Table 10.1 Forecasts for economic development, annual percentage change

	1997–2010	2010–2020
GNP	1,9	1,1
Industrial output	2,3	2,1
Private consumption	2,4	1,9
Public consumption	1,2	0,8
Export	3,5	2,9

Source: The National Institute of Economic Research

It is assumed that, in terms of *GNP*, the economy will grow by an average of 1.9 percent per annum over the 1997-2010 forecast period, which is of a level with the growth rate in Sweden during the 1970s and 1980s. It is assumed that, for the period from 2010 to 2020, the economy will grow at a slower rate, averaging 1.1 percent per annum, which is thus considerably lower than the historical rate of growth of GNP. This is based primarily on assumptions concerning population growth: the number of persons of active working age will start to decline from 2008. Average working hours will be reduced, as will the number of persons in employment. However, productivity development is assumed to be relatively good, which will support the growth in GNP[77].

The National Institute of Economic Research's calculations show that, on average, *industrial output* is expected to increase by 2.3 percent per annum between 1997 and 2010, falling to 2.1 percent per annum between 2010 and 2020. This is of the same order as during the 1980s, but lower than in recent years after recovery from the recession at the beginning of the 1990s.

The calculations also show that the structure of industry is expected to change towards more knowledge-intensive industries. As far as industrial energy demand is concerned, this means that the less energy-intensive industry is expected to grow relatively more than the more energy-intensive industry.

[77] The National Institute of Economic Research.

Table 10.2 Actual and forecast GNP and industrial output development, annual percentage change.

	GNP	Industrial output
Actual development:		
1960–1970	4,6	5,8
1970–1980	2,0	1,2
1980–1990	2,2	1,8
1990–1999	1,5[1)]	3,4[2)]
Forecast:		
1997–2010	1,9	2,3
2010–2020	1,1	2,1

Note: Statistics Sweden presents GNP by a revised method from 1980:

1) 1990-1993: -1,6 percent, 1993-1999: 3,1 percent

2)1990-1993: -3,5 percent, 1993-1999: 7,0 percent.

Source: Statistics Sweden and the National Institute of Economic Research.

Private consumption is assumed to grow relatively considerably, particularly during the first decade. A comparison with historical development shows that the forecast is higher than corresponding growth during the 1970s and 1980s, and considerably higher than growth during the 1990s. On average, private consumption is expected to increase more than the growth in GNP.

It is assumed that *public consumption* will grow by an average of 1.2 percent per annum between 1997 and 2010, and somewhat more slowly (at 0.8 percent per annum) between 2010 and 2020. In other words, it will not grow as rapidly as will private consumption. In comparison with historical development, this forecasted growth is similar to that during the 1980s and 1990s, but lower than the growth during the 1970s and 1980s.

Exports are assumed to grow by an average of somewhat less than 3.5 percent per annum between 1997 and 2010, which is similar to the increasing growth during the 1970s and 1980s. It is assumed that growth will be somewhat less over the period from 2010 to 2020: in other words, the growth in Swedish GNP will continue to be dependent on relatively strong growth in exports.

Table 10.3 Actual and forecast development of private and public consumptions, annual percentage change

	Private consumption	Public consumption
Actual development:		
1960-1970	3,8	5,7
1970-1980	1,6	3,2
1980-1990	1,7	1,7
1990-1999	1,0	0,7
Forecast		
1997-2010	2,4	1,2
2010-2020	1,9	0,8

Source: Statistics Sweden and the National Institute of Economic Research.

Prices of fossil fuels

Table 10.4 shows the assumptions concerning the prices of fossil fuels and the dollar exchange rate.

Table 10.4 Import prices of crude oil, coal, natural gas and the dollar exchange rate for 1997, 1999, 2010 and 2020.

	1997	1999	2010	2020
Crude oil, USD/barrel	19,1	18,25	17	22,5
Coal, USD/tonne FOB	44,1	32,6	42	42
Natural gas, USD/MBtu	2,3	1,7	2,6	3,5
Exchange rate	7,6	8,27	7,5	8,26

Source: IEA, International Energy Agency, European Union Energy Outlook to 2020

The calculations of consumer prices for *petrol, diesel fuel, gas oil and heavy fuel oil* are based on an estimate of the future world market price of crude oil, prepared by IEA (the International Energy Agency). In the short term, the price of oil is determined by changes in demand and by production rates, particularly in the Gulf countries. At present, the price is fluctuating substantially up and down. However, the forecast prices are average prices for the period 1997-2010 and for 2010-2020.

In the somewhat longer term, which is the case for the scenarios presented here, the prices are controlled more by fundamental factors such as total world production and total world demand. It is assumed that the price of oil will rise during the latter part of the scenario period. According to IEA, this will partly be due to the fact that non-OPEC production will have reached a peak and started to decline, which will result in an increasing market share for the OPEC countries, who are assumed to force the prices up. Nevertheless, despite the fact that production will start to decline in some regions, IEA does not believe that access to oil as a whole will be a limiting factor during the coming decades.

In recent years, the costs of oil prospecting, pumping and distribution have fallen considerably, and this development is expected to continue. It has therefore been assumed that the price of crude oil will fall to USD 17 per barrel by 2010. However, as the reserves start to become used up, the price will rise as the difficulty of recovering the oil increases. This is expected to contribute to the rise in prices between 2010 and 2020.

The forecasts include considerable elements of uncertainty. It is difficult to determine how large reserves really are, and it is also difficult to forecast world economic development and the total growth in demand for oil.

The *coal price forecast* is also based on assumptions from IEA. Prices are expected to remain fairly stable between 1997 and 2020, and not to track the prices of oil. This is because most of the large coal-producing countries have started projects aimed at increasing their production of coal. At the same time, too, coal production is expected to increase in some of the large user countries.

The prices of coal fell substantially during the 1980s and 1990s, but are now expected to stabilise at USD 42 per tonne, which is somewhat higher than the lowest level reached in 1999.

There is no clear world market price for natural gas, due to the fact that the distribution systems are geographically restricted to various regions, of which northern Europe is one.

The import *prices of natural gas* are based on a price forecast in the EU 'European Union Energy Outlook to 2020'. The price of natural gas is expected to rise slowly over the period 1997-2010. Based solely on the development of supply and demand, the price ought to rise more than has been assumed. However, as the price of natural gas largely follows the price of oil in Europe, it is expected that the increase will be somewhat less. Nevertheless, after 2010, the demand is expected to increase so substantially that it will be necessary to import gas from regions such as Russia and North Africa, which would involve higher distribution costs and significantly increased prices.

It is not expected, however, that the higher import prices would fully find their way through to consumers, due to the fact that the gas market is in process of liberalisation in a similar way to that of the electricity market. It is expected that the profits on gas sold to consumers will fall.

As far as *LNG* is concerned, no sufficiently accurate information concerning its costs or probable time of large-scale introduction is available. This development has therefore not been considered in the scenarios.

Tables 10.5 and 10.6 are based on the above import prices of unprocessed fossil fuels, and show the resulting calculated consumer prices.

Table 10.5 Fuel prices for large heating plants, group heating plants, larger and smaller industries, in SEK/MWh, including energy and environmental taxes.

	1997[1]		1999[2]		2010[3]		2020[3]	
Large heating plants								
Gas oil	312	(173)	308	(181)	349	(224)	372	(224)
Heavy fuel oil	256	(167)	266	(171)	292	(215)	327	(215)
Coal	222	(177)	227	(186)	282	(240)	293	(240)
Group heating plants								
Gas oil	341	(181)	329	(181)	369	(224)	393	(224)
Heavy fuel oil	275	(175)	278	(175)	304	(214)	336	(214)
Coal	232	(177)	234	(182)	286	(234)	297	(234)
Large industry								
Gas oil	193	(5,)	180	(53)	179	(54)	202	(54)
Heavy fuel oil	148	(5,)	150	(58)	136	(59)	172	(60)
Coal	126	(81)	123	(82)	123	(81)	137	(84)
Natural gas	153	(37)	150	(40)	157	(41)	203	(41)
Smaller industry								
Gas oil	213	(53)	201	(53)	200	(54)	223	(54)
Heavy fuel oil	159	(59)	161	(58)	149	(59)	181	(59)
Coal	136	(81)	132	(80)	133	(81)	144	(81)

Note: The amount of tax is shown in brackets.

[1] This price includes the average tax during 1997. The tax rate was changed on 1st July 1997.

[2] The price for 1999 includes tax from 1st January 1999.

[3] The price for 2010 and 2020 includes the latest tax rate, from 1st January 2001.

Source: Energy and climate in Sweden, the Swedish National Tax Board and our own calculations.

Table 10.6 Fuel prices for large properties and detached houses, SEK/MWh, including taxes and value-added tax.

	1997[1]		1999[2]		2010[3]		2020[3]	
Large properties								
Gas oil	421	(261)	411	(263)	464	(317)	491	(322)
Heavy fuel oil	340	(240)	348	(245)	381	(291)	421	(299)
Coal	290	(235)	293	(241)	358	(306)	371	(308)
Detached houses								
Gas oil	448	(267)	439	(269)	490	(322)	516	(327)
Natural gas	396	(173)	409	(187)	464	(234)	558	(253)

Note: The amount of tax, including value-added tax, is shown in brackets.

[1] This price includes 25 percent value-added tax and the average tax during 1997. The tax rate was changed on 1st July 1997.

[2] The price for 1999 includes 25 percent value-added tax and tax from 1st January 1999.

[3] The price for 2010 and 2020 includes 25 percent value-added tax and the latest tax rate, from 1st January 2001.

Source: Energy and climate in Sweden, the Swedish National Tax Board and our own calculations.

The price of electricity

2000 was the fifth year of the liberalised electricity markets in Sweden and Finland: the market in Norway had been liberalised in 1991. Competition on the market increased more in 1999 and 2000 than it had done in the earlier years, due to pressure on the utilities to bring down their costs as a result of good availability of electricity and low prices on the power exchange.

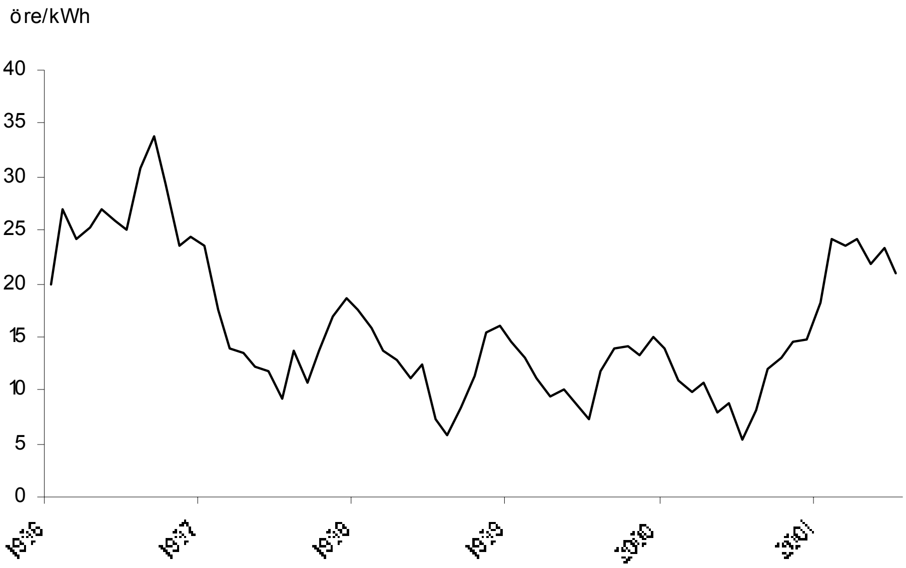
Before liberalisation of the electricity markets in the respective countries, trade between them had been controlled by bilateral agreements between purchasers and sellers. This still occurs today, although there is now also a common market place, in the form of Nord Pool. Prices on Nord Pool are determined for the next 24 hours on an hour-by-hour basis, being set as an equilibrium price at the intersections of the supply and demand curves.

1996, the first year of the liberalised electricity market, was a dry year, which resulted in the price of electricity rising steadily until the end of the year, to produce an average system price of 266 SEK/MkWh. Since then, the price has fallen substantially, to 146 SEK/MWh in 1997, 123 SEK/MWh in 1998 and 118 SEK/MWh in 1999. This can be explained partly by adequate precipitation and partly by the growing competition on the common electricity market. The lowest prices to date were achieved in 2000, as a result of good precipitation: during some days in July, the 24 hour-mean price lay below 40 SEK/MWh. By November 2000, a typical weekday system price was about 140 SEK/MWh.

The system price during 2001 has hitherto been high: during the first half of the year, it lay between 200 and 240 SEK/MWh. The amount of snow in the mountains, and particularly in the Norwegian mountains, was less than in previous years, resulting in less run-off in the spring.

Nord Pool also has a term market, trading in electricity for longer periods than the next 24 hours. In the middle of August, the three-year term price was around 18 Norwegian øre/kWh, indicating the likelihood of a future increase in the price of electricity.

Figure 10.1 Spot price of electricity on the Nordic power exchange (NordPool), 1996-2001, öre[78]/kWh.



Source: Nord Pool.

Future electricity prices

The electricity market in Sweden has changed substantially in recent years, both in terms of structure and of organisation, which makes it more difficult to forecast price changes. In addition, the Swedish market is affected by developments on the electricity markets of neighbouring countries, not only in the Nordic area but also around the Baltic, i.e. Germany, Poland, the Baltic states and north-west Russia. These countries, too, are experiencing ongoing changes in their electricity

[78] 1 SEK=100 öre

markets. A further factor that affects the Swedish electricity market is the EC Electricity Market Directive[79].

Our assessments of the future electricity market have assumed that competition in the production and supply sectors will continue to increase. Today, there is significant power production overcapacity in some of Sweden's neighbouring states. Denmark and Germany are two examples: the electricity markets in both countries have been liberalised, and the Single Electricity Market Directive supports the concept of a Europe-wide competitive electricity market. Market mechanisms mean that the various parties involved will strive to reduce surplus capacity in various ways. It is felt that, in 20 years' time, the market will be in balance, which means that there will not be the same amount of surplus capacity as there is today.

It is difficult to judge how further power demand will be met, as the electricity markets in northern Europe are becoming increasingly integrated, which provides new opportunities, and results in changed conditions, for greater utilisation of existing production capacity and the construction of new production facilities.

On a properly operating electricity market, the price of electricity should be determined by the marginal production cost, which varies over the year and depends on demand and on the structure of the system. At any given time, the short-term marginal cost of electrical energy is determined by the variable cost of the most expensive form of production in use at the time, together with what is known as a shortage cost component that reflects the ability of the production system actually to supply the power. In other words, the short-term marginal cost varies throughout the year. At present, the short-term marginal cost of electricity on the Nordic market is determined by the variable cost component of coal-fired cold condensing power in Denmark at those times of the year when demand is highest.

The long-term marginal cost is determined by the total production costs, i.e. both the fixed costs and the variable costs. In future, when growing demand for electricity will mean that more expensive forms of production will have to be used more, the short-term marginal costs will rise. New production capacity will become economically viable, and may be built, when the short-term marginal cost in the system equals the long-term marginal cost.

The long-term marginal cost varies, depending on what the future electricity production system looks like. If the nuclear power plants are assumed to have a fixed life of 40 years, it will be new natural gas-fired combined cycle plant that will be on the margin, and thus determining the marginal cost. This cost has been

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[79] EC 3638/1/96, 'The European Parliament and the Council's Directive 96/92/EC Concerning Common Rules for the Single Electricity Market'.

calculated as being about 300-350 SEK/MWh[80] for a natural gas-fired combined cycle cold condensing power station. The cost calculation includes an assumption of rising natural gas prices up to 2020.

In the second case, in which it is assumed that the life of the nuclear power stations will be extended by appropriate reinvestment, it will be electricity production from renewable energy sources and, during certain periods, from the 'renovated' nuclear power plants, that will determine the marginal cost. The cost of electricity production from renewable energy sources includes the present 150 SEK/MWh subsidy.

The scenarios have assumed limited imports of electricity, which means that the price of imported electricity does not have any greater effect on the system price of electricity in Sweden. It is assumed that the northern European market will be in balance in 2020.

It is on the above basis that the system price of electricity in 2020 has been assumed. It represents a mean value of the total costs of electricity from the various types of production plant at the margin during the year. In the 40-year nuclear power plant case, this gives a system price of 300 SEK/MWh, while the renovation of nuclear power plants case gives a price of 230 SEK/MWh. These prices are higher than those applying during the years 1997-2001.

Table 10.7 Electricity prices and transmission charges for different customer groups, including spot taxes and value-added tax, SEK/MWh.

	Electricity-intensive industry	Medium-sized industry	Electric heating	Domestic electricity
1997				
Price of electricity	234	244	276	292
Grid charge	57	93	216	411
Spot tax	0	00	126	126
Total price including spot taxes and value-added tax	**291**	**337**	**772**	**1036**
1999				
Price of electricity	197	196	214	218
Grid charge	57	93	206	398
Spot tax	0	0	128	128
Total price including Spot taxes and value-added tax	**254**	**289**	**685**	**930**

80 The production cost varies, depending on the assumptions made for efficiency and annual operating time.

2010				
Price of electricity	230	235	245	250
Grid charge	50	82	190	362
Spot tax	0	0	181	181
Total price including spot tax and value-added tax	**280**	**317**	**770**	**991**
2020 reinvestment in nuclear power				
Price of electricity	240	245	255	260
Grid charge	47	77	179	340
Spot tax			181	181
Total price including spot tax and value-added tax	**287**	**322**	**768**	**976**
2020 40-year nuclear life				
Price of electricity	310	315	325	330
Grid charge	47	77	179	340
Spot tax			181	181
Total price including spot tax and value-added tax	**357**	**392**	**856**	**1064**

Source: E 17 SM, Statistics Sweden, the Special Taxes Office in Ludvika, Tax Authority in Gävle and our own calculations.

Price of district heating

The price of district heating varies from one town to another, depending on the conditions surrounding its production. However, in 1997, the average price of district heating to domestic consumers was 430 SEK/MWh, including tax and value-added tax. In general, industry pays a lower price for heat than do domestic consumers. However, the price varies widely, and is estimated as being in the range 200-300 SEK/MWh, excluding value-added tax, in 1997.

It is expected that the price of district heating will remain unchanged up to 2020, due to the fact that the prices of the biofuels from which much of the heat is produced are also expected to remain unchanged.

The biofuels market

The forest products industry has long used biofuels to meet its needs of process heat. The chemical pulp industry uses black liquor from wood digestion as a fuel to produce process heat and recover the chemicals. This heat is often also used to raise steam for electricity production. The quantity of black liquor is proportional to the amount of pulp produced, and thus also to the heat demand. The pulp and paper industry also uses wood fuels in the form of waste etc. not used for pulp production. This means that the use of biofuels in the industry can be seen as a more or less closed cycle, in comparison with other users of biofuels. In 1999, the amount of energy supplied by black liquor was 34 TWh.

Sawmills produce a considerable quantity of wood fuels in the form of bark, chips and sawdust. In 1999 this amounted to almost 3 million tonne dry weight, equivalent to about 14 TWh. Some of this is used to meet the sawmills' own requirements for heat in timber driers etc., while a considerable quantity is sold as fuel or as the raw material for the downstream production of processed fuels.

Biofuels have long been used for heating in the residential sector, with logs dominating the use for small-scale residential heating. The proportion of wood chips and processed fuels is small, although the use of pellets for heating detached houses has increased rapidly in recent years, now amounting to almost 100 000 tonnes/year, or almost 0.5 TWh.

Utilities that supply district heating and group heating use a considerable quantity of biofuels, mainly in the form of unprocessed wood fuels such as forest chips and by-products. The quantity of biofuels used for the production of steam and hot water has increased substantially, from 10.7 TWh in 1994 to 16.5 TWh in 1999. 3.3 TWh of biofuels were used for electricity production in 1999, with 2.0 TWh of them being used in industry.

Biofuels' potential

The assessments of the potential availability of biofuels in Sweden differ from one source to another[81]. The forecasts for 2010 range from 80 to 160 TWh. Of this quantity, about 45 TWh consists of use within the forest products industry (mainly black liquors) and small-scale log-firing, which lies outside the competitive market. The interval for 2020 is 85-180 TWh, of which about 45 TWh are outside the market. Any net imports of biofuels must be added to these quantities. The figures do not include the contribution from refuse.

[81] In 1999, the Swedish Energy Agency prepared a report for the Climate Committee, bringing together the various sources of information and forecasts of renewable energy sources that were available, entitled 'Renewable energy sources - present status and development potentials. A report on existing material'. PM 1999-10-01, report to the Climate Committee.

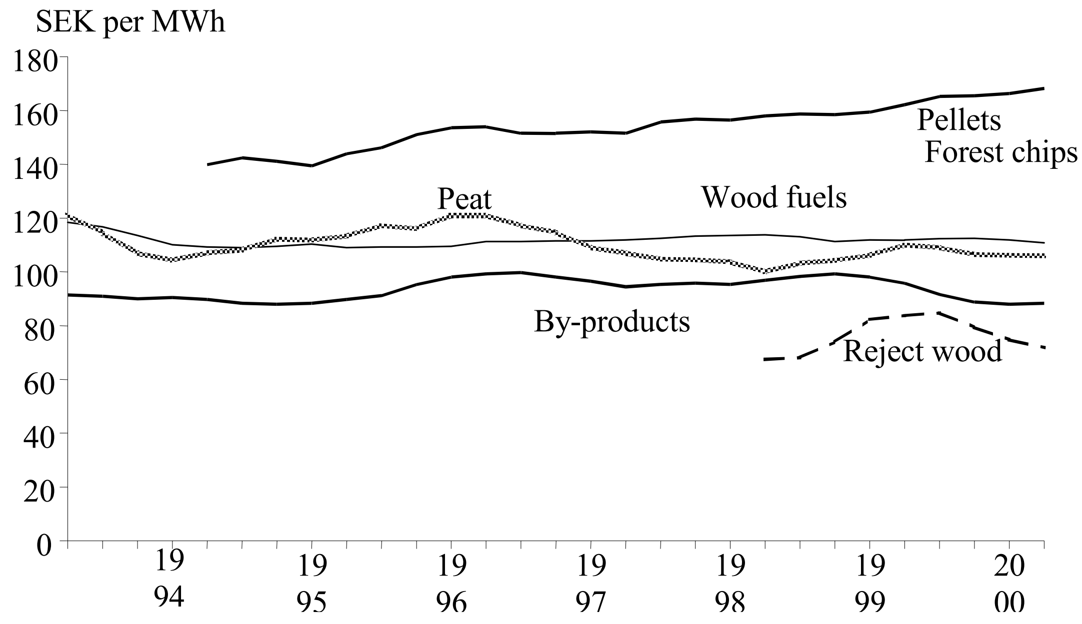
Prices and volumes today

The unprocessed wood fuels used in detached houses are usually obtained from sources other than the open market, and so it is not possible to give any prices for them.

In 1999, the price of pellets for domestic users was about SEK 290/MWh, including transport.

Figure 10.2 shows the costs of various types of biofuels, as supplied to district heating plants. These prices have been relatively stable for a long time.

Figure 10.2 Prices of purchased fuels for district heating.



Future biofuel prices

The price development of biofuels has been relatively stable over a long period of time, and we feel that future biofuel prices will continue to remain stable at the present level.

The changes in the market picture that can be expected are that the processed biofuels will increase their market share as a result of being a more refined fuel than the unprocessed biofuels. There is still a significant unutilised production capacity for pellets, which means that price changes can be expected to be modest.

As far as the unprocessed wood fuels - forest chips, by-products and reject wood - are concerned, the more expensive products will meet competition from the burnable refuse that must not be disposed of in landfill with effect from 2002, and which must therefore be separated from other refuse. Forest chips are already encountering strong competition from the cheaper by-products and from reject wood.

Taken together, all this means that there is increasing polarisation of the biofuel market. It is expected that the quantities of processed wood fuels and of the cheapest types of unprocessed fuels will increase, at the expense of the most expensive unprocessed biofuels.

Energy taxes 2001

The scenarios are based on present taxes, as of 1st January 2001. Tables 10.8 and 10.9 show the present rates of energy and environmental taxes. The rates differ between industry and other users, with industry paying no energy tax and only 35 percent of the carbon dioxide tax that is paid by other users.

Table 10.8 Energy and environmental taxes from 1st January 2001, excluding value-added tax

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Tax, SEK/ MWh
Fuels[1)]					
Gas oil, SEK/m^3 (< 0,1 % sulphur)	688	1 527	-	2 215	224
Heavy fuel oil, SEK/m^3 (0,4 % sulphur)	688	1 527	108	2 323	215
Coal, SEK/tonne (0,5 % sulphur)	293	1 329	150	1 772	234
LPG, SEK/tonne	134	1 606	-	1 740	136
Natural gas/methane, SEK/1000 m^3	223	1 144	-	1 367	141
Crude tall oil, SEK/m^3	2 215	-	-	2 215	221
Peat, SEK/tonne, 45 % moisture content (0,24 % sulphur)	-	-	40	40	15
Motor fuels[2)]					
Petrol, environmental class 1, SEK/l	3,26	1,24	-	4,5	516
Petrol, environmental class 2, SEK/l	3,29	1,24	-	4,5	519
Other petrol, SEK/l	3,92	1,24	-	5,16	592
Diesel, environmental class 1, SEK/l	1,51	1,53	-	3,04	311
Diesel, environmental class 2, SEK/l	1,79	1,53	-	3,27	334
Diesel, environmental class 3 or other, SEK/l	2,04	1,53	-	3,57	358
Natural gas/methane, SEK/m^3	0	1,04		1,04	107
LPG, SEK/kg	0	1,26		1,26	106
Electricity use:					
Electricity, northern Sweden, SEK/MWh	125	-	-	125	125
Electricity, rest of Sweden, SEK/MWh	181	-	-	181	181
Electricity, gas, heat or water supply, SEK/MWh					
Northern Sweden,	125	-	-	125	125
Rest of Sweden	158	-	-	158	158
Electric boilers, > 2 MW, 1/11-31/3, SEK/MWh					
Northern Sweden	148	-	-	148	148
Rest of Sweden	181	-	-	181	181

Note: In addition to these taxes, there is also value-added tax at 25 percent, although not for industry. Boilers, gas turbines and stationary combustion facilities with an annual output of at least 25 GWh pay an environmental charge of SEK 40/kg of NO_x emissions. This charge is repaid in proportion to the energy production and in inverse proportion to the emissions of the plant concerned. The tax on nuclear power is based on the thermal output power of the reactors: under certain defined operating conditions, this is intended to be equivalent to a tax of 27 SEK/MWh on the electrical output. In addition, nuclear power pays 1,5 SEK/MWh as a levy for disposal of the earlier nuclear research activities and facilities at Studsvik and an average of 10 SEK/MWh for financing future disposal of spent nuclear fuel.

1) Fuels used for electricity production are exempt from energy and carbon dioxide tax, but are subject to sulphur tax. Fossil fuels for heat production in CHP plant pay half the rate of energy tax and full carbon dioxide and sulphur taxes. Biofuels are free of tax for all users.

2) Aviation fuel is not directly taxed. Domestic air traffic, however, is taxed through the Swedish Civil Aviation Administration's environmentally-related airport handling charges and passenger fees.

Source: The Tax Administration and our own calculations.

Table 10.9 Energy and environmental taxes for industry, agriculture, forestry and fisheries from 1st January 2001, excluding value-added tax.

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Tax, SEK/ MWh
Gas oil, SEK/m^3	0	534	-	534	54
Heavy fuel oil, SEK/m^3	0	534	108	642	59
Coal, SEK/tonne	0	465	150	615	81
LPG, SEK/tonne	0	562	-	562	44
Natural gas, SEK/1000 m^3	0	400	-	400	41
Crude tall oil, SEK/m^3	534	-	-	534	53
Peat, SEK/tonne, 45 % moisture content (0,24 % sulphur)	-	-	40	40	15

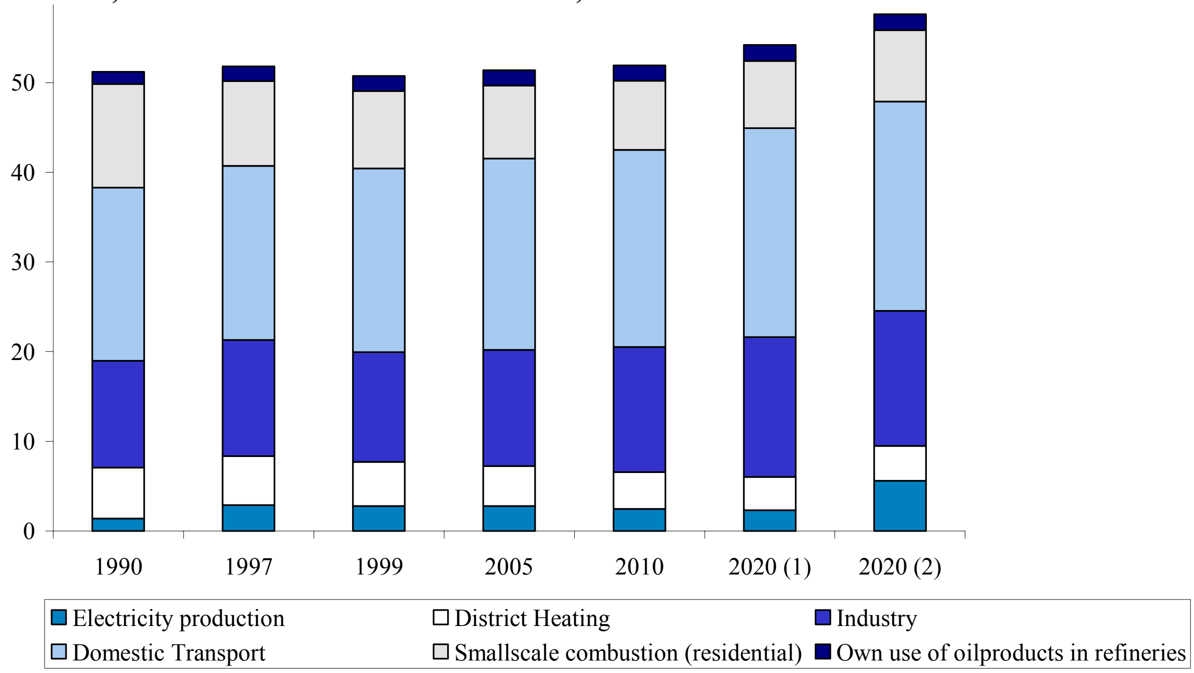
Note: When purchasing heat, industry can reclaim the energy tax and 65 percent of the carbon dioxide tax on the fuels used for producing the heat.

Source: The Tax Administration and our own calculations.

10.3 Carbon dioxide emissions in the scenarios

The scenario calculation shows that carbon dioxide emissions up to 2010 will be essentially unchanged. During the second part of the scenario period, from 2010 to 2020, it is calculated that emissions will increase by almost 5 percent in the unchanged electricity prices case, and by over 11 percent when electricity prices start to rise as a result of the phase-out of nuclear power production and the need to build new power production facilities. The scenarios are based on 1997 as the reference year. The figures do not include emissions from foreign maritime transport or air traffic, which are dealt with separately.

Figure 10.3 Carbon dioxide emissions from the energy sector in 1990, 1997 and 1999, with scenarios for 2010 and 2020, million tonnes carbon dioxide.



Carbon dioxide emissions until 2010

Carbon dioxide emissions until 2010 are cacluculated to be essentially unchanged, although there will be differences between sectors, with emissions increasing in the transport and industry sectors, but decreasing from district heating production and in connection with the use of energy in the residential sector. Emissions from electricity production will also decline up to 2010.

The industry and transport sectors exhibit a clear relationship between energy use and the expected growth of the economy. Although biofuels will increase relatively much within the industrial sector, the use of fossil fuels will also increase, resulting in increased carbon dioxide emissions. The emissions from the transport sector in 2020 come from the use of fossil fuels, although increasing use may be made of alternative motor fuels in certain defined sectors, such as for public transport in urban areas.

The use of oil in the residential sector will be replaced primarily by increased use of district heating and electricity and, to some extent, by greater use of heat pumps.

The proportion of biofuels used for district heating production is expected to increase to over 60 percent of the total fuel input to the sector in 2010. Electricity production will see an increase in wind power production, biofuelled CHP production and small-scale hydro power. In addition, a net import of about 4 TWh of electricity is expected.

Carbon dioxide emissions, 2010-2020, Alternative 1

This scenario foresees reinvestments in the nuclear power plants, with continued operation on commercial terms, resulting in an increase of somewhat less than 5 percent in carbon dioxide emissions between 2010 and 2020. The overall emission trend will continue in approximately the same way as for the period up to 2010, with emissions increasing in the transport and industry sectors and reducing in connection with district heating production and the supply of energy to residential buildings. Emissions from electricity production will fall slightly.

The proportion of biofuels used for district heating production will continue to rise, while the residential sector will show an increase in the use of wood fuels, heat pumps and district heating. However, the use of district heating is not expected to increase to the same extent as during the previous period. Wind power production is expected to increase, as is biofuelled CHP production. Imports are restricted to 4 TWh, and it should not be necessary to build any new fossil-fuelled electricity production capacity.

Carbon dioxide emissions, 2010-2020, Alternative 2

The 40 year-life scenario for nuclear power foresees an increase of over 11 percent in emissions, with significant increases from the electricity production sector, amounting to over a doubling of emissions by 2010.

In 2020, production from the nuclear power stations would amount to approximately 41 TWh, which can be compared with almost 64 TWh in the reinvestment scenario. Five reactors would be closed, in 2012, 2014, 2015, 2016 and 2020 respectively.

To make up the loss of nuclear power production, it is assumed that it would be primarily land-based wind power and biofuelled power production that would continue to increase. Next in order would be offshore wind power and natural gas-based electricity production. Again, the importation of electricity in this scenario alternative is limited to 4 TWh in 2020.

Table 10.10 Carbon dioxide emissions by sectors, 1990, 1997, 1999 and scenarios to 2020, million tonnes

	1990	Base year 1997	1999	2005	2010	2020(1)	2020(2)	1997-2010 %	2010-2020(1) %	2010-2020(2) %
Electricity production	1,4	2,9	2,8	2,8	2,5	2,3	5,6	-14	-5	127
District heating	5,7	5,5	4,9	4,4	4,1	3,7	3,9	-25	-10	-5
Industry	11,9	12,9	12,2	13,0	14,0	15,6	15,1	8	12	8
Transport, excl. foreign maritime and air transport	19,3	19,4	20,5	21,3	22,0	23,3	23,3	13	6	6
Residential, service etc. (small-scale combustion)	11,6	9,5	8,6	8,1	7,7	7,5	8,0	-19	-3	3
Refinery fuels	1,4	1,7	1,7	1,7	1,7	1,8	1,8	4	3	3
Total	**51,2**	**51,8**	**50,7**	**51,4**	**51,9**	**54,2**	**57,6**	**0,2**	**4,4**	**11**
Total in accordance with Statistics Sweden[1)]	51,3	52,1	51,7							
Foreign maritime transport	2,2	4,3	4,8	5,2	5,6	6,6	6,6			
Foreign air transport	1,8	1,9	2,2	2,6	2,9	3,6	3,6			

1) Excluding diffuse emissions.

Note. 1. To some extent, the Administration's calculations for carbon dioxide emissions for 1990, 1997 and 1999 differ from those prepared by Statistics Sweden in conjunction with the Environmental Protection Agency. These differences consist partly of how fuel usage is distributed between the sectors, and also on the use of different statistical sources (statistics are updated from 'Preliminary' to 'Definitive'). The energy statistics for 1999 are preliminary, which can explain why the difference for this year is greater.

Note. 2. Due to rounding up or down, totals do not always agree exactly with the sums of the individual amounts.

The significance of gas price

The assumption concerning the price of gas is important in deciding what new power production facilities will be brought on line. The scenarios foresee a relatively high price of gas in 2020. If a lower gas price would be assumed, offshore wind power would have difficulty in competing with new natural gas-fired combined cycle cold condensing power production, which would result in higher carbon dioxide emissions.

Effects of the higher electricity price on electricity use

The price of electricity rises when more expensive production capacity is brought on line, which would therefore somewhat reduce the use of electricity in industry and the residential sector. In industry, it is particularly the most electricity-intensive sectors which could be expected to cut back production or transfer it to cheaper countries overseas. Although this would affect primarily the use of electricity, it would also have some effect on fossil fuels and district heating, both of which would be somewhat reduced. The residential sector would see some change from the use of electricity for heating to greater use of oil. The use of heat pumps would also decline, while there would be some increase in the use of wood fuels. There would also be a decline in the production of district heating from heat pumps in comparison with the situation in the lower electricity price scenario. The reduced production of heat from heat pumps in the district heating sector would be replaced primarily by greater use of biofuels.

Emissions after 2020

In the 40 year-life nuclear power scenario, the remaining nuclear capacity would be closed down between 2020 and 2025. If this loss of nuclear power production was replaced by fossil-fuelled electricity production, there would be substantial increases in carbon dioxide emissions.

Substantial increase in renewable energy sources

The scenarios foresee the use of biofuels increasing from 90 TWh in 1997 to about 130 TWh in 2020, which would help to keep down the increase in carbon dioxide emissions. Most of the biofuels would be used for district heating production, which is an effect of the structure of the taxation system.

More use would also be made of biofuels for electricity production in CHP plant. At the same time, wind power production would increase, small-scale hydro power production would be expanded and there would be improvements in the efficiency of the existing large hydro power stations. Together, these points would result in greater use of renewable energy sources for electricity production, with a particular increase in wind power production when the nuclear power plants are shut down after 40 years' operation.

This development is sensitive to the support provided for renewable electricity production, and which has been assumed in the scenarios. In absolute terms, this support has been assumed to be 150 SEK/MWh. A system of trading in certificates for electricity from renewable energy sources is being investigated at present: the price of certificates (support for electricity from renewable energy sources) will depend on the requirements in respect of the total proportion of electricity from renewable energy sources. In addition, it will vary with time, not only in terms of short-term variations, but also in terms of longer term price changes.

The need for support would be less in a situation in which the future electricity price rises and production cost falls, which would tend to reduce the price of the certificates with time. However, it is too complicated in the scenario calculations to attempt to allow for short-term and long-term price variations, and so a support of 150 SEK/MWh has been assumed for the entire scenario period.

A higher level of support than as assumed in the calculations would not have much effect on the scenario results, as there are already significant quantities of electricity from renewable energy sources. Even if the level of support was higher, there are circumstances that limit how much electricity can be supplied from renewable sources. Wind power, for example, is limited by the availability of other power that can be regulated at a reasonable cost, and by how the quantity of power that can be transmitted over the grid without requiring substantial grid reinforcements. At the same time, the rate of expansion of wind power is restricted by the inertia in the present-day planning and permission process. Electricity production in biofuelled CHP plant is limited by the size of the heat sink, while small-scale hydro power production is limited by the number of mini power stations that can be built.

A lower level of support would affect primarily offshore wind power production, as this costs more than the other alternatives. Offshore wind power production comes into the picture when electricity prices rise (Alternative 2). On the basis of present-day cost calculations, a lower level of support could be expected to result in the construction of natural-gas fired combined cycle cold condensing plant rather than of offshore wind production capacity. The level of the price of gas also affects the cost relationships between the two forms of power production.

Sensitivity analyses using the MARKAL model[82] indicate that a reduction in the support from 150 SEK/MWh to 100 SEK/MWh would have relatively little effect on the country's electricity production system. By 2010, there would be somewhat less land-based wind power production, but there would be no effect on the scenario calculations for 2020.

[82] There are several dimensions of the function of an electricity production certificate trading system that MARKAL is incapable of describing. In reality, the certificate price level would be affected by investors' expectations of the certificate system, such as long-termism, how much of the particular production will be required, a change in the price of certificates with time, and technical development. MARKAL does not consider these uncertainties, as the model is based on a perfect overview of the future, which means that it is necessary to be careful when interpreting its results. For a more detailed description of the sensitivity calculations, see the 'Calculations with MARKAL - Material for the Swedish Energy Agency's Climate Report 2001' report, ER 15:2001.

If, on the other hand, the amount of support was reduced to 50 SEK/MWh, the effects would be greater. 2010 would see a loss of 7 TWh of electricity production from renewable energy sources in the 40 year-life nuclear reactor scenario, or a loss of 5 TWh in the continued operation scenario. The biggest difference would be that no new wind power production capacity would be built. Most of the loss of production capacity would be made up by an increase in the import of electricity and production in natural gas-fired combined cycle cold condensing plant. Similarly, there would be no introduction of offshore wind power in 2020 at this level of support in the 40 year-life scenario: instead, production in natural gas-fired combined cycle cold condensing plant would be increased. In the continued nuclear power production scenario, offshore wind power would not be built at any of the support levels.

What this says is that the effect of the lower levels of support would be less in 2020 than it would be in 2010, due to the fact that the price of electricity would have risen, so that less support would be needed to make renewable power production profitable. This applies particularly in the 40 year-life scenario.

The sensitivity analysis shows that a higher level of support would not have any noticeable effect on the scenario results while, in the other direction, the level of support would have to be considerably less before it caused any greater changes in the electricity production system. Another uncertainty in the scenario results is how the market will react to a certificates trading system. It is uncertain how the market will react in the short term in particular. In the longer term, it is assumed that the system would have become established, and that there would be more construction of new production capacity. In addition, another condition for a substantial expansion of electricity production from renewable energy sources is that the present inertia in the processing of applications should be reduced.

Import of electricity

The scenarios have limited the import of electricity. It is assumed that the northern European electricity market is in balance, which means that production capacity would be appropriate to demand, thus reducing the amount of power available for importation. In addition, net imports are further restricted by the fact that some of the cross-border links must be reserved for importation to Sweden and Norway during dry years. In addition, it is assumed that new production capacity would be built in Sweden.

The scenarios expect a net import of between 4 and 6 TWh. This electricity would not be produced in Sweden, and would therefore not affect Swedish emissions of carbon dioxide, but it would affect emissions in the country in which the electricity is produced. However, the magnitude of these emissions depends on in what country the electricity is produced.

In order to illustrate the importance of this importation on carbon dioxide emissions in Sweden, we have calculated the effect of a net zero import in 2020. Instead, the 4 TWh that would previously been imported is assumed to be produced in natural gas-fired power plants, which would increase carbon dioxide emissions by 1.4 million tonnes.

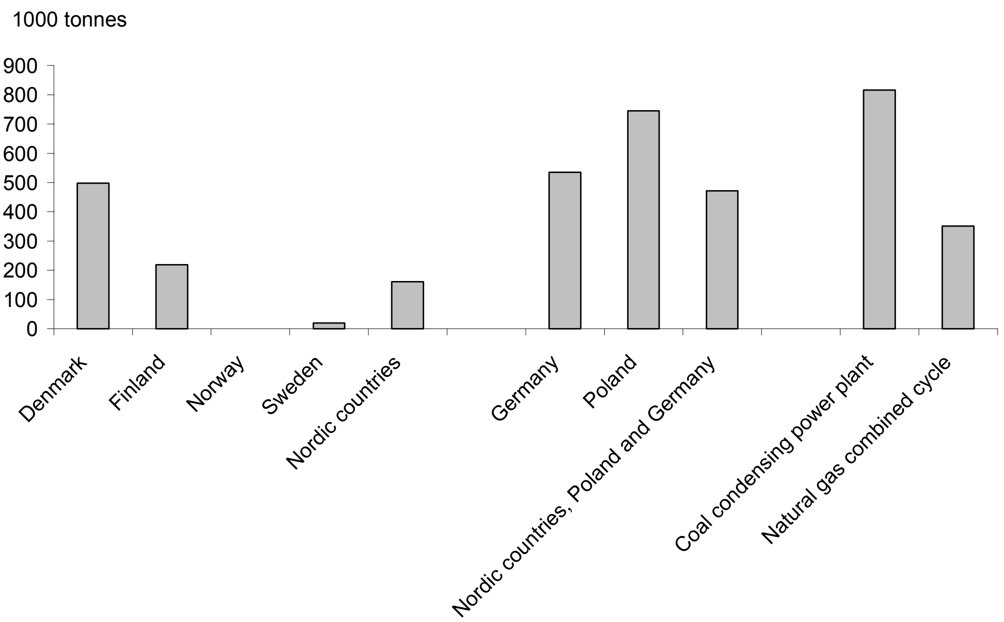
Sweden has cross-border links for electricity with Denmark, Germany, Finland, Norway and Poland. In general, it can be assumed that electricity in the northern European electricity market is produced in the plants having the lowest production costs. At any given time, producers in countries with low production costs will be exporting to countries with higher production costs.

The cross-border flows of electricity in northern Europe are affected by weather conditions. Norway and Sweden have high proportions of electrically heated buildings, which means that their electricity demand increases substantially during cold periods.

The amount of precipitation also has a considerable effect on cross-border electricity flows. In dry years, production capacity in the Swedish and Norwegian hydro power plants is reduced, thus increasing the demand for imported electricity, which then flows from countries with a higher proportion of thermal power production. This situation is reversed during wet years.

Figure 10.4 shows the average emissions of carbon dioxide per TWh of electricity in Sweden and in the countries that can export electricity to Sweden. It also shows the emissions per TWh of electricity for the other Nordic countries and for Germany and Poland. These emission levels have been calculated by dividing emissions from the electricity production sector by the total electricity production in each country. The figure also shows emissions per TWh of electricity from coal-fired cold condensing and natural gas-fired combined cycle plant.

Figure 10.4 Average emissions of carbon dioxide per TWh of electricity, 1997, and emissions from the production of 1 TWh of electricity in coal-fired cold condensing and natural gas-fired combined cycle plant.



Note. In the above diagram, 'Nordic countries' do not include Sweden.
Source: Our own calculations and statistics from IEA, Electricity Information. The figures for Sweden are taken solely from our own calculations.

10.4 Energy balance

Energy use

During the 1990s, total final energy use increased by over 5 percent between 1997 and 2010, final energy use is expected to increase by over 8 percent. Final energy use in the second forecast period, from 2010 to 2020, is expected to continue to increase. Energy use in the transport and industry sectors will increase by more than in the residential and service sector.

The use of electricity differs in 2020, depending on the make-up of the electricity production system. In Alternative 2, the price of electricity is higher, which affects its use in industry and the residential sector. See also Sections 10.7 and 10.8.

The total energy use figure includes distribution and conversion losses, together with the losses in the nuclear power stations. This means that total use varies considerably between the two alternatives. In the 40-year life scenario (Alternative 2) total energy use is lower. Total energy use between 1997 and 2020 would increase by over 11 percent in scenario 1, and by 4 percent in scenario 2.

Energy supply

In the same way as for total energy use, total energy supply is also affected by the magnitude of nuclear power production, as the losses in the nuclear power plants are so large. The supply of fuels increases in both scenarios, of which a couple of effects are that transport work would increase and there would be a greater proportion of thermal power production due to a cutback of nuclear power production.

The supply of oil would continue to increase during the period, with the greatest increase occurring in the transport sector. The scenarios also expect natural gas supply to increase: about 30 TWh of natural gas can be used in Sweden without having to expand the main distribution system. Natural gas-fired power production would come into the picture in Alternative 2, in which some nuclear reactors would be closed by 2020. This would result in a very substantial increase in the supply of natural gas, amounting to 24 TWh in 2020, i.e. still within the capacity of the existing trunk distribution system. A significant quantity of wind power is also expected to replace the loss of nuclear power production.

The assumption concerning the price of natural gas in 2020 affects the corresponding calculation of by how much its use would increase. If the price is below that used in the scenarios, demand would increase in both the industry sector and for electricity production. If this occurred, it would be necessary to expand the capacity of the trunk distribution system.

The supply of biofuels increases considerably during the scenario period, as a result of the fact that they would be increasingly used for electricity and district heating production. With the assumption of a unified support system for electricity from renewable energy sources, in conjunction with present tax rules, it would become very profitable to use more biofuels in the supply sector. The total supply of biofuels lies within the framework of potential supply forecasts for Sweden. Biofuels can also be imported. The entry for biofuels, peat etc. does not include refuse or black liquors. The scenarios expect the proportion of fuel used for energy supply to increase, while the proportion of heat declines[83]. The proportion of refuse used for fuel is assumed to increase as a result of the ban on disposing of combustible refuse in landfill with effect from 2002.

Table 10.11 Energy supply, 1990–2020, TWh and per cent.

	1990	1997 base year	1999	2005	2010	2020 alt. 1	2020 alt. 2	Development, 1997-2020, alt.1 %	Development, 1997-2020, alt.2 %
Use:									
Final energy use	365	382	384	400	415	435	432	14	13
Of which:									
Industry	140	153	153	162	172	183	178	20	17
Transport	75	76	80	84	86	91	91	19	19
Residential, service etc.	150	153	151	154	157	161	162	5	6
Foreign maritime transport	15	23	26	29	32	38	38	65	65
Non-energy purposes	29	22	18	20	22	27	27	24	24
Distribution and conversion losses	175	189	198	183	184	188	144	-1	-24
of which in nuclear power production	139	145	152	138	138	138	89	-5	-38
Total use	583	616	625	632	653	688	641	12	4
Supply:									
Total fuel supply	298	327	326	345	363	398	417	22	27
Of which:									
Oil products	195	201	199	207	213	232	234	15	16
Natural gas and town gas	7	9	10	8	9	9	24	4	171
Coal and coke	30	27	26	27	27	27	27	2	0
Biofuels, peat m.m.	67	90	91	102	114	129	132	42	46
Waste heat, heat pumps	8	9	10	9	9	9	7	2,0	-18
Hydro power, gross	73	70	72	68	70	71	72	1	3
Nuclear power, gross	206	213	224	203	203	203	132	-5,0	-38
Wind power, gross	0	0	0	1	4	4	10		
Import/export of electricity	-2	-3	-7	7	4	4	4		
Total supply	583	616	625	632	653	688	641	12	4

1) Thermal energy from the reactor, in accordance with the UN/ECE method.
2) Excluding electricity contribution.
Source: Statistics Sweden and our own calculations

[83] The use of peat is associated with a relatively high emission factor in the emission calculations, amounting to 107 gram CO_2/TJ.

10.5 Electricity supply

The supply of electricity is expected to increase by about 10 TWh, or by 7 percent, between 1997 and 2010. The increase during the 1990s has not been as great as this: between 1990 and 1999, electricity use increased by somewhat over 2 percent. This can be explained by the recession at the beginning of the 1990s which resulted in electricity use stagnating and, during certain years, actually declining. It is expected that electricity use will continue to increase for the scenario period up to 2020.

Two different alternatives have been calculated for the period from 2010 to 2020, due to uncertainty concerning the future of nuclear power production. In the one case (Alternative 1) nuclear power production is foreseen as being continued for as long as it is economically viable, while in the second case (Alternative 2) it is foreseen as being phased out as the reactors reach an age of 40 years. The first alternative assumes that, at appropriate times, reinvestments would be made in order to renovate the reactors and power stations, and we have therefore assessed likely costs for such reinvestments. Continued operation of nuclear power production affects both the production mix in the country's power system and the price of electricity.

Both scenario alternatives foresee a continuing increase in the use of electricity, although Alternative 2 expects several reactors to be closed before 2020. All told, this is expected to result in an increased demand for production capacity. Just how this additional capacity would be provided is difficult to assess: although it could be affected by future technological development, the scenarios for the period up to 2020 have assumed that only technologies that are relatively well established today would be included. This therefore includes certain steam and gas turbine processes, together with wind power. Section 10.10 describes the technologies that might achieve a commercial breakthrough during the period.

When and how new production capacity enters the electricity market will depend on the demand for electricity, electricity prices and the taxation system. Other forms of support, such as investment supports and operational subsidies, also affect the situation. Both scenarios foresee an increase in the demand for electricity, which will mean that increasingly expensive forms of production in the existing system will be utilised. It might finally be necessary to build new power stations, which would result in higher electricity prices.

Electricity supply today

Today, most electricity in Sweden is produced from hydro power or nuclear power, with only a smaller amount produced by thermal power.

Statistically average production from the Swedish *hydro power plants* varies, depending on on which set of statistics the actual energy production volume is based. Previously, using climate statistics from 1950-1996, the normal year production for hydro power was calculated as 64.2 TWh. However, in the light of the substantial precipitation in recent years, it may be necessary to revise this figure somewhat. Nevertheless, further investigation is required in order to be able to arrive at a new figure for normal year production from the Swedish hydro power plants. The scenarios have used a preliminary value of just over 65 TWh for this normal year production.

Normal year hydro power production provides about 45 percent of Sweden's present-day total electricity production. It can vary significantly from one year to another, as inflow to the reservoirs varies during the year and from year to year. During dry years, hydro power production can be 10-15 TWh lower than during a normal year, with the situation being reversed during wet years. Apart from 1996, inflow to the reservoirs has been higher than normal throughout the 1990s.

Although the installed capacity of *wind power plants* has increased substantially over the last ten years, it still made up only about 0.8 percent of total installed capacity in 2000. Technical development in wind power technology has resulted in lower production costs, larger units and improved supply of electricity to the grid.

At present, the production capacity from the Swedish *nuclear power plants* is somewhat over 68 TWh, provided that no production is lost due to unplanned shutdowns[84].

Conventional thermal power is based on the combustion of various fuels, powering either steam or gas turbine processes. Fuels used are coal, oil, natural gas, peat, other biofuels and refuse. During the base year of 1997, the fuel that was most used, in conventional thermal power plants, was oil, followed by biofuels and coal.

The Nordic countries have a long tradition of *cross-border power exchanges*. In recent years, this has been formalised into a Nordic power market with a common trading exchange in the form of Nord Pool. At any given time, utilities in

[84] Production losses are defined as being either availability-dependent or non-availability-dependent. Availability-dependent production losses are such as those due to regular testing, faults and annual overhauls. Non-availability-dependent losses are those caused by coastdown, output reductions, higher cooling water temperatures and external faults.

countries having low production costs export to other countries with higher production costs. Power flows vary over the year, the week and the day.

An important element of power exchanges between Sweden, Norway, Denmark and Finland is to balance temporary surpluses or deficits of electricity. This means that the power flows vary during the year, and from one year to another, due to such causes as temperature, precipitation and economic conditions. During years with normal precipitation, both Norway and Sweden depend on imports of electricity at certain times of the year.

With the exception of the dry years of 1994 and 1996, Sweden has been a net exporter of electricity to its neighbouring countries throughout the 1990s. However, this situation changed in 2000, when the country had a net import of 7.5 TWh of electricity, mainly due to good availability of cheap hydro power in Norway and Sweden. Thermal power plants have difficulty in competing with hydro power, as the Nordic countries now have a joint electricity market, with production concentrated on those facilities operating at the lowest cost.

Calculation conditions

Support for renewable electricity production

The scenarios include continuation of support for the production of electricity from renewable energy sources. Support is provided for electricity production from biofuels, wind power and for investments and expansion of hydro power.

The amount of the subsidy is 150 SEK/MWh. How a trading system for certificates for electricity from renewable sources might be created is being investigated at present. The price of the certificates (support for electricity from renewable energy sources) will depend on the quotas set for the required total proportion of renewable electricity in the system, and will vary with time. The scenarios have assumed a figure of 150 SEK/MWh throughout the scenario periods.

Nuclear power

Both scenarios have assumed that the second Barsebäck reactor would be shut down before 2005, which would reduce the country's production capacity by somewhat over 4 TWh. For the other reactors, Alternative 1 assumes that appropriate reinvestments would be made, to extend their operating lives. Alternative 2 assumes a life of 40 years. Table 10.12 shows the installed capacities of the nuclear power stations, their dates of commissioning and when they would be due for closure at the end of a 40-year life.

Table 10.12. Outputs, year of start-up and year of closure of the Swedish nuclear power stations after a 40-year life.

Reactor	Start-up year	Date of closure after 40 years operation time	Output (MW)
Barsebäck 2	1977	Before 2005	600
Oskarshamn 1	1972	2012	445
Oskarshamn 2	1974	2014	605
Oskarshamn 3	1985	2025	1 160
Ringhals 1	1976	2016	835
Ringhals 2	1975	2015	875
Ringhals 3	1981	2021	918
Ringhals 4	1983	2023	923
Forsmark 1	1980	2020	968
Forsmark 2	1981	2021	969
Forsmark 3	1985	2025	1 158

Reinvestment costs for continued operation of nuclear power production

It is not possible to put an exact figure on the future costs of extending the technical life of the country's nuclear power stations, as this will depend on such factors as the operating conditions, safety requirements and the power rating of the reactors.

The power utilities have given their views on the possible lives of the power stations in a report to the Energy Commission, with the report including presentation of various economic considerations[85]. The report notes that, between 1983 and 1994, the average cost per reactor has been of the order of SEK 200 million/year. Bearing in mind the fact that requirements applicable to the reactors and their operation may become more stringent in the future, the report estimates that this annual cost may increase to about SEK 250 million/year per reactor.

Substantial investments have been made in several nuclear power stations during the latter half of the 1990s[86]. Bearing this in mind, and starting from the various effects of wear and tear that were found during these renovations, it is felt that an investment level of about SEK 300 million/year and reactor would be a reasonable assumption for use in the scenario calculations. This rate of investment represents a requirement of 40 SEK/MWh on the electricity produced. Today, the total

[85] The life of the Swedish nuclear power stations, January 1995.
[86] See Appendix 6, 'Reinvestment requirements in the nuclear reactors'.

production cost of electricity in the nuclear power stations, i.e. including both fixed and variable costs, is between 17 and 19 SEK/MWh.

Combined heat and power production

As the demand for electricity rises, it becomes necessary to bring increasingly expensive production facilities on line, before finally having to build new production capacity, both of which factors result in higher electricity prices. The scenarios expect utilisation of existing CHP capacity to increase: in addition, new district heating production capacity and CHP capacity will be built.

Just when and how new CHP production capacity will be brought on line depends on changes in electricity use, the price of electricity, the taxation system (including any other forms of subsidies) and the demand for heat. In addition, the classic factor simply of the age of the existing plant also affects when new plant is required. The economic viability of CHP production is greatest in those cases where the choice lies between investing a new heat-only production capacity or in CHP.

Import and export of electricity

There is at present a relatively substantial excess production capacity in Sweden's neighbouring countries, particularly in Denmark and Germany. However, in the longer term, this surplus capacity can be expected to be reduced as a result of competition on the electricity market, which will have the effect of reducing surplus capacity in Sweden's neighbouring countries. In the longer term, this will mean that it will become more difficult to import power.

Assuming a 'business as usual' approach in the scenarios for the period up to 2020, it is assumed that new power production capacity would be built in Sweden. On the other hand, a different set of circumstances would arise if the production capacity was built elsewhere and the electricity transported between the various countries. The utilities would then need to strengthen their cross-border links in order to be able to market power in Sweden. However, for this situation to be viable, it would necessary for the costs of building and operating new production capacity to differ quite considerably from one country to another. In addition, the construction of links between Sweden and other countries would require permission from the Government.

Political and environmental restrictions in Sweden could also result in new production capacity being constructed in other countries, with the power then being supplied to Sweden via upgraded links. The scenario calculations have been based on the assumption that energy and environmental policies in the Nordic countries would be as they are now, i.e. in terms of taxes, fees and other regulations etc. In addition, it is assumed that, as now, some of the trading in electricity would continue to be for system regulation purposes. This means that a certain amount of cross-border capacity must be available in order to deal with any temporary power surpluses or deficits. Just how large the net imports of power could be during a normal year depends primarily on how Sweden and Norway can deal with one or more dry years: some of the cross-border capacity must be reserved for power imports to Sweden and Norway during dry years. The scenario calculations have assumed a maximum normal-year import of power of 7 TWh in 2010. In addition, this assumes that there would still be a certain degree of capacity available in the system as a whole, i.e. in the whole of the Nordic countries. For 2020, the calculations assume a maximum net import of 4 TWh. As the system as a whole is assumed to be in balance in 2020, this means that, as a net importer, Sweden would be suffering from a shortfall of production capacity within the country.

Development until 2010

Development until 2010 is expected to be the same, regardless of which alternative for nuclear power production is assumed.

Sometime before 2005, electricity production capacity from the country's nuclear power stations is expected to be reduced by about 4 TWh, as a result of the closure of Barsebäck 2. The other reactors would remain in operation until 2010: even with the 40 year-life scenario, the first reactor would not be due for closure until 2012.

The results of the calculations show that the actual net importation requirement in 2010 would be less than the 7 TWh limit that has been assumed (see above). This can be explained by the fact that electricity production from renewable energy sources is expected to become increasingly viable: biofuelled CHP production and wind power are assumed to qualify for the operational subsidy for electricity from renewable sources, which have the effect of reducing their costs.

It is expected that thermal power production would increase, particularly in CHP plant. In 1997 fossil fuels, i.e. oil, coal and natural gas, provided over 70 percent of the fuel input for electricity production, with biofuels providing 28 percent. By 2020, it is expected that the proportion of biofuels used for thermal power production would have increased to 46 percent, with fossil fuels declining to 54 percent.

The subsidy for electricity from renewable sources also makes it possible to improve the efficiency of existing hydro power production capacity and to construct small-scale hydro power stations. Taken together, all this would result in an increase of over 3 TWh in hydro power production capacity during a normal year.

Scenario until 2020, Alternative 1

The assumed costs for reinvestments in nuclear power in Alternative 1 mean that nuclear power production can continue to be profitable. This means that the reactors will therefore continue in operation, thus eliminating the need for new production capacity in the form of, for example, natural gas-fired production or offshore wind power.

It is assumed that electricity production from CHP plant will increase, both in industry and in public district heating systems, with the latter accounting for the greater increase. Increase in the use of district heating improves the scope for CHP production, using the district heating networks as heat sinks, while the financial support for electricity from renewable energy sources makes it viable to invest in biofuelled CHP plant rather than in simple hot water boiler plant. Within industry, increasing industrial output provides increased scope for the production of electricity. Some of the increased industrial electricity production would be due to the 150 SEK/MWh subsidy for electricity from renewable energy sources, which would make it viable to produce electricity from biofuels.

It is expected that the total fuel supply for electricity production would increase as a result of the increasing demand for electricity. Biofuelled production would increase, as it would be supported by the subsidy for electricity from renewable energy sources. This would mean that fossil fuels would provide a reduced proportion of the total fuel quantity used for electricity production. It is expected that, in 2020, the maximum import facility for electricity would be fully utilised.

Scenario until 2020, Alternative 2

The second alternative sees the nuclear power reactors being shut down as they reach an age of 40, resulting in a need for new electricity production capacity. The loss of production capacity from the reactors assumed to be due for shutting down between 2010 and 2020 would amount to over 20 TWh. Several factors influence the choice of type of production capacity coming on to the market, including production costs, possible State subsidies and the overall development of electricity prices.

The 2020 scenario foresees the increased demand for new production capacity being met by increased production from biofuelled CHP plants, wind power plants, hydro power plants and natural gas-fired combined cycle cold condensing plant.

Today, onshore wind power production is a well-established technology. As a result of falling costs, expectations of increasing revenues and the effect of the subsidy system, it is expected that onshore wind power production will expand.

At present, the cost of offshore wind power production is higher, due to the fact that installation is more complicated. This will have the effect of delaying any substantial expansion of offshore wind power, as the price of electricity will have to rise before the technology becomes competitive. For this reason, it is only in Alternative 2 that offshore wind power is expected to expand substantially during the scenario period leading up to 2020.

Alternative 2 sees four reactors (in addition to Barsebäck 2) being shut down before 2020. Although these four reactors are the country's smallest, they would still result in a total power production loss of 2760 MW, increasing the risk of power shortage. A further reactor would be shut down in 2020.

Alternative 2 sees four reactors (in addition to Barsebäck 2) being shut down before 2020. Although these four reactors are the country's smallest, they would still result in a total power production loss of 2760 MW, increasing the risk of power shortage. A further reactor would be shut down in 2020, which would mean that production capacity from the country's nuclear power stations would have fallen to somewhat over 40 TWh by 2020. As the remaining reactors are closed after 2020, there would therefore be a total production loss of over 40 TWh, which would have a serious effect on the country's electricity system.

A high proportion of wind power production in the system would affect the power balance. Just how much production from wind power and other 'uncontrollable' sources the electricity system can accept depends on the availability of correspondingly 'controllable' power production. This is discussed in more detail in the next section, concerning the effect of future electricity production capacity on the country's electricity system.

Natural gas-fired combined cycle condensing plant is expected to make up some of the additional power requirement in this scenario: just how great a proportion this would be depends a lot on the price that is assumed for natural gas.

The scenario analysis assumes relatively substantial rises in the price of natural gas between 2010 and 2020, which would improve conditions for offshore wind power production. It is assumed that in 2020, when the loss of production from nuclear power would be over 20 TWh, that about 6 TWh would be provided by offshore wind power plants. On the other hand, with a lower price of natural gas in 2020, the result would be that more natural gas-fired electricity production capacity would be built.

The remaining reactors would be shut down between 2020 and 2025. With the same assumptions as applying for the 2020 scenarios, it can be expected that fossil-fuelled production capacity would replace the closed nuclear power production capacity after 2020.

Table 10.13 Electricity balance, 1990–2020, TWh and per cent

	1990	Base year 1997	1999	2005	2010	2020 alt. 1	2020 alt. 2	Percentage change 1997-2020 alt. 1	1997-2020 alt. 2
Use									
Total use, net	**139,9**	**142,6**	**143,3**	**148,4**	**152,0**	**158,4**	**153,6**	**11**	**8**
of which:									
Industry	53,0	52,7	54,5	56,7	58,6	62,0	59,2	18	12
Transport	2,5	3,0	3,0	3,1	3,2	3,2	3,2	7	7
Residential, service etc.	65,0	69,6	68,9	71,8	74,2	76,9	75,9	10	9
Supply									
Net production	141,7	145,3	150,8	141,8	147,9	154,3	149,6	6	3
of which:									
Hydro power	71,4	68,2	70,9	66,2	68,6	69,2	70,1	1	3
Wind power	0,0	0,2	0,4	1,4	3,9	4,2	10,5	21 times[1)]	52 times[1)]
Nuclear power	65,2	66,9	70,2	63,6	63,6	63,6	41,3	-5	-38
Industrial CHP	2,6	4,2	3,9	4,5	4,9	5,6	6,4	33	52
Public CHP	2,2	5,3	5,2	6,0	6,8	11,7	13,5	121	156
Cold condensing, fossil fuels	0,2	0,4	0,2	0,1	0,1	0,0	7,9	-100	20 times[1)]
Gas turbines	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
Import/export	-1,8	-2,7	-7,5	6,6	4,2	4,0	4,0		
Total supply, net	**139,9**	**142,6**	**143,3**	**148,4**	**152,0**	**158,4**	**153,6**	**11**	**8**

1)Not a percentage, but the number of times increase of production.

Table 10.13a Fuels used for electricity production, TWh and per cent

	1990	1997	1999	2005	2010	2020 alt 1	2020 alt 2	Development 1997-2020 alt. 1, percent	1997-2020 alt. 2, %
Fuel input:	**7,1**	**13,9**	**13,2**	**14,2**	**15,7**	**22,5**	**38,8**	**62**	**179**
Oils (incl. LPG)	1,8	5,6	5,0	5,1	4,5	4,0	4,4	-29	-22
Natural gas	0,5	0,7	0,6	0,5	0,7	1,0	15,7	40	22 times[1)]
Biofuels, peat etc.	2,5	3,9	3,6	4,6	7,3	14,8	15,5	272	291
Coal (incl blast furnace gas)	2,4	3,7	4,0	3,9	3,2	2,8	3,2	-24	-12

1) Not a percentage, but the number of times increase of production.

The effect on the electricity supply system

The scenario calculations for the period up to 2020 expect changes in the country's installed electricity production capacity. These changes will affect the country's electricity supply system in several ways.

A common element in both scenarios for the period up to 2020 is that Barsebäck 2 would have been shut down before 2005 and that the proportion of electricity supplied by wind power and biofuelled CHP would have increased. However, both these forms of production capacity have a lower utilisation and availability than has nuclear power production. In Alternative 2, which sees nuclear power being phased out after 40 years' operation, the use of wind power production would increase substantially by 2020: there would also be a noticeable increase in the use of natural gas for electricity production.

Electrical energy cannot be stored, but must be produced at the same rate as it is used. In the country's present electricity system, hydro power stations and their reservoirs have been designed in order to be able to change their output quickly in response to changing system load. However, with a significant proportion of production capacity in the form of wind power, a corresponding proportion of power production will depend on wind conditions, which means that production will vary with time. The result of this is that attempting to maintain a balance between production and consumption at all times could become much more difficult. One way of reducing the effect of substantial wind variations is to ensure that the wind power units are built in different parts of the country.

Although there is sufficient reserve capacity in the Nordic power system to meet energy requirements during years with normal precipitation, there is very little surplus capacity, even today, when coping with system load peaks. Even during normal years, Norway and Sweden depend on imports of electricity at certain times of the year. Extremely dry years could see an energy shortage in the Nordic countries, while a longer period of cold weather could result in a substantial power deficit.

The risks of a power shortage in Sweden vary from one area to another. As far as the electricity supply system is concerned, the country is divided up into three areas: northern, central and southern. This division is due to the bottlenecks in the transmission grid, and to the fact that much of the production occurs in the north of the country, while major load occurs in the south. It is therefore particularly southern and central Sweden that are at greatest risk of power shortage.

Both scenarios foresee Barsebäck 2 being shut down before 2005, which will noticeably increase the risk of a power shortage in southern Sweden, thus placing increased reliance on Oskarshamn 1 for maintaining the power balance in the south of the country. In the event of a serious power shortage, power cuts are the only way of maintaining system frequency.

The 40 year-life scenario results in the two smallest reactors, Barsebäck 2 and Oskarshamn 1, being closed first. Although the effect in terms of energy supply would not be too severe, the fact that both these reactors are in the south of the country means that there will be an increased risk of power shortages in the area. A 40 year-life would see Oskarshamn 1 being shut down in 2012. In order to maintain the necessary power balance, there would have to be substantial changes in the Swedish electricity distribution system, either by installing new high-utilisation production plant in the south or by increasing grid capacity from the north.

These first closures would be followed by successive closures of the reactors in the central part of the country, starting in 2014, which would increase the pressure to build new production capacity. All the reactors would be closed by 2025.

The 2020 scenarios foresee the construction of natural gas-fired combined cycle condensing plant. Bearing in mind the structure of the present grid system, they should preferably be sited in the vicinities of the closed nuclear power plants. However, the present natural gas distribution system covers the south-west parts of the country, while the Forsmark and Oskarshamn nuclear power stations are in the east.

The northern European electricity system

Today, Swedish nuclear power is part of the base load production capacity of the northern European electricity system. Base load power production capacity is that which has a high utilisation and a high availability. Today, power is produced in the northern European electricity system in order of merit, i.e. by plant having the lowest production cost. This has resulted in plant having a high production cost being closed because it is not profitable on the present-day electricity market. Much of the closed production capacity is in the form of base load plant, which has had the result that the demand for base load power will increase throughout Europe. The future shutdown of nuclear power production in Sweden and Germany will further increase the demand for new base load power production.

A high proportion of wind power production in the northern European electricity system means that there will be a need for rapid-start standby capacity in order to maintain the power balance when wind power plants cannot produce electricity.

10.6 District heating

District heating is used primarily for heating in residential buildings and commercial and similar premises. A smaller amount (which is also sometimes referred to as back-pressure power) is used in industry. Between 1990 and 1999, use increased by 10 TWh, or 23 percent. Over the same period, the use of biofuels for district heating production increased from 10 TWh to over 26 TWh, while the use of coal as fuel fell from 9 TWh to 3 TWh. The reason for this change is to be found in taxation: biofuels are untaxed, while fossil fuels attract both energy tax and carbon dioxide tax. Between 1990 and 1999, the total tax on coal increased from somewhat over 50 SEK/MWh to over 180 SEK/MWh.

In 1999, 75 percent of the energy input for district heating production was provided by various types of fuels: biofuels accounted for over 50 percent. The remaining energy input came from electric boilers, heat pumps and waste heat. For the sake of comparison, it should be mentioned that oil supplied over 90 percent of the energy input for district heating in 1980.

Scenarios 2010-2020

Increasing use

The use of district heating will increase throughout the scenario period, with the use in 2020 estimated as being 19 percent greater than in 1997. The greatest increase will occur during the first part of the period, in the form of over 6 TWh to the residential sector.

Changes in supply

The greatest change in the supply of district heating is expected to occur in the composition of the input energy sources, with the use of fossil fuels, heat pumps and electric boilers expected to decline in favour of greater use of biofuels.

The use of biofuels is expected to amount to about 40 TWh by 2020, so that they make up over 85 percent of the total fuel input. The price relationships between the various fuels means that it will be profitable throughout the scenario period to use biofuels, the price of which is expected to remain constant while the price of fossil fuels will rise somewhat. In addition to continued substitution of fuels in existing plant, construction of new biofuelled CHP capacity is expected as old hot-water-only boiler plants are decommissioned.

It is expected that the energy input from electric boilers will decline as a result of the higher price of electricity. It is also expected that such boilers will, to some extent, be taken out of service early, as their heat production costs are high. The present generation of heat pumps will be getting quite old, and will require reinvestment to extend their lives, unless they are replaced by new capacity. The viability of heat pumps is affected by the price of electricity. Although the scenarios expect a certain amount of new capacity and reinvestment, the overall contribution of energy supply from heat pumps to district heating is expected to decline.

Table 10.14 District heating energy balance, 1990, 1997 and 1999, with scenarios for 2010 and 2020, TWh

	1990	1997	1999	2005	2010	2020 (1)	2020 (2)	Percentage change 1997-2020 (1) %	Percentage change 1997-2020 (2) %
Use									
Total final use	34,3	41,9	43,3	45,9	48,0	49,9	49,8	19	19
Of which:									
Industrial	3,6	4,3	4,0	4,6	5,0	5,9	5,8	38	36
Residential, service etc.	30,7	37,6	39,3	41,3	43,0	44,0	44,0	17	17
Distribution & conversion losses	6,8	7,9	7,0	6,8	6,7	6,9	7,1	-12	-11
Total use	**41,1**	**49,8**	**50,3**	**52,7**	**54,8**	**56,8**	**56,9**	14	14
Supply									
Fuel:									
Oil, including LPG	4,1	6,1	5,1	4,3	3,6	2,4	2,6	-61	-57
Biofuels	10,4	23,9	24,8	30,3	34,9	39,9	41,9	67	75
Coal, including blast furnace gas	8,2	4,0	3,3	2,8	2,3	1,4	1,5	-65	-62
Natural gas	2,0	3,1	3,2	3,0	2,8	2,5	2,6	-21	-17
Other energy inputs:									
Electric boilers	6,3	1,8	1,5	0,9	0,0	0,0	0,0	-100	-100
Heat pumps	7,1	7,0	7,5	7,2	6,9	6,3	4,0	-10	-43
Waste heat[1]	3,0	3,8	4,8	4,3	4,3	4,3	4,3	13	13
Total supply	**41,1**	**49,8**	**50,3**	**52,7**	**54,8**	**56,8**	**56,9**	14	14

Alt. 1: Nuclear power operated as long as it is viable. An assessment of the necessary reinvestments has been made.

Alt. 2: Nuclear power plant shut down after 40 years.

[1)] Waste heat from industry and the residential, service sector etc.

Note: Due to rounding up or down, total figures may not always agree exactly with the sum of the individual figure.

10.7 Industry

A small number of energy-intensive sectors use more than two-thirds of the total energy used in Swedish industry. They are the pulp and paper industry, the iron and steel industry, other metal-producing industries and the chemical industry. However, despite their high proportion of energy use, their aggregated proportion of total industrial output is considerably less, amounting to less than a quarter, as shown in Table 10.15. The engineering industry is not regarded as energy-intensive, although it does use a considerable quantity of energy in absolute terms due to its high output volume.

Table 10.15 Industrial output value, energy and electricity use, percentages, 1999

	Proportion of output value	Proportion of energy use	Proportion of electricity use
Pulp and paper industry	8	46	41
Iron, steel and metal works	5	16	14
Chemical industry etc.	12	7	13
Engineering industry	49	8	13
Other industry	27	23	19
Total	**100**	**100**	**100**

The energy source used within the individual sectors varies. Coal and coke, for example, are used primarily in the iron and steel industry, where they provide over half of the sector's energy requirement. Biofuels play an important part in the forest products and pulp and paper industries, while oil is used in most sectors and electricity is widely used in all of them. Electricity is the single largest energy carrier in the metals, chemicals, engineering and mining industries. The pulp and paper industry uses the most electricity in comparison with other sectors, whether regarded in absolute terms or in relation to the industry output.

In the short term, it is production volumes that determine energy use in industry, and this is particularly the case in the energy-intensive sectors. In the longer term, total energy use in industry is affected by several factors, such as technical development, energy prices and structural changes.

Development during the 1990s

Output

Industrial output fell substantially during the severe recession through which Sweden passed at the beginning of the 1990s, with output cutbacks occurring to a greater or lesser degree in all sectors. Between 1989 and 1992, total industrial output value fell by over 10 percent. Output in the pulp and paper industry fell by 3.3 percent, and in the iron and steel industry by 15 percent, with both industries being important in terms of the country's energy use. However, the downward trend was reversed in 1993/1994, with output rising sharply in several of the sectors of importance for energy use. Not only the iron and steel industry, but also the pulp and paper industry, increased output from the middle of the 1990s. The greatest increase in output occurred in the engineering industry: between 1993 and 1999, industrial output increased by 7 percent per annum on average, which can be compared with an annual decline of 3.5 percent between 1990 and 1993.

Energy use

As, in the short term, energy use is very dependent on output, it fell substantially during the beginning of the 1990s: between 1989 and 1992, total energy use declined by over 12 TWh, or by more than 8 percent. Although much of this can be ascribed to the general fall in manufacturing output, there were also other factors that affected both energy use and its composition. In 1991, Sweden was the first country in the world to introduce a carbon dioxide tax, which substantially cut the use of fossil fuels. Although the tax was reduced for industry in 1993, it was raised again in 1996. During this period, the pattern of oil use reflected quite well the taxation levels in industry. See also Appendix 7, Sensitivity Analyses.

Several energy-intensive sectors substantially increased their output in 1994, which immediately affected energy use. Between 1994 and 1999, total energy use rose by about 6 percent. Although the use of oil also rose in parallel with the increases in output, it was still lower than during the 1970s-1980s, despite a higher level of output. The use of electricity paralleled the total use of energy, rising by about 9 percent between 1993 and 1999. It should also be mentioned that the use of biofuels increased by over 21 percent between 1990 and 1999. There was a similar development for natural gas.

Calculation conditions and assumptions

The average annual growth rate of industrial output value is expected to rise by 2.3 percent until 2010, and then by 2.1 percent until 2020, with the greatest growth occurring in the engineering industry, being 3.3 percent and 2.9 percent respectively over the two periods.

Table 10.16 Industrial output value and average annual percentage change, 1990 and 1997, and scenario calculations for 2010 and 2020, SEK x 10^9

	1990	%	1997 Base year	2010 scenario	2020 scenario	1997-2010 %	2010-2020 %
Mining	10,8	-4,6	10,3	11,1	11,1	7,8	0,0
Foodstuffs	104,5	3,8	108,5	112,8	118,6	4,0	5,1
Clothing	13,7	-16,8	11,4	11,6	12,0	1,8	3,4
Forest products	50,0	-6,0	47,0	51,5	55,2	9,6	7,2
Pulp and paper	71,0	11,7	79,3	97,5	104,5	23,0	7,2
Graphical	51,9	-2,3	50,7	60,8	62,6	19,9	3,0
Chemical	95,1	25,7	119,5	158,6	185,0	32,7	16,6
Petrochemical	25,9	10,0	28,5	30,0	34,8	5,3	16,0
Quarrying	22,9	-31,4	15,7	17,0	18,0	8,3	5,9
Iron and steel	40,5	21,7	49,3	61,7	71,3	25,2	15,6
Other metals	16,2	1,2	16,4	19,4	21,4	18,3	10,3
Engineering	327,5	45,5	476,5	730,9	977,4	53,4	33,7
Other industry	23,7	11,4	26,4	26,9	29,8	1,9	10,8
Total industry	**827,1**	**22,2**	**1 011,0**	**1 359,8**	**1667,0**	**34,5**	**22,6**

Note: Development between 2010 and 2020 is based on Alternative 1.
Source: The National Institute of Economic Research and Statistics Sweden.

It is assumed that energy taxation rates and policies as of 1st January 2001 will apply throughout the period under investigation (see Section 10.2). In addition to the general reduction rules for taxation of industry, there are two further rules, the 0.8 percent and 1.2 percent rules[87]. The latter applies only to manufacturers of cement, lime, glass and stone, and means that carbon dioxide tax that exceeds 1.2 percent of the products' sales value is refunded. The 0.8 percent rules means that all companies whose carbon dioxide tax exceeds 0.8 percent of sales value receive a further reduction. The amount of taxation revenue that exceeds these limit values amounts to about 12.5 percent of the general carbon dioxide tax[88].

In addition to the general level of business in the individual sectors, energy use also depends on structural changes in industry and on improvements in the efficiency of energy use. It is assumed that these improvements occur mainly in connection with investments in new production capacity, involving new technology, although there will also be a steady rate of improvement in connection with reinvestments and improvements of existing production facilities. The rates of growth in the various sectors will result in continued structural change. The proportion of total industrial output generated by the energy-intensive sectors is very important in determining specific energy use in

[87] The 1.2 % rule is due to expire on 31st December 2002. No time limit has been set for the 0.8 % rule.

[88] This is an underestimate as far as diesel fuel and LPG are concerned. These fuels will be taxed at a higher percentage rate as a result of the EU Mineral Oils Directives 92/81/EEC and 92/82/EEC.

industry as a whole. It is expected that the proportion of total output value generated by these sectors will fall throughout the scenario period. This means that restructuring and improvements in the efficiency of energy use will result in a steady reduction in specific energy use for industry as a whole.

Scenario to 2010

The 2010 scenario expects the use of energy in industry to increase from 153 TWh to almost 172 TWh, or by 12 percent. This is accompanied by an increase of over 34 percent in industrial output, which means that specific energy use is expected to decline by 16 percent over the whole period, and specific use of electricity by more than 17 percent.

The changes in energy use will differ from one sector to another. Table 10.17 shows the changes that have occurred between 1990 and 1997, and what the pattern of energy use is expected to be in the reference scenario for 2010.

The use of coal and coke is expected to increase, with that of coal increasing at a higher rate, primarily as the result of new process technology that permits a higher proportion of coal to be used in the reduction process in the iron and steel industry. A further reason for the increasing proportion of coal is that the Swedish coke plants have reached capacity.

The use of oil is expected to increase only slightly, due primarily to the fact that by far the largest user of oil (the pulp and paper industry) is expected to increase its use of biofuels at the expense of oil. The increase in the use of biofuels could be even greater, except that there are tendencies that indicate that the forest products industry will sell some of its residual products fuel to other sectors. This is because manufacturing industry enjoys a preferential rate of only 35 percent of the general carbon dioxide tax rate, which means that oil is relatively cheaper when used by industry than when used by other sectors, with the exception of the electricity sector. It is primarily the iron and steel industry which, as a result of increased output, will increase its use of oil, and thus contribute to an overall increase in its use.

The use of natural gas is expected to increase only marginally. Although, in price terms, natural gas is competitive with oil, which is what it would primarily tend to replace, its actual use cannot increase to any greater extent until the necessary supply infrastructure is extended.

The use of district heating is expected to increase by about 0.8 TWh to 5 TWh, with the greatest individual increase being expected in the engineering industry, where the substantial growth in output will increase the need for new premises.

There are also similar tendencies within the non-energy-intensive parts of industry, e.g. in parts of the chemical industry[89].

The use of electricity, including electricity in refineries, is expected to increase by almost 6 TWh to nearly 60 TWh in 2010, with the greatest single increase, of over 2 TWh, being assumed to occur in the pulp and paper industry. This is based on assumptions concerning growth in this sector. It is felt that present capacity needs to be expanded: even if substantial investments are made during the period, they will be concentrated mainly on increasing production capacity, which will therefore have the effect of slightly reducing specific electricity use. The iron and steel industry, too, is expected to increase its use of electricity to some extent, primarily as a result of an increase in the capacity of production of raw steel.

Scenario 2010-2020

Two scenarios have been investigated for the period between 2010 and 2020. Alternative 1 foresees the country's nuclear power stations, with the exception of Barsebäck 2, continuing to produce electricity until 2020. The prices of electricity in this alternative are assumed to be largely unchanged. Alternative 2 sees reactors being shut down after a 40-year life, with the result that electricity prices would rise to almost 300 SEK/MWh.

Alternative 1: Only slightly increased electricity prices

The 2010-2020 scenario expects energy use to increase from 172 TWh to over 183 TWh, with industrial output increasing by about 22 percent. In absolute terms, the value of industrial output would increase by about SEK 307 x 10^9, with no less than SEK 247 x 10^9 coming from the engineering industry. The use of energy is expected to increase at a lower rate than during the period from 1997 to 2010, due partly to technical development, and partly to an increasing proportion of non-energy-intensive industries.

Table 10.18 shows that both specific energy use and specific electricity use will fall, by 15 percent and 14 percent respectively.

It is expected that the proportion of coal used, in relation to the proportion of coke, will continue to increase during the period. The explanation for this is the same as for the previous period.

[89] Potentially, the use of district heating can be affected by companies in the pulp and paper industry and in the iron and steel industry selling their heat production plants to energy utilities which then sell the heat back to them. This has occurred, for example, at SCA Ortviken. This would lead to a greater use of district heating. Another effect would be to reduce the use of energy in industry, as the losses would now be debited to the heating sector.

The use of oil is expected to increase from about 20 TWh to 24 TWh over the period. This represents a more substantial increase than during the previous period, which can be explained by the fact that an increasing proportion of the residual product fuels from the forest products industry (biofuels) will be sold to other sectors and replaced by oil. This is because industry pays a preferential rate of only 35 percent of the general carbon dioxide tax rate, while other sectors (apart from the electricity sector) pay the full tax rate.

The use of electricity is expected to increase by 3.4 TWh, with most of the increase occurring in electrically-intensive sectors such as the pulp and paper industry and the iron, steel and metals industry.

Alternative 2: Higher electricity prices

The assumption of a higher price of electricity affects the use of energy by industry. In this scenario, the use of electricity is expected to amount to somewhat over 59 TWh, i.e. 3 TWh less than in the alternative with lower electricity prices. The 300 SEK/MWh price of electricity would also have lesser effects on the use of coal, coke and oil, which would decline somewhat.

The effect of the higher price of electricity can be described in two parts: as an output effect, with output falling as a result of higher production costs, and as a substitution effect, with other forms of energy carriers becoming relatively cheaper in relation to electricity.

In this case, the output effect is expected to manifest itself by the most electrically-intensive sectors either phasing out production or transferring it to another country. The sectors most likely to do this are those concerned with the manufacture of primary aluminium and of ferro-alloys: these two industries alone use over 2.5 TWh of electricity today. An electricity price of 300 SEK/MWh would also affect some parts of the chemical industry, the production of mechanical pulp and the production of newsprint.

If a few electrically-intensive sectors produced or discontinued production, there would be knock-on effects on the use of coal, coke and oil, which would decline somewhat.

The substitution effect is regarded as having less effect in this case, which can be explained by the fact that electricity is a high-quality energy carrier that is difficult to replace in those sectors where it would be economically attractive to replace its use by that of some other form of energy carrier.

Scenario results in relation to historical development

The use of energy by industry over the scenario period from 1997 to 2020 is expected to increase by almost 30 TWh. This should be compared with energy use during the previous 30-year period (from 1970 until today), during which it remained unchanged, despite an increase in output of over 70 percent.

Industrial output during the scenario period is assumed to grow somewhat more slowly than the historical growth rate, and to be coupled with continued technical development and structural change. Seen in this perspective, the calculated increase in energy use up to 2020 can seem substantial.

An explanation for the unchanged use of energy between 1970 and today is that there were extensive conversions from oil to electricity during the 1970s and 1980s. The change away from oil to electricity conceals the fact that there has been an increase in end-use quantities of energy use.

Since the middle of the 1970s, the use of oil in industry has fallen from about 74 TWh to somewhat over 20 TWh, while the use of electricity during the same period has increased only from about 33 TWh to somewhat over 53 TWh. The conversion losses, in other words, have been transferred to an earlier link in the chain. The use of district heating has also contributed to concealing the increased end-use quantities of energy. If the conversion losses associated with the use of electricity in industry were charged to the industrial sector, it would be seen that the use of energy has increased over the last 30 years. However, the potentials to replace oil, or to increase the use of electricity, to the same extent as occurred between 1970 and 1990, do not exist during this scenario period, which means that the increase in energy demand becomes visible in a different way from what was the case during the 1970s and 1980s.

Table 10.17 Energy use by sectors, 1990, 1997 and 1999, and scenarios for 2010 and 2020, TWh

	1990	1999	1997 Base year	2010	2020 Alt.1	1997-2010 %	2010-2020 %
Mining	4,0	4,1	4,5	4,5	4,5	0,0	0,0
Foodstuffs	7,2	6,8	6,8	7,0	7,3	2,9	4,3
Textiles	1,1	0,9	0,9	0,9	0,9	0,0	0,0
Forest products	9,5	13,2	13,1	14,0	15,1	6,9	7,9
Pulp and paper	61,3	70,3	68,6	78,5	82,7	14,4	5,4
Graphics	0,7	0,8	0,8	0,8	0,8	0,0	0,0
Rubber	0,4	0,7	0,7	0,7	0,7	0,0	0,0
Chemical	9,6	9,5	9,7	11,7	12,2	20,6	4,3
Petroleum and coal	1,0	0,8	0,8	0,9	1,0	12,5	11,1
Quarrying	7,4	5,3	5,5	5,7	5,9	3,6	3,5
Iron and steel	18,6	21,1	20,9	23,5	26,2	12,4	11,5
Metals	3,8	3,6	3,6	4,1	4,5	13,9	9,8
Engineering	11,6	11,4	11,8	13,1	14,6	11,0	11,5
Other industry	3,5	2,4	3,0	3,0	2,9	0,0	-3,3
Total industry	139,8	150,1	149,7	168,6	179,3	12,6	6,3

Alt. 1: Nuclear power is assumed to operate as long as it is viable. An assessment of the necessary reinvestments has been made.

Note: The totals figures in the table above do not agree exactly with the totals in Table 18, which shows energy use by energy carriers. This is due to the fact that the statistics have come from different sources.

Table 10.18 Energy use in industry, 1990, 1997 and 1999 and scenarios for 2010 and 2020, TWh

Energy carrier	1990	1999	Base year 1997	2010	2020 Alt. 1	2020 Alt. 2	1997-2010 %	2010-2020(1) %	2010-2020(2) %
Energy coal	7,1	4,9	5,3	6,1	6,8	6,3	15	11	3
Coke [1)]	9,7	9,9	10,6	11,5	12,0	11,5	8	4	0
Biofuels, peat etc. [2)]	42,8	52,2	51,5	60,4	61,6	61,6	17	2	2
Natural gas	2,8	3,7	3,1	3,5	3,7	3,6	13	6	3
Diesel fuel	0,3	0,2	0,2	0,2	0,2	0,2	0	0	0
Gas oil	4,6	3,6	4,9	5,2	6,4	6,2	6	23	19
Medium-heavy fuel oils	11,6	13,6	14,5	14,9	17,7	17,5	3	19	17
LPG	4,1	5,9	5,5	6,1	6,5	6,3	11	7	3
Town gas [3)]	0,1	0	0	0	0	0	0	0	0
District heating	3,6	4,0	4,3	5,0	5,9	5,8	16	18	16
Electricity	53,0	54,5	52,7	58,6	62,0	59,2	11	6	1
Total	140	153	153	172	183	178	12	6	3
Production value, SEK x 10^9	828	1 116	1 011	1 360	1 667	1 646	34,5	22,6	21,0
Specific energy use, kWh/SEK of production value	0,169	0,137	0,151	0,126	0,110	0,108	16	15	14
Specific electricity use, kWh/SEK of production value	0,064	0,049	0,052	0,043	0,037	0,037	17	14	14

Alt. 1: Nuclear power is assumed to operate as long as it is viable. An assessment of the necessary reinvestments has been made.

Alt. 2: Nuclear power production shut down after 40 years.

1) Coke also includes coke oven and blast furnace gas.

2) Biofuels include black liquors in the pulp and paper industry.

3) Town gas is included with natural gas for the forecast years.

Note. Due to rounding up or down, the totals figures do not always agree exactly with the sums of the individual figures.

Source: Statistics Sweden and our own calculations.

10.8 Residential, service etc.

In 1999, energy use in the residential, service etc. sector amounted to 151 TWh, or almost 40 percent of Sweden's total final energy use[90].

Almost 87 percent of energy use in this sector occurs in residential buildings and commercial premises, where it is used for space heating, domestic hot water production and the operation of appliances. The use of energy in land use applications accounts for about 5 percent of total use in the sector, with holiday homes accounting for over 1 percent and other service activities for 7 percent. These '*other service activities*' include the construction sector, street lighting, effluent and water treatment plants and power stations.

As much of the energy use in the sector is for space heating, the actual amount in any given year depends on temperature conditions. In order to make the figures comparable, energy use is therefore converted to an equivalent in a statistically average climate year. 1999 was considerably warmer than normal, so the actual energy use was almost 6 TWh lower than the temperature-corrected use.

Development during the 1990s

The temperature-corrected value for energy use in the sector has varied between 154 and 161 TWh during the 1990s, with total use not following any clear trend. It increased towards the middle of the period, after which it has declined somewhat. In 1999, the temperature-corrected use of energy amounted to about 157 TWh.

This relatively stable use of energy can be partly explained by the low level of residential construction during the period. Over the 1990s as a whole, the amount of new building work has been very low, with indoor areas increasing only marginally.

Changes in energy taxation, and the availability of withdrawal of grants, have affected the change from oil to other energy carriers. The use of fuel oils for heating fell by almost 35 percent between 1990 and 1999, being replaced primarily by electricity in detached houses and by district heating in apartment buildings. During the period, the use of district heating increased from 34 TWh to 42 TWh, while the use of electricity fluctuated between 67 TWh and 72 TWh. In addition to electric heating, this figure for electricity use also includes domestic

[90] Final energy use relates to the use of energy carriers in their converted forms, e.g. petrol, electricity, wood chips and heat, but does not include the conversion losses.

electricity and electricity for building services systems. The use of electricity for general domestic purposes has risen throughout the period.

In the shorter term, the use of energy in the sector is very sensitive to price changes, which is due to the fact that domestic users have difficulty in changing, or are reluctant to change, their living habits and equipment inventories. In the short term, changes in the price of electricity and oil affect primarily those who are in a position to change between different types of fuels and electricity for heating, i.e. who have flexible heating systems. Combination boilers, which can do this, are installed primarily in detached houses, which is therefore where the ability quickly to change energy carriers lies. To some extent, apartment buildings and commercial premises also have this ability, but not to the same extent. It is estimated that 10-20 percent of the over 100 TWh of total energy use for heating can be switched between electricity, oil and, to some extent, logs, thus quickly changing heating systems in response to changing prices.

In the long term, higher energy prices result in the adoption of energy conservation measures such as additional thermal insulation, upgrading of windows and the installation of heat pumps. Rising prices can also affect occupants' habits, e.g. in the form of indoor temperatures or the use of showers. Higher energy prices, in other words, can reduce energy use in the sector.

Calculation conditions and assumptions

The calculations of energy use in the residential and service sector etc. are based on such factors as assumptions concerning the country's residential and commercial premises stock, energy prices, investment costs, technical development and public and private consumption. In addition, the calculations allow for the fact that there is some inertia before households and companies adjust to new conditions.

The amount of heated indoor area is very important in determining developments in energy use in the residential and service sector. New building and extensions affect the total heated area in the sector, and thus also the requirement for heating. Domestic electricity and electricity for building services systems also increase as floor areas increase.

The forecast from the National Board of Housing, Building and Planning indicates a relatively low level of residential building construction up to 2010, with an average of about 20 000 dwelling units being completed per year. The forecast for the years from 2010 to 2020 expects the rate of new buildings to increase, with the number of completed residential units being expected to lie between 25 000 and 30 000 per year. Approximately half of the residential units would be in detached houses, with the other half in apartment buildings.

Energy price developments are important in determining energy use. The relative prices of different forms of energy carriers, together with investment costs, efficiencies and the particular rate of interest applied, all decide whether it is worthwhile for a household to convert, e.g. to change from oil-fired heating to district heating. Other factors that can affect the willingness of households and companies to invest in energy conservation measures include the structure of taxation systems and taxation rules.

As we have assumed that energy prices will continue to remain low, the rate of improvement in the efficiency of energy use for heating will also be low over the period from 1997 to 2020. It is expected that, as a result of improvements in the efficiency of energy use, specific net energy use for heating (i.e. the use of energy for heating per unit of residential or commercial area) will decrease by 0.05 percent per year in detached houses and by 0.1 percent per year in apartment buildings and commercial premises. In addition to improvements in the efficiency of energy use, indoor temperature settings and the use of domestic hot water also affect specific net use.

Improved annual mean efficiencies of heating systems also reduce the amount of energy required for heating. The annual mean efficiencies used in the scenarios allow for boiler efficiencies, wasted heat, distribution losses and poorly adjusted control systems. These efficiencies are expected to improve over the period, with the greatest improvements occurring in log-fired and oil-fired boilers, as boiler efficiencies are assumed also to improve.

The number of heat pumps is expected to increase through the period. A heat pump abstracts heat from rock, the ground, air or water and supplies it to the building's heating system, where it can either complement an existing heating system or form part of an entirely new heating system. Heat pumps that abstract heat from the outdoor air, or recover it from ventilation air, are suitable for use as complementary heat sources, while those abstracting heat from rock, the ground or lake water can supply 80-90 percent of the space heating and domestic hot water requirement of a detached house, with the remaining 10-20 percent usually being supplied by electric immersion heaters or an oil-fired boiler. A heat pump of this latter type normally supplies 2-3 times as much energy as is used for powering it.

This expected increase in the use of heat pumps means that the actual amount of energy used for space heating and domestic hot water production will decline. Although heat pumps are powered almost exclusively by electricity, whether or not the use of electricity will increase or not depends on the type of heating system that was in use before the heat pump was installed. If the house was previously heated with electricity, then the use of electricity will decrease, but it will increase if the house was originally heated by oil. The scenarios expect heat pumps to be installed primarily in houses with oil-fired heating, as their net energy use is higher than in electrically heated houses. The higher the energy use, the greater the profitability in investing in a heat pump.

The scenarios have assumed that households that want to continue to use oil for heating when their boiler is due for replacement will not invest in an oil-only boiler, but in a combination boiler. Admittedly, being able to use electricity involves some additional cost, but once the investment has been made, it enables the household to use whichever energy carrier is cheapest at the time. During the summer, for example, when electricity tariffs are low, electricity is often used for supplying heating and domestic hot water. In addition, a combination boiler provides higher security: if the burner should fail, for example, electricity can be used while the burner is being repaired.

In the country's existing building stock, the high growth of private consumption is expected to contribute to an increase in the use of domestic electricity, as the scenarios expect the ownership of appliances to increase more rapidly than can be offset by improvements in the efficiency of energy use, particularly in apartment buildings. This is because ownership of, for example, dishwashers and individual washing machines, is expected to increase in apartment buildings. At present, the proportion of apartment having dishwashers and washing machines is relatively low: most apartment buildings have common utility rooms, with a number of washing machines and laundry appliances being provided for use by the occupants of the building. In addition, the scenarios assume that the number of computers and TV receivers will continue to increase. To this must be added the use of domestic electricity in new buildings. Electricity for building services systems is also expected to increase, as a result of the building of new commercial premises.

Scenario 1997-2010

The calculations for 2010 indicate continued steady growth of energy use in the residential and service sector, although there will be a change in the proportions provided by different energy carriers. The use of electricity and district heating is expected to continue to increase, while that of oil will decrease.

Electricity use is expected to increase particularly for the powering of appliances, although some of the increase will be due to greater use of electric heating. Domestic electricity and electricity for building services systems is expected to increase by 3.5 TWh, while the use of electricity for electric heating will increase by 0.8 TWh. The reason for this increase in the use of electricity for heating is due above all to an assumption that about 80 percent of new detached houses will install some form of electric heating. A reason for this high rate of installation, despite the high running costs, is that the installation costs are low and electric heating is a relatively maintenance-free form of heating. Conversions from oil-only boilers to combination boilers in the detached house sector will also contribute to an increase in the use of electric heating.

In 1997, the existing rock, earth and lake water heat pumps in detached houses, apartment buildings and commercial premises supplied about 6.5 TWh of heat. With the expected increase in the use of heat pumps by 2010, the amount of heat that they supply will continue to increase, amounting to 7.6 TWh in 2010.

Some conversion of detached houses and apartment buildings with electric boilers, to heat pumps and district heating, will tend to restrain the rate of increase of electric heating.

The expected increase of 4.4 TWh in the use of district heating between 1997 and 2010 is explained by the connection of new buildings to district heating systems, together with conversion of houses with oil-fired heating and those with waterborne electric heating systems. It is assumed that district heating will be installed, supplying about 80 percent of heating requirements, in newly-built apartment buildings and commercial premises. The proportion of such apartment buildings will be somewhat higher than that of commercial premises, as apartment buildings are often in the centres of towns, where there is a greater likelihood of an existing district heating system being available.

The reduced use of oil, to 6.7 TWh, is due to the assumption of conversion to district heating and the installation of heat pumps. It is expected that a smaller proportion of oil-heated buildings will change to the use of pellets, used in smaller group heating plants, e.g. as might be operated by local authority energy companies. One or more apartment buildings may be connected to such boiler units. Individual pellets-fired boilers can be installed in detached houses, or a small group of houses might be connected to a central pellets-fired boiler.

Table 10.19 Temperature-corrected energy use in the residential and service sector etc., by energy carriers, 1990, 1997 and 1999, with calculated values for 2010 and 2020, TWh.

	1990	1999	1997 Base year	2010	2020 alt. 1	2020 alt. 2	1997-2010 percent	2010-2020(1) %	2010-2020(2) %
Total energy use	**162,3**	**156,6**	**156,3**	**157,2**	**161,2**	**162,2**	0,6	2,5	3,2
Electricity, total	68,2	70,3	70,3	74,2	76,9	75,9	5,5	3,6	2,3
Electric heating	29,0	22,8	26,8	27,6	26,0	25,0	3,0	-5,8	-9,4
Domestic electricity	17,9	19,2	18,7	21,1	23,2	23,2	12,8	10,0	10,0
Building services systems in commercial premises	15,8	19,2	18,0	18,5	20,8	20,8	2,8	12,4	12,4
Electricity in land use applications	1,5	1,4	1,6	1,5	1,4	1,4	-6,3	-6,7	-6,7
Electricity in other service	4,0	7,7	5,2	5,5	5,5	5,5	5,8	0,0	0,0
District heating, total	34,5	41,7	38,6	43,0	44,0	44,0	11,4	2,3	2,3
Oil, total	45,1	31,6	34,1	26,8	26,0	27,8	-21,4	-3,0	3,7
Wood fuels	12,5	10,8	11,3	11,2	12,4	12,6	-0,9	10,7	12,5
Gas	1,4	2,1	1,9	2,1	1,9	1,9	10,5	-9,5	-9,5
Coal	0,5	0,0	0,1	0,0	0,0	0,0	-100,0	0,0	0,0

Alt. 1: Nuclear power is assumed to operate as long as it is viable. An assessment of the necessary reinvestments has been made.

Alt. 2: Nuclear power production shut down after 40 years.

Note: 'Oils' include LPG. 'Gas' refers to town gas and natural gas.

Source: Statistics Sweden, Annual balances and Energy statistics for detached houses, apartment buildings and commercial premises and our own calculations.

Scenarios 2010-2020

The calculations for the period 2010 to 2020 expect total energy use in the residential and service sector etc. to increase by between 2.5 percent and 3.2 percent, depending on the assumptions concerning the price of electricity. This will mean that energy use will be at about the same level as at the beginning of the 1990s.

Alternative 1, which expects nuclear power production to continue and the price of electricity to be about the same as in 2010, foresees a greater use of electricity, district heating and wood fuels. The use of oil is expected to continue to decline, not at anywhere like the same rate as occurred between 1997 and 2010. The total use of electricity is expected to increase by 2.7 TWh between 2010 and 2020, with district heating increasing by 1 TWh.

The increase in the use of wood fuels is expected to occur primarily in the form of pellets, increasing from 0.6 TWh to about 2 TWh over the period. The main reason for this assumption is that it is assumed that the use of pellets will result in cost savings, coupled with a more favourable view of pellets by users. However, some limitations have been assumed, e.g. because the use of pellets is space-demanding.

Despite an increase in the total use of electricity, the use of electric heating is expected to decline towards 2020. In detached houses, it will be primarily the use of electricity in combination boilers that will decline, while the decline in apartment buildings and commercial premises will be mainly in the use of direct electric heating and waterborne electric heating.

The total use of energy for space heating and domestic hot water production is expected to decline by 0.1 percent, partly as an effect of a continued increase in the use of heat pumps. The heating energy supplied by heat pumps is not included in the energy use figures: it is expected to be equivalent to 9.9 TWh in 2020, which is an increase of over 2 TWh in relation to 2010.

The main reason for the higher use of electricity is an increase in the use of domestic electricity and electricity for building services systems.

In Alternative 2 (with nuclear power production being phased out after 40 years) a higher price of electricity is expected to result in reduced use of electric heating and greater use of oil, as compared with Alternative 1[91]. This would also affect total energy use, which is expected to be about 1 TWh higher than for the corresponding case with a lower price of electricity[92].

In Alternative 2, the use of electricity is expected to be 1 TWh less, as the use of electric heating from combination boilers, and of heat pumps, would decline. The use of oil is expected to increase from 26.8 TWh in 2010 to 27.8 TWh in 2020, which would represent a change in the trend, as the use of oil has been steadily declining throughout the 1990s. The use of wood fuels would also increase somewhat as the price of electricity rises.

Summarising, it can be noted that the total use of energy in the residential and service sector etc. in 2020 would be very close to that in 1990. However, the first scenario period, from 1997 to 2010, is expected to show a somewhat lower energy use than during the second scenario period.

[91] The price of electric heating would increase by about 10 %, including taxes.

[92] The use of oil and wood fuels would increase more than the amount by which the use of electricity declines. This is due partly to an assumption that there would be fewer heat pumps. Heat pumps deliver more energy than is used for driving them. In addition, efficiencies for electricity are higher than those for oil and pellets.

The proportions of different energy carriers will be changed significantly by the end of the period. The greatest changes will be in the increase of the use of electricity and district heating, together with the substantial decrease in the use of oil. The exception to this is in Alternative 2 for 2020, where the use of oil is expected to increase somewhat as a result of the higher price of electricity. The changes during the scenario period follow the same trends as during the 1990s.

Depending on which alternative for 2020 is chosen, the use of district heating between 1990 and 2020 would increase by 28 percent, with the use of electricity increasing by 13 percent or 11 percent. During the same period, the use of oil would decline by 42 percent or 38 percent. The use of wood fuels is expected to be at the same level in 2020 as in 1990, although the use of pellets would increase at the expense of logs towards the end of the period.

An increase in the number of heat pumps is assumed to reduce total energy use for 2010 and 2020. However, when the energy supplied by the heat pumps is taken into account, energy use for heating in 2020 would be greater than in 2010.

The increased use of energy during both scenario periods is ascribed to a higher rate of new building and greater use of electricity for powering domestic appliances. The use of electric heating, however, is expected to decline between 2010 and 2020.

10.9 The transport sector

In 1999, the use of energy in the transport sector (excluding bunkering for foreign maritime transport) amounted to 91 TWh, or over 23 percent of Sweden's final energy use[93]. 48 TWh of petrol, and 25 TWh of diesel fuel, were used. Bunkering of foreign maritime transport amounted to 17 TWh.

Energy use in this sector, excluding bunkering for foreign maritime transport, increased by 8 percent between 1990 and 1999. The use of diesel fuel increased by 25 percent and that of aviation fuel by 22 percent, while the use of petrol declined by over 2 percent. The period (1990-1999) started on a note of deep recession. However, by the middle of the decade, the economy was recovering, and has subsequently grown substantially during the second half of the decade, which can explain the relatively high rate of increase in the use of diesel fuel and aviation fuel. The reduction in the use of petrol can be ascribed partly to the tax rises on fossil fuels that were applied at the beginning of the 1990s. In addition, the average specific fuel consumption of new private cars has fallen by 8 percent

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[93] Final energy use relates to the use of energy carriers in their converted forms, e.g. petrol, electricity, wood chips and heat, but does not include the conversion losses.

between 1997 and 1999[94]. The number of private cars with diesel engines has increased from 2.9 percent in 1990 to 4.6 percent in 1999.

Today, the use of alternative motor fuels - i.e. ethanol, rapeseed methyl ester (RME), biogas and natural gas - is marginal in the perspective of total fuel use in the transport sector. On the assumption that present-day guide measures and incentives would apply throughout the scenario period, it is not felt that there will be any greater use of these motor fuels during the period. This is primarily because the fuel costs and vehicle costs for the use of such fuels are higher than those for petrol and diesel vehicles, although a further element is the fact that there is no significant distribution system for alternative motor fuels, and there are only a few filling stations and service stations for them. However, this assessment does not exclude the possible greater use of alternative motor fuels in certain defined sectors, e.g. for public transport in urban areas.

Table 10.20 The use of alternative motor fuels and the number of vehicles in 2000.

Fuel	Consumption
Ethanol	Approx. 26 000 m^3
RME	Approx. 10 000 m^3
Biogas	Approx. 10 000 m^3
Natural gas[1]	7 million m^3
Electricity	No figures given

[1] Use in 1999.
Source: The Swedish Biogas Association and Statistics Sweden. It should be emphasised that the figures for ethanol and RME do not cover all production and sales units, and so are therefore not statistically reliable.

Calculation conditions

Calculations of future energy use in the transport sector are based on political decisions that have been made within the framework of the present energy, environmental and transport policies, which means, for example, that present rates of energy and environmental taxation would apply throughout the scenario period and that, in addition to existing infrastructure, the scenario considers only uncompleted but confirmed road and rail investments due to start before the end of 2001.

Growth of passenger traffic (i.e. both by private and public transport) is closely linked to economic development, with assumptions concerning disposable

[94] As measured by the EU method.

income, employment levels, population sizes and structures and the costs of various forms of transport being particularly important.

Goods transport depends primarily on general business levels, which means that assumptions of such factors as GNP development, industrial output and employment are important in forecasting future goods transport requirements.

Assumptions concerning fuel price developments affect primarily passenger traffic, and particularly the use of cars. The amount of goods traffic is not affected to the same extent by the price of fuel. In terms of fuel use, it is primarily the use of petrol that is affected, although the use of both petrol and diesel fuel is affected by changes in fuel prices through the effect of higher prices encouraging improved efficiency.

Assumptions concerning technical development (improvements in efficiency) are also included in assessments of the development of energy use. However, it is not felt that new technologies, such as hybrid vehicles or fuel cells, that might be developed during the period, will achieve any commercial breakthrough during the period: see also Section 10.10. However, during the second scenario period, from 2010 to 2020, a greater proportion of hybrid and fuel cell vehicles could result in a higher rate of efficiency improvement among certain groups of vehicles. Such new technologies could also put pressure on the development of traditional combustion engines, thus contributing to an improvement in their efficiency.

It has also been assumed that the ACEA agreement will be honoured. This is a voluntary agreement between the EC Commission and the European automotive industry (ACEA), with the stated objective of reducing carbon dioxide emissions from new private cars by 25 percent by 2008, in comparison with their 1995 emission levels[95].

It is assumed that the fuel efficiency of commercial vehicles will continue to improve in line with historical trends.

Scenario for traffic development to 2010 and 2020[96]

The amount of *passenger travel* during the second half of the 1990s has steadily increased: today, we not only travel more often, but also further than before. The greatest increase in passenger transport has occurred in the use of the private car: today, the car is by far the most important form of travel, providing more than three-quarters of passenger transport in Sweden.

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[95] EC Commission Recommendation 1999/125/EC.
[96] Source: Swedish Institute For Transport And Communications Analysis

Car travel has been calculated on the basis of assumptions concerning the number of cars and the costs of owning and running them. It is expected that car ownership will increase from 419 to 510 cars per thousand persons between 1997 and 2010; an increase of 22 percent. After 2010, ownership is expected to increase by 11 percent, to 568 cars per thousand persons in 2020. This affects the results of the forecast in the form of a continued strong growth in vehicle traffic.

On the other hand, the costs of running a car are expected to be lower in 2020, as a result of average fuel consumption being expected to decline. At the same time, it has been assumed that the price of petrol would remain unchanged, which would therefore reduce the average fuel costs per kilometre by about 14 percent. This kilometre cost has been assumed to be unchanged after 2010. The number of persons using each car has been assumed to remain constant, i.e. the number of vehicle-kilometres would increase at the same rate as the amount of passenger traffic.

It has been assumed that ticket prices on trains and long-distance buses would be unchanged in terms of fixed prices. On the other hand, the price of air tickets has been assumed to rise somewhat by 2010. The prices of regional public transport have been assumed to remain largely unchanged. The number of domestic air departures has been assumed to increase in total by about 20 percent by 2010. Railways would also carry more passengers by 2010, while the amount of traffic carried by long-distance buses would be the same in 2010 as in 1999.

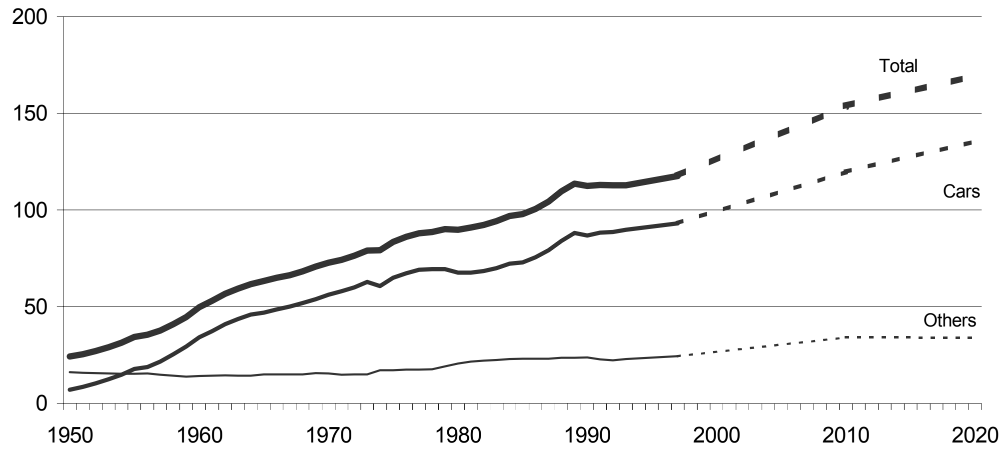
In total, passenger transport is expected to increase by an average rate of 1.8 percent per year between 1997 and 2010, falling to 1.0 percent per year between 2010 and 2020. The private car would account for the greatest absolute increase, and the greatest relative increase, in passenger traffic by 2010.

Air traffic, too, is expected to increase strongly until 2010, and to continue to do so until 2020, by which time its rate of increase will have overtaken that for the use of cars. The demand for air travel is closely linked with economic development, and so the assumption of continued favourable development of domestic incomes therefore feeds through into continued rapid growth of air traffic, in terms of the number of passengers, despite the fact that the number of take-offs/landings is assumed to remain unaltered over the period from 2010-2020.

Rail traffic is expected to increase almost as strongly as car traffic up to 2010, although considerably more slowly between 2010 and 2020, as a result of the assumption that there will be no further investments in railway infrastructure after completion of those started in 2001, and to the fact that the number of train journeys (i.e. of the rolling stock) will remain constant at the 2010 level.

The scenario for transport work in Sweden up to 2020 shows hardly any departure from the trend that has been maintained since the Second World War (Figure 10.5). Admittedly, the calculated growth for private car traffic is higher than between 1993 and 1997, but it is also lower than during the 1980s.

Figure 10.5 Actual growth of personal transport work between 1950 and 1997, with projections to 2020, 10^9 person-kilometres.



Goods transport grew rapidly during the 1950s and 1960s, at approximately the same rate as the country's GNP. Although the rate of growth has been lower in subsequent decades, it is still substantial. In 1997, road transport of goods accounted for over 40 percent of the country's total transport work, as measured in tonne-kilometres. Over 20 percent of goods transport was by rail, with water transport accounting for the remaining 35 percent. Measured in tonne-kilometre, the proportion of freight carried by air is negligible in this context, although it is of greater importance in terms of the value of the goods carried.

The growth of goods transport depends naturally on the growth of physical volumes, as well as on an increase in the value of the goods per unit of weight. The scenarios described here have assumed that the average running cost of goods transport will remain unchanged, with the cost savings resulting from greater fuel efficiency being offset by other cost increases. As far as the railways are concerned, special capacity investments for freight transport are expected to reduce delays.

The scenarios for 2020 foresee total goods transport work increasing by 25 percent by 2010, and by a further 18 percent by 2020. Of the increased quantity of goods carried, a steadily increasing proportion will be carried by road. The market share of road traffic is expected to rise to 46 percent in 2010, and to almost 50 percent in 2020.

Table 10.21 Traffic and transport work for passenger and goods transports to 2020

Traffic and transport work	1990	1997	1999	2010	2020	1997-2010	2010-2020
Traffic work, 10^9 vehicle-kilometre							
Private cars	61,4	65,8	68,4	87,3	99,5	33 %	14 %
Buses	1,0	1,2	1,2	1,3	1,2	8 %	-5 %
Heavy goods vehicles	1,8	2,3	2,3	3,2	4,2	41 %	28 %
Light goods vehicles	5,3	5,0	5,7	7,0	9,0	41 %	28 %
Transport work, 10^9 person-kilometre							
Private cars	86,9	93,1	96,9	119,7	135,6	29 %	13 %
Buses	12,4	13,9	14,6	15,0	14,3	8 %	-5 %
Rail	6,5	6,9	7,6	8,7	8,9	26 %	2 %
Domestic air traffic	5,2	3,8	4,3	4,7	5,5	24 %	18 %
Transport work, 10^9 tonne-kilometre							
Heavy goods vehicles	27,5	34,4	34,0	47,4	54,0	38 %	26 %
Rail	18,4	18,4	18,2	20,3	21,1	10 %	7 %
Water	25,6	29,0	27,9	34,8	37,5	20 %	14 %

Source: Swedish Institute For Transport And Communications Analysis

Scenarios for energy use to 2010 and 2020

The 2010 scenario expects the main increase in the use of fuel to occur in the use of diesel fuel and aviation fuel, with a 40 percent increase in the use of diesel fuel and a 30 percent increase in the use of aviation fuel (for both domestic and international air traffic). The use of diesel fuel is determined largely by growth in the economy, and particularly by the growth of sectors making considerable use of road traffic.

Despite the fact that specific fuel consumption of diesel vehicles is expected to decline, a relatively substantial increase in the number of diesel private cars, together with a very substantial increase in the proportion of diesel-driven light goods vehicles, will contribute to an overall increase in the total use of diesel fuel. The proportion of transport work carried out by diesel-powered private cars is expected to increase from less than 5 percent in 1997 to almost 10 percent in 2010. In 1997, almost 30 percent of the transport work performed by light goods vehicles was performed by diesel-powered vehicles. This proportion is expected to have increased to almost 80 percent by 2010, with a further approximately 4 percent by 2020.

The forecast of the growth in the use of aviation fuel is based on the Civil Aviation Administration's forecast for the number of take-offs and landings. This expects the total number of landings to increase by over 60 percent between 1997 and 2010, with the greater part of this growth being accounted for by international traffic.

It is expected that the use of petrol will increase by almost 4 percent between 1997 and 2010. This rate of increase is higher than occurred during the 1990s, but lower than that of the 1970s and 1980s.

Electricity use for rail transport was more or less constant during the 1970s and 1980s, but increased during the 1990s. It is expected to increase further, by about 7 percent, by 2010.

Domestic maritime transport uses both gas oil and medium/heavy fuel oils. The use of gas oil is expected to increase by a total of about 35 percent between 1997 and 2010, with the use of the heavier oils being expected to decline by 9 percent over the same period. The use of energy for overseas maritime transport (bunkering) is expected to increase by a total of 32 percent over the period.

Total energy use in the transport sector, excluding bunkering for foreign maritime transport, is expected to increase by 0.7 percent per annum between 1997 and 2010. This can be compared with an average historical rate of increase between 1970 and 19997 of 1.5 percent per annum.

The scenario for 2020 has been calculated using the same methods as for 2010, but with other economic conditions. Both private consumption and the rate of growth of industrial output are forecast as showing a somewhat lower rate of development for 2010-2020 than during the period from 1997 to 2010.

An increasing proportion of hybrid and fuel cell vehicles during the second scenario period will improve the rate of efficiency improvement for certain groups of vehicles. This new technology can also spur the development of traditional combustion engines. However, it is difficult to forecast developments in these vehicles and technologies, or at what rate they will be introduced to the market.

The growth of energy use in the transport sector until 2020 is expected to follow the same trend as during the period to 2010, i.e. with the use of diesel fuel and aviation fuel increasing the most (apart from the use of gas oil).

The use of diesel and aviation fuels is expected to increase by 8 percent and 23 percent respectively. The use of petrol will increase by somewhat less than 4 percent between 2010 and 2020, while the use of electricity is expected to remain at the same level as in 2010.

The use of gas oil by domestic shipping is expected to increase by a total of 30 percent between 2010 and 2020, with a decrease in the use of the heavier fuel oils of 17 percent over the period. Energy use for overseas shipping is expected to increase by a total of 18 percent over the period.

Total energy use in the transport sector, excluding bunkering for overseas shipping, is expected to increase by 0.8 percent per annum between 2010 and 2020.

Summarising, energy use in the transport sector up to 2020 is expected to increase at a slower rate than historical development. One of the reasons for this is the assumption that the ACEA agreement will be fulfilled, so that the rate of improvement in energy efficiency of private cars will be higher than the historical rate of improvement. Energy use during the second half of the period will be reduced as a result of various factors, including a lower rate of growth of GNP than during the first part of the period.

The ACEA agreement is a relatively important part in the scenario calculations. On average, the annual improvement in efficiency is expected to amount to 0.75 percent per annum until 2020, as compared with 0.2 percent per annum that would have been the case without the agreement. Over the period of the scenario, this provides a saving of about 2 million tonnes in emissions of carbon dioxide. When assessing what the rate of improvement of efficiency would have been without the ACEA agreement, we have started from the historical rate of improvement. During the 1980s and 1990s, improvements have been essentially offset by stronger engines and larger and heavier vehicles, as well as more equipment, such as air conditioning.

Table 10.22 Energy use in the transport sector, 1990–2020.

Fuel	Unit	1990	1999	Base year 1997	2010	2020	1997–2010 %	2010–2020 %
Domestic transport								
Petrol	1 000 m^3	5 589	5 453	5 576	5 770	5 990	3,5	3,8
Diesel fuel	1 000 m^3	2 052	2 565	2 097	2 940	3 180	40,2	8,2
Gas oil	1 000 m^3	96	115	74	100	130	35,1	30,0
Medium/heavy fuel oils	1 000 m^3	64	41	33	30	25	-9,1	-16,7
Aviation fuel	1 000 m^3	235	299	298	223	274	-25,4	23,0
Electricity	GWh	2 475	3 024	2954	3 150	3 150	6,6	0,0
Total	TWh	75,4	80,5	76,4	86,1	91,1	12,6	5,9
International transport								
Diesel fuel/gas oil	1 000 m^3	179	257	291	372	440	27,8	18,3
Medium/heavy fuel oils	1 000 m^3	568	1 371	1 174	1 556	1 830	32,5	17,6
Aviation fuel	1 000 m^3	706	851	767	1 170	1 436	52,4	23,0
Total	TWh	14,7	25,5	22,9	31,7	36,9	38,7	16,3
Total	TWh	90,1	106,0	99,3	117,7	129,0	18,5	9,6

Note. The use of aviation fuel by domestic and international aviation is as calculated by the Civil Aviation Administration. According to the Administration, domestic aviation accounted for 25 percent of fuel use in 1990, and 28 percent in 1997. In 2010 and 2020, it is expected to account for only 16 percent of aviation fuel use. International maritime traffic and aviation traffic are not included in the calculations of Swedish carbon dioxide emissions.

10.10 Future energy conversion methods

If any new technology is to achieve a commercial breakthrough, it must be competitive and there must be prospects of a clear market for it within a reasonable time. Although the Swedish energy market is of particular interest, there needs also to be potential international market to act as a driving force for the companies developing the potential new technology. In addition to technical potential, competitiveness depends on several other factors, such as developments in electricity prices, fuel prices, taxation, grants and the ability to obtain any necessary planning or operating permissions etc.

Future energy systems may be based on many different principles, with the ability to operate in small scale can bring both energy economy and environmental benefits. Small-scale CHP already exists in Sweden, although it is used to only a very limited extent.

When attempting to look 20 years forward in time, it is difficult to decide which technologies may achieve commercial breakthroughs. Technical development is proceeding rapidly, so that new technologies and new energy conversion concepts will be operating against backgrounds of different conditions than those applicable to present-day technologies.

The scenarios have not included any assumptions that new energy conversion methods are likely to appear on the market to any greater extent. However, several methods of electricity production, heat production and transport do have some possibility of approaching commercial availability over the next few decades. Some technologies, such as certain steam and gas turbine processes, heat pumps and wind power, are already relatively well established, and so they have been included in the energy system scenarios for the period up to 2020. Other technologies need more time before they can achieve commercial viability. Developments in the transport sector are aimed at improving flexibility, so that it will be possible to use different types of drive systems for fuels over a transition period.

The following pages describe various technologies within the fields of electricity production, heat production and transport that could approach commercial breakthrough during the next 10 to 20 years.

Electricity and heat production

The market conditions under which CHP operates have changed, from a monopolistic system to a more open and competitive system. Solar cells, micro turbines, fuel cells and other technologies that are on the way towards commercial establishment are mainly small-scale, which would make it possible to construct decentralised electricity and heat production systems. One reason for a small-scale approach is that the present liberalised market imposes different conditions in respect of returns than was the case under the earlier market.

The benefits of decentralised and small-scale electricity production is that the reliability of the electricity system is improved through reduced utilisation of, and dependence on, distribution and transmission systems, while small-scale plants, which are often of modular construction, make it easier to match production to requirements.

There are two different groups of new production technologies: those based on combustion or gasification, and those based on chemical or physical processes.

No new large-scale heat production processes are expected to be commercialised for the next few decades. Developments within this area are expected to concentrate on improving the efficiency of existing technologies. For small-scale heat production, it is expected that there will be further development of solar heating and heat pumps.

Combustion-based technology

Combustion-based electricity production produces low-grade heat that must be removed. Combined heat and power production (CHP) makes efficient use of the energy in the fuel, as the heat rejected by the heat engine can be used in industrial processes or for district heating, resulting in a high overall process efficiency. Today, commercial technologies involve the use primarily of steam turbine processes based on the combustion of biofuels, refuse or coal, or gas turbine processes for natural gas-fired CHP. By combining the gas turbine with a steam turbine process, the heat in the gas turbine exhaust can be used, resulting in a high proportion of electricity for a given quantity of heat.

The objective of global research and development into combined heat and power technology is to improve the cost efficiency of plants, while reducing their environmental impact. Both steam and gas turbine processes can be improved as far as performance, arrangement and costs are concerned.

Natural gas-fired CHP will probably largely be based on processes using large and medium-sized gas turbines. Efficiencies have improved over the last decade, thus reducing costs.

Biofuelled technologies can become interesting in a longer time perspective, primarily for use in indirectly fired gas turbines. Technical development of biofuelled gasification is in progress, and using the gas in a combined cycle improves the electrical process efficiency.

Natural gas-fired micro turbines for small-scale distributed CHP production can become commercially available during the scenario period. For them, too, the use of biofuels may enter the picture

Electricity and heat production without combustion

Electricity and heat producing facilities that utilise physical or chemical processes, instead of combustion processes, have several benefits. Fuel cells, solar cells, solar heating, heat pumps and wind power are examples of non-combustion energy conversion processes. The advantages of fuel cells, solar cells and solar heating, in particular, are that they have no moving parts, are quiet and have almost zero emissions.

A fuel cell produces electrical energy directly from chemical energy in an electrochemical cell. The main thrust behind their development is the major interest in applications in the transport sector, although the technology also has considerable prospects for stationary use in small-scale CHP production.

Solar heating is a way of utilising energy from the sun by heating water which can then be used for heating purposes. Today, solar heating can meet only a part of the annual heating requirements of a building, and so combination systems are being developed that include, for example, biofuels. So far, the costs of solar heating have been too high for the technology to make a real market breakthrough. However, costs have started to fall in recent years.

Another way of using solar energy is to use solar cells to convert the sunlight to electricity. After wind power, solar cells are the most rapidly growing energy source worldwide. However, the low price of electricity in Sweden makes it difficult for power production from solar cells to achieve economic viability, which means that solar cell technology is at present used primarily in certain niche markets.

Transport

The combustion engine will continue to be developed, reducing its fuel consumption and emission levels. Today, the costs of more fuel-efficient technology are not much higher than those of conventional technology. Nevertheless, despite this, there has not been much interest from private users:

factors such as purchase price, engine power, safety and equipment levels are still regarded as more important that fuel economy.

The combustion engine is being developed so that it can run on fuels other than petrol or diesel fuel. Alternative fuels that are of current interest today are primarily methanol, ethanol, natural gas and biogas. Development is aimed at improving flexibility. During a transition phase, it will need to be possible for different types of drive systems or fuels to be used in the same vehicle. Those technologies that are closest to commercial breakthrough are hybrid vehicles, ethanol-fuelled vehicles and FFVs (flexible fuel vehicles). A hybrid vehicle has two alternative drive systems, e.g. an electric motor and a combustion engine, while an FFV vehicle is capable of using different fuels simultaneously, e.g. ethanol and petrol.

In the longer term, the automotive industry is pinning its hopes to fuel cell technology. Fuel cells require a continuous supply of hydrogen and oxygen in order to work. Optimum efficiency is obtained when using pure hydrogen and pure oxygen, but this is difficult in mobile applications as the respective storage systems are bulky, while the storage of hydrogen can involve serious safety problems in the event of incorrect handling. Oxygen can be abstracted directly from the air, which would reduce the number of components on the vehicle. In automotive applications, hydrogen can be stored either in safe storage systems or be obtained from other fuels, such as methanol, ethanol, natural gas or petrol, which would require the use of fuel converters.

Fuels

The new electricity production, heat production and transport technologies are based on use of the traditional fuels of oil and coal, although there are several benefits from the use of other fuels. Biofuels, natural gas, hydrogen, methanol and ethanol are examples of fuels that could increasingly replace oil and coal.

Although natural gas is a fossil fuel, it does have the benefit (in relation to other fossil fuels) of resulting in lower emissions. It can burnt directly, without requiring preheating or gasification, which means that natural gas-fired plants have a higher efficiency than those using oil or coal. In addition, the higher efficiency means that its specific emissions of NO_x and carbon dioxide per kWh are reduced. It can be used in both large and small gas turbine processes, in fuel cells and as a motor fuel. At present, methanol can be produced at a lower cost from natural gas than it can be produced from biomass.

Biofuels in various forms - whether solid, liquid or gas - will be important, as they make no net contribution to the greenhouse effect. Solid and gaseous forms are used primarily for electricity and heat production, while liquid forms of biofuels, such as ethanol and methanol, can be used in the transport sector.

Hydrogen is the ideal fuel for fuel cells and, in the longer term, is regarded as being the fuel that will be used, as it has no harmful emissions. However, there are many problems associated with its use. There is no existing infrastructure for its distribution, and it will be difficult and expensive to modify the present system. There are also safety problems associated with the use of hydrogen, as it is very explosive. It also requires considerable quantities of energy to produce the gas.

In addition to the costs of obtaining and preparing traditional fuels, the degree of substitution from them to other fuels depends on the ultimate costs of emitting carbon dioxide. It is particularly the adverse effect of fossil fuel emissions on the climate that indicates the need for a move to alternatives with less environmental impact. Research into separating and depositing carbon dioxide can also affect developments: see Section 10.11.

Nevertheless, the use of fossil fuels will continue to be dominant over the next few decades.

10.11 Carbon dioxide separation and deposition

Technologies for both separation and deposition of carbon dioxide already exist, although they are used to only a very limited extent. As yet, when they are used, it is not the reduction in carbon dioxide emissions that is the determining reason.

The scenarios to 2020 have not included possible storage of carbon dioxide. Over this period, however, the technology will be developed and costs will presumably be reduced. The extent to which carbon dioxide is separated and deposited will depend on the cost of the alternative, which is the cost of simply emitting carbon dioxide to the atmosphere.

Today, under favourable conditions, the cost of separating and depositing carbon dioxide is about the same as the Swedish rate of tax on carbon dioxide emissions, i.e. almost 400 SEK/tonnes of carbon dioxide. Most of the cost is involved in the separation process.

Methods of separation

The methods of carbon dioxide separation that are available are:

- chemical and physical absorption processes[97]

[97] Absorption: carbon dioxide is absorbed by the active constituents of the absorbent.

- adsorption processes
- cryogenic condensation
- membrane separation processes
- air separation and combustion with oxygen and recycled flue gases

The commonest processes are the absorption-based processes, and it is these that are generally discussed in connection with separation of carbon dioxide from power stations. As an example, 200 tonne/day of carbon dioxide are separated from a 300 MW power station at Shady Point in the USA (ABB Lummus Crest).

Oxygen combustion is regarded as lying a few years into the future. If the carbon dioxide is to be deposited, it must be released (regenerated) from the absorbent. This is done by heating, by pressure reduction and/or by stripping with an inert gas[98].

All separation processes involve a reduction in the overall power station efficiency, as energy is required for, or in the form of:

- driving fans and compressors to compensate for greater pressure drop after separation
- driving pumps for circulating the absorption liquid and cooling water
- heat for regeneration of the absorption liquid, or for powering pumps for flashing[99]

Absorption and regeneration of carbon dioxide

Both chemical and physical absorption use a liquid to trap the carbon dioxide. The difference between the two processes is that, in chemical processes, the carbon dioxide reacts chemically with the absorption liquid, while in physical processes it is dissolved in the liquid. There are also methods that use both processes. Physical absorption is less suited to high carbon dioxide concentrations in the flue gases and high pressures, while chemical absorption is suitable both for low and high concentrations and pressures. Regeneration is more expensive when using chemical absorption, as the process requires more energy. This is because, after chemical absorption, regeneration requires thermal energy in order to boil the absorption liquid, which is more energy-demanding than in flashing.

The cost of absorption and regeneration varies, depending on the type of plant used. If it is a CHP plant, most of the energy in the electricity and steam can be recovered in the form of heat which is suitable for district heating. If the recovered energy can be sold as district heating, there will be no overall total energy loss, which means that the costs lie in the range 8-22 öre/kg of carbon

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[98] Inert: Non-reactive. The gas does not easily participate in chemical reactions at normal pressures and temperatures (e.g. nitrogen and the inert gases).

[99] Flashing: sudden evaporation by expansion, achieved by pressure reduction.

dioxide, depending on the fuel and the production method. However, in the case of a cold condensing plant, there is no marketable use for the heat to which the energy used in the separation process is converted, which means that the cost lies in the range 140-300 SEK/tonnes of carbon dioxide.

Carbon dioxide separation is most suitable for incorporation in new plants: it is too expensive to install the necessary equipment in existing power stations.

It should be added that none of the separation methods that are at present used today is optimised for use in large combustion plants. However, it is likely that costs and energy consumption can be substantially reduced in the future.

Transport of carbon dioxide

There are two alternatives for transporting large volumes of carbon dioxide: by pressure vessel (trains/ships) or by pipe. The greater the volumes, the better the finances of a pipe as opposed to pressure vessels.

Using a real rate of interest of 7 percent and a write-down period of 20 years, the total cost of building and operating a 200 mm diameter pipe with an on-land length of 700 km, has been calculated as 200-250 SEK/tonnes of carbon dioxide. The total cost for corresponding transport by train has been calculated as 12-14 öre/kg of carbon dioxide, to which must be added a cost for 140-160 SEK/tonnes for connecting piping systems and buffer storage.

The International Energy Agency quotes a price of a 300 km piping system as between 100 and 300 SEK/tonnes of carbon dioxide[100].

Disposal of carbon dioxide

Carbon dioxide can be deposited in several ways and at several sites, such as:

- abandoned oil and gas wells
- operational oil and gas wells
- deep saline aquifers
- coal layers that cannot be worked[101]
- the deep ocean.

[100]Carbon dioxide capture and storage, IEA, September 2000. All cost information from IEA is from this publication.

[101]Coal layers that cannot be worked: Coal layers which, for various reasons (generally because they are too deep) cannot be used for coal production.

Deposition in abandoned oil and gas wells is attractive due to the fact that their geology is well known, they have been proven to be capable of storing gases or liquids for millions of years, there is an existing infrastructure and it may be possible to re-use some of the drilling equipment for carbon dioxide injection.

Carbon dioxide is already injected today into a number of operational oil and gas wells in order to increase the recovery of oil and gas. Put simply, the method (CO_2-EOR, Enhanced Oil Recovery) involves raising the pressure to force up the oil or gas that cannot be recovered by traditional means.

Deep saline aquifers are also already being used at one site, the Sleipner Field in the North Sea. Natural gas with a 10 percent carbon dioxide concentration is abstracted from the Heimdall formation from a depth of about 2000 m. The carbon dioxide is separated and then deposited in the Utsira formation, which is an aquifer at a depth of about 800 m. Almost 1 million tonnes of carbon dioxide per year have been deposited since 1996. If the carbon dioxide was not removed, the gas could not be sold. Deposition also means that the operators avoid carbon dioxide tax.

Unworkable coal beds can also store a large quantity of injected carbon dioxide. Provided that the beds are never subsequently worked, the carbon dioxide will never be released to the atmosphere. The process releases methane, which can be used. At present, methane is recovered from coal beds by pressure reduction using the CBM (Coal Bed Methane) method, although simultaneous injection of carbon dioxide would increase the yield (ECBM, Enhanced Coal Bed Methane). Even if the methane is burnt, two carbon dioxide molecules will have been bound in the coal bed for each methane molecule released, which means that the coal beds can be regarded as a net sink. Demonstration trials of ECBM are in progress in New Mexico: over 100 000 tonnes of carbon dioxide had been pumped down by September 2000.

The most uncertain technology at present is that of deep ocean disposal, primarily because we cannot safely say for how long the carbon dioxide would remain in the ocean, coupled with obvious monitoring problems. Large-scale trials are planned by PICHTR (Pacific International Center for High Technology Research), although it is uncertain when they will be performed.

Storage capacity

Storage capacity on a global scale is substantial, although there are also considerable uncertainties in the assessment. The International Energy Agency estimates that the total deposition capacity in abandoned oil and gas wells already amounts to 920 Gtonne, or 45 percent of total carbon dioxide emissions between now and 2050, as forecast by IPCC.

The storage potential in deep aquifers is estimated as amounting to 400-10 000 Gtonne, or 20-500 percent of total emissions, although further investigations are needed. Non-workable coal beds are estimated as having a potential exceeding 15 Gtonne, or over 1 percent of emissions between now and 2020. This means that the total capacity for underground deposition is estimated as being in the range 1335-10 935 Gtonne.

Deep ocean deposition is the most uncertain. The oceans already contain about 50 times more carbon dioxide than is in the atmosphere. The $CO_{2(g)} \Rightarrow CO_{2(aq)}$ reaction between the atmosphere and surface water is very fast, so any increase in the carbon dioxide concentration of surface waters would quickly increase the concentration in the atmosphere. The deep ocean layers, on the other hand, are separated from the atmosphere by the surface layers, and also separated from the surface layers by the thermocline[102]. The turnover time for the deep ocean layers is 3000-5000 years, so there would not be any immediate release of carbon dioxide to the atmosphere if the gas was dissolved in the deep ocean layers. Computer models have shown that, if carbon dioxide was injected at a depth of 1500 m, half of it would still be in the ocean 500 years later. If it was injected at a depth of 3000 m, or deeper, about 80 percent would still be in the ocean after 500 years. Injection at depths of more than 3000 m will result in the carbon dioxide forming a lake of liquid carbon dioxide or carbon dioxide hydrate. This would increase the retention times in the oceans, but would also have a strong local environmental impact. The potential for deep ocean storage depends entirely on the environmental impact and storage times that can be accepted. The deep oceans provide the most difficult conditions for assessing the storage times and for monitoring the carbon dioxide pumped down.

Geological formations (deep aquifers) that could be suitable for the deposition of carbon dioxide exist in the neighbourhood of Sweden beneath Skåne and Denmark, as well as beneath the Baltic between Gotland and Lithuania. The aquifer beneath Skåne and Denmark is most favourably sited, with an estimated storage capacity of up to 10 Gtonne, with about 3.5 Gtonne of this being stored beneath Skåne. Today, Sweden's annual carbon dioxide emissions amount to about 60 Mtonne.

Costs of deposition

The costs of deposition vary widely. In some applications, there is actually a profit in pumping down carbon dioxide, although it is doubtful whether this should actually be referred to as deposition at all, as the gas is pumped down for a different reason. IEA estimates the cost of below-ground deposition of carbon dioxide as between 10 and 30 öre/kg. Vattenfall has estimated the cost of storing

[102] Thermocline: A sharp temperature difference that separates the surface layers from the deep ocean layers, falling from about 10 °C (average temperature of the world ocean surface layers) to 4 °C. The density difference between the water masses means that they do not mix.

carbon dioxide in the above-mentioned deep aquifers below Sweden as 80-100 SEK/tonnes.

Summary and comments

Summing the above figures results in a cost interval between 30 and 90 öre/kg of carbon dioxide. The costs estimates are, in other words, very uncertain, as the technologies in many cases are unproven, or have not previously been used for this particular purpose. It is particularly the cost of separation that should come down in the future.

Separation and deposition of carbon dioxide is most appropriate in connection with large-scale applications. The methods described above are all more or less suitable for such operation.

The most expensive component in the chain is the separation stage, although it is also this for which there is the greatest potential for process improvements. Today, the most interesting methods of separation and regeneration are either chemical absorption in combination with thermal regeneration, or physical absorption in combination with regeneration by flashing. Air separation and combustion with oxygen and recycled flue gases are further in the future, while other separation processes are at present regarded as of lesser priority.

Methods of transport being considered are either by pipe or in pressure vessels. Both methods are today used for gas transport, and the technologies are known.

Deposition methods that are of most interest at present are deposition in deep saline aquifers, abandoned oil and gas wells or non-workable coal beds. Pumping carbon dioxide down into operational oil and gas wells is not strictly deposition, but rather '*improved recovery of oil and gas with the help of carbon dioxide*'. In this application, in other words, the carbon dioxide is not a waste product, but part of the recovery process. Where the process is being used for oil and gas recovery, the carbon dioxide used is obtained from the earth's crust, not by separation from combustion processes. This is because the former method of producing the carbon dioxide is cheaper.

The reason for not making greater use today of methods of separating and deep depositing carbon dioxide is that the alternative cost (of simply discharging the carbon dioxide to atmosphere through a chimney) is lower. There will be no deposition of carbon dioxide until it is given a value in the form of taxation or some other form. If the process becomes economically attractive, other present obstacles in the form of legislation etc. (e.g. the EC ban on the transportation of waste across national borders, or the ban on disposing of waste at sea) can doubtless be resolved.

11. Overall effects of economic instruments

11.1 Introduction

The 2010 scenario in the report calculates that carbon dioxide emissions from the energy sector[103] during the scenario period will be essentially unchanged. The scenario calculations are based on assessments of such factors as economic growth and fuel price developments. In addition, it has been assumed that the present level of energy and environmental policy and measures will continue to apply throughout the scenario period.

Policies and measures that affect emissions have been changed during the 1990s. All told, these changes represent a tightening-up of measures intended to reduce or slow the increase of emissions.

The following pages describe the effects of changed economic instruments on carbon dioxide emissions from the energy sector during the 1990s, i.e. the effects of higher energy and environmental taxes, as well as those of grants and operational subsidies for energy production from renewable sources.

In order to analyse the effects of the economic instruments, the model calculations have been made on the basis of two different sets of measures and incentives; those of 1990 and 'current levels'. The actual calculations have been made using the MARKAL model, described in Appendix 4[104]. Two parallel sets of scenario calculations have been made. As the other calculation parameters are the same in both scenarios, it is possible to identify the differences in development of the energy system as a result of changes in the economic instruments[105].

As it is difficult to judge the effects of the various economic instruments, it is important to realise that all the incentives incorporate some degree of uncertainty, which means that the results must be interpreted with considerable care.

It has been assumed in the '*present day economic instruments*' scenario that current (2001-01-01) levels of energy and carbon dioxide tax apply throughout the period investigated. Further, it has been assumed that the present level of operational subsidy for wind power production is applied throughout 2002. It has

[103] The energy sector includes emissions from combustion processes in power stations and district heating plants, as well as from industry, combustion processes for heating in domestic households and transport.
[104] See also the separate input data report with all MARKAL calculations.
[105] The other calculation parameters are those used as the starting point for the main scenario in Sweden's third national report.

been assumed that, with effect from 2003, electricity production from wind power, biofuelled CHP and small-scale hydro power is covered by a certificates trading system to encourage the use of these forms of production[106]. This is simulated in the calculations by means of a subsidy amounting to 150 SEK/MWh: at the same time, the present operational subsidy for wind power production would have been discontinued.

Current levels of energy and carbon dioxide taxation are shown in Table 11.1. Industry pays no energy tax, and only a reduced rate of carbon dioxide tax. There is also a sulphur tax, at the rate of SEK 30/kg of emitted sulphur, and an NO_x levy for larger combustion plant, although this is not included in the description.

Table 11.1 Energy and carbon dioxide taxes in the '*Present-day economic instruments*' scenario, SEK/MWh

	Energy tax	CO_2 tax	CO_2.tax industrial
Gas oil	70	154	54
Heavy oil	64	141	49
Coal	40	181	63
Natural gas	21	106	37
LPG	10	126	44
Petrol	377	142	50
Diesel fuel	206	154	54
Electricity	181		
Electricity, heating plants etc.	158		

The '*1990 economic instruments*' scenario assumes that taxation as of 1st January 1990 would be applied throughout the period under investigation: the results are shown in Table 11.2. At the time (1990), there was no carbon dioxide tax, which was introduced on 1st January 1991. The energy tax of the time was also levied on the use of energy by industry. There was no value-added tax on the use of energy, while the sulphur tax and NO_x levy were yet to be introduced. Value-added tax on energy was introduced on 1st March 1990. There was no operational subsidy for wind power or investment grants for any special energy production technologies.

[106] The reason for including this certificates trading system in the '*Present day economic instruments*' scenario is that Parliament has decided that such a system will be introduced with effect from 2003. The exact structure of the system is being considered at present by the ELCERTH Committee.

Table 11.2 Energy taxes in the '1990 *economic instruments*' scenario, SEK/MWh

	Energy tax
Gas oil	109
Heavy oil	100
Coal	62
Natural gas	32
LPG	16
Petrol	303
Diesel fuel	109
Electricity	92
Electricity, industry	70
Electricity, heating plants etc.	92

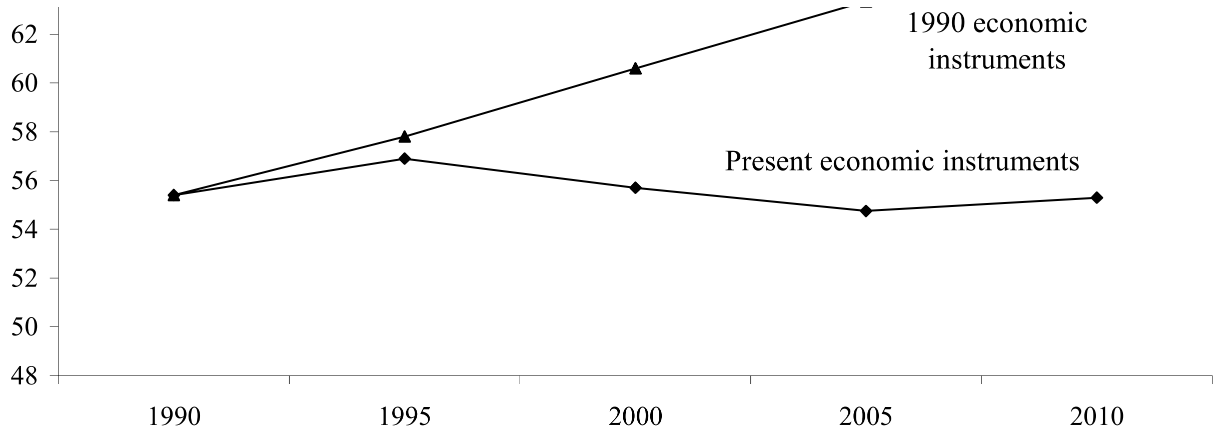
In both scenarios, electricity production is exempt from energy and carbon dioxide tax. However, the fuel for heat production in CHP plants was subject to energy tax in the 1990 economic instruments scenario. In the present-day scenario, heat production is subject to the full carbon dioxide tax and half the energy tax.

11.2 Results

Depending on the scenario assumptions for economic instruments, the results of calculations of developments in the energy system show different levels of use of fossil fuels, and thus different levels of carbon dioxide emissions, as shown in Figure 11.1. The present-day economic instruments scenario results in emission levels considerably lower than those in the 1990 economic instruments scenario.

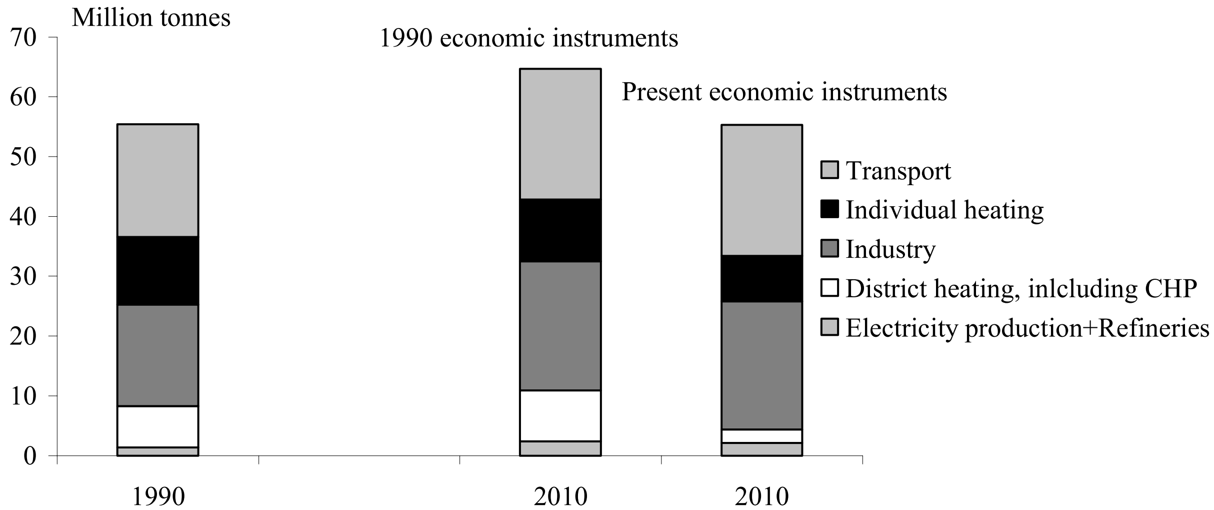
In other words, in the longer term, calculated emissions of carbon dioxide can be expected to be 15-20 percent lower with the present-day economic instruments than with the 1990 levels. In 2010, for example, total carbon dioxide emissions are expected to be 55 Mtonne when calculated on the basis of the present-day economic instruments, as against 65 Mtonne in the 1990 economic instruments scenario: in other words, a difference of 10 Mtonne. 2010 emissions of carbon dioxide, as expected by the present-day economic instruments scenario, would be at approximately the same level as in 1990, i.e. 55.4 Mtonne. However, it is important to bear in mind that both the 2010 scenarios include a net electricity import of over 4 TWh, of which any associated emissions have not been included in the calculations. In 1990, Sweden exported 3 TWh of electricity.

Figure 11.1 Total carbon dioxide emissions as expected by the two scenarios, million tonnes CO_2



It is highly probable that the calculated difference in emissions is an underestimate of the true effect, as calculations with the MARKAL model do not include the effects on energy use of differences in energy prices. In most cases, taxes are lower in the 1990 economic instruments scenario, which would therefore result in a greater demand for energy in this scenario. Just how great this difference would be depends on price differences and on the particular end-user sector considered.

Figure 11.2 Effects of economic instruments during the period 1990-1999, by sectors, million tonnes CO_2



Note 1: The model calculation shows only marginal differences in emissions from the industrial sector, and no differences in admissions from transport. See the comments further down in this description.

It is primarily in the district heating production and individual heating of residential and commercial premises sectors that carbon dioxide emissions would be greater with the 1990 levels of economic instruments. It is important to remember that the present-day taxation system is not being compared with a set of conditions completely without economic instruments or incentives. Even in 1990, Sweden had introduced high taxes on fossil fuels, resulting in a considerable move away from their use and a change to renewable energy production. A scenario entirely without taxation on fossil fuels would show even greater carbon dioxide emissions.

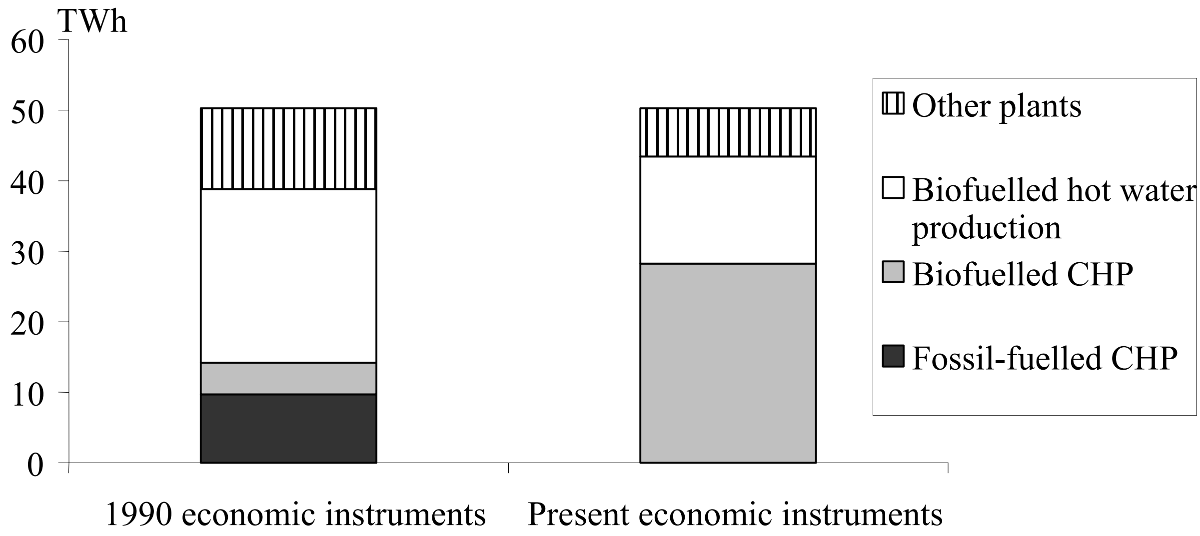
District heating production

The effects of the changes resulting from the economic instruments are greatest in the district heating production sector. The 1990 economic instruments scenario sees a modest increase in emissions over the next 10 years, while the scenario based on present-day economic instruments results in a substantial decrease in emissions.

The increase in carbon dioxide emissions with the 1990 economic instruments scenario can be explained by greater use of fossil-fuelled CHP. The only factor preventing it from becoming even greater is that biofuelled hot water production is competitive even at the 1990 taxation level.

Application of the present-day economic instruments results in a different development of district heating production, with the grants for biofuelled CHP production and the high level of taxation on fossil fuels resulting in a substantial expansion of biofuelled CHP by 2010. More than half of district heating production would then be from biofuelled CHP. In addition, that element of supply not provided by biofuelled CHP would consist almost entirely of biofuelled hot water production. Biofuel, in other words, is expected to be by far the most predominant fuel for district heating production in the present-day economic instruments scenario.

Figure 11.3 District heating production in 2010 with the two scenarios



Electricity use and electricity production

Electricity use is higher in the present-day economic instruments scenario than in the 1990 economic instruments scenario. This is due partly to the fact that the support provided for production such as wind power and biofuelled CHP reduces production costs: in addition, the relative competitiveness of electricity improves as a result of the considerably higher taxes on energy use based on fossil fuels.

Almost all of the difference in electricity use between the two scenarios can be explained by a different level of electricity use for heating residential buildings and commercial premises. The use of both waterborne electric heating and of heat pumps would be greater in the present-day economic instruments scenario: by 2010, the difference in the amount of electricity used for heating would be about 5 TWh.

Electricity production also differs in the two scenarios, primarily as a result of the assumed certificates trading system, represented here by a 150 SEK/MWh subsidy for electricity production from wind power, biofuelled CHP and small-scale hydro power[107]. In addition, the taxes on the use of fossil fuels for CHP production are considerably higher in the present-day economic instruments scenario. However, the two largest sources of electricity production in the

[107] Solar cells and biofuelled cold condensing power production are also included in the calculations of the effects of the certificates trading, but these forms of power production have not been considered.

country, large-scale hydro power and nuclear power, are essentially the same in both scenarios.

The present-day economic instruments scenario sees a considerable expansion in wind power production even by 2005. By 2010, the scenario assumes that the entire land-based potential of 4.5 TWh/year would have been built and be in operation. Imports of electricity would increase at the same time, and the amount of power produced by CHP would also increase between 2005 and 2010.

Individual heating of residential buildings

Depending on which scenario is used, there is a considerable difference in the breakdown of types of heating used for residential buildings and commercial premises. Put simply, the present-day economic instruments scenario improves the competitiveness of electricity, with oil becoming less competitive as a result of taxes on it rising more quickly than those on electricity. In addition, the price of electricity[108] by about 2010 is expected to be somewhat lower in the present-day economic instruments scenario as a result of the support for wind power, biofuelled CHP and small-scale hydro power. Biofuels and district heating, too, would be more competitive, and both scenarios foresee an increase in their use.

Industry

Energy use in industry differs only marginally between the two scenarios. In both cases, there is expected to be some reduction in the use of biofuels as a result of the limited supply of biofuels being utilised more effectively by other sectors, primarily for district heating production.

As described above, the model calculations do not adjust the demand for energy in response to changes in energy prices.

In many cases, the taxes on electricity and fuels for use in industry are lower in the present-day economic instruments scenario than in the 1990 economic instruments scenario, and this applies particularly for electricity. This means that the present-day economic instruments scenario can be expected to result in a somewhat greater demand for energy, but no separate calculation of this effect has been made.

[108] As used here, the 'price of electricity' refers to the shadow price of electricity production. (This is approximately the same as the marginal cost of electricity production.) The shadow price of electricity is one of the calculation results from the model.

Transport

Both scenarios give the same expected results for the transport sector. The higher tax on petrol and diesel fuel in the present-day economic instruments scenario improves the competitiveness of alternative motor fuels, but not sufficiently to result in users switching fuels. As the model does not react to changes in the demand for transport, in the form of reduced transport work or reduced fuel consumption resulting from higher taxes in the present-day economic instruments scenario, the MARKAL calculations have been complemented by a separate calculation for the effects of the taxes on the use of petrol and diesel fuel.

Petrol and diesel fuel are used almost exclusively for road transport, and account for over 80 percentof the total energy use of the transport sector (excluding bunkering for foreign maritime transport).

Price elasticities have been included in the calculations of the effects of higher taxes on petrol and diesel fuel, with an elasticity of -0.7 for petrol and of -0.2 for diesel fuel[109]. According to the calculations, petrol use with the 1990 economic instruments would have been over 2 percent higher in 2010 than it would have been with the present-day economic instruments level. This is equivalent to over 1 TWh of energy, or 0.3 million tonnes of carbon dioxide emissions. The demand for petrol, in other words, is relatively inelastic, i.e. it is not greatly affected by price rises. However, it is open to discussion as to whether prices have now reached such a high level that price signals are actually starting to have an effect, i.e. that demand is becoming more elastic.

The price elasticity for diesel fuel is lower than that for petrol, which automatically means that prices have less effect on its use than they do on the use of petrol.

11.3 Summary of conclusions

The use of biofuels is strongly encouraged by the level of present-day economic instruments, with most of the increase occurring in district heating production. Although the 1990 economic instruments scenario also foresees an increase in the use of biofuels, this would be at a considerably slower rate.

It is within the field of district heating production that the effects of the different levels of economic instruments are most noticeable. The present-day economic instruments scenario expects more than half of district heating production in 2010

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[109] 'The Effects of Changes in Fuel Taxation', by the Expert Group for Investigations of the Public Economy, Ds 1994:55.

to be provided by biofuelled CHP, with the greater part of other district heating (i.e. not from CHP) also coming from biofuels.

The use of electricity is foreseen as being greater in the present-day guide measure scenario as a result of cheaper production (resulting from the 150 SEK/MWh operational subsidy) and more expensive alternatives (with the tax on fossil fuels increasing more than the tax on electricity).

The 150 SEK/MWh subsidy, as used in the present-day economic instruments scenario, results in more electricity production (and an earlier introduction) from biofuelled CHP, wind power and small-scale hydro power. Wind power would not be competitive with the 1990 economic instruments level.

More electricity is used for heating and heat pumps in the present-day economic instruments scenario.

The use of biofuels in industry is seen as increasing somewhat in both scenarios. The limited amounts of biofuels available would be used more effectively in other sectors.

The present-day economic instruments scenario improves the conditions for alternative motor fuels by increasing the tax on petrol and diesel fuel, but not sufficiently as needed to bring about any significant changes in the use of fuels.

It is important to remember, when interpreting the results, that the certificates trading system has been simulated by a 150 SEK/MWh subsidy for certain forms of electricity production. This is an estimate, seen as an average over the entire period. Bearing in mind the other uncertainties, this particular value should be seen as a good approximation: no one can today say with certainty what level the price of certificates will adopt, nor how it will vary with time.

Finally, it should be pointed out that even the 1990 level of economic instruments resulted in a clear move away from the use of fossil fuels.

Appendix 1. Energy taxes, 2001

Tables B1 and B2 show the present levels of Swedish energy and environmental taxes. The taxes differ between industry and other users: industry pays no energy tax, and only 35 percent of the carbon dioxide tax that is paid by other users.

Table B1 Energy and environmental taxes from 1st January 2001, excluding value-added tax[3)]

	Energy Tax	CO_2 tax	Sulphur tax	Total tax	Tax SEK/MWh
Fuels[1)]					
Gas oil, SEK/m³	688	1 527	-	2 215	224
(< 0,1 % sulphur)					
Heavy fuel oil, SEK/m³	688	1 527	108	2 323	215
(0,4 % sulphur)					
Coal, SEK/tonne	293	1 329	150	1 772	234
(0,5 % sulphur)					
LPG, SEK/tonne	134	1 606	-	1 740	136
Natural gas / methane, SEK/1000 m³	223	1 144	-	1 367	141
Crude tall oil, SEK/m³	2 215	-	-	2 215	221
Peat, SEK/tonne, 45 % moisture content	-	-	40	40	15
(0,24 % sulphur)					
Motor fuels[2)]					
Petrol, env. class 1, SEK/l	3,26	1,24	-	4,5	516
Petrol, env. class 2, SEK/l	3,29	1,24	-	4,5	519
Other petrol, SEK/l	3,92	1,24	-	5,16	592
Diesel fuel, env. class 1, SEK/l	1,51	1,53	-	3,04	311
Diesel fuel, env. class 2, SEK/l	1,79	1,53	-	3,27	334
Diesel fuel, env. class 3, or other, SEK/l	2,04	1,53	-	3,57	358
Natural gas / methane, SEK/m³	0	1,04		1,04	107
LPG, SEK/kg	0	1,26		1,26	106
Electricity use					
Electricity, northern Sweden, SEK/MWh	125	-	-	125	125
Electricity, rest of Sweden, SEK/MWh	181	-	-	181	181
Electricity, gas, heat or water supply, SEK/MWh					
Northern Sweden,	125	-	-	125	125
Rest of Sweden	158	-	-	158	158
Electric boilers, > 2 MW, 1/11-31/3, SEK/MWh					
Northern Sweden,	14,8	-	-	14,8	14,8
Rest of Sweden	18,1	-	-	18,1	18,1

Note: In addition to the above taxes, value-added tax at 25 percent must also be added (but not for industry). An environmental levy, amounting to SEK 40/kg of NO_x emissions, is applied to boilers, gas turbines and stationary combustion plant having an annual energy production of at least 25 GWh. This levy is then repaid, in proportion to energy production and in inverse proportion to emissions.

1) Fuels used for electricity production pay lower rates of energy and carbon dioxide tax. Fossil fuels used for heat production in CHP plants pay half the normal rate of energy tax and the full rate of carbon dioxide and sulphur taxes. Biofuels are untaxed for all users.

2) Aviation fuel is not taxed directly. Domestic air traffic is taxed, however, by the Civil Aviation Administration's environmentally related landing and passenger fees.

3) Fuels used for electricity production are exempt from energy and carbon dioxide tax, but do pay sulphur tax. The tax on nuclear power is based on the thermal output power of the reactors: this is intended to be equivalent, under certain defined operating conditions, to a tax of 27 SEK/MWh on the electrical output. In addition, nuclear power pays 1.5 SEK/MWh as a levy for disposal of the earlier nuclear research activities and facilities at Studsvik and an average of 10 SEK/MWh for financing future disposal of spent nuclear fuel.

Source: The Tax Administration and our own calculations.

Table B.2 Energy and environmental taxes for industry, agriculture, forestry and fisheries from 1st January 2001, excluding value-added tax.

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Tax, SEK/MWh
Gas oil, SEK/m^3	0	534	-	534	54
Heavy fuel oil, SEK/m^3	0	534	108	642	59
Coal, SEK/tonne	0	465	150	615	81
LPG, SEK/tonne	0	562	-	562	44
Natural gas, SEK/1000 m^3	0	400	-	400	41
Crude tall oil, SEK/m^3	534	-	-	534	53
Peat, SEK/tonne, 45 % moisture content(0,24 % sulphur)	-	-	40	40	15

Note: When purchasing heat, industry can reclaim the energy tax and 65 percent of the carbon dioxide tax on the fuels used for producing the heat.

Source: The Tax Administration and our own calculations.

Appendix 2. Research funding, 1998-2000

Table B3 Funding granted for programme level research, 1998-2000

Development areas/sub-areas	1998 SEK million	1998 per cent	1999 SEK million	1999 per cent	2000 SEK million	1999 per cent
1. FUEL-BASED ENERGY SYSTEMS	231,4	53 %	274,8	47 %	207,4	42 %
1.1 Biofuels, incl. ash recycling	44,4		64,6		43,8	
1.1.1 Bioenergy systems, overall	23,0		10,1		20,3	
1.1.2 Forest fuels	8,9		39,4		11,4	
1.1.3 Meadow fuels/energy plantations	10,1		10,1		10,1	
1.1.4 Ash recycling/handling	2,5		5,1		2,0	
1.2 Refuse fuels, incl. Biogas	10,8		10,2		8,0	
1.3 CHP	129,0		120,9		106,1	
1.4	40,9		67,7		32,0	
1.5	6,2		11,3		17,5	
1.5.1	1,7		5,6		9,5	
1.5.2 Stationary fuel cells	4,5		5,7		8,0	
2. TRANSPORT	34,3	8 %	91,5	16 %	49,5	10 %
2.1 Bio-based motor fuels	13,6		22,2		20,8	
2.1.1 Ethanol	13,0		18,5		18,0	
2.1.2 Other alternative motor fuels	0,6		3,7		2,8	
2.2 Combustion engines	19,6		49,5		13,9	
2.3 Electric and hybrid vehicles and fuel cells			16,4		4,0	
2.4 Transport systems	1,1		3,3		10,7	
3. ELECTRICITY PRODUCTION/ELECTRICAL TECHNOLOGY	84,6	19 %	66,5	11 %	86,4	18 %
3.1 Hydro power	2,0		4,2		8,4	
3.2 Wind power	29,9		26,1		39,9	
3.3 Solar cells, incl. ancillary systems	0,3		5,9		9,3	
3.4 Power production technology/ transmission/distribution	52,5		30,4		28,8	
4. INDUSTRY	32,1	7 %	62,9	11 %	53,8	11 %
4.1 Unit processes within industry	31,5		61,5		50,5	
4.2 Ancillary systems in industry	0,7		1,4		3,3	
5. THE BUILT ENVIRONMENT	45,4	10 %	64,7	11 %	56,7	12 %
5.1 Heating/cooling/climate screens	24,9		56,4		44,3	
5.1.1 Small-scale combustion	4,8		20,9		20,6	
5.1.2 District heating	4,6		15,8		5,6	
5.1.3 Solar heating	5,4		10,0		0,7	
5.1.4 Heat pumps	7,8		7,4		12,2	
5.1.5 Energy storage	2,4		2,2		5,2	
5.2 Components, systems and building services systems	20,6		8,2		12,5	
6. SYSTEM/INTERNATIONAL/ETC.	12,4	3 %	27,4	5 %	38,4	8 %
6.1 Energy system studies etc.	6,6		6,5		20,2	
6.2 Overall international cooperation	5,7		21,0		18,2	
Total	**440,3**	**100 %**	**587,8**	**100 %**	**492,3**	**100 %**

Appendix 3. Research organisations in Sweden

The Swedish Research Council is a public authority under the Ministry of Education and Science, with a duty of supporting fundamental research of the highest quality in order to ensure Sweden a position as a leading research country. This is ensured by the Swedish Research Council:

- having a majority of scientists in its management
- fostering inter-disciplinary and multi-disciplinary research
- encouraging modernisation and equality
- encouraging joint working and communication.

The Council has a **Director-general**, who is supported by a Deputy Director-general, a Chairman and a Board. The Board consists of a majority of scientists, appointed by election from the country's body of scientists. The Government appoints other members of the Board.

The Council has three research area councils:

- medicine
- natural science and technical science
- humanistic and social science.

The majority of the members in the three councils are also appointed from the body of the country's scientists. Each of the councils has its own chairman and secretary. The secretaries are employed by the central administration, and thus constitute a direct link between the councils and the central administration personnel. There is also a committee for scientific training, appointed by the Board of the Swedish Research Council.

The Swedish Agency for Innovation Systems supports research and development in technology, occupational health and safety and transport for which there is a specific requirement, and works to ensure that new knowledge is applied to products, processes, services and occupational health and safety as effectively as possible.

The identification of possible growth areas, determination of the innovation system in connection with these areas and of initiatives needed to reinforce the system constitute an important part of Agency's work.

The innovation system is the network of parties involved in the creation, dissemination and application of new knowledge and new technology.

The Agency concentrates its activities on several different innovation systems:
- National innovation systems
- Sartorial innovation systems
- Innovation systems in regions.

Each of these systems involves different parties, from trade and industry, research and politics, who together and in dialogue can create added value from new knowledge. The Agency's objective is to encourage needed research and development to contribute to the development by Sweden of internationally leading innovation systems that can be expected to result in sustainable growth and development in society.

The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning was established on 1st January 2001, and is a newly-founded state research council under the Ministry of the Environment. It has taken over the research previously supported by the Swedish Council for Building Research, the Forestry and Agriculture Research Council and some of that previously supported by the Environmental Protection Agency and the Council for Planning and Coordination of Research.

The Council supports fundamental research and infill research in the fields of the environment, land use applications and the structure of society. It supports ecologically sustainable growth and development of society, multi-disciplinary and interdisciplinary research, joint international research and the exchange of experience. In addition, it is responsible for the provision of information on research and the dissemination of research results.

The Council's five programme areas are:

The environment: Research in this field is concerned with overall aspects of the natural environment, and is intended to contribute to understanding of human influences on fundamental mechanisms and necessities for life. This working area covers research that cannot be directly linked to land use applications or the structure of society.

Agriculture and horticulture, fishing and reindeer husbandry: Research in this field is intended to further sustainable development within the named areas.

Forestry and the natural environment: Research in this area is intended to assist sustainable utilisation of natural resources in the forest landscape.

The built environment: This research is intended to assist the realisation of buildings and facilities that are stimulating, safe, healthy and make efficient use of energy and resources. Support is also available for development work and experimental building.

Spatial planning: Research in this area is intended to help the move towards sustainable development of urban areas, rural areas and regions.

Appendix 4. Methods used in the scenario calculations

The scenarios for carbon dioxide emissions from the energy sector are based on calculations and assessments of expected development of the energy system, consisting of both energy used and energy supplied. Scenarios are developed for various sub-sectors of the energy system, and are then put together to arrive at an energy balance. Energy used must balance with energy supplied. The user side of the balance includes final energy use in the industry, residential and service and transport sectors, together with conversion and distribution losses and the energy used in foreign maritime transport. The supply side of the balance consists of the total supply of fuels, together with the input from hydro power production, nuclear power production, wind power and the net import of electricity.

Different methods of calculation are used for each sub-sector, and are described below.

The methods and analyses used are based on national economics. A fundamental starting point is that total energy use and the relative proportions of the different forms of energy carriers and supplies vary in response to expected energy prices, public economic activity and technical development. International developments, too, affect the Swedish energy system. Inputs from the political side are those as decided in terms of policy by the Government and Parliament in the form of current energy and environmental policy.

Calculations made using the MARKAL model have provided a basis for the scenario description in the third national report. A brief general description of the model is given below.

Methodology for the industrial sector

The scenarios of energy use in industry up to 2010 and 2020 are based partly on results from the National Institute of Economic Research's EMEC model and, to some extent, on the MARKAL model. The EMEC model provides economic conditions for a number of industrial sectors, as well as for the manufacturing industry as a whole. Where data is require for sectors that are not included in the EMEC model, we have used our own assessments. However, they have to fall within the overall envelope represented by the total rate of development of the country's manufacturing industry, i.e. our figures for any sector cannot be such as would result in a rate of growth exceeding the total rate of growth for the manufacturing industry as arrived at by the EMEC model.

A scenario of energy use in industry has then been developed, starting from the economic conditions and the assumed prices of energy. This work has involved extensive contacts with various organisations within industry, sector organisations and the Agency's own experts in certain sectors. These contacts have discussed the results from the EMEC model, development expectations for various products and larger investments that are likely to be made during the period. Production envelopes for various products are very important, as the total demand for energy, and the types of energy, depend on this. Technology that would be introduced during the period is also, of course, very important. All material and knowledge created in this process is reviewed and cross-compared in order to arrive at the scenarios.

The scenarios for industrial energy demand have also been used as an input for the MARKAL model calculations. The results given by the model have been carefully checked and cross-compared with other calculated results.

Methodology for the residential, service sector etc.

Much of the energy use in the residential, service sector etc. goes for heating of residential buildings and commercial premises. Economic growth and population growth determine the extent of new construction, renovation and conversion of residential buildings and commercial premises, and this in turn determines the need for heating.

The amount of energy used for heating is affected by temperature conditions. As the conditions vary, correction is applied in order make figures comparable between one year and the next, by indicating how much energy would have been used in any given year if the climate conditions during that year had been '*statistically average*'. With this correction applied, it then becomes possible to see how energy use has been affected by other factors. The calculations disregard the effect of temperature by assuming that the forecast years in the scenario will all be statistically average. Temperature correction is based on degree-day statistics from the Swedish Meteorological and Hydrological Institute (SMHI).

In addition to energy for heating, electricity is also used for the operation of building services systems and for the powering of domestic appliances etc. in residential buildings. Energy use has also been calculated for the sub-sectors of agricultural and land use applications, holiday homes and other services.

The heating sector

In the short term, the amount of energy used for heating depends largely on the type of heating systems installed in the various properties. However, an exception to this is detached houses having what are known as combination boilers, i.e. boilers that can be switched at any time between the use of oil and the use of electricity. Heating systems tend to be replaced primarily when an existing system wears out.

One of the ways in which heating needs have been calculated is through the use of the so called *DoS-model*. This requires the following input data:

- Energy use, broken down by types of heating systems and types of properties (detached houses or apartment buildings/commercial premises)
- Forecasts of new building production and demolition of old buildings
- Average improvement in the efficiency of energy use over the period
- Average life of the various types of heating systems, which determines the overall need for replacement during the forecast period
- Investment costs for various energy systems, real rates of interest and writedown times
- Energy prices (not power prices, as *DoS* produces a forecast for all power prices)
- Efficiencies for the various types of heating systems and likely changes in them
- Maximum potential for various heating systems. As the model assumes that consumers will choose the most economic replacement alternative, the person using the model must enter various limitations. Despite the fact that heat pumps are probably the most economical alternative, it is unlikely that all those changing systems will choose heat pumps: instead, the figure might be, for example, only 20 percent.

With these assumptions, the model will calculate the expected energy use of different forms of energy carriers for different electricity prices. It also optimises operation of combination heating systems.

The MARKAL model (see the separate description) has also been used for calculating heating requirements for residential buildings and commercial premises. The results from the two models have then been compared, and assessments of the results regarded as the most likely from the two models have then led to the final results.

Domestic electricity and electricity for building services systems

Energy requirements for domestic electricity in residential buildings and for building services systems in commercial premises have been calculated on the basis of a growth factor based on assumptions concerning economic development. Private and public consumptions are important factors.

Energy use in the entire sector

By adding the energy use for domestic electricity and building services systems to the energy required for heating, we obtain the resulting energy use in residential buildings and commercial premises, which makes up over 85 percent of total energy use in the sector. To this must be added energy use in agricultural applications (agriculture, forestry and fishing), holiday homes and other services (electricity, gas, water and sewage plants, street lighting etc.). Calculations for these small sub-sectors are simpler, often on the basis of given economic conditions for the respective sectors.

The transport sector

The scenarios for emissions from the transport sector have been prepared in two stages: scenarios for transport work, and scenarios for energy use, broken down by energy carriers.

Transport work[110]

The scenarios for transport work in the Climate Report have been prepared using the model system jointly developed by SIKA, the National authorities for transportations and Vinnova (the former Communications Research Board).

Personal transport

Information on actual travel, the frequency and performance of physical travel systems available, population structure etc. has been used in order to develop the SAMPERS personal transport model. Information on actual travel was taken from the Riks-RVU (nowadays RES) national travel survey, providing statistics from about 30 000 interviews between 1994 and 1997. This information has then been further complemented by statistics on travel habits, types of transport available and demography in order to produce models representing the demand for personal transport. Aspects modelled have included travel frequency (i.e. the number of journeys per person and day), destinations and types of transport. These models are what is known as logit models[111]. The choice of routes has also

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[110] SIKA

[111] What is known as the logit model (D. McFadden, 1974) can be described as follows. We assume that the individual can choose between a number (say *J*) of different alternatives. *X* represents the characteristics of the alternatives, and *Z* represents the characteristics of the individuals that can be observed by the researcher in his data. The alternatives in a typical study could be car, bus or underground train, with *X* including information on the cost of journeys and the time taken and *Z* providing input on age, income and education. However, in addition to *X* and *Z*, there are further characteristics of individuals and choice alternatives that determine the individual's benefit-maximising choice, but which the researcher cannot

been modelled, using the Canadian Emme/2 network analysis system. Input data in the form of economic development, population changes and changes in the transport system is required in order to run a forecast. The system is suitable for analysing the effects of such factors as changes in the type or frequency etc. of transport available, changed prices or demographic changes. SAMPERS consists of five regional models for short journeys, the national model for long domestic journeys and a model for overseas journeys. Analyses can be performed, and results presented, at regional, national or international levels.

Goods transport

SAMGODS, the Swedish national model system for goods transport, can most fairly be described as a set of separate models, developed partly for purposes completely other than for analysis of the national demand for goods, but which have been linked together in order to work together in a relatively efficient and consistent manner. The system consists primarily of two parts: one consisting of models that handle the demand for transport, and one that handles the transport network and transport market. Geographically disaggregated matrices of the demand for goods within Sweden and between Swedish and foreign regions are provided by the demand models. This demand is then assigned to various forms of transport and routes by the network models. A cost-minimising algorithm enables the model system to produce forecasts of transport flows by various forms of transport, to analyse transport chains and the effects on the transport system of transport policy measures or of changes in the transport infrastructure.

The use of fuel

Almost 60 percent of the energy used for domestic transport is provided by petrol. A top-down approach is used, in the form of a demand model, in order to assess changes in the use of petrol. The demand for petrol is based on assumptions concerning price development for petrol and changes in domestic incomes[112], together with estimated elasticities. Price elasticity is assumed to be -0.7, and income elasticity to be 0.6[113]. In addition, the model includes assumptions concerning technical development, i.e. the rate of efficiency improvement. However, the model is limited in its abilities, in that it does not incorporate any adjustment mechanism, which means that it is not, for example, capable of

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observe. These characteristics are summed in a 'random term'. Models of this type are regularly used in investigating individuals' choice of forms of travel, although they have also been used in a wide range of other applications, such as investigation of choice of housing, living area and education. (Source: Royal Academy of Sciences, Popular Science Information, the Bank of Sweden's Alfred Nobel Prize for Economic Science, 2000.)

112 Forecasts of developments in private consumption are used as a measure of future income development.

113 'Effects of Changes in Petrol Taxation', the Expert Group for Public Economic Investigations, Ds 1994:55.

indicating when in time a rise in the price of petrol would have the greatest effect on the demand for petrol.

Diesel fuel provides over 30 percent of the energy use for domestic transport. Again, the top-down demand model is used in order to forecast developments in the use of diesel fuel. This model is based on assumptions concerning future developments in various industrial sectors: those that have been found to have the greatest effect on the use of diesel fuel are the pulp and paper industry, the petrochemical industry and the engineering industry. The model also allows for changes in the price of diesel fuel (with a price elasticity of -0.2), and for technical development.

4 percent of energy use in the transport sector is provided by aviation fuel. The calculations concerning the future use of aviation fuel are based on the Civil Aviation Administration's forecast of the number of landings at Swedish airports. This forecast is, in turn, derived from a forecast of the number of passengers. The number of landings is determined by assumptions on the type of aircraft and load factor development. The passenger forecast is based on the use of a demand function, which utilises the relationship between demand for air travel and economic growth, together with price developments.

Electricity provides 4 percent of the energy used in transport. Forecasts of future electricity use are based primarily on the investment decisions that have been made concerning expansion of railborne traffic systems.

A further 2 percent of energy requirements in the transport sector are met by fuel oils for domestic water transport. Changes in the use of gas oil and medium/heavy fuel oils are affected primarily by the type and volume of traffic between Gotland and the mainland. Forecasts of the use of fuel oils for overseas maritime transport, known as bunkering, are based on assumptions concerning the future development of imports and exports.

As far as the use of alternative motor fuels is concerned, forecasts are based partly on information on technical developments for the various fuels, and partly on political decisions. Technologies already exist to allow the use of a range of alternative fuels. However, the fact that they are not used to any greater extent today is due partly to the resulting fuel and vehicle costs being higher than corresponding costs for the use of petrol and diesel fuel. The limited availability of suitable distribution systems, storage depots and service stations also hampers the introduction and use of alternative motor fuels. The situation is further complicated by the considerable present uncertainty concerning aspects such as future taxation of alternative motor fuels, and how this would affect the use of such fuels.

Electricity and heat production

The forecasts for the use of electricity and heat in the scenarios are based on an iterative process, which tests to see whether the production system can keep pace with demand, and also whether the energy system as a whole remains in balance. However, the production of electricity and district heating is based on demand from the user sectors.

The user sectors and supply, i.e. for electricity and district heating production, both use input data in the form of economic conditions and fuel prices. Forecasts of electricity production costs by means of new power generation capacity, and calculations of the variable production costs from existing capacity, are based on the resulting fuel prices and on the taxation and subsidy systems.

Some allowance is made for technical developments in the various production methods for electricity and district heating, and allowance is also made for the fact that various subsidies will have the effect of assisting the introduction of new production capacity in certain forms of power generation.

The present electricity production system is relatively well mapped out, with information available on the existing production capacities of the various forms of power production and on limitations of the overall production system. As necessary, special investigations of costs in the electricity production system have been carried out.

The forecasts of CHP are based on data concerning the present power and heating systems. District heating production in a future system is also given by its use in the industrial and residential and service sectors. The starting point for these calculations is that prices are optimised for each type of district heating system, i.e. choosing the cheapest boilers or heat pumps at any given time. In addition, CHP has to be optimised against the electricity prices during a year.

Forecasts of changes in the power balance are based on the principle that production capacity would be used in cost order of merit, i.e. using the cheapest form of production first. Marginal costing means that the price reflects the cost of producing an additional kilowatt-hour of electricity. Over a year, the short-term marginal cost is defined as a time-weighted mean value of the variable costs of the most expensive form of production capacity used at different times, plus what is known as a shortage cost component. This shortage cost is intended to reflect the supply capability of the production system. It is low in a situation where there is surplus production capacity, but increases as demand increases within the framework of a given system.

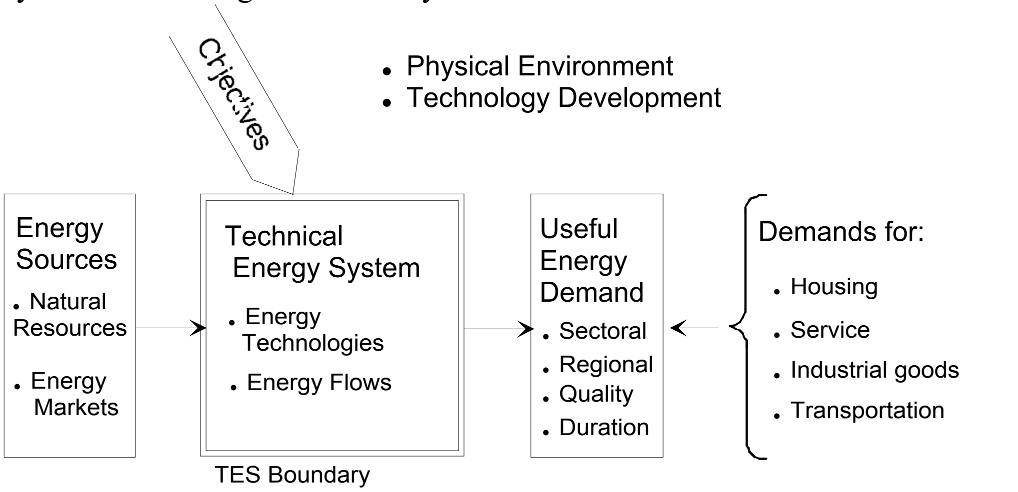
A short general description of MARKAL and its use

MARKAL is a dynamic linear programming model, developed within IEA-ETSAP in the middle of the 1970s for analyses of the technical energy system. It has been continuously improved, and is now in world-wide use. Briefly, it works by using an exogenously specified demand for various energy services in a number of sectors of society to power the model, which attempts to achieve the specified demand at the least possible cost.

The model includes a large number of technologies, both present-day and future, covering everything from large-scale power production to small-scale end-user energy conversion technologies and efficiency improvement measures. In addition, there are a large number of boundary conditions, such as environmental requirements and technical performance. The normal time horizon is 10-25 years.

MARKAL is generally used for scenario analyses, with the scenarios being formed (selected) from various forecasts of the development of factors associated with the energy system. The schematic diagram below describes the technical energy system and its environment, with the surrounding factors being gathered under four main headings: energy markets, energy demand, technical development and environmental requirements.

The Schematic structure of the MARKAL model, showing the technical energy system (TES) and the four surrounding factors, is shown below. The arrow symbolises the target function of the model, being generally a minimisation of system costs with given boundary conditions.



MARKAL optimises the development of the technical energy system over the period of investigation, on the basis of:

- a given target function,
- forecasts of developments in the four surrounding factors, *and*

- given boundary conditions (system limitations).

The commonest target function in MARKAL is cost minimisation in terms of public economic criteria. The results from the model are then in the form of the most cost-efficient development of the energy system, subject to the assumptions concerning the development of surrounding factors and the specified boundary conditions.

The models also allow target functions other than economic functions to be selected: it is, for example, possible to operate the model in such a way as to minimise greenhouse gas emissions.

There are many factors that can be used as boundary conditions, such as capacity limitations (in respect of expansion of certain technologies or for power transfer between countries), potentials (e.g. limits on the available quantities of refuse fuels), emission limitations (e.g. greenhouse gases, in accordance with the Kyoto Protocol) etc.

Appendix 5. The method for calculating the cost efficiency and carbon dioxide efficiency of work in the changeover programme

Cost efficiency - measures of cost efficiency and carbon dioxide efficiency

The proposed measures are **cost per kWh of electricity** and **cost per kg of reduced carbon dioxide emission**.

The cost efficiency of the changeover programme[114] should be regularly evaluated and reported, using a number of simple and easily comprehended key indicators. These key indicators would be used partly to rank the performance of various programme activities, and partly to assess the efficacy of the programme in relation to conventional energy system alternatives. This latter comparison is of key importance in determining the relevance of the model. However, for such comparisons to be possible, it is necessary to include the costs of emissions from the conventional energy system alternatives in the calculation. As the main use of the model is to provide an equable ranking of different alternatives in terms of their cost efficiency performance, the method therefore makes it possible systematically to concentrate on those measures that are most cost-efficient for society. In other words, the proposed measures of cost efficiency do not quantify the commercial economic profitability of the various aspects of the changeover programme. They are, however, measures of the relative competitiveness of different measures, and also provide a picture of the competitiveness of the measures in relation to best conventional technology.

The purpose of the short-term changeover programme is to provide new indigenous sources of renewable electrical energy that can replace nuclear power production, as well as to improve the efficiency of energy use, in order to reduce the absolute amount of replacement power production capacity needed. The two measures that are proposed are therefore **cost per kWh of electricity produced** and **cost per kg of carbon dioxide emission avoided**. With a more general approach, in which heat production, transport and the use of energy in industry are also included, the 'cost per kWh of electricity' quantifier can be replaced by the 'cost per kWh of energy' quantifier. Such an approach is likely to be necessary if, for example, it is to be possible to meet the country's climate undertakings. The method is therefore also suitable for use outside the framework of the changeover

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[114] i.e. of changing the country's energy system to one that takes most of its energy from sustainable sources.

programme, e.g. for comparing the cost efficiency and carbon dioxide efficiency of alternative motor fuels with the corresponding efficiencies of new electricity production. However, it is also possible to decide whether the cost of a kWh of alternative electrical energy is cost-efficient in comparison with a kWh of conventionally produced electricity. In the longer term, the model can be expanded to include costs of avoiding other environmentally hazardous or health-hazardous emissions. As the values of avoided emissions can be added together, it would be possible to produce an overall ranking of the environmental and health effects of various alternatives.

In most energy contexts, it is the energy content in the fundamental energy supply that is the lowest common denominator. Admittedly, there are efficiency gains and losses associated with the particular technology used to process and convert the energy. This is clear in the case of electricity production: the conventional cold condensing power production process cannot convert more than about 40 percent of the input energy into electricity at best, while a modern gas turbine combined cycle can achieve efficiencies of about 60 percent. However, as the cost per supplied kWh, or avoided kg of carbon dioxide, is calculated on the basis of the particular production technology, allowance can also be made for differences in efficiencies.

Some key starting points

If comparisons are to be relevant and comparable, they must be made in a consistent, standardised manner. The boundary conditions must be the same for all calculated alternatives. However, this can be difficult, as the sub-activities in the programme range over a wide field, from the supply of new electricity to improving the efficiency of energy use in domestic households.

Costs to society form the base

Production costs

One of the more important questions is therefore whether cost comparisons should be based on producer costs or consumer prices. With the price transparency that nowadays exists in the energy sector, coupled with the good insight that the Agency has into the production costs of both existing and possible alternatives, the calculations should be based on actual production costs, which better describe the cost to society than do the consumer prices. However, this must include all the production costs in the entire chain, right from the cost of obtaining the raw materials through to any conversion costs borne by the user.

Taxes

Energy taxation has become an important guide measure in persuading consumers to choose some alternative form of energy, and so ordinary decision budget calculations therefore include taxes and tax rebates as an important element. However, a cost efficiency calculation should not include tax as a parameter in its own right. Tax has nothing to do with the efficiency of various alternatives, but is instead purely a method of financing or a means of persuading consumers to choose some particular alternative in preference to another one. In the former case, tax must be assumed to affect various alternatives if and when they rise above a certain market share. In the latter case, tax provides a means of compensating for the insufficient cost efficiency of alternatives, and should if anything be a result of the calculations, rather than a basis for them.

A kW saved is worth as much as a kW produced

Is a kWh saved (in the changeover programme) worth as much as a kWh produced? This is a fundamental question in the consideration of results. Consider, for example, an electricity system which is in balance, but which experiences a certain annual increase in demand, and which therefore has to invest in a certain amount of new production capacity each year in order to prevent any power shortages from arising. However, if the cost of offsetting the increase in demand by improving the efficiency of electricity use is lower than the cost of new electricity production capacity, it is economically preferable to do so rather than to invest in new production capacity. However, if the electricity system is not in balance, it is quite easy to show that a saved kWh does not have the same value as a produced kWh. If there is a surplus of electricity production capacity, the producers will attempt to sell their surplus at a lower price. In this case, improving the efficiency of use will not change the amount of overall use, but simply alter its mix. It is not, in other words, possible to save electricity 'now' that could be used sometime in the future in order to reduce production capacity.

However, the changeover programme is concerned only with Sweden's electricity supply system. It might be possible to claim that, to the extent that saved electricity is exported to users outside Sweden, or is possibly used to reduce imports to Sweden, a lasting saving has been achieved. It is assumed in this analysis that the value of each saved kWh of electricity is the same as the value of a newly produced kWh.

Energy, not power

The nuclear power production to be replaced is primarily base-load production, which means that the new production capacity or the energy saved should also be of base-load character. However, in the near future, there will be a need for peak load production capacity and for measures to reduce peak load demand. It is therefore assumed that the value of base load and peak load is the same, although it may be necessary to distinguish between them in the longer term in order to avoid over-investment in measures intended to counter peak load demand.

Natural gas-fired combined cycle plant provides the benchmark

The country's energy policy states that nuclear power should be replaced primarily by indigenous, renewable electricity production. In purely general terms, investments in renewable power production capacity on a liberalised European electricity market must compete with corresponding investments in gas-fuelled electricity production capacity. This means that the long-term objective must be to reduce the cost of renewable electricity production (with allowance for external effects) to the same level as that of a natural gas-fired combined cycle plant.

The value of avoiding carbon dioxide emissions is equal to the cost of disposing of carbon dioxide

As yet, there are no generally accepted calculations of the costs of carbon dioxide emissions in the form of climate and environmental consequences. The alternative measure that can be used at present is that of the cost of disposing of the carbon dioxide. However, some form of benchmarking should be employed in this area, too: to the extent that there will be international trading in emission rights, it is the price of such rights that should constitute the benchmark. This trading has already started, and is growing strongly. The prices of emission rights are based partly on the underlying costs of producing emissions using the best available technology, and partly on the price of using carbon dioxide sinks (see also the attached sub-appendix).

Other emissions

It is possible to complement the model with the cost per avoided kg of emission of sulphur, nitrogen, carcinogenic particles etc. The USA has an established trade in nitrogen emissions, monitored by the EPA. Prices are published regularly, and it should therefore be relatively simple to complement the model with these values.

Methods of calculation

Investments

All investment costs are included, i.e. including State or other grants. Secondary investments, such as modifications to the grid in order to be able to receive power from, for example, wind power plants, are also included.

Depreciation time and real rate of interest

The investment cost is spread over the expected life of the object of the investment. In the case of larger infrastructure investments, the writedown time is often taken to be 25 years. As far as individual items of equipment are concerned, the life is often expressed in the form of operating hours. When this has been converted to calendar years, on the basis of normal expected use, the life can vary from one to ten years, depending on the type of equipment. The standard models used for evaluating applications and projects are usually based on the same calculation conditions. The capital cost is calculated in the form of an annual annuity, i.e. so that the annual cost, including the real rate of interest, is the same each year. However, the standard models that are used for such purposes as the evaluation of grant applications generally use a present value calculation approach, i.e. so that the sum of all future costs and revenues is discounted to the value as of the decision date. The annuity method spreads all the costs equally over time, regardless of when they arise.

Operating, maintenance and fuel costs

All operating, maintenance and fuel costs are included in the calculations. The standard models used for such purposes as evaluation of grant applications etc. are based on the same conditions.

The benchmark price

The benchmark price, against which each new or saved kWh of electricity is compared, is the price of a new kWh of electricity from a gas-fired combined cycle plant. The model calculations assume that natural gas is available throughout the country, and on the same terms as the average for other EU states.

With these conditions, the benchmark price (as based on the price of gas and the dollar exchange rate in August 2000) is about 240 SEK/MWh of electricity produced. However, the cost for the carbon dioxide (see below) must also be added to this cost, with the result that the total cost of each kWh produced is about 300 SEK at present price levels.

The carbon dioxide shadow price

The shadow price of carbon dioxide has been calculated as 250 SEK/tonne. The gas-fuelled combined cycle plants that are used as the benchmark production reference produce about 0.25 kg of carbon dioxide per kWh of electricity, which means that each MWh of electricity from such a plant carries a carbon dioxide cost of 60 SEK.

In order to be able to compare the cost efficiency of any particular alternative with that of conventional fossil-fuelled consumption, we need to include the carbon dioxide emissions of the fossil alternative in the calculations. There are no generally accepted calculations of what the value of a kg of avoided carbon dioxide emission is, but there are ways of indirectly giving the carbon dioxide a shadow price.

Prices ranging from less than 50 SEK/tonne up to 250 SEK/tonne have been noted in international trading in carbon dioxide emissions in recent years. The prices at the bottom end of the range relate primarily to the use of carbon dioxide sinks, while those in the 100-250 SEK range are for direct physical means of reducing emissions from production processes.

International research is beginning to agree that large-scale storage of carbon dioxide is possible. It can be assumed that the cost of storage in such systems, when properly established, will be about 250 SEK/tonne. The technology is being steadily improved, which will in turn improve the accuracy of costing this alternative.

A further possible alternative of dealing with carbon dioxide emissions is to use only the hydrogen atom in hydrocarbon molecules, and to store the carbon atoms in a suitable solid form. At present, the costs per kg of avoided carbon dioxide emission are very high.

In addition, various countries (including Sweden) are operating a large number of joint implementation projects in Eastern Europe, with the aim of reducing those countries' carbon dioxide emissions. The cost per avoided kg of carbon dioxide in these projects is very low.

Regardless of whether the emission reduction is achieved by actually physically reducing the emission, or by depositing in an approved manner, the market value put on avoided carbon dioxide emissions is less than 250 SEK/tonne. The very low prices for the utilisation of carbon sinks are associated partly with the fact that the method is dubious in the long term: most experts are of the opinion that carbon sinks will merely postpone the evil day by a few decades, after which the problem will return. It can also be assumed that the present low cost of reductions effected through joint implementation projects will gradually rise as the cheapest and simplest projects are completed. The shadow price of carbon dioxide can be assumed to lie in the range 100-250 sek/tonne. As cost efficiency comparison is used to rank and compare the results of projects, rather than for normal profitability assessments, the magnitude of the shadow price is not decisive in determining the results. However, to be on the safe side, we have proposed a value of 250 SEK/tonne.

Cost per avoided kg of carbon dioxide emission

It is assumed that each kWh of electricity supplied or saved replaces 1 kWh of electricity from a gas-fired combined cycle plant. Each kWh of electricity from such a plant produces a carbon dioxide emission of about 0.25 kg, which means that 4 kWh of renewable or saved electricity reduces the emission of carbon dioxide by 1 kg. (If, instead, coal-fired cold condensing plant is used as the reference benchmark, the cost efficiency would have a higher value, as 1 kWh of electricity from such a plant gives us about four time as much carbon dioxide as does a gas-fired combined cycle plant. However, coal-fired cold condensing plant cannot reasonably be taken as the benchmark reference for new electricity production, whether in Sweden or in the rest of Europe. As already pointed out above, the European alternative to renewable electricity is electricity from gas-fired combined cycle plant. New coal-fired cold condensing production plant could become relevant in the really long term, when large-scale carbon dioxide deposition has become commercial.)

The cost of each avoided kg of carbon dioxide emission is therefore equal to the production costs per kWh of electricity multiplied by a factor of four.

Combined heat and power plants

Cost distribution between heat and electricity

Electricity from CHP power stations is more complicated to deal with, as it is necessary to distinguish between the costs and revenues for electricity and for heat. The normal budget programmes calculate the aggregated profitability of a CHP plant on the basis of given prices for electricity and heat: neither the capital, operating, maintenance or fuel costs are normally apportioned between heat and electricity production.

The input material includes a calculation in which the investment costs have been apportioned between the cost of a heating plant and the additional cost that would be involved in upgrading it to a CHP plant. From this, together with assumptions on how the operating, maintenance and fuel costs could be apportioned between electricity and heat, it has been possible to calculate a cost for the production of 1 kWh of electricity.

Conversion to district heating

The marginal cost of connecting property to an existing district heating system has been assumed to amount to SEK 20 000 per property. The marginal cost of producing an additional MWh of district heating, including losses, has been assumed to be SEK 240. The starting point is therefore that the existing heating plant has the necessary capacity to accept more subscribers without requiring any work other than connecting the properties to the existing system. A writedown time of 15 years, with a 4 percent real rate of interest, has been applied to the property-owners' and heating plant's investment costs. This shorter writedown time is justified by the fact that the conversion does not involve the same fundamental infrastructure investments by society, as does the construction of a power station.

Appendix 6. Reinvestment requirements for the nuclear power stations

In a report entitled 'The life of the Swedish nuclear power stations', produced by the Swedish power utilities and submitted to the Energy Commission's Expert Group for Power Production and Energy Supply[115], the power companies give their views on the expected life of their power stations, together with information on economic considerations. The report points out that the power stations were designed and built for a life of at least 40 years, that the nuclear power industry has experience of major conversion and modernisation projects, and that there is considerable economic room for maintenance (amounting to SEK 2000 million per year for a 1000 MW block), when compared with the cost of other methods of producing electricity.

The report assumed that the production cost of electricity from alternative sources was 400 SEK/MWh, which provided enormous scope for reinvestments. However, if we assume an electricity price of 220 SEK/MWh, the potential for reinvestments is around SEK 500 million per year and block.

On average, over the period from 1983 to 1994, the maintenance and modernisation costs have amounted to about SEK 200 million per year and block. Bearing in mind the fact that requirements may become stricter in the future, it is estimated that this cost could increase to an average of about SEK 250 million per year and block, equivalent to a production cost of 120-150 SEK/MWh of electricity.

The need for reinvestment for extended technical life

When a nuclear power station is designed, a certain technical life is assumed for, and assigned to, its large important components. This is because certain design criteria, including those relating to fatigue, require a number of load variations to be tested. In making the fatigue calculations for Swedish nuclear power stations, the designers followed the recommendations used in the USA of testing equipment for the number of load variations expected to occur during 40 years of operation. For this reason, the number of load changes, known as transients, in the nuclear power stations is constantly monitored, and the results are subtracted from the load budget that was assumed by the designers. Few load changes occur during constant, steady-state operating conditions, which means that the budget is only slowly counted down.

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[115] January 1995.

There are also various damage mechanisms that constantly attack the performance of materials with time. Examples are the effects of radiation, different types of corrosion and thermal ageing. Analysis of technical lives is concentrated primarily on large, heavy components that are difficult or expensive to replace, or which would involve personnel in being exposed to radiation doses, e.g. buildings, reactor tanks, steam generators, other pressure vessels and larger pumps and valves. Smaller components are replaced regularly, as part of the work of normal maintenance programmes.

Sweden's Nuclear Technology Act specifies safety requirements in nuclear facilities of all kinds. The Swedish Nuclear Power Inspectorate (SKI) and the National Institute of Radiation Protection (SSI) exercise surveillance of safety and radiation protection, and specify the requirements motivated by safety and radiation protection considerations. If safety is not regarded as satisfactory, SKI can withdraw a plant's operating permission, while the Government, in the interest of safety, can withdraw permission to operate any nuclear activity if there are major reasons to do so.

Potential performance can be assessed only on the basis of known conditions, which means that any assessments of future performance potential are always associated with some degree of uncertainty, although the actual potential may turn out to be better or worse than as assessed.

The life of plants can also be restricted by the occurrence of certain types of severe operational problems, resulting in such overloads or damage that the reactor can no longer be approved for continued operation. Such events have occurred in other countries.

Factors such as operational experience of the block concerned and of other blocks, statistical information on the life of components and the results of research, are all used in order to identify any signs of old age or incipient wear and tear, to plan necessary maintenance work and economically to optimise maintenance in respect of safety and radiation protection. Since the middle of the 1970s, reliability data for components in Swedish and Finnish nuclear power stations has been collected in a database and systematically analysed.

Extending the life of nuclear power plants: experience from the USA

Nuclear power plant operating licences in the USA are granted for a limited time, normally 40 years, although many plants are regarded as being capable of operating for a longer period of time. In May 1995, the USA Nuclear Regulatory Commission (NRC) published a programme that set out the conditions for extending operating permissions by 20 years, to a total of 60 years. Important aspects are those concerning the way in which ageing of safety-critical systems and components is dealt with, and to what extent it is necessary to modernise the plants.

Of the American nuclear power stations two, San Onofre and Trojan, have been closed after technical problems with leaking steam generator tubes. Although it would be technically possible to replace the tubes, the state Public Utility Commission refused permission to increase the price of electricity, which meant that the plants were closed for economic reasons. Yankee Rowe is an older PWR power station, which was to have been used in order to investigate the requirements that NRC planned in order to extend its life beyond 40 years. However, it was found to be so difficult to determine the condition of the reactor pressure vessel materials after radiation that it was decided to close the plant. The reactor output was only 167 MW, which meant that it would have been difficult to find the major sums that replacement of the pressure vessel would have involved.

At present two plants, Calvert Cliffs and Oconee, have been granted an extension of their operating permissions. NRC assumes that, within five years, it will receive over twenty applications for extension of operating permission. Interviews with the plant owners indicate that it is likely that about 85 percent of those plants now in operation will apply for extensions.

The costs of the reinvestments that have been made in the USA are somewhat higher than those that have been made in Sweden, apart from the renovation of Oskarshamn 1. According to NRC, this is largely due to the fact that the quality of initial planning of the work has been somewhat poorer.

Past investments in the Swedish nuclear power stations

Between 1975 and 1995, SEK 2561 million were invested in the Barsebäck nuclear power station, with SEK 1332 million of this between 1978 and 1995. On average, over 17 years, somewhat over SEK 78 million/year were invested in the two reactors, i.e. about SEK 40 million/600 MW per year. During this time, about half of all the components in the plant were replaced. SEK 707 million were invested between 1996 and 1998, amounting to an average annual investment of over SEK 235 million. Backed by an investment of over SEK 125 million per year and block, the Barsebäck management is of the opinion that the plant is equivalent to a modern nuclear power station in terms of the safety levels applied to new nuclear power stations.

Between 1994 and 1998, over SEK 3000 million were invested in Oskarshamn, with SEK 2200 million being for modernisation of Reactor 1 and for preparation for modernisation of Reactor 2. The modernisation of Reactor 1 that was carried out during the 1990s cost about SEK 1700 million, and has brought the reactor up to the standard of a new plant. A great amount of work was put into minimising the radiation doses to which personnel could be exposed during the renovation. Such a major renovation of a reactor that had been in operation has never previously been performed. Similar renovations in the future can learn from this project, thus significantly reducing their costs.

SEK 1600 million has been invested in Ringhals between 1995 and 1997, with investments of over SEK 3000 million being budgeted for the period from 1997 to 2001. This represents an annual investment of SEK 150 million per block, and will be applied for modernisation of all the blocks at Ringhals.

The most expensive maintenance of the pressurised water reactors has been for the steam generators. In several cases, the steam generator tubes have displayed ongoing damage. The steam generators in Ringhals 3 were replaced in 1995 at a cost of SEK 800 million, with the new steam generators being designed for a higher power rating.

The control computers for all the reactors have also been replaced as part of the reinvestment programmes.

Assessment of future investment requirements

During the 1990s, substantial renovations of the Swedish nuclear power reactors have been carried out in order to modernise them and improve their performance. An investment level of SEK 300/year and block (1000 MW), as needed to ensure a technical life of 60 years, is a reasonable assumption in the light of historical investments and of the ageing processes found during the renovations. This rate of investment is equivalent to an electricity cost of 40 SEK/MWh.

The cost of extending the technical life of a nuclear power station is thus dependent on the operating conditions, the safety requirements and the power rating of the plant. It is not possible to say exactly what these costs might amount to, although the investments in Oskarshamn 1 can perhaps provide an indication of the likely levels. Many of the investments that are needed in order to extend the technical life of the reactors can also have the effect of increasing the power output, which means that they can be economically justified for this reason alone.

Appendix 7. Sensitivity analysis

The results of the calculations of future emissions of carbon dioxide are dependent on the assumptions made concerning energy policy, economic development, technical development and so on. They are surrounded by a number of uncertainties, including those relating to the assumptions concerning parameters on which the calculations are based. The effects of this can be illustrated by various sensitivity analyses, which are described in this appendix in respect of a number of selected assumptions in the respective user sectors of industry, residential and transport.

The calculations were made for the Climate Committee in the spring of 2000, and are reproduced in their entirety in the publication 'Energy and Climate in Sweden, EB 4:2000'. As the scenarios for Sweden's third national report have been revised, the results of the calculations are not in full agreement with the new scenario calculations. Nevertheless, the analysis described here gives a picture of the sensitivity of a number of important assumptions.

Sensitivity analyses, industry

Two sensitivity analyses have been prepared for the 2010 scenario. The table below shows the results from calculations based on a high growth rate (3.0 percent) and a low growth rate (1.7 percent) for industry as a whole. The purpose of this example is to create an uncertainty interval around the reference scenario in order to show the uncertainties that the industrial growth parameters cause in respect of energy use, and thus also in respect of carbon dioxide emissions. Varying the annual growth rates from 1.7 percent to 3.0 percent also affects the structure of the industrial sector. Based on historical development, and on the trends that have been discerned, it is reasonable to assume that structural changes will increase in step with a higher industrial growth rate. A consequence of this assumption is that the energy-intensive sectors of industry will account for a greater proportion of industrial output in the low alternative than they do in the reference and high alternatives, which should be borne in mind when interpreting the results.

Table B4. Results from alternative calculations with low and high growth rates

	Main scenario	Low growth rate	High growth rate
CO_2 emissions, million tones	13,2	12,7	13,6
Percentage difference of CO_2 emissions relative to the reference scenario		-3,0	3,7
Electricity use, TWh	58,6	55,4	62,5
Energy use, TWh	168,6	160,4	177,5
Output value, SEK 1000 million	1 360	1 260	1 476
Specific energy use, kWh/SEK of added value	0,124	0,127	0,120
Specific electricity use, kWh/SEK of added value	0,043	0,044	0,042
Specific CO_2 emissions, kg/SEK of output value	0,0097	0,0101	0,0092
Specific CO_2 emissions, kg/kWh	0,078	0,079	0,077

Energy use, as calculated in the low and high growth rate scenarios respectively, amounts to between 160 TWh and 178 TWh, with electricity use ranging correspondingly between 55 TWh and 63 TWh. Carbon dioxide emissions would be expected to increase or decrease by about half a million tonnes in the high growth rate and low growth rate cases respectively. The specific carbon dioxide emissions are higher in the low growth rate case than in the high growth rate case as a result of the assumption that a higher growth rate would coincide with a higher rate of structural rationalisation. The same applies in respect of the analysis of specific usage of electricity and energy. The response to a change in growth rates of electricity and energy use is considerably greater in the low growth rate case than in the high growth rate case, due to the fact that structural rationalisation would proceed more rapidly with a higher growth rate than with a lower growth rate.

Effects of higher carbon dioxide taxes on industrial energy use

The level of the carbon dioxide tax rate is very important in determining the mix and use of energy by industry. This could be seen during the 1990s. Carbon dioxide tax in Sweden was introduced in 1991, followed by a reduction for industry in 1993 and then a rise in 1996. Over this period, the pattern of oil use reflected fairly well the taxation levels applicable to industry. The use of oil declined substantially between 1990 and 1992. Although some of this reduction can be ascribed to the general downturn in industrial output during the period, the fact that it was also influenced by the carbon dioxide tax is revealed by a comparison with the use of electricity. Between 1990 and 1992, the use of oil declined by about 20 percent, while that of electricity declined by only 6 percent.

Exactly what effects a rise in carbon dioxide tax has on energy use depends on several factors. There are at present two relief rules for industry, in the form of the 0.8 percent and the 1.2 percent rules. The 0.8 percent rule has the most impact, coming into effect when the amount of carbon dioxide tax payable by an individual company reaches 0.8 percent of the company's output sales value, and substantially reducing the tax rate of any amounts further payable.

Despite this, production in those companies to which the relief rules apply results in only a smaller proportion of carbon dioxide emissions. In 1999, the monetary value of this reduction amounted to about SEK 200 million. On the other hand, the results in respect of energy use, and the composition of the energy mix, are very dependent on whether or not it is assumed that the relief rules would continue to be applied with higher carbon dioxide tax rates. The carbon dioxide tax loses its determinant effect when a company starts to qualify for relief. The effect of the relief rules is that the marginal cost of fossil fuels becomes cheaper, i.e. the cost of using these fuels falls.

Several calculations of the effects that higher carbon dioxide taxes would have on energy use and carbon dioxide emissions in and from industry were made as part of the Swedish Energy Agency's work of preparing material for the Climate Committee. These calculations, which to some extent were bound up with the results from the National Institute of Economic Research's EMEC model, assume that the relief rules would remain. The calculations showed that, despite substantial rises in the rate of carbon dioxide tax, industrial carbon dioxide emissions would fall only marginally. In fact, they would actually increase from certain sectors.

If it is assumed that the relief rules were withdrawn, higher carbon dioxide taxes would presumably have much greater effect on energy use and carbon dioxide emissions from industry. This would result from two different effects, the output effect and the substitution effect.

The output effect means that output can fall as a result of rising production costs, which would therefore also reduce energy use and carbon dioxide emissions. The substitution effect, by which fossil fuels would be replaced to some extent by non-fossil fuels, arises as a result of an increase in the cost of using fossil fuels. Increasing the carbon dioxide tax would change the relative prices between fossil and non-fossil fuels.

It is the substitution effect that the State wishes to achieve through the carbon dioxide tax, as the output effect incurs an additional cost in the form of loss of output.

As Swedish industry has now paid a carbon dioxide tax for ten years, it is reasonable to assume that it has by now implemented the cheapest measures aimed at reducing carbon dioxide emissions. This means that the costs of effecting further emission reductions are high in comparison with those of industry in many other countries. Further, most of the carbon dioxide emissions from industry are produced by sectors whose products compete on international markets, which means that the ability to pass on costs to consumers in the form of higher carbon dioxide taxes is limited. Therefore, although further increases in the carbon dioxide tax rate would certainly reduce carbon dioxide emissions, this would mainly be done through production cutbacks or closures. However, the scale of these effects would also depend on events in countries with which the Swedish industries were competing.

Sensitivity analysis, the residential sector

The results in the scenarios are based on calculations that, in turn, are based on a number of assumptions. As there is considerable uncertainty relating to these assumptions, a number of sensitivity analyses have been performed in order to show how changes in the assumptions can affect the results. The analysis, which covers the period to 2010, relates to the residential and commercial premises sub-sector, which accounts for the greater part of total energy use in the sector.

Energy use and carbon dioxide emissions in the residential and service sector etc. are not as greatly affected by the growth rate of the economy.

The calculation assumptions of which the effects are analysed are the growth of heated indoor areas, efficiencies and change in specific net energy use for heating, domestic electricity and electricity for building services systems[116]. A high case and a low case have been calculated.

The results of this sensitivity analysis clearly indicate that the assumed values given to the above parameters have a considerable effect on the results for 2010.

The following factors have been changed in the assumptions in the high growth rate case:

- the rate of new building, and of extension, expansion etc., is 50 percent higher than in the main scenario,
- improvement in efficiencies has been halved in comparison with the basic assumption,
- no improvement in the efficiency of heating.

These changes to the assumptions in the main scenario result in total energy use in the sector being expected to increase from 157 TWh to 164 TWh in 2010. Most of this increase would be due to increases in the use of electricity and district

[116] Further factors are population growth, number of persons in households etc. However, these parameters have not been included in this senstivity analysis.

heating, with electricity use increasing by 3 TWh and district heating increasing by almost as much. This would have the effect of not increasing carbon dioxide emissions that can be directly ascribed to the residential and service sector by more than 0.3 million tonnes. However, a higher use of district heating would contribute to increasing carbon dioxide emissions from district heating production by 0.4 million tonnes.

The following factors have been changed in the assumptions in the low growth rate case:

- the rate of new building, and of extension, expansion etc., is halved in comparison with the main scenario,
- improvement in efficiencies is 50 percent higher than in the basic assumption,
- improvement in the efficiency of heating is assumed to be twice as high.

In this low growth case, energy use would be about 7 TWh less than in the main scenario, i.e. giving a total energy use in the sector of 150.1 TWh. In this case, too, the effects would be noted mainly in the use of electricity and district heating. The use of oil would decline somewhat, reducing emissions from the sector by 0.3 million tonnes. Emission reductions from district heating production, as a result of less use of district heating in residential buildings and commercial premises, would amount to 0.2 million tonnes. Electricity use would be expected to decline by 3 TWh.

Effects of higher carbon dioxide tax

Several calculations of the effects of higher carbon dioxide taxes were made as part of the Swedsih Energy Agency's work of preparing material for the Climate Committee. The emphasis has been on space heating of residential buildings and commercial premises, which accounts for almost 65 percent of total energy use in the sector.

In 1997, an estimated 10-20 TWh were used for heating in systems where the energy input can be varied between electricity, oil and - to some extent - logs. It is particularly in detached houses with combination boilers that it is possible quickly to change the type of energy source. In our calculations, in order to avoid an excessive increase in the use of electricity in response to a rise in the price of domestic fuel oil, the energy tax on electricity has been progressively increased. The electricity tax rates corresponding to the two carbon dioxide tax rates are 210 SEK/MWh and 250 SEK/MWh respectively.

The length of time since any particular tax has been introduced is a factor that affects the magnitude of the effects on energy use in the residential and service sector. Conversion to some other form of heating tends to be considered primarily in connection with the necessity to replace a heating system at the end of its life.

It is assumed that 65 percent of domestic heating systems will be replaced between 1997 and 2010. This does not apply in houses having direct electric heating, as these are not systems in which the entire system fails: instead, it is possible to replace one electric radiator at a time. Tax rises would need to be extremely high before they could persuade the property-owner to replace a working system.

Among those affected by an increase in the rate of carbon dioxide tax are those using oil or gas for heating. When an old oil-fired boiler expires, many owners take the opportunity of choosing an alternative form of heating. If district heating is available in the area, this can be one such alternative: others include the use of pellets or the installation of a heat pump. However, the installation of a pellets-fired boiler or stove is not always appropriate in an urban area, due to its effect on the local environment.

Awareness among property-owners of the possibility of using pellets is very important in determining whether the use of pellets will increase or not. At present, pellets-fired boilers and stoves are not particularly well known, and so they are often not among the alternatives considered when a property-owner is thinking of investing in a new heating system.

It can be worthwhile, in response to a substantial rise in carbon dioxide taxation, to convert a heating system before the end of its life. However, the question here is how a property-owner who has recently invested in a new oil-fired or combination boiler would react to making a new investment, and whether the household's or company's economy would permit it. This is one of many uncertainty factors in the calculations.

The alternative for those who do not need to replace their heating system, but who nevertheless want to reduce their heating and domestic hot water costs, is to improve the house's climate screen. The profitability of upgrading windows and applying additional thermal insulation improves when the tax goes up. Lowering the indoor temperature, too, and cutting down on shower time, can also have a considerable effect on domestic energy costs. Both tax scenarios assume that such measures would be increasingly employed in response to rising tax rates.

If the carbon dioxide tax rate is increased to 820 SEK/tonne[117], it starts to become profitable to convert heating systems in detached houses that have a working boiler, fuelled only by oil. It becomes viable to replace the burner in the existing boiler, changing to the use of pellets instead of oil. In addition, it is expected that a few properties in this group would change to district heating. It would be economical for larger apartment buildings and commercial premises to replace a working system before the end of its life. The calculations include the effects of

[117] On 1st January 2001, the carbon dioxide tax rate was 530 SEK/tonne and from the 1st of January 2002, approx 600 SEK/tonne.

conversions of oil-fired and electric boilers to district heating, heat pumps and pellets-fired boilers.

This scenario assumes that the electricity tax has been raised to 210 SEK/MWh, which would make it worthwhile for the owners of detached houses having waterborne electric heating to change to some other type of heating system when the old electric water heater needs to be replaced. In this case, it is district heating that is the most profitable alternative, although heat pumps could also be of interest, and so some degree of conversion away from waterborne electric heating is expected. A higher proportion of electricity in combination systems, together with a greater number of heat pumps, accounts for the fact that electricity use would not decline, despite the conversion away from electrically heated buildings and less use of domestic electricity and electricity for building services systems.

The scenario with a carbon dioxide tax of 1440 SEK/tonne, and an electricity tax of 250 SEK/MWh, is expected to result in leaving only a few purely oil-fired boilers in operation. It is assumed that no property-owner needing to invest in a new heating system would choose an oil-fired boiler. However, a number of combination systems could be expected to be left in operation.

It is expected that the use of oil for heating would decline drastically with a carbon dioxide tax rate of 1440 SEK/tonne. In addition, despite an increase in the number of heat pumps and a relatively high usage of electricity in combination systems, it is expected that the overall use of electricity would also decline. This is due partly to the expectation that there would be fewer combination systems than there would be in the other tax scenario, and partly to the fact that the higher energy prices would provide an incentive to improve the efficiency of use of domestic electricity and electricity for building services systems. It is expected that the use of wood fuels and district heating would increase substantially in comparison with the use expected on the basis of present-day taxation levels.

Sensitivity analyses, the transport sector

A number of sensitivity analyses have been made in order to determine how sensitive the results of the scenario are to changes in the underlying assumed conditions.

Developments in private consumption, together with growth in industrial output, are important in determining developments in the use of petrol and diesel fuel respectively. In turn, these two fuels account for a substantial proportion of energy use in the transport sector. Although their use has hitherto been relatively insensitive to price changes, their use has continued to increase significantly despite rising prices.

Sensitivity analyses have been carried out for these variables and fuels for the period from 1997 to 2010. The boundary figures have been a high rate (2.8 percent) and a low rate (2.0 percent) of annual percentage growth in private consumption, and a high rate (3.0 percent) and a low rate (1.7 percent) of annual industrial output growth rate. The corresponding growth rates in the main scenario are 2.4 percent per annum for private consumption and 2.3 percent per annum for industrial output growth rate.

In addition, we have calculated how energy use would be affected by assuming that the ACEA agreement would be fulfilled[118]. The results of this agreement have a relatively substantial impact on the calculations. The average annual rate of efficiency improvement until 2020 is taken to be 0.75 percent, as against only 0.2 percent that is assumed to be the case without the agreement. Over the scenario period, this is equivalent to a reduction in emissions of about 2 million tonnes. The starting point in assessing how great the rate of efficiency improvement would be without the ACEA agreement is that of historical development. The improvement in the efficiency of fuel use that occurred between the 1980s and the 1990s has largely been offset by more powerful engines, larger and heavier vehicles and the use of more ancillary equipment, such as air-conditioning.

Table B5 Sensitivity analyses for the use of petrol and diesel fuel.

Assumption **(The main scenario assumptions within brackets)**	**Departure (percent) from the main scenario** [1)]
Use of petrol	
Private consumption (2.4 percent per annum)	
- 2.8 percent per annum	3,3
- 2.0 percent per annum	-3,0
Improvement in fuel efficiency, including the ACEA agreement (-13 percent)	
- excluding the ACEA agreement (-3 %)	11,3
Use of diesel fuel	
Industrial output growth rate (2.3 % per annum)	
- 3.0 % per annum	6,5
- 1.7 % per annum	-5,1

1) Energy use.

The calculations previously made for various tax rates in fossil fuels for the Climate Committee[119] can illustrate the sensitivity of the use of petrol and diesel fuel to various price changes. An increase in the tax to 600 SEK/tonne of carbon dioxide could be expected to result in a reduction of 2 percent in the use of petrol and of 1 percent in the use of diesel fuel, in comparison with the results from the

[118] ACEA 'European Automobile Manufacturers' Association'. The ACEA agreement is a voluntary agreement between the EU Commission and the automotive industry in Europe, Japan and Korea, to reduce carbon dioxide emissions from new private cars by 25 % between 1995 and 2008.

[119] Energy and climate in Sweden: Scenarios 2010'. Swedsih Energy Agency, EB 4:2000.

corresponding scenario calculation with a carbon dioxide tax rate of 370 SEK/tonne[120]. This increase in tax is equivalent to an increase of 11 percent in the price of petrol and 10 percent in the price of diesel fuel, in comparison with the 1997 prices. Increasing the tax to 1440 SEK/tonne of carbon dioxide is equivalent to an increase of 39 percent in the price of petrol and 53 percent in the price of diesel fuel, again in comparison with 1997 prices. It is calculated that the effect of such a rise would be to reduce the use of petrol by 11 percent, and that of diesel fuel by 12 percent.

[120] The carbon dioxide tax rate was increased on 1st January 2001 to 530 SEK/tonne and to further approx 600 SEK/tonne from de 1st of January 2002.

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