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# Indicators of $CO_2$ emissions and energy efficiency

## Comparison of Finland with other countries

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# Abstract

The generic technology options recommended by the Intergovernmental Panel on Climate Change (IPCC) to reduce fossil fuel $CO_2$ emissions include efficiency improvements both in the supply and use of energy, switching to less carbon-intensive fuels, and switching to renewable energy resources. The present study considers, using indicators based on statistics, to which extent these options are already being utilized in various OECD countries.

The efficiency of energy production is high in Finland, due to extensive utilization of cogeneration of electricity and heat both for industry and for the tertiary and residential sectors. The use of sustainably produced biomass for combined heat and power generation is the largest in the world. About 10% of the total national electricity production is generated using wood-derived fuels and modern power plant technologies.

Improvements in the energy efficiency of manufacturing industries during the last twenty years in Finland are similar to the average in OECD countries, and the relative decrease in $CO_2$ intensity has been more rapid than that in the OECD as a whole. In the manufacturing of pulp and paper, and iron and steel, Finnish industries are among the most efficient; however, the differences in energy intensities among the countries considered are relatively small in these sectors.

The energy use and $CO_2$ emissions attributable to the Finnish residential sector are low, despite the cold climate, due to good insulation of houses and cogeneration of heat and power. If the dependency of heating energy demand on climatic conditions is accounted for using heating degree-day corrections, the values for Finland are among the lowest among the western industrialized nations. The energy demand in Finland for the transport sector is in general relatively low; in particular, the energy use in road freight transport per tonne-kilometer is the lowest of the countries studied.

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# Tiivistelmä

Hallitusten välisen ilmastopaneelin (IPCC:n) suosittelemat teknologiavaihtoehdot fossiilisperäisten $CO_2$-päästöjen rajoittamiseksi ovat tehokkuuden parantaminen sekä energian tuotannossa että käytössä, siirtyminen vähemmän hiiltä sisältäviin polttoaineisiin sekä siirtyminen uusiutuviin energianlähteisiin. Tässä tutkimuksessa tarkastellaan tilastoihin perustuvien tunnuslukujen avulla sitä, missä laajuudessa näitä vaihtoehtoja jo käytetään eri OECD-maissa.

Energian tuotannon tehokkuus on Suomessa korkea, koska lämmön ja sähkön yhteistuotantoa käytetään laajasti sekä teollisuudessa että lämmityssektorilla. Kestävällä tavalla tuotetun biomassan käyttö polttoaineena yhdistetyssä lämmön ja sähkön tuotannossa on laajinta maailmassa. Noin 10 % Suomen sähköstä tuotetaan nykyaikaisilla teknisillä ratkaisuilla käyttäen puuperäisiä polttoaineita. Uutta teknologiaa kehitetään energian tuotannon tehokkuuden parantamiseksi edelleen.

Suomen teollisuudessa energian käytön tehokkuuden paraneminen on ollut kahtena viime kymmenenä vuotena likimain yhtä voimakasta kuin OECD-maissa keskimäärin ja $CO_2$-intensiteetti on laskenut nopeammin kuin OECD:ssä keskimäärin. Selluloosan ja paperin sekä raudan ja teräksen valmistuksessa Suomen teollisuus on keskimääräistä tehokkaampaa, toisaalta tarkasteltujen maiden välillä erot olivat suhteellisen pieniä.

Energian käyttö ja $CO_2$-päästöt asumissektorilla Suomessa ovat alhaiset huolimatta kylmästä ilmastosta rakennusten hyvän eristyksen sekä lämmön ja sähkön yhteistuotannon takia. Jos lämmitystarpeen riippuvuus ilmasto-olosuhteista otetaan huomioon astepäivälukukorjauksen avulla, Suomen lämmitystarve on alhaisin läntisistä teollisuusmaista. Energian kysyntä liikennesektorilla on yleisesti ottaen suhteellisen alhainen, erityisesti energian kulutus maantietavaraliikenteessä tonnikilometriä kohti on tarkastelluista maista alhaisin.

Tutkimuksen tulosten mukaan suuri osa IPCC:n suosittelemien teknologiavaihtoehtojen tarjoamasta päästöjen rajoituspotentiaalista on Suomessa jo käytössä, ja voidaan arvioida, että kustannustehokas lisäpotentiaali on siten suhteellisen rajoittunut. Jatkuvaa tutkimus- ja kehitystyötä tehdään kuitenkin energian käytön tehokkuuden parantamiseksi. Teknologiavaihtoehtojen laaja käyttö on saavutettu pääosin ilman ulkopuolista energiantuotannon ja teollisuuden ohjausta.

# Preface

Mitigation of the threat of global climate change is a challenge to mankind. Under the UN Framework Convention of Climate Change, solutions for reducing the emissions of greenhouse gases leading to climate change are being sought. The solutions should be effective and fair, the varying conditions of different countries should be considered. This report considers how the countries differ with respect to their energy production and consumption; the efficiency of energy production, intensity of energy use, and $CO_2$ emissions are especially discussed. The main emphasis is devoted to the conditions and situation in Finland.

This work has been carried out at VTT Energy under contracts with the Ministry of Trade and Industry (KTM) and with several companies and industrial federations. The work was guided by a steering group which comprised of members from all funding organizations and from VTT Energy. The chairperson of the steering group was Dr. Tellervo Kylä-Harakka-Ruonala of the Confederation of Finnish Industry and Employers (TT). Other members of the steering group included Mr. Jaakko Ojala of the Ministry of Trade and Industry, Ms. Anneli Nikula of Finergy, Mr. Pertti Laine of the Finnish Forest Industries Federation, Mr. Jaakko Tusa of the Finnish Petroleum Federation, Ms. Carola Teir-Lehtinen and Mr. Jukka-Pekka Nieminen of Neste Ltd., Mr. Heikki Niininen and Mr. Juhani Santaholma of the IVO Group, Mr. Jouko Rämö of the PVO Group, Ms. Ulla Sirkeinen and Mr. Jouni Punnonen of the Confederation of Finnish Industry and Employers, and Dr. Pekka Pirilä of VTT Energy.

# Contents

# List of country acronyms

*Countries considered in the study.*

| Acronym | Country |
|---|---|
| AUS | Australia |
| AUT | Austria |
| BEL | Belgium |
| CAN | Canada |
| CHE | Switzerland |
| DEU | Germany |
| DNK | Denmark |
| ESP | Spain |
| FIN | Finland |
| FRA | France |
| GBR | United Kingdom |
| GRC | Greece |
| IRL | Ireland |
| ITA | Italy |
| JPN | Japan |
| MEX | Mexico |
| NLD | Netherlands |
| NOR | Norway |
| NZL | New Zealand |
| PRT | Portugal |
| SWE | Sweden |
| USA | United States |
| EU | EU countries |
| EU-7 | DEU, DNK, FIN, FRA, GBR, ITA, SWE |
| EU-8 | DEU, DNK, FIN, FRA, GBR, ITA, NLD, SWE |
| EU-9 | BEL, DEU, DNK, FIN, FRA, GBR, ITA, NLD, SWE |
| Nordic | DNK, FIN, NOR, SWE |

# 1 Introduction

According to the UN Framework Convention on Climate Change, the atmospheric concentrations of greenhouse gases should ultimately be stabilized at a level that would prevent dangerous anthropogenic interference with the climate system. To attain this objective the emissions of greenhouse gases should be limited considerably. Countries differ from each other in their potential for reducing emissions and in the economic consequences of emissions limitations. This is due to their different natural conditions and resource base, energy systems, and economies, including historical development and wealth.

Currently it remains very difficult to estimate the economic costs of emission control in a comparable manner in different countries. Emission reductions of equal percentages in various countries would lead to very different costs for national economies. As the measures should be quite extensive to attain significant emission reductions, high requirements are also given for the cost-efficiency of the measures to be taken. Flexibility and cost-efficiency in the emission-reduction process could be achieved through joint implementation and tradable emission rights. These types of international arrangements, however, require institutional capacity at the national and multinational levels, and they include also many questions the settling of which might be complicated.

The differences among countries can be described with indicators that depict the natural circumstances and socio-economic conditions of countries in relation to possibilities of reducing emissions of greenhouse gases. These types of indicators can be based on international statistics such as those of the OECD or UN. One set of indicators describing the characteristics of national energy systems has been presented by Lehtilä et al. (1997). At least two large international programmes are being undertaken by the OECD/IEA and EU in this field (Bosseboeuf et al. 1996, IEA 1997). Indicators similar to the ones presented in this report have also been calculated in other studies (e.g. Schipper & Perälä 1995, IEA 1997).

The Intergovernmental Panel on Climate Change (IPCC 1996a, 1996b) gives the following generic technology options for the reduction of fossil fuel $CO_2$ emissions: 1) improvement of energy efficiency in industry, transportation, and the commercial/residential sector, 2) improvements in efficiency of fuel conversion (e.g. combined heat and power (CHP) production and more efficient generation of electricity), switching to less carbon-intensive fuels, and switching to renewable sources of energy. In addition, the IPCC lists others, e.g., increased use of nuclear energy, and capture and disposal of $CO_2$ emissions from fossil fuel utilization.

The objective of the present study is to consider to what extent some of the recommended measures are already being utilized in various industrialized countries. This is done by deriving, on the basis of statistics, indicators describing the efficiency of energy production and use and the specific $CO_2$ emissions. The indicators for energy and emission intensity are compared among a number of OECD countries. The special features of the Finnish energy production and consumption system are also discussed.

Chapter 2 outlines the general methodology used in the work and lists the main data sources used for the sectoral studies. Chapter 3 describes important factors that explain some of the differences in energy use and greenhouse gas emission balances among countries, focusing on developed market economies. Chapter 4 investigates the characteristics of national energy supply systems. The issues treated include carbon intensity of the primary energy supply, energy sources used for electricity generation, the extent of present and past use of renewable energy sources, the overall efficiency of power production, combined heat and power, and the role of district heating in heat supply.  Moreover, energy intensities in the petroleum-refining sector are briefly discussed.

Chapter 5 presents indicators for energy use and $CO_2$ emissions in the manufacturing sector. In addition to the aggregate level of total manufacturing, some aspects of structural changes are handled, and the energy-intensive pulp and paper and iron and steel sectors are further investigated on a more detailed level. Chapters 6 considers similar analyses for residential and transport energy use and emissions.

To provide some background information about the focal points in energy-related research and development (R&D) work in Finland, Chapter 7 gives an overview of the wide national energy R&D programmes currently running. Finally, Chapter 8 summarizes both the main methodological issues involved in the study and the most significant conclusions that could be drawn from the analyses.

# 2 Methods and sources of statistical data

The countries included in the indicator calculations have been selected among the OECD countries on the basis of data availability and relevance for the comparison with Finland. Due to the lack of sectoral data of even reasonable quality, non-OECD countries have not been considered in this study. The countries and acronyms for each country are listed in the List of Country Acronyms.

International data on *energy production and consumption* on the national level have been primarily taken from the IEA Basic Energy Statistics (IEA 1996a). The consumption of each fuel is normally reported in mass units in the IEA database. The energy contents of the fuels used have been calculated by multiplying the fuel consumption by country-specific (lower) heating value of the fuel, as given in the IPCC Greenhouse Gas Inventory Manual (IPCC 1995). In order to calculate the fossil *$CO_2$ emissions* from fuel combustion, the consumption of each fuel is multiplied by the IPCC reference fuel emission factors (IPCC 1995). The emission factors have been corrected with fractions of carbon not oxidized, as recommended by the IPCC.

Basically, all the energy consumption reported in the IEA statistics has been accounted for. Notable exceptions include marine bunkers, and the 'non-energy use'-category. The use of feedstocks in chemical industries has been counted as raw material use to the maximum extent recommended by the IPCC guidelines (IPCC 1995). IEA itself considers all the feedstocks to the chemical industry as energy use.

With regard to the total consumption data, relying on the IEA data was deemed to be justified on the basis of some earlier comparisons of national and international energy and emission statistics (Lehtilä et al. 1997, IEA 1995, Marland et al. 1994). On the level of individual sectors, however, the IEA statistics contain a considerable amount of energy consumption data that have been misallocated to the wrong end-use sectors. Due to lack of other comprehensive, good-quality data sources, the IEA statistics have still been used as the main source of basic data. Additionally, however, the Energy Analysis Program of the Lawrence Berkeley Laboratory has provided summary data on the residential and transport sectors from their extensive international databases on sectoral energy use (LBL 1997, IEA 1997). For transport energy use, the statistics compiled by the European Conference of Ministers of Transport (ECMT) have also been used as reference.

For manufacturing energy use, the IEA basic energy statistics were the only available international data source of reasonable quality, and were therefore used. It should be pointed out, however, that for many countries the split of manufacturing energy use among different subsectors appears to be strikingly rough or incorrect in the IEA database, especially for the 1970s, but for some countries also for later years.

Good quality data from the LBL were available for the delivered energy use in the residential sector for nine countries (excluding Finland). The LBL data were basically used as such for all these countries, except for Italy and Denmark. In the case of Italy the residential use of wood was not included in the LBL data, which was corrected on the basis of other data sources (EC 1996, IEA 1996a). For Denmark, using the LBL data resulted in serious consistency problems with the energy sector data (interactions with electricity and heat generation), which could be avoided by using the IEA statistics.

The quality of the IEA data for transport could be regarded as fairly satisfactory. Unfortunately, the data contain no information on the split of energy use between passenger and freight transport; therefore, the energy consumption in road and rail transport was allocated to passenger and freight transport according to the LBL data (see also Section 6.2). For inland and coastal navigation and air transport, the LBL data were used solely, as the IEA data contain insufficient information on the split of fuel consumption between domestic and international carriers.

The efficiency indicators calculated are typically ratios of energy consumption or emissions to some measure of *activity level* in the sector considered. The activity measure used for manufacturing industries is the value added in constant price level. Furthermore, the amounts of value added have been adjusted with purchasing power parities (PPP). Time series for the PPP-adjusted value added at the 1990 price level for each manufacturing sector have been obtained from the OECD Sectoral Database (OECD 1997a). Since the aggregation level of the Sectoral Database is relatively high, however, more detailed splits between subsectors were in some cases needed (e.g. between iron and steel manufacturing and the manufacturing of non-ferrous metals). In such cases, the major additional data source was the OECD Industrial Structure Database (OECD 1997b).

For the measure of activity level in the residential sector, the total volume or floor area of residential buildings or the population could be used. The volume or floor area of dwellings, however, is best applicable only for the study of space heating or lighting energy use, and even the requirements of space heating are hardly proportional to the floor-area itself, but rather to the square root of it. Therefore, population was chosen as the primary activity level against which the total residential energy consumption and emissions were calculated. Nevertheless, to obtain a more complete picture, indicators based on the floor area of dwellings have been included as well. The population data were taken from Penn World Tables (Heston et al. 1995), Statistics Finland (1996c), and the UN (1995). The international data on floor areas were obtained from the LBL (1997).

In the transportation sector, the activity level is the total amount of passenger-kilometers or the total amount of tonne-kilometers for passenger and freight transport, respectively. The international activity data were obtained from ECMT statistics (ECMT 1995, 1997) and from the LBL databases (LBL 1997).

For a more detailed analysis of the forest sector, specific energy uses in pulp and paper production in Finland have been taken from an earlier VTT study (Lehtilä 1995). Statistics on the outputs of various products have been taken from the FAO database (FAO 1997). The FAO data for Finland were consistent with national sources (Forest Research Institute 1996). For corresponding calculations for iron and steel manufacturing all data have been taken from statistics compiled by the International Iron and Steel Institute (IISI 1996).

The IEA data for Finland have not been used as such, but have been carefully revised with data from national sources (e.g. Statistics Finland 1995, 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, Nippala et al. 1995, Mäkelä et al. 1996, Finnra 1997). Nevertheless, an attempt has been made to maintain the revised data as consistent as possible with the IEA data. For example, it has been taken care that the total national level consumption of each fuel is equal to the amount in the IEA database, unless it is clearly erroneous. The quality of all the Finnish data used for the indicators was estimated to be quite good.

# 3 Factors affecting energy use and $CO_2$ emissions

Countries differ with respect to their natural conditions and resources and history of development of industry and economy in general. In a cold climate, energy is needed for the heating of buildings, and in a warm climate energy might be used for cooling. In sparsely populated countries average transport distances are long. Natural resources can provide energy, e.g. hydropower, but the utilization of natural resources can also increase the demand for energy, as in the manufacturing of metals or forest products.

The structure of primary energy supply in some countries is presented in Figure 1. Certain countries, e.g. Norway or Sweden, have abundant domestic hydropower resources while some others rely to a high degree on domestic or imported fossil fuels. With respect to nuclear power the national policies differ significantly, France and Sweden utilize it very much, and some others such as Austria or Denmark not at all in domestic energy supply.

The structure of energy consumption also varies among countries (Figure 2). In some countries, as in Finland, the percentage of energy use in industry is large, due especially to energy-intensive industries such as manufacturing of pulp and paper and both ferrous and non-ferrous metals. In some other countries the relative weight in energy consumption is in the residential/commercial and transport sectors. In the case of Finland, about 90 % of the paper produced is exported, such that Finland provides paper for an average population ten times larger than its own. This is a result of economic development based on the utilization of natural resources.

The wide differences among countries can also be seen in the average specific $CO_2$ emissions from electricity generation (Figure 3). Countries with abundant hydropower and large nuclear programmes have the lowest specific emissions per kilowatt-hour of electricity. Efficiency of combustible fuel-based electricity production can be improved with the utilization of combined generation of heat and electricity, as in Denmark, Finland, and The Netherlands. Countries that produce electricity almost solely with coal-based condensing power plants have the highest specific emissions.

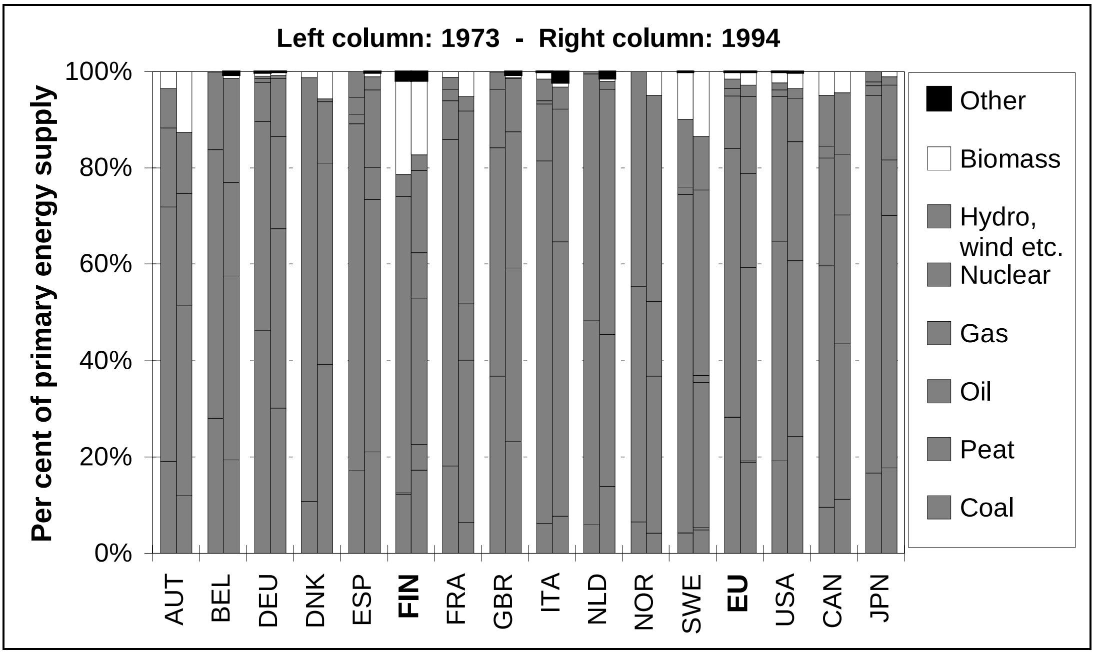



*Fig. 1. Structure of primary energy supply by energy source in selected OECD countries in 1973 and 1994, according to IEA methodology.*

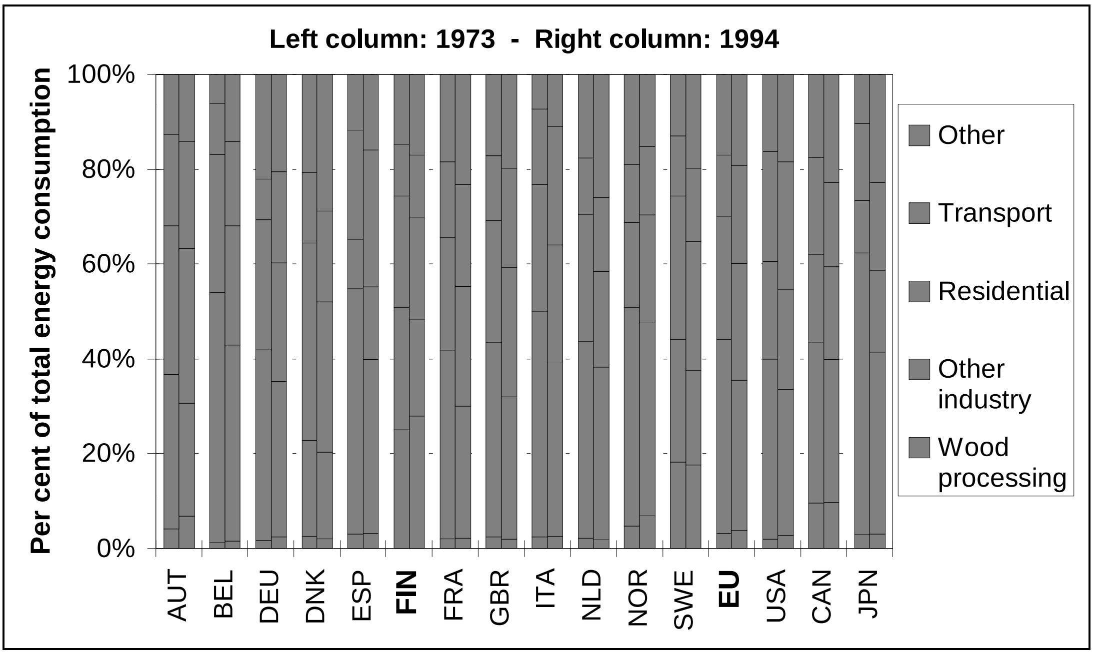



*Fig. 2. Structure of energy consumption by energy end-use sector in selected OECD countries in 1973 and 1994. All primary energy allocated to end-users of energy.*

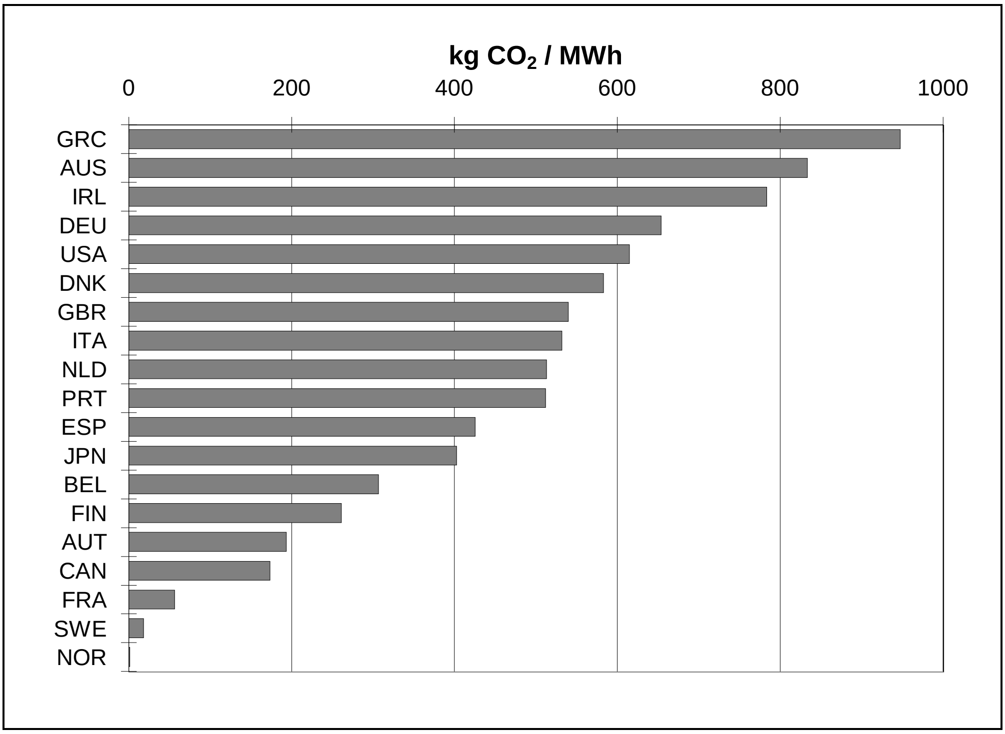



*Fig. 3. Average specific $CO_2$ emissions from electricity generation in selected OECD countries in the year 1994.*

The impact of exports on national energy use and $CO_2$ emissions can be studied in more detail. Economic models may be used to estimate the energy use and emissions by final demand category. The expression “embedded energy” means all the direct and indirect use of energy that is needed along the production chain of goods and services used in each final demand category considered. Embedded fossil fuel $CO_2$ emissions are those caused by this energy use.

Estimates of embedded energy and fossil fuel $CO_2$ emissions by final demand category in the Finnish domestic economy have been derived using an input-output model at the University of Oulu (Mäenpää & Tervo 1994). The input-output tables are a systematic, closed, total description of the production of goods and services with regard to their final use. The input-output tables can be used in the calculation of the total amounts of energy needed in the production, directly and indirectly, of a given type and amount of final demand.

The input-output model applied in the study considers 20 classes for the description of energy production and emissions, and 29 classes of economic branches. The database for the calculations was obtained from the statistics of Energy and National Accounts for 1990 of Statistics Finland.

Energy use in private consumption covers the direct energy use of households and private non-profit institutions. In addition, it includes the energy embedded in goods and services purchased by households or used as intermediate inputs of private non-profit institutions. Energy use in public consumption consists of direct energy use of central and local government, as well as the energy embedded in goods and privately produced services used as intermediate inputs of central government and local authorities.

Figure 4 gives the energy and emission intensities of aggregated final demand categories, including the computational intensity for imports. The energy intensity is highest in the export category (Fig. 4a), which reflects the energy-intensive manufacturing of pulp and paper and metals for export. These products form a considerable part of the exports from Finland. The energy intensity of the exports is 60% higher than that of the imports. In the calculation of the figure for imports it has been assumed that the production abroad occurs with similar economic and energy structure as in Finland. The lowest energy intensity is in the public consumption category, which consists to a large extent of services.

The intensity of fossil fuel $CO_2$ emission in the export category is in relative terms lower than the energy intensity for exports. The emission intensity of the exports is only about 20% higher than that of the imports; this is due to extensive use of wood-based by-product fuels, which are utilized within the Finnish wood-processing industry.

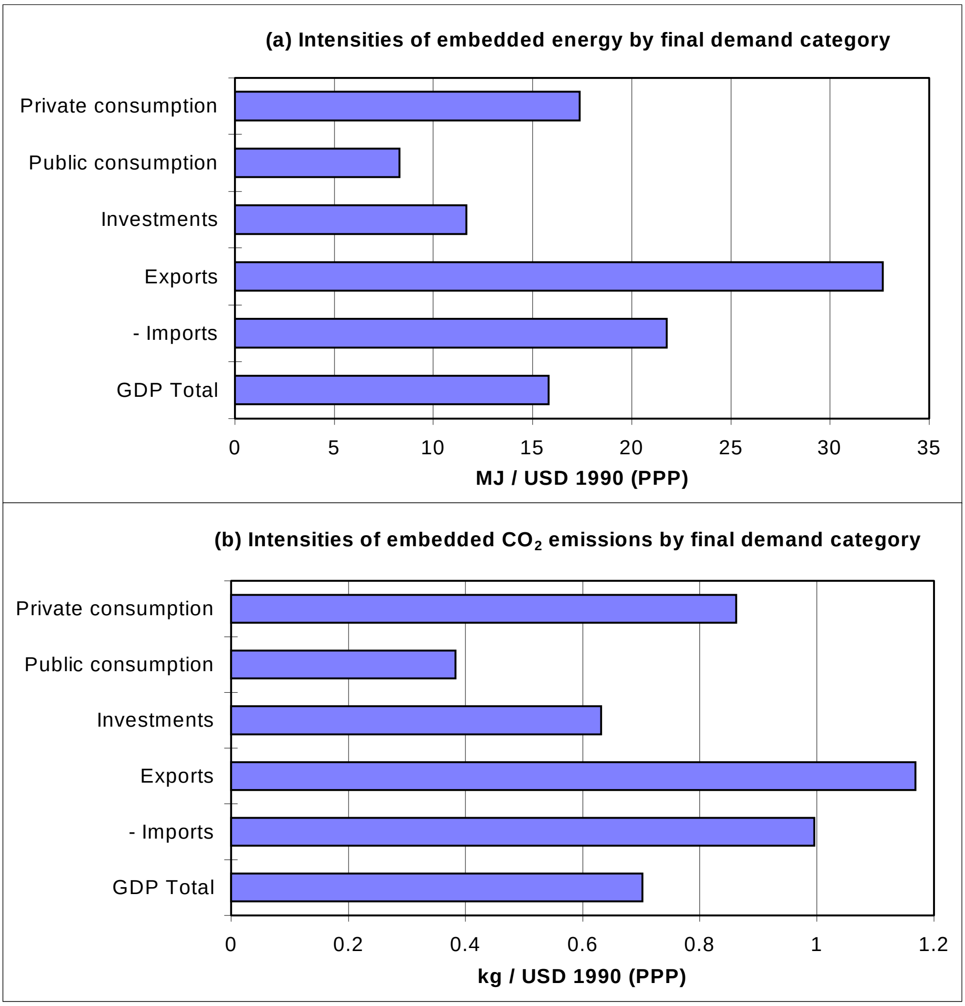



*Fig. 4. Intensities of embedded energy (a) and fossil fuel $CO_2$ emissions (b) by final demand category of Finland's domestic economy in 1990 (Mäenpää & Tervo 1994).*

The structures of primary energy supply and energy consumption in each country are influenced by natural conditions and natural resources of the country, as well as development of the economy, including the connections to other national economies. Hence, countries are in very different situations with regard to their greenhouse gas emissions.

# 4 Energy supply

## 4.1 Primary energy supply

The total annual primary energy supply (domestic supply, equal to total consumption) per capita varies in the OECD countries between about 40 GJ in Turkey and about 320 GJ in the USA (1994). In Finland the total consumption is somewhat higher than the OECD average, as shown in Figure 5. Clear reasons, however, exist for the relatively high total energy use: the climate is the coldest among the European countries, transport distances are long due to the very sparse population, and the structure of the manufacturing industries is energy-intensive.

Because there are important, country-specific circumstances affecting the total energy consumption, energy efficiency comparisons among countries should be done on a level detailed enough to support explicit consideration of such factors. Therefore, comprehensive sectoral analyses are needed for comparative energy efficiency studies to be well-grounded. The sectoral analyses made in the present study clearly show that the high overall energy consumption in Finland is not stemming from inefficient use of energy, but primarily from national circumstances and the structure of industrial sectors.

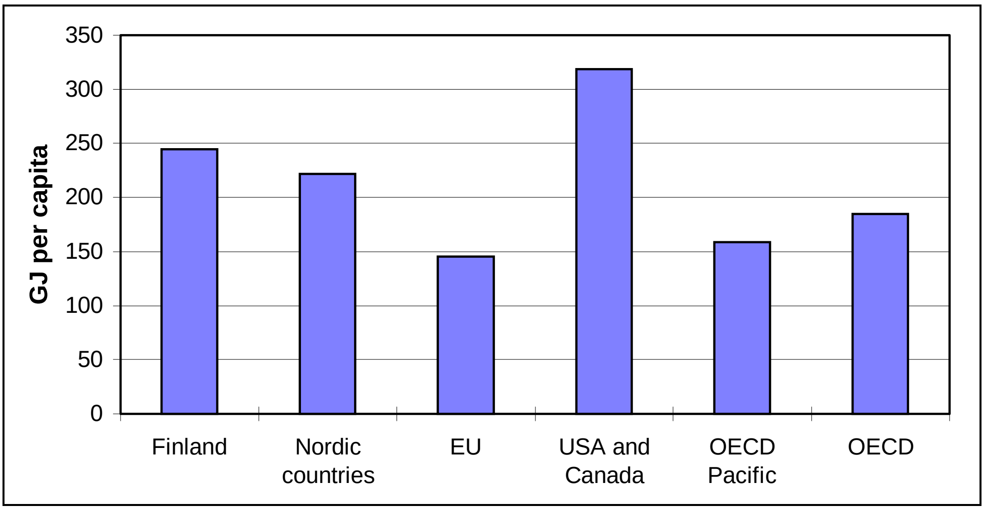



*Fig. 5. Total annual primary energy consumption per capita in Finland and other OECD countries in the year 1994, according to IEA methodology .*

It should be pointed out that the primary energy data used in this report are based on the methodology adopted by the IEA and the European Commission. Accordingly, nuclear power is converted into primary energy with a 33% gross efficiency, and hydro and wind power with 100% efficiency. For example, in the UN energy statistics a 38.5% gross efficiency is used for both nuclear and hydro/wind. If the UN methodology were used, the Swedish and Norwegian per capita consumption of primary energy would both be higher than in Finland.

As already briefly discussed in Chapter 3, the structure of the primary energy supply varies considerably among OECD countries, mainly according to indigenous energy resources, access to natural gas networks, and attitudes towards nuclear power. In 1994 the total primary energy supply within the EU consisted about 19% of coal or peat, 40% of oil, 20% of gas, 16% of nuclear, and only about 2% of hydro or wind, and 3% of biomass.

Carbon dioxide emissions also vary according to national circumstances. The average specific $CO_2$ emissions per unit of primary energy consumption have been slowly decreasing during the past 20 years in OECD countries (Fig. 6).

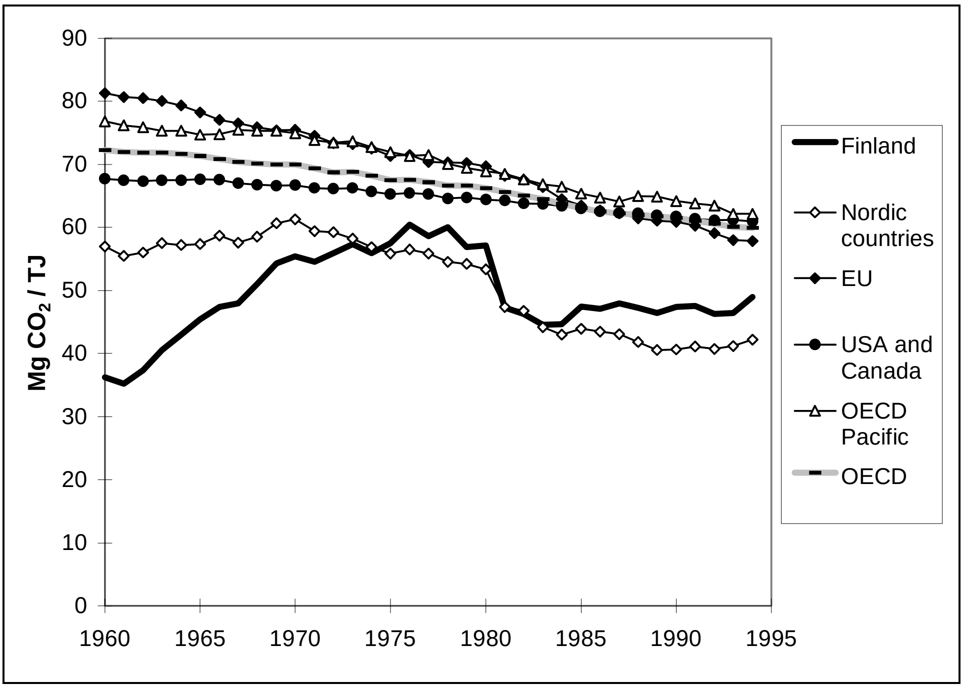



*Fig. 6. $CO_2$ emissions per unit of primary energy in selected countries.*

In Finland the average specific emissions were very low in the early 1960s, due to the large shares of hydropower and wood biomass in the total energy supply. In the past 10–12 years the Finnish emissions appear to have become stabilized at the level of about 50 Mg $CO_2$ / TJ, which is over 20% less than the average among OECD countries. The most important single factor behind this difference is the prominent role of biomass in the Finnish energy supply. Moreover, the introduction of nuclear power contributed to substantial reductions both in the specific and total national $CO_2$ emissions between the late 1970s and early 1980s.

The contribution of renewable energy sources (including hydro) to the total primary energy supply is illustrated in Figure 7 for Finland and major groups of OECD countries. In general, the role of renewables diminished until the first oil crisis during the early 1970s.  Since then, the average percentage of renewable energy has increased in the OECD countries by about 50%. At present hydro-power and biomass have roughly equal shares in the total EU primary energy supply, the combined share being only about 5% of the total primary energy.  In Finland, the total share of renewables was in 1994 about 19% of the total primary energy supply, i.e. almost four times as large as the EU average.

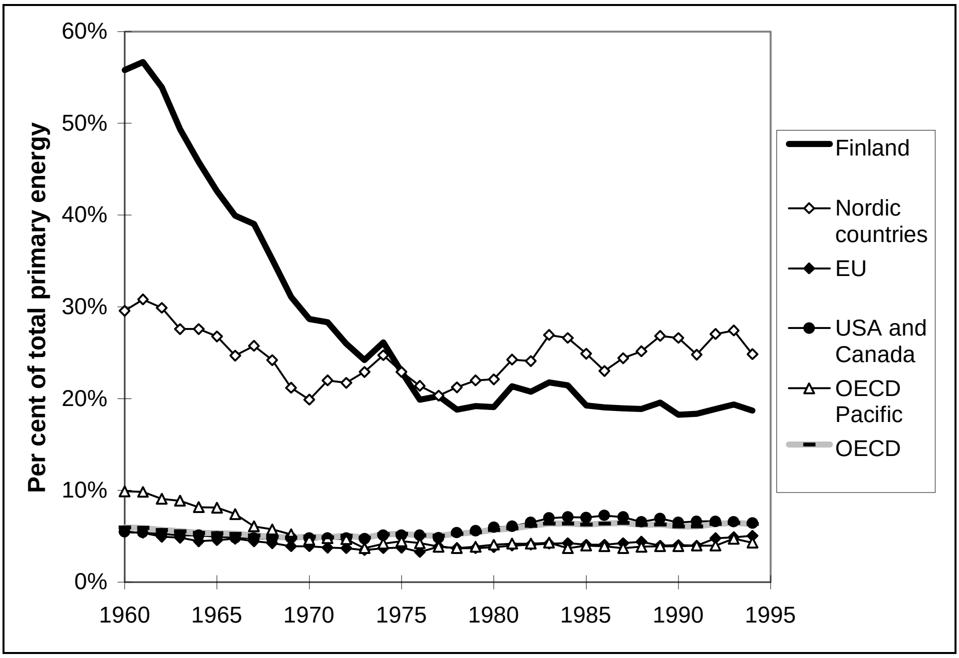



*Fig. 7. Share of renewable energy sources of total primary energy consumption in selected countries.*

However, in all countries producing hydro power, the role of hydro energy is actually much more pronounced than its primary energy share indicates. This is because hydropower is reported in the primary energy statistics assuming a 100% gross efficiency, and normally about a 1% difference between gross and net generation. Hydro energy can therefore be viewed as a rather precious form of primary energy.

With regard to the utilization of biomass for energy, Finland has been the leading country in western Europe throughout the period studied, 1960–1995. Furthermore, while even in many developed countries a major proportion of the biomass use has been so-called traditional firewood, in Finland most of the utilization has long occurred in state-of-the-art cogeneration plants. In 1994, biomass accounted for about 15% of the total primary energy in Finland, which was about five times as much as the average in the EU or in the USA. A comparison of the utilization of biomass for energy is presented in Figure 8 for selected OECD countries.

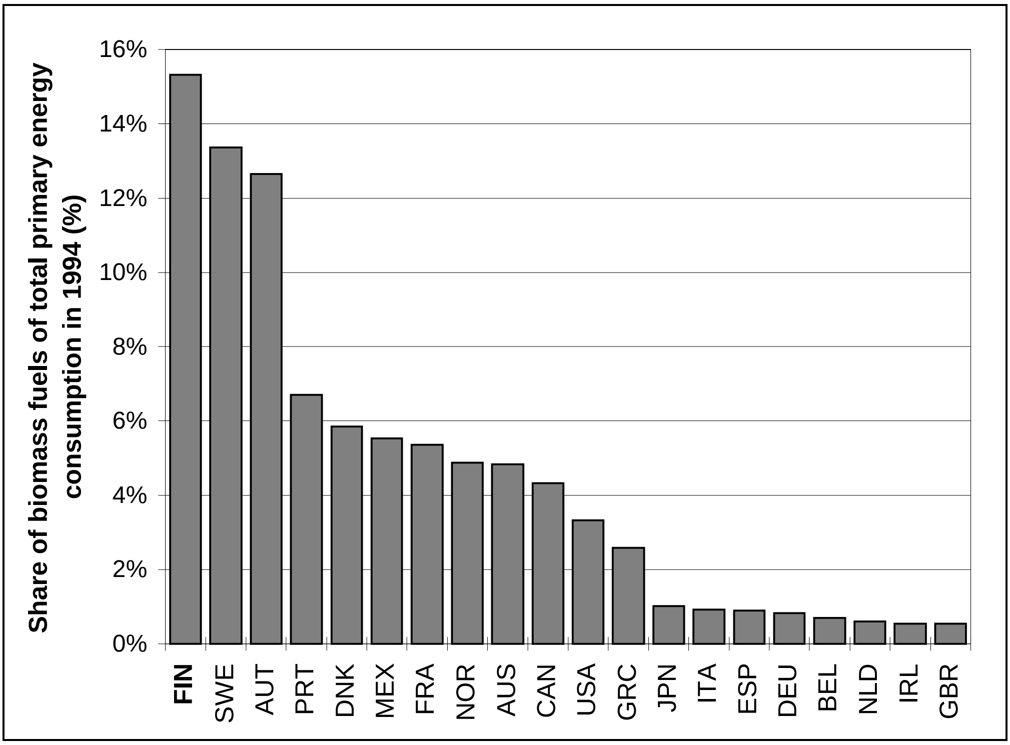



*Fig. 8. Share of biomass fuels of total primary energy consumption in selected countries in the year 1994.*

## 4.2 Power and heat generation

### 4.2.1 Electricity supply

The electricity generation sector is usually one of the most important sources for $CO_2$ emissions. Some countries with large hydro resources or a very prominent role of nuclear power can, however, manage with only very little fossil fuel-based electricity generation. Such countries include Norway, Sweden, France, Canada, and to a lesser extent also Austria.

The structure of electricity generation by energy source is shown in Figure 9 for selected OECD countries. Countries with a very high reliance on fossil fuels in power production include Denmark, Greece, and Ireland. Apart from the much larger use of biomass, Finland appears to have a production structure almost similar to the average over EU. However, it should be pointed out that this figure does not show anything about the technologies used for electricity generation, but only the energy sources.

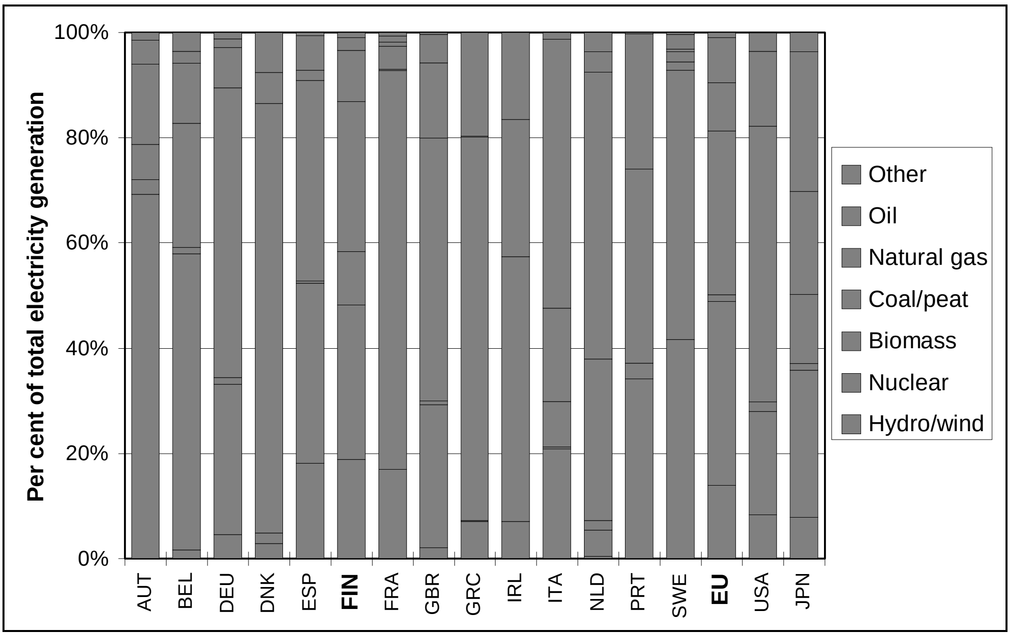



*Fig. 9. Electricity generation by energy source in selected countries. Per cent shares of gross electricity output.*

*Table 1. Average specific $CO_2$ emissions from electricity generation in Finland and other OECD countries in the year 1994.*

| | **Finland** | **EU** | **USA** | **OECD** |
|---|---|---|---|---|
| **g $CO_2$ / kWh** | 260 | 405 | 615 | 480 |

In Figure 3 of Chapter 3 the large differences in specific $CO_2$ emissions from power production were already illustrated. Table 1 presents a summary of the estimated specific emissions in the year 1994 for Finland, EU, the USA, and the OECD as a whole. Despite the seemingly similar structure by energy source in Finland and in the EU, the Finnish electricity sector appears to be much less carbon intensive. There are two important reasons for this difference: The very important role of combined heat and power (CHP) production, and the exceptionally large use of biomass for thermal power generation in Finland. With its high total energy efficiency (80%–90%) and low distribution losses, combined heat and power can improve the overall efficiency of the power generation sector considerably. CHP systems will be discussed in more detail in section 4.2.2.

Reducing the $CO_2$ emissions from electricity generation by increasing the use of renewables is a high-priority policy target in many countries. Most of the hydro resources are already fully utilized in European countries, including Finland. Therefore, in the medium term (10–30 years), significant additional potential can mainly be identified in biomass fuels and wind energy. In Figure 8 it was already shown that biomass fuels have in many countries an important contribution to the primary energy supply. Nevertheless, in power generation biomass has in most countries still only little role. At present, the only developed country with significant biomass-based power generation is Finland. This is clearly seen from Figure 10, which presents the penetration of both biomass- and wind energy-based electricity generation in a number of OECD countries.

In Finland biomass accounts for as much as 10% of the total electricity generation. The second largest shares are in Portugal and Austria, which both reach a penetration of about 3%. In all other countries, biomass accounts for 2% or less of the total electricity generation. The average in EU countries was only 1.2% in the year 1994.

Total installed wind power capacity has been expanding rapidly throughout the world during the 1990s. Figure 10 presents the contribution of wind power to total electricity generation in OECD countries. The data are for the year 1995, which was the latest year for which good statistics were available for the study. The results show that although the use of wind power is constantly increasing, a relatively long period of time is still needed before wind generation will play any significant role in overall electricity supply in the EU or in the USA. Denmark is at present the only country with over 1% of electricity based on wind. The wind share in Denmark was in 1995 as high as about 3%, while the EU average was only 0.2%. In Finland the share was less than 0.1% in 1995, but the official policy target is to reach a wind power capacity of 100 MWe by the year 2005, corresponding to 0.3–0.4% of total electricity generation.

With reference to the overall percentages shown also in Figure 10, Finland is at present the leading country in utilization of renewable biomass or wind energy for electricity generation. Biomass is mainly used in advanced fluidized-bed combustion (FBC) CHP plants, or in recovery boilers utilizing waste liquors from pulping. Box 1 takes the use of FBC technologies into closer view.

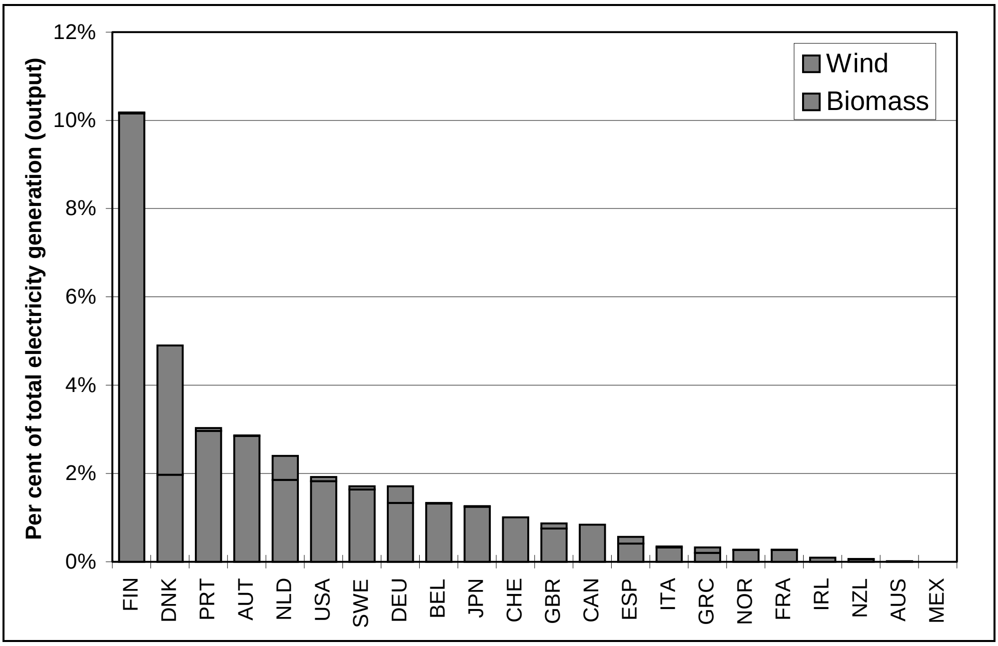



*Fig. 10. Share of biomass and wind based electricity production of total electricity generated in selected countries (biomass share in 1994, wind in 1995).*

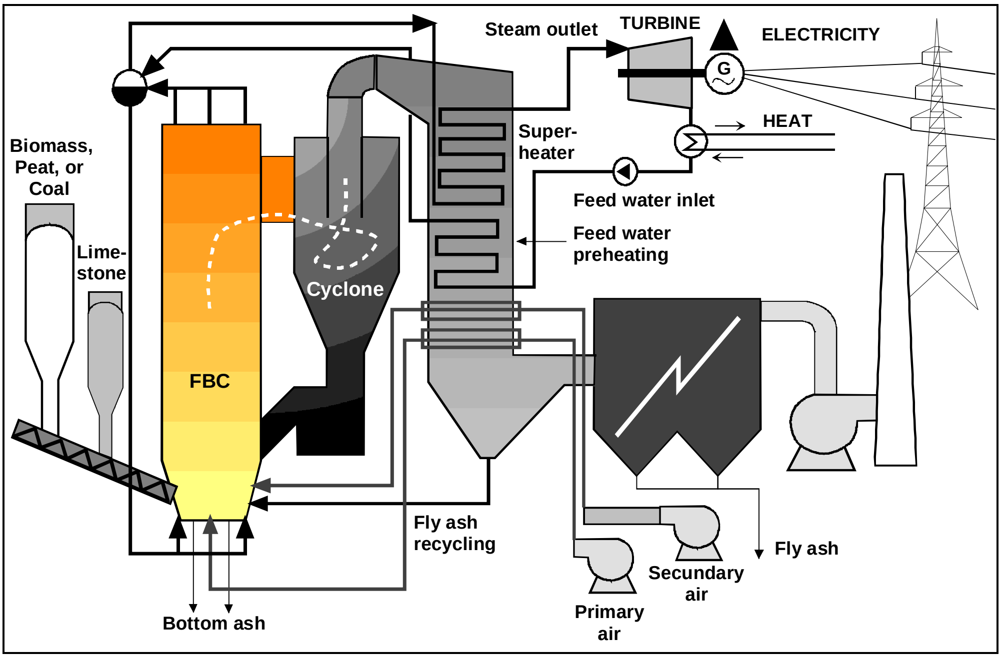
*Box 1. Example of an efficient biomass-based cogeneration system (adapted from Salokoski & Äijälä 1996).*

Fluidised bed combustion is a main technology for biomass fired plants. It has also made small-sized combined heat and power plants more cost-effective. Fuels of different quality can easily be burnt in a fluidised bed because of its high heat capacity. Sulphur reduction is quite easy to carry out by adding limestone or dolomite into the bed. Also $NO_X$ emissions are low because of the low combustion temperature.

In Finland, there are many fluidised bed boilers in use for CHP generation. They are usually suitable for many different fuels. A substantial amount of logging residues from forestry could be used as fuel. Under these circumstances, there are good prospects for further increases in biomass utilisation. However, the costs of employing the new biomass reserves will limit the economic potential of biomass utilisation.

A great deal of research and development work is carried out for the development of improved harvest technologies for wood-based biomass. The development work is needed to integrate the harvesting of industrial wood material with that of logging residues. The Finnish government has set an objective to increase the biomass utilisation by 25% by the year 2005.

The schematic figure below presents the main components of a CHP plant based on modern fluidised bed technology and fuelled partly or completely with biomass. The FBC technology could also be used in separate biomass gasifiers to be added in existing or new plants using pulverised coal. In this way co-combustion of coal and biomass could be applied widely, to the extent competitive biomass supply is available at each plant site.




Biomass-fired CHP plant based on fluidised bed combustion

### 4.2.2 Combined heat and power

Characteristics of CHP

Combined heat and power generation (CHP), or cogeneration, is the simultaneous production of usable heat and electricity in the same plant. All thermal power plants produce large quantities of heat in addition to electricity, but in a CHP plant the temperature of the by-product heat is kept high enough that it can be used e.g. for space heating, or in industrial processes. Raising the temperature of the heat results in less electricity being generated. Therefore, the balance of heat and electricity output is optimized according to the particular value of electricity and heat at the plant site.

CHP plants are located in such a way that the by-product heat can be utilised within as small transmission distances as possible. The obvious reason for this is that the losses and investment costs related to heat transmission are much higher than those for the transmission of electricity. Sufficient demand for the by-product heat either in manufacturing plants or in buildings is, of course, a prerequisite for a CHP scheme to become beneficial.

Three main types of CHP applications are generally distinguished:

- On-site industrial CHP plants
- Small-scale CHP for buildings in the tertiary sector and other large heat consumers
- Urban/community district heating schemes based on CHP

In condensing thermal power plants, significant amounts of energy are wasted through the cooling systems. The total energy efficiency of such power plants is at present typically in the range of 40–50%. In CHP systems, the total usable energy efficiency is much higher, as the by-product heat can be utilized. Consequently, the total energy efficiency of CHP systems is typically 80–90%, and only 10–20% of the energy contained in the fuel is lost. Some additional efficiency gain can usually be achieved by smaller distribution losses in CHP generation compared to larger-scale central power plants. Atmospheric emissions per unit of produced energy are reduced accordingly.

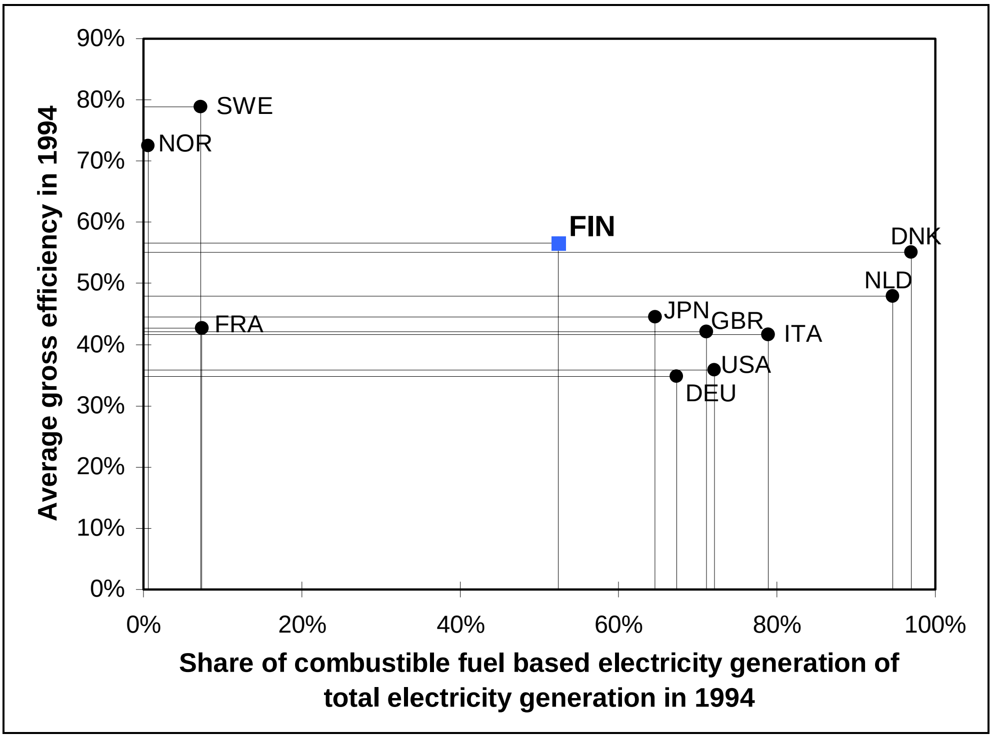



*Fig. 11. Average gross efficiency and scale of combustible fuel based electricity generation in selected OECD countries.*

The average efficiency of combustible fuel-based electricity generation can, in principle, be calculated for all OECD countries on the basis of IEA basic energy statistics (IEA 1996a). However, one difficulty is that the energy consumption of CHP plants can be allocated to electricity and heat generation in a number of different ways. Perhaps the most straightforward method is to define the energy efficiency of electricity and heat generation to be equal in a CHP scheme. The average efficiencies based on this approach are shown in Figure 11.

As can be expected, in countries where the percentage of CHP is large, the average efficiency of combustible fuel based generation is high. In Sweden and Norway the proportion of CHP in the total electricity generation is relatively small, but it is very high compared to total combustible fuel-based generation. Therefore, also the average efficiency is very high in these countries, but the corresponding impact on total energy consumption remains small. Among countries where combustible fuel based generation accounts for over 50% of the total electricity generation, Finland appears to have the highest average efficiency. Denmark is at a similar level, and The Netherlands is third with almost 50% average efficiency.

Due to the high overall energy efficiency, cogeneration reduces $CO_2$ emissions considerably. In Figure 12, the specific emissions from CHP plants are compared with the emissions from a condensing plant, and those from separate power and heat plants. In the case of condensing plants, efficiencies of 40% and 50% are assumed for coal-fired plants and natural gas fired combined-cycle plants (NGCC), respectively. In the case of CHP plants, total energy efficiencies of 86% and 88% are assumed for coal fired and NGCC plants. The power to heat ratio is assumed to be 0.54 for coal-fired CHP and 1.0 for NGCC. Additionally, because of the decentralized nature of CHP, the distribution losses related to CHP generation are assumed to be 3%-points lower than with condensing plants.

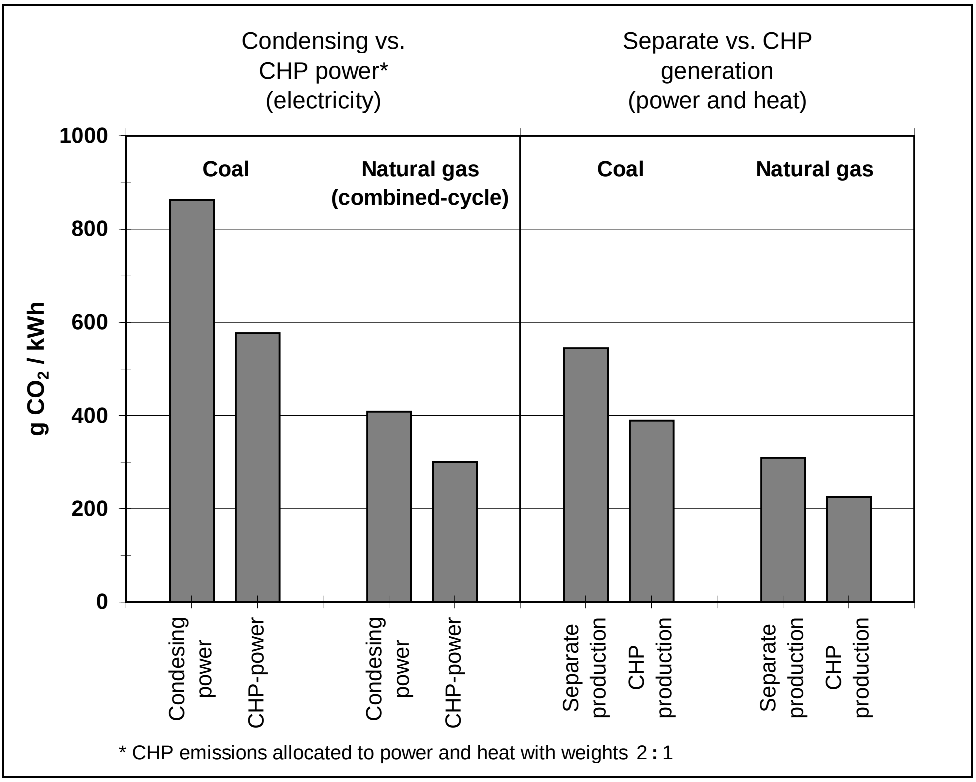



*Fig. 12. Comparison of $CO_2$ emissions per produced energy between condensing power plants and CHP plants, and between separate power and heat generation and CHP generation.*

By allocating the $CO_2$ emissions from a CHP plant to electricity and heat with weights 2 : 1 (i.e. the specific emissions of the electricity produced are twice as high as those of the heat produced), the $CO_2$ emissions per kWh of electricity are in a CHP plant about 30% lower than in a condensing plant, as illustrated in Figure 12. To avoid using artificial weights for the allocation of emissions to power and heat, the total emissions from CHP generation can also be compared with separate power and heat generation with the same output quantities. In this comparison, which is shown on the right hand side of Figure 12, the emissions reduction achieved by CHP generation is again found to be nearly 30%.

## Status of CHP within EU

Within the European Union, CHP has often been viewed as uneconomical without financial support. The savings in energy use have been considered to be more than offset by the high capital costs due to the generally much smaller size of CHP plants compared with central power plants. Therefore, CHP has often been deemed to be in the need for governmental subsidies.

However, other important factors behind the weak economics have been regulatory practices, and unfavourable structures within the electricity industry, with monopoly generators and demarcation agreements. Power markets have been in many countries practically closed, leading to very unfavourable economic and licensing environment for cogeneration. Access to the national power transmission grids has been often much too limited for contracts between independent cogenerators and third parties. Additionally, the costs of back-up (reserve) and top-up power have been in many cases set unduly high for cogenerators (Vainikka 1997).

Denmark and The Netherlands are among the leading countries with respect to CHP generation. However, during the past decade, large increases in CHP generation have only been possible with strong government support, e.g. in the form of tax incentives and subsidies. In contrast to these two countries, CHP generation in Finland has a very high market share primarily because of its own economic merits in a cold climate and for the energy-intensive process industries.

As soon as the regulatory environment will allow fair market conditions for cogeneration, CHP systems could become economically attractive also in other countries for a much larger number of operators as well as for industrial host companies demanding process heat. High-efficient larger-scale and less capital intensive district CHP schemes could be made possible by investments in the infrastructure needed in district heating networks. With such changes in the electricity and heat markets, CHP could become self-financing, and a competitive option also for industrial host companies.

The present share of cogeneration of the total electricity generation is shown in Figure 13 for all EU countries (excluding Luxembourg). The total shares of CHP are based on a comprehensive review published in 1997 (Cogen 1997). As to the estimated split of cogeneration into industrial and district/small scale generation, data from several recent sources have been used (Cogen 1997, Euroheat 1996, IEA 1996a). In terms of per capita generation of electricity in CHP systems (in full CHP mode), Finland is clearly the leading country in Europe.

With regard to the overall contribution of CHP to the total national electricity generation, the average share over all EU countries is about 10%. Denmark has

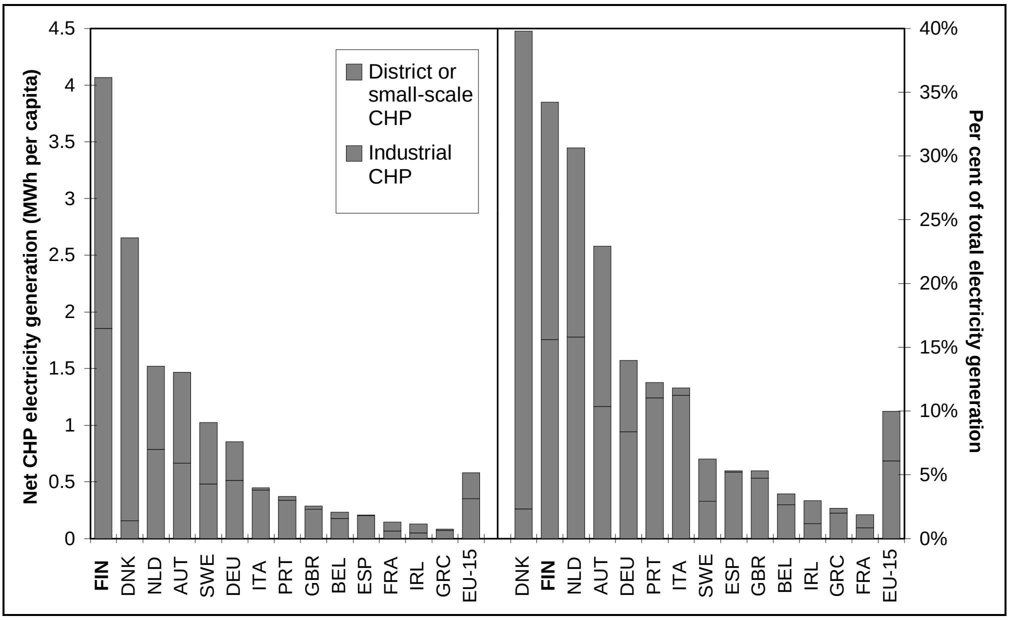



*Fig. 13. Share of cogeneration of total national electricity generation in EU countries (Sources: Cogen 1997, Euroheat 1996, IEA 1996a).*

achieved the highest share of 40%, while Finland is second with a share of 34%. Three other countries, Netherlands, Austria, and Germany, have also achieved a position well above the EU average. In general, industrial CHP appears to have a more prominent role than district or small-scale CHP. Industrial schemes account for about 60% of the total CHP generation within EU. The few countries where district/small scale CHP dominate, are Denmark, Finland, Austria, and Sweden.

It has been estimated that the overall share of CHP in the electricity generation of the EU countries could be increased to about 30% during the next decades (Cogen 1997). This would mean a huge potential for additional CHP generation within the EU. However, the potential can be assessed to be most significant in countries which today have a relatively low CHP share. In Finland, on the other hand, about 80% of all the heat loads served by plants of 1 MW size or above are already being utilized for CHP, and further potential is thus quite limited.

### 4.2.3 District heating

District heating means the distribution of hot water or steam from one or more sources to multiple buildings. The heat sources can be combined heat and power plants, plants producing only heat, or other sources of heat (such as geothermal or industrial waste heat).

The utilisation of larger-scale and high efficiency community CHP plants can be most successful in conjunction with building up and expanding district heating networks in densely populated areas. Although the network introduces some distribution losses, district heating systems are generally at least as energy-efficient as individual heating systems. They also support more efficient control of atmospheric emissions than individual systems. Moreover, district heating systems are also reliable and economical on a long-term basis. In times of unfavourable price developments, district heating networks make it possible to switch to the most economical fuel for heat production. An important part of the production system, the district heating network, remains unaffected. District heating from CHP plants is a classic example of replacing energy with capital.

Particularly in the Nordic countries, district heating has developed into a very important source of heat supply for residential, commercial, institutional, as well as industrial buildings. At present, the Nordic energy utilities annually deliver annually about 380 PJ of district heat and hot water to the pipelines.

Estimates for the market shares of district heating in some countries are shown in Figure 14. The share in Finland has been calculated on the basis of the volumes of residential and commercial buildings. For other countries, recent international statistics have been used (Nordvärme 1995, Euroheat 1997, AGFW 1996). The largest market share for district heating is found in Denmark, but in Finland the share is practically at the same level. The much lower shares in major EU countries (Germany, France, United Kingdom) clearly show that these countries have the most significant potential for additional district CHP.

Perhaps surprisingly, in USA district heating has a market share comparable to that in France. At present, most of the district heating supply in USA is provided to commercial buildings. Furthermore, due to the importance of cooling as well as heating, a new concept called "trigeneration" has been introduced in USA. In addition to hot water and electricity, this concept also incorporates the efficient generation of chilled water for district cooling purposes.

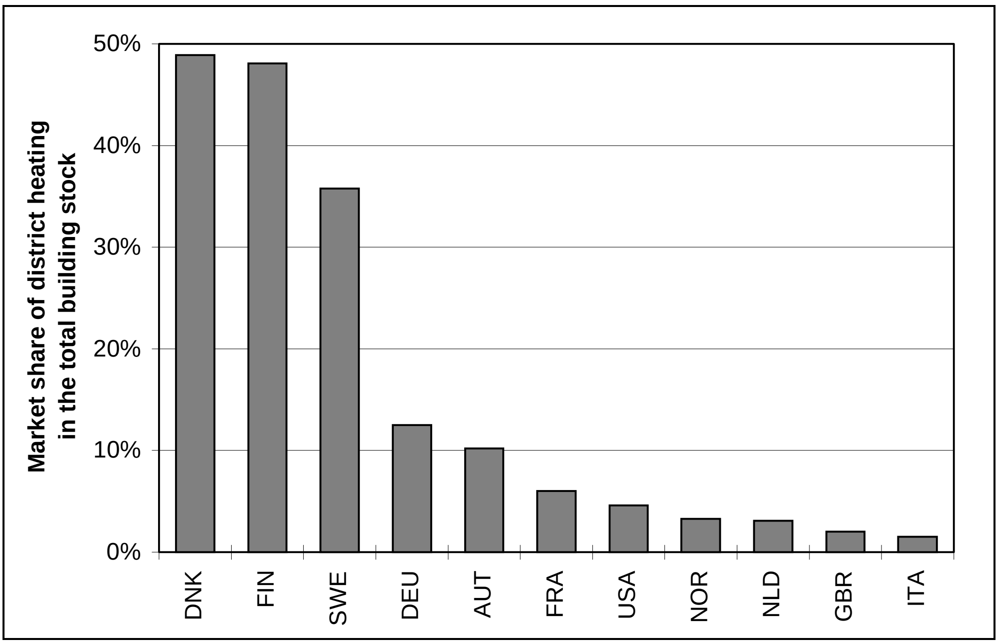



*Fig. 14. District heating market share of space heating in the total building stock, excluding industrial buildings.*

## 4.3 Petroleum refineries

The petroleum refining industry produces from crude oil a great diversity of oil products reaching from light distillates to asphalt and from fuel oils to complicated chemical products. The energy use of oil refineries depends on the level of the technology but also on types and amounts of products (product mix). Also the size of the refinery and the amounts produced can have an impact on the energy efficiency. Greater unit sizes and capacity utilization rates give possibilities for improved efficiency through the integration of processes. Production of cleaner reformulated motor fuels with high oxygen or low sulphur content tends to increase energy use. However, environmental benefits are obtained in the form of improved air quality in cities.

The refinery fuel consumption normally falls between 2 and 7 per cent of the crude oil refined, i.e. 0.02–0.07 GJ / 1 GJ crude (IEA 1996b). For inter-country efficiency comparisons, product-level information would be necessary. The IEA and OECD statistics do not give such information, and therefore energy efficiency comparisons are not made based on them. Instead, the energy efficiency is assessed using a relative energy efficiency indicator, the Energy Intensity Index (EII), developed and computed by Solomon Associates (Solomon 1995). Solomon Associates is a well-known commercial consultant on issues related to energy efficiency in petroleum refining.

The EII is defined as the ratio of the actual refinery energy consumption divided by the sum of the refinery standard energy consumption. Usually EII is expressed in terms of percentage, i.e. multiplied by a factor of 100. The refinery standard energy consumption is calculated as the sum over all process units by multiplying the unit utilized capacity by unit reference energy coefficient. The unit reference energy coefficients are based on the technology of early 1980s when the EII was developed. The coefficients' values rely on process operation data and present typical energy consumption for each process unit or technology type. Hence, in a modern refinery using state-of-the-art technology, lower values than 100 can be achieved. In fact, lower values than the reference energy coefficients are recommended for most existing process units.

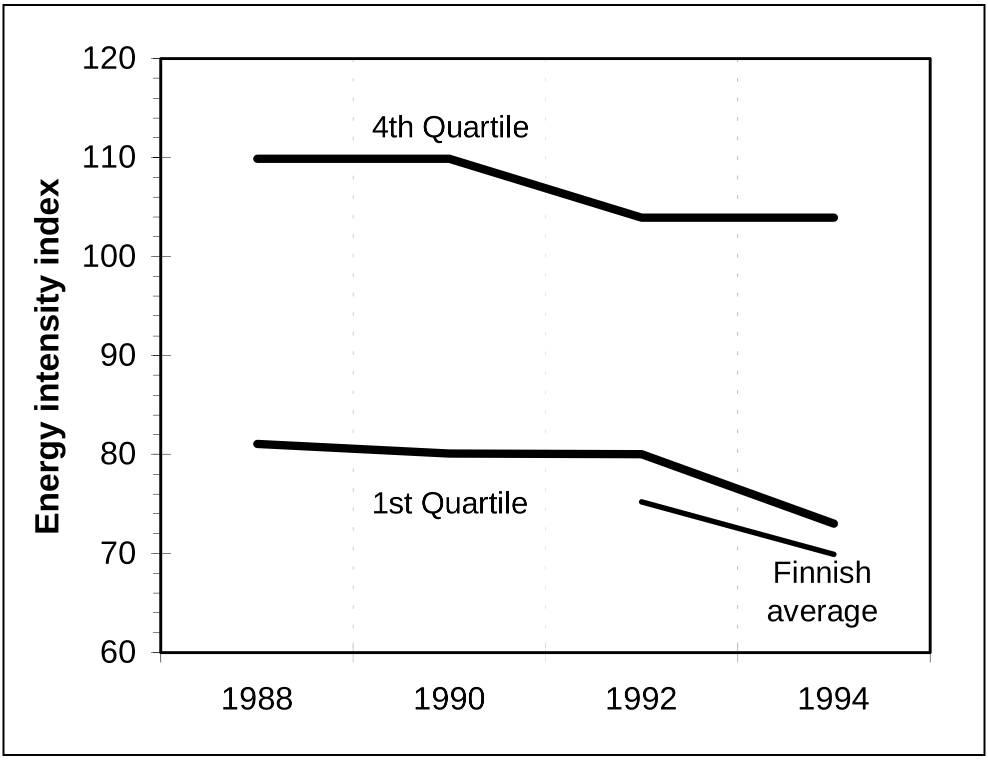



*Fig. 15. Energy intensity index for petroleum refineries. Index value 100 represents state-of-the-art technology in the early 1980s.*

According to the results of the Solomon studies, the EII of the Finnish petroleum refining industry is below the first quartile of the EII distribution of European and Middle East refining industries (Figure 15). A slow decreasing trend in the EII is visible.

# 5 Energy use and emissions due to manufacturing industries

## 5.1 Manufacturing as a whole

### 5.1.1 Methodology

The manufacturing industries include the industrial sectors in the ISIC 3 category (International Standard Industrial code), with the exception of petroleum refineries. The IEA basic energy statistics follow the ISIC classification. The industrial sectors available in the IEA data, and the acronym used for each sector are presented in Table 2. Although in Finland the industrial classification is usually based on a slightly different system (presently the TOL-95 system), the most important part of the data obtained from Statistics Finland follow the TOL-79 system, which is almost fully consistent with the ISIC system.

The indicators calculated for the manufacturing industries describe the development of energy use, electricity use, and $CO_2$ emissions in proportion to the value added. The calculation of the intensity of electricity use is straightforward, but the calculation of the indicators for energy use and emissions are somewhat more complicated. Because of the large differences in the qualities of different final energy forms, only the **primary energy equivalent** of the energy use is considered in the indicators. The energy use thus consists of the energy of all the fuels consumed within the manufacturing sector, including the fuels used for industrial self-production of electricity and heat, as well as the energy used outside the manufacturing sector to produce the electricity and heat sold to the manufacturing sector. All end-use sectors are assumed to purchase electricity or heat with the same average primary energy intensity, which is determined by the average efficiencies of public electricity and heat generation and distribution.

Correspondingly, the $CO_2$ emissions from manufacturing energy use include the emissions from fuel combustion within the manufacturing sector, and the emissions from the fuels used to produce the electricity and heat sold to the manufacturing sector. Similarly as in the energy calculations, the $CO_2$ emissions from public electricity and heat generation are allocated to all end-use sectors

*Table 2. Industrial sectors distinguished by IEA energy statistics.*

| Acronym | Description | ISIC code |
|---|---|---|
| Manufacturing | | |
| FOO | Food processing, beverages, tobacco | 31 |
| TEX | Textiles and leather | 32 |
| WOO | Wood and wood products | 33 |
| PAP | Pulp, paper and printing | 34 |
| CHE | Chemical industry | 351, 352, 354–356 |
| NME | Non-metallic minerals | 36 |
| IRO | Iron and steel | 371 |
| NFE | Non-ferrous metals | 372 |
| MAC | Machinery and non-transport equipment | 38, excluding 384 |
| TEQ | Transport equipment | 384 |
| INO | Non-specified industry (other manufacturing) | 39 |
| Other industry (only the most significant sectors included) | | |
| AGR | Agriculture, forestry and fishery | 11–13 |
| EMI | Coal mining | 21 |
| OGX | Oil and gas extraction | 22 |
| MIN | Mining and quarrying | 23, 29 |
| ERE | Petroleum refineries | 353 |
| POW | Electricity and heat generation and distribution | 41, excluding 4102 |
| EGA | Gas manufacturing and distribution | 4102 |
| CON | Construction | 50 |

according to the same average specific emission factors for all the electricity or heat sold to the end-use sectors.

The primary energy equivalent of other than combustible fuel based electricity and heat generation (geothermal, hydro, wind, nuclear power, and net imports of electricity) has been calculated by assuming a 50% net efficiency for electricity generation, and a 90% net efficiency for heat. These efficiencies are assumed to correspond with the efficiencies of today's best available combustible fuel-based technologies for separate electricity or heat generation. By using such generic computational efficiencies for the non-combustibles, one can eliminate the somewhat artificial differences in primary energy efficiencies between e.g.

countries with abundant hydro power and countries with little hydro resources or a large nuclear power program.  For the calculation of the specific $CO_2$ emissions this method has no effect.

For each country considered, 15 different indicators on the intensity of manufacturing energy use and $CO_2$ emissions have been calculated.  The first three indicators (Figures B:1 and B:2, Appendix B) illustrate the total energy use, the total electricity use, and the total $CO_2$ emissions per value added.  As explained above, the total energy use and emissions include also the energy consumption outside the manufacturing industry needed for the generation of the electricity and heat purchased by the industry.

The following six indicators (Figures B:3 – B:6) present the corresponding developments in three energy intensive subsectors (PAP, IRO, and NFE), and in other manufacturing. This distinction between the three energy intensive subsectors and other subsectors was made in order to point out the large differences in the structure and energy intensity of manufacturing among countries. Furthermore, by separating out just these three energy intensive sectors a significant part of the differences among countries can be explained, and these will be investigated in more detail in Sections 5.2 and 5.3. It should be pointed out, that the PAP sector includes the non-energy-intensive printing and publishing industries, which in several countries dominate the value added produced by this sector.

The remaining six indicators (Figures B:7 – B:10) present a more detailed analysis of the factors behind the changes in the intensities in energy use and emissions. The *structure effect* is calculated by comparing the actual development with a hypothetical case where the structure of the manufacturing sector is assumed to be constant over the whole period 1970–1994. Constant structure means that the shares of the total value added by subsector remain unchanged. The resulting indicator shows how much the changes in the top-level structure have affected the intensity of energy use or emissions.

The *inside intensity effect* is calculated by comparing the actual development with a hypothetical case where the end-use intensities of energy use or emissions are kept constant in each subsector.  The resulting indicator shows, how much the intensities in energy use or emissions have actually changed within the manufacturing industry, if the impacts of structural changes are not counted. Intensity changes in the energy production sector outside the manufacturing sector are not included in the "inside intensity" effect.

Finally, the *total intensity effect* include both the "inside intensity" effect and intensity changes caused by efficiency improvements or carbon intensity changes in the public electricity and heat generation sector. This indicator thus shows the total improvements (or degrading) in the intensity of industrial energy use in terms of primary energy use or specific emissions. More exact formulations of the decomposition into structure and intensity effects are shown in Box 2. An elaborate treatment of various decomposition methods is given in Greening et al. (1997).

The changes in the structure of the manufacturing sector between 1973 and 1993 are illustrated in Figure 16. One can see that in Finland the energy intensive sectors (PAP, IRO, NFE, and CHE) have all increased their share of the total value added. In most other countries the combined share of pulp and paper and basic metal has been decreased. Chemical industries have in most cases increased their share, but the product mix has in general become less energy intensive.

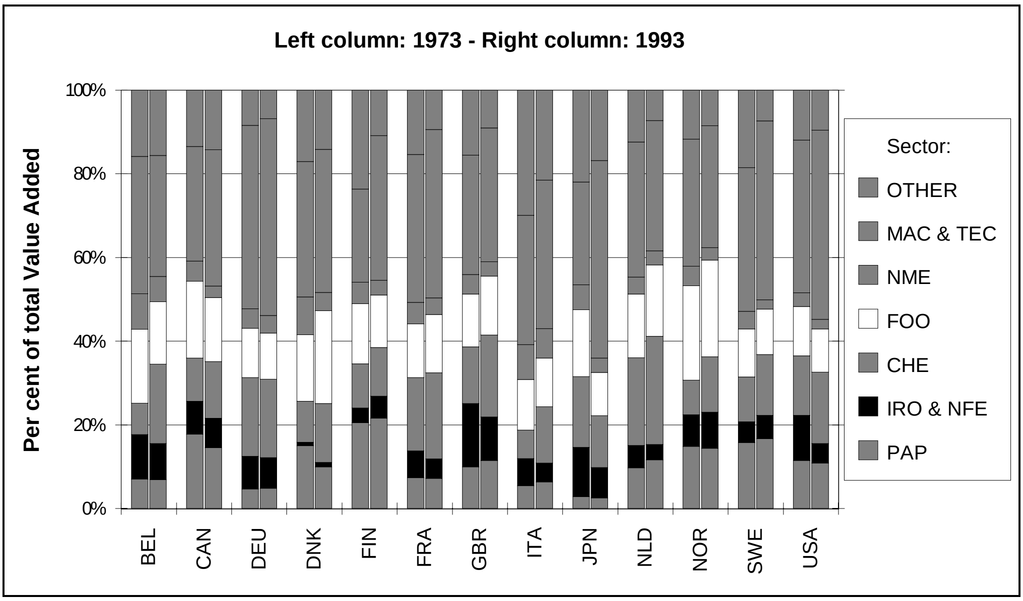



*Fig. 16. Structure of the manufacturing sector on the basis of value added in selected OECD countries in 1973 and 1993.*

*Box 2. Formulas for the structural and intensity effects.*

Let

$$P_t = A_t \sum_{i=1}^{n} S_{it} (IPI_{it} + IEO_{it} IOE_t + IHO_{it} IOH_t)$$

$$PCS_t = A_t \sum_{i=1}^{n} S_{ia} (IPI_{it} + IEO_{it} IOE_t + IHO_{it} IOH_t)$$

$$PCI_t = A_t \sum_{i=1}^{n} S_{it} (IPI_{ib} + IEO_{ib} IOE_t + IHO_{ib} IOH_t)$$

$$PCT_t = A_t \sum_{i=1}^{n} S_{it} (IPI_{ib} + IEO_{ib} IOE_b + IHO_{ib} IOH_b)$$

where:

$n$ = number of subsectors
$a$ = reference year for constant structure
$b$ = reference year for constant intensities
$d$ = base year for the indexes (commonly $a = b = d$)
$P_t$ = actual primary energy consumption in year $t$
$PCS_t$ = primary energy in year $t$ with constant structure
$PCI_t$ = primary energy in year $t$ with constant inside intensity
$PCT_t$ = primary energy in year $t$ with constant total intensity
$A_t$ = aggregate activity level (value added) in year $t$
$S_{it}$ = activity in subsector $i$ per aggregate activity in year $t$
$IPI_{it}$ = intensity of own primary energy use per activity level in subsector $i$ in year $t$
$IEO_{it}$ = intensity of external electricity use per activity level in subsector $i$ in year $t$
$IHO_{it}$ = intensity of external heat use per activity level in subsector $i$ in year $t$
$IOE_t$ = intensity of primary energy in external electricity in year $t$
$IOH_t$ = intensity of primary energy in external heat in year $t$

Then

$$ICS_t = \frac{P_t PCS_d}{P_d PCS_t}, \quad ICI_t = \frac{P_t PCI_d}{P_d PCI_t}, \quad ICT_t = \frac{P_t PCT_d}{P_d PCT_t}$$

where:

$ICS_t$ = index for the structural effect in year $t$
$ICI_t$ = index for the inside intensity effect in year $t$
$ICT_t$ = index for the total intensity effect in year $t$

### 5.1.2 Indicator results

The development of the **total manufacturing energy use and emissions** per value added is shown in Figure B:1 for ten European countries, and in Figure B:2 for major other OECD countries as well as for the average of the Nordic and EU countries. The total energy intensity has been slowly decreasing in almost all countries. Only in Norway and Australia no clear trend can be identified. Differences among countries are large, but these can be largely explained by differences in the structure of manufacturing and in the natural resources (e.g. hydropower). The average energy intensity in Finland is more than twice as high as the average in the EU. Nevertheless, in Norway and Canada the intensity is yet higher, and in Sweden and Australia it is roughly at the same level.

With respect to **$CO_2$ emissions**, Finland differs much less from the average in the EU. As with energy use, the general trend has been towards decreasing $CO_2$ emissions per value added, but the changes have been more prominent than in the energy intensity. In Finland the decreases have been nearly as large as in the EU on average. In Australia both the energy use and $CO_2$ emissions per value added have increased, which probably can be explained by the large expansion of energy intensive basic metal manufacturing.

Unlike the total energy use, the **consumption of electricity** has been slowly increasing in most countries. The development in Finland has been very similar to the average in Nordic countries and in Canada. No clear sign of the saturation of the electrification in manufacturing can yet be seen in any other country than Japan. However, due to the compensating impact of efficiency improvements, in the EU countries the average electricity use per value added has been quite stable throughout the period.

When looking at the **three energy intensive sectors** (PAP, IRO, NFE) one might expect the differences among countries to be much smaller. However, the differences are still roughly of the same magnitude, as shown in Figures B:3 and B:4. For a large part the this can be explained by differences in the structure of manufacturing within the sectors. For example, the printing and publishing industries, and the further processing of paper into end-products, are included in the PAP sector. Additionally, among the non-ferrous metals the energy requirements of the different manufacturing processes vary considerably. In Finland the average energy intensity in these three sectors is more than twice as high as the average in all manufacturing. In general, the development of energy and emission intensity has been slowly decreasing, but the improvements have not been as prominent as in the other sectors. This general observation applies to Finland as well. As mentioned above, the developments and the large differences among countries in these sectors are investigated in more detail in Sections 5.2 and 5.3.

The average development in the **other manufacturing sectors** is shown in Figures B:5 and B:6. The differences among countries are much smaller than in the preceding cases. A distinct decrease can be seen in the average energy and emission intensity during the period 1974–1994. The energy intensity of the Finnish other manufacturing is well in the middle of the countries studied, and the $CO_2$ emission intensity is lower than in most of the countries. The Finnish specific emissions are only about a half of those in USA and Canada. The improvements both in efficiency and specific emissions have been significant in all countries, but in Finland the improvements have been particularly large after the year 1973, as shown in Figure 17.

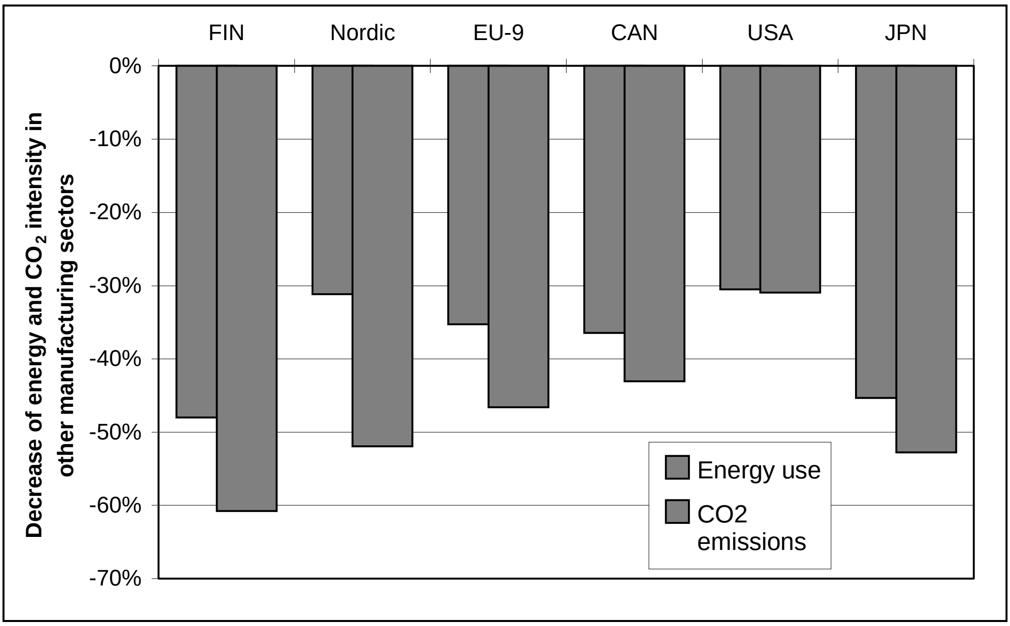



*Fig. 17. Decreases in the intensity of energy use and $CO_2$ emissions (based on value added) during 1974–1994 in manufacturing excluding basic metal and pulp and paper manufacturing .*

The impact of the **changes in the top-level structure** of manufacturing, and the changes in the actual energy and emission intensities within the subsectors are illustrated in Figures B:7 – B:10.  According to the results, the changes in the top-level structure generally explain only a small part of the overall change in the intensities.  A notable exception appears to be Japan, where the structural impact has been around 20% during 1974–1994. In Finland, the changes in structure have been towards higher energy intensity, which means that the actual intensity improvements within the subsectors are larger than what the average results for the total manufacturing indicate.  Shifts in structure towards higher energy intensity have also occurred in Norway and Australia.

The improvements in **energy intensity** within the subsectors ("inside intensity") vary between less than 10% in Canada and Australia, and more than 60% in Belgium. However, it should be emphasized that in many cases the changes include substantial stuctural changes within the subsectors. The seemingly very large improvements in Belgium are mainly the result of  profound structural changes within basic metal and chemical manufacturing. Similarly, in Australia one of the most rapidly expanding branches has been aluminium manufacturing, which makes the comparison based on total non-ferrous metals unfair.  Such lower-level structural changes, which to some extent have been occurred in all countries, undoubtedly deteriorate the balance of inter-country comparisons.

Improvements in Finland have followed a pattern similar to that in most other European countries.  While the average improvement in energy intensity has been 36% for the EU countries, in Finland it was 24% during 1974–1994. But compared with the average in the Nordic countries, Finland has made slightly larger improvements in energy intensity. The changes in the specific energy use and $CO_2$ emissions within the manufacturing sector are illustrated in Figure 18.

Taking into account also the changes in the energy intensity of the public power and heat generation has only a small impact on the results.  For example, in Finland no significant changes have occurred in the average primary energy efficiency of power generation during the 20 years' period 1974–1994 (bearing in mind the computational efficiency of non-combustible based power generation).  Therefore, the improvements in the total intensity are almost equal in amount with the improvements inside the manufacturing sector only.

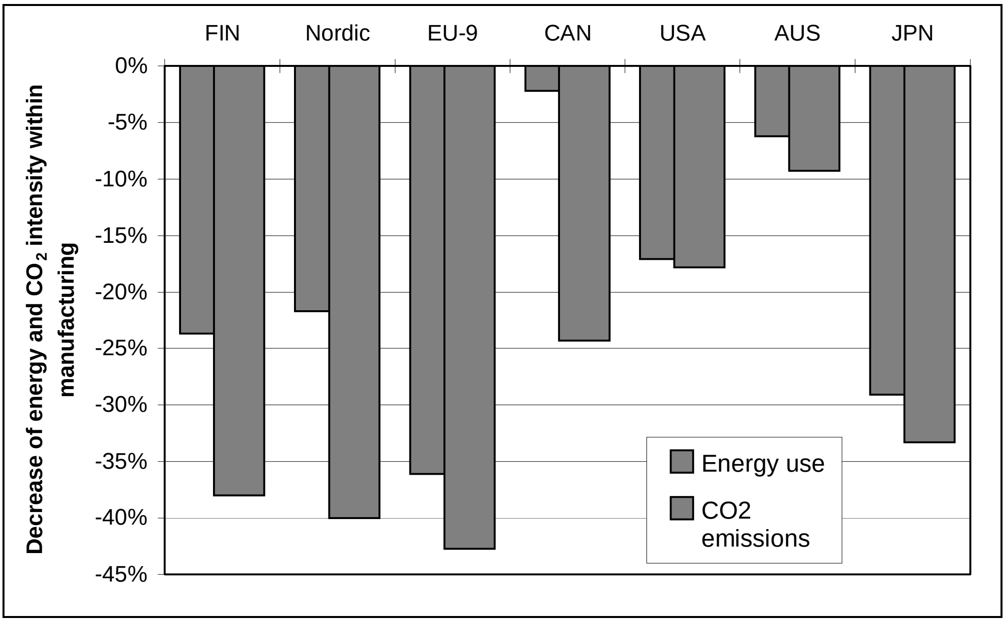



*Fig. 18. Decreases in the intensity of energy use and $CO_2$ emissions (based on value added) within the manufacturing industries during the period 1974–1994, excluding the structure effect and efficiency changes in the energy sector.*

In terms of $CO_2$ emissions the intensity improvements have been surprisingly large in many countries. The average decrease in the EU countries is over 40%, while almost equally large improvements have been achieved in Finland: 38% during the period 1974–1994. When the impact of changes in the public power and heat generation sector are included, the average decrease in the EU countries is raised to 47%. In Finland the development of the power sector has brought no additional improvements to the specific $CO_2$ emissions during the whole 20-year period, but large improvements have occurred in the beginning of the 1980s due to the introduction of nuclear power in the electricity generation system.

## 5.2 Wood processing industries and the forest sector

### 5.2.1 Greenhouse gas balance of the total forest sector in Finland

The wood processing industry uses roundwood harvested from forest ecosystems to produce sawn goods and wood-based panels in wood-products industries, and fiber products in pulp and paper industries. Forest ecosystems exhibit significant carbon exchange with the atmosphere through photosynthesis and respiration processes. The area of forest and scrub land in Finland is about 23 million hectares. Forest ecosystems also act as a significant storage of carbon. The carbon storage and flows of the total forest sector in 1990 are depicted in Fig. 19 in the case of the Finnish forest industries. The biomass of the tree and surface vegetation of the forest ecosystems in Finland form a considerable storage of about 690 Tg C (Pingoud et al. 1996, MoE 1997). The growth of the forest exceeded the drain considerably and the carbon storage increased by about 8 Tg C in 1990. Fig. 20 shows the development of the carbon balance of the biomass of the Finnish forest ecosystems; after about 1970 the forest growth has been clearly greater than the cuttings and natural drain (Kanninen et al. 1993).

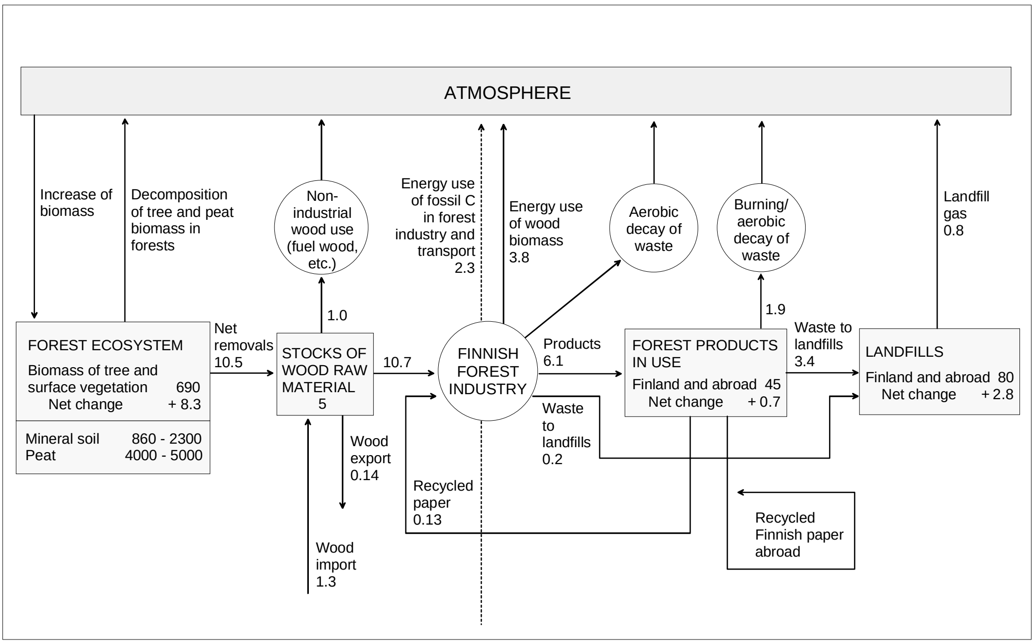



*Fig. 19. Carbon reservoirs (Tg) and fluxes (Tg C $a^{-1}$) of the Finnish forest sector in 1990 (Pingoud et al. 1996).*

The forest industry uses, to a large extent, wood as an energy source, not as raw material only. About half of the roundwood is used in manufacturing of sawn goods and wood-based panels, and the rest in manufacturing of pulp and paper. Pulp is produced by using mechanical or chemical processes. In mechanical pulping more of the mass of the wood raw material can be utilized for end-products than in chemical pulping, but externally produced energy is needed. In chemical pulping the lignin part of the wood can be utilized as a source of energy, and a smaller amount of end-products is obtained, but in a modern plant, energy can be generated even more than needed in the pulping process.

Figure 19 shows also the use of fossil fuels in harvesting, production and transports in the Finnish forest industry in 1990. The forest industry products which are in use form also a carbon storage which is increasing. The main part of this storage consists of long-lived products (e.g. timber in houses) of wood-products industries. The short-lived products like paper and paper board contribute at most about 10–20 % to the total storage. Export of the products of the

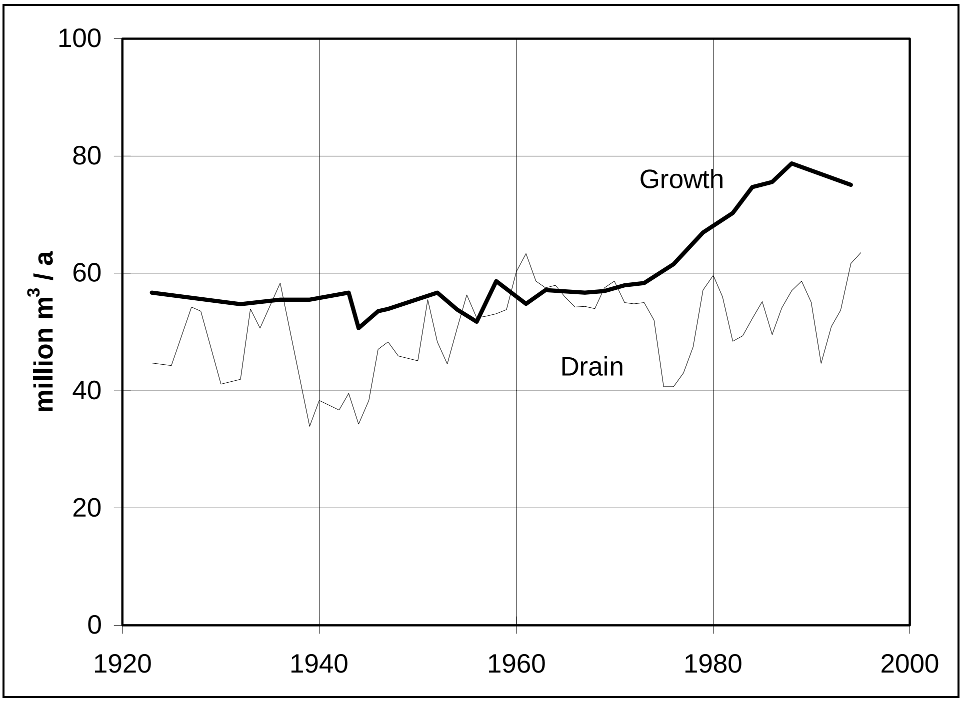



*Fig. 20. Annual growth of stemwood volume, and drain due to fellings, silvicultural measures and natural mortality in Finland during the years 1923–1995.*

Finnish forest industry is large and about two thirds of the product carbon pool is abroad. The old products in landfills form also a considerable carbon pool, even greater than the products in use. The matter in landfills decays and produces landfill gas. About half of this gas is methane, whose contribution to greenhouse warming is considerably greater than that of carbon dioxide. The estimated carbon storage in the product pool and in the waste management part of the product life-cycles is also given in Figure 19.

Figure 21 gives an overview of the greenhouse impact of the total Finnish forest sector in 1990, defined as the wood supply and products of the forest industries in Finland. The carbon sequestration due to forest growth exceeding the cuttings is considerable. Also the growth of the carbon storage of the products in use and in landfills exerts impacts on the sink side of the carbon balance. Imported roundwood, methane emissions from the landfills and use of fossil energy are counted as emissions. Roundwood imports can conservatively be interpreted as emissions. Namely, if there were no import of roundwood, the cuttings in Finland would be greater to keep the output of the forest industry at the same level, and so the carbon sink of the Finnish forest ecosystem would be smaller.

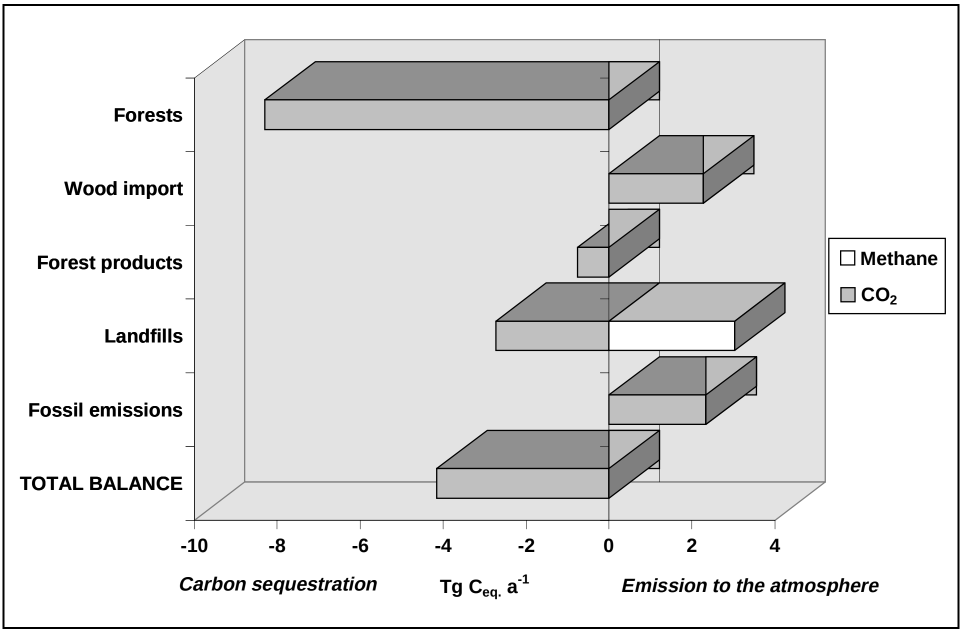



*Fig. 21. Greenhouse gas balance of the total Finnish forest sector in the year 1990 (Tg $C_{eq.}$ $a^{-1}$). The total balance is on the carbon sequestration side mainly due to the carbon sink from forest growth exceeding cuttings.*

In a more optimistic way it could be assumed that the roundwood imports to the Finnish industry are from sustainably managed forests so that their impact on ecosystem carbon storage is zero on average. The methane emissions from landfills are converted to $CO_2$ equivalents using a GWP-factor for 100 years' integration time. The net impact of the total forest sector is, however, in the sequestration side mainly due to the large carbon sink in the forest ecosystems. The order of the net impact in terms of carbon sequestration was about 4 Tg $C_{eq}$ in the year 1990, which is about 15 Tg expressed in $CO_2$ equivalents.

### 5.2.2 Use of industrial by-products and waste for energy

Figure 22 gives an overview of the Finnish forest industry energy use divided into external energy (fuels and electricity) input to the industry system and into energy generated within the system using by-product fuels like wood waste and black liquor. The numbers are for the whole wood processing industry, including the manufacturing of sawn timber and panels as well as pulp and paper. About two thirds of the fuel use within the forest industry is based on by-products and waste, and more than one third of the electricity consumed is generated within the industry, mainly using by-product and waste fuels. Energy statistics consider these almost totally as primary energy use, although they can to a large extent also be seen as internal energy flows of industrial processes. The fuels are usually efficiently utilized in cogeneration of heat and electricity for the processes.

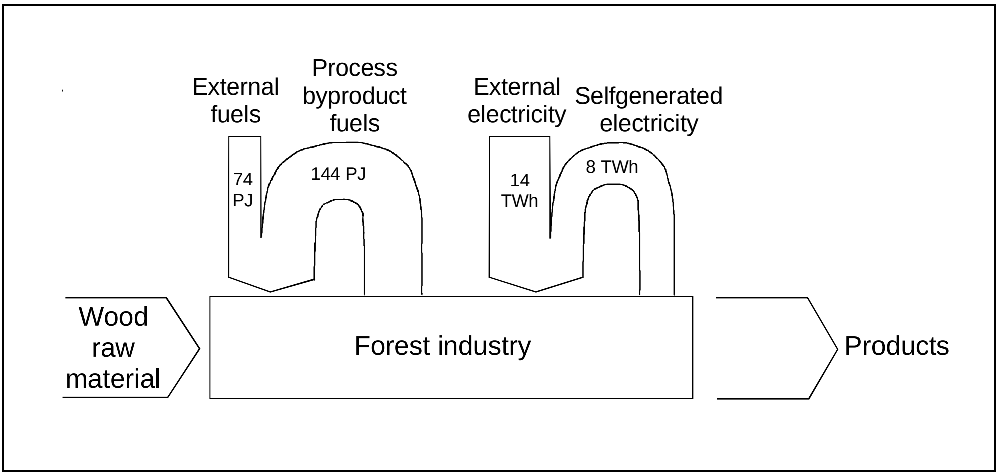



*Fig. 22. Flows of energy and raw material supply in the Finnish forest industries in the year 1994.*

The extent of use of by-product fuels is relatively large in four major pulp and paper exporting countries. In Figure 23A this is expressed in terms of the share of the by-product energy of the total energy supply. The percentages are calculated by comparing the by-product-based fuel use of the autoproducer plants and the by-product-based energy use within the forest industry with the primary energy consumption of the forest industry. In Sweden the value is highest due to large utilization of black liquor fuel from chemical pulping, in Finland the value is somewhat lower due to the greater share of mechanical pulping. In Finland, however, the share of electricity produced using by-product fuels is very high, almost 30% of the total use of electricity within the forest industry (Fig. 23B). Stringent economic and environmental requirements constitute the incentives behind the sparing use of roundwood and the extensive utilization of wastes and by-products.

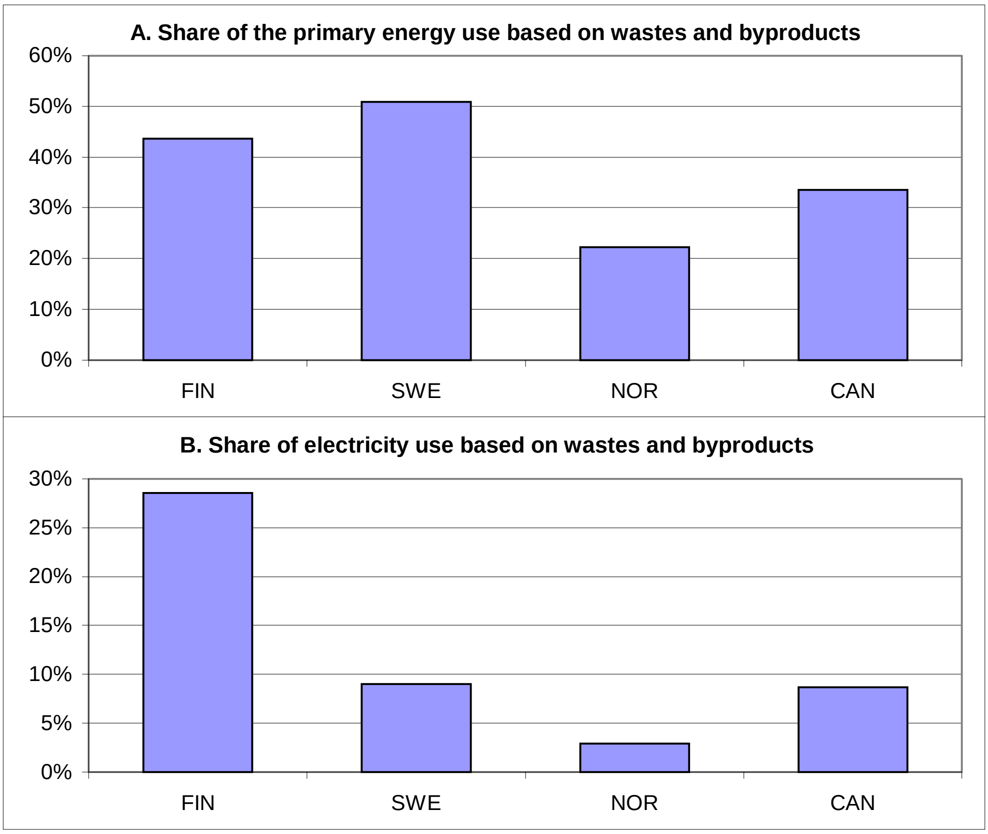



*Fig. 23. The role of (A) by-products and waste in primary energy consumption, and (B) by-product based selfproduction in total electricity consumption of wood processing industries in some major wood processing countries.*

### 5.2.3 Energy efficiency indicators

Methodology

The wood processing industries considered in this section include manufacturing of pulp, paper and paper products. Printing and publishing industries are excluded because they are non-energy-intensive and because in several countries they dominate the value added produced by the PAP sector. The structure of the PAP sector without printing and publishing is still different in various countries. For example in Germany, Japan and United States 60-70 per cent of the value added produced by the PAP sector without printing and publishing comes from paper products industries which are much less energy-intensive than pulp and paper industries. In Finland only 10 per cent of value added comes from paper products. Consequently countries are comparable only if the structure of the PAP sector is similar. The countries considered in this study are Finland, Sweden, Norway and Canada, whose value added produced by the PAP sector without printing and publishing is mostly (70–90 per cent) based on pulp and paper industries.

In the IEA data the printing and publishing industries are not separated from the PAP sector. In order to separate these out, Finnish data for printing and publishing have been used. Assuming that electricity and other energy use per value added of printing and publishing is the same in other countries than Finland, electricity and other energy use in different countries can be calculated. This has been done by multiplying the Finnish indicators for printing and publishing with the value added produced by each country's printing and publishing industries. Fitted trend-lines were used for exact indicators to eliminate small fluctuations.

Printing and publishing industries are assumed to purchase all electricity from the central grid, and therefore the calculated electricity use has been converted to primary energy and $CO_2$ emissions with national public electricity factors. Other energy use is already in primary energy terms. The $CO_2$ emissions of other energy use have been calculated assuming that all other energy is light fuel oil whose emission factor is 72.6 g($CO_2$)/MJ. The calculated total primary energy use, electricity use and $CO_2$ emissions have been subtracted from the corresponding values of the PAP sector reported by IEA.

Different product distributions among pulps and papers can cause difficulties when countries are compared to each other. The products manufactured by pulp and paper industries have different values added and different specific energy uses. A country which manufactures products with low energy requirements and high value added compared to other products may seem to be more energy-efficient than a country whose products have high energy requirements and low value added. To eliminate these effects another approach has been used.

The products of pulp and paper industries have been divided in seven groups:

- mechanical pulp,
- semi-chemical pulp,
- chemical pulp,
- recycled pulp,
- newspaper,
- printing and writing paper,
- other papers,
- boards.

For these groups specific energy uses have been estimated with the help of Finnish data, where the classification of products is yet more detailed. The aggregate estimates were derived by using production-weighted mean values. The Finnish specific energy use data are available separately for electricity, heat and direct fuel use (e.g. Lehtilä 1995, Timonen 1995).

The estimated Finnish specific energy uses have been calibrated to be consistent with IEA data for the year 1993. This has been done by multiplying specific energy uses with Finland's production data and comparing the resulting total energy use to the corresponding amount calculated from the IEA data (without printing and publishing). Electricity has been converted to primary energy with specific factors for the Finnish pulp and paper industry, taking into account own power production and net purchased power. Heat has been converted by assuming an 80 per cent net efficiency. The calibration has been done individually for electricity, and together for heat and direct fuel use. The correction was 6.4 per cent for electricity and 0.3 per cent for heat and direct fuel use.

The calibrated specific energy uses have been applied to each country's production values. Electricity has been converted to primary energy with national factors for electricity use in pulp and paper manufacturing as in the case of Finland. And for heat an 80 per cent net efficiency has again been assumed. The calculated energy amount has been compared to the energy amount from IEA data. If the calculated amount is smaller than the amount from the IEA data then the Finnish specific energy uses are on an average lower than the ones of the compared country and vice versa. The comparison is made for three different years and the two first years are compared to year 1993.

## Indicator results

The development of the pulp, paper and paper products industries energy use and emissions per value added is shown in Figure B:11 for Finland, Sweden, Norway and Canada. The total energy intensity has been slowly decreasing only in Finland while in Norway and Canada it has been slowly increasing. In Sweden no clear trend could be identified. The values of Norway are surprisingly low in the beginning of 1970's, which are caused by the lack of other energy use than electricity. There might be shortcomings in IEA data, or there is no other energy use in Norway for 1970–75. Differences among countries have been decreasing and they are quite small after 1985.

The consumption of electricity per value added has been increasing in all countries except in Finland, in which it has been quite steady. In Norway this indicator has more than doubled in twenty years. Differences between Finland, Sweden and Canada are also in this case quite small after 1985.

With respect to $CO_2$ emissions from fossil fuels, differences among countries are much larger. In Finland and Sweden emissions have been decreasing, while in Canada they have been increasing. In the 1990s Finland and Canada are on the same level but Sweden and Norway are much lower. This can be largely explained by differences in the national energy mix, particularly in the utilization of nuclear and hydro power. In Norway $CO_2$ emissions decrease with increasing electricity use and vice versa because nearly all emissions originate from other energy use.

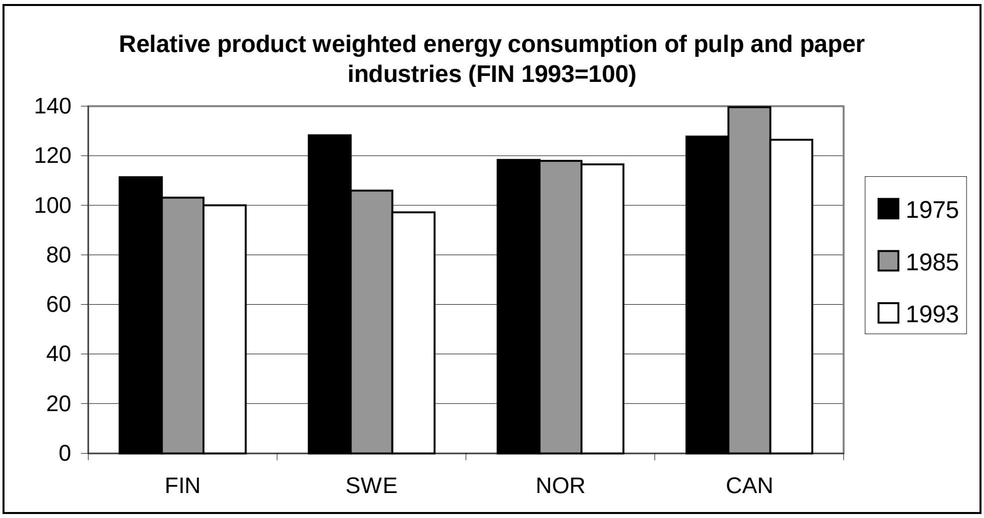



*Fig. 24. Relative product weighted energy consumption index of pulp and paper industries in some major pulp and paper producing countries.*

The results of product-based comparison are shown in Figure 24 for Finland, Sweden, Norway and Canada. In Finland and Sweden the energy-efficiencies have been improving. One can see that the Finnish specific energy uses have been, on average, lower than in other countries except for Sweden in 1993.

## 5.3 Iron and steel manufacturing

### 5.3.1 Production processes

Of the ferrous metals the use of non-steel cast iron is very small compared to the use of steel, an therefore the analysis is here focused on the production of steel. Steel production is divided in two routes: ore-based steel production and scrap-based steel production. This is necessary because these two routes use different processes which have different specific energy uses, and because the shares of ore- and scrap-based steel production vary in different countries.

Ore-based steel production includes ore preparation, blast furnace process and basic oxygen furnace process (BOF). Coke-making is not included in this study because self-sufficiency rates of coke production vary among different countries; for example in Germany the rate is 35 per cent, and in Finland 80 per cent. Ore is usually prepared before it is put in the blast furnace in which pig iron is produced. Nowadays nearly all pig iron is used as raw material in BOF steel production. In the BOF process most of the carbon and impurities are burned away from the molten pig iron by blowing oxygen into the molten metal.

Scrap-based steel is usually produced in electric arc furnaces (EAF) in which electric current melts the scrap. As this is the only process needed, scrap-based steel production requires much less energy than ore-based steel production. The other parts of the life cycle of scrap are not taken into account.

### 5.3.2 Energy efficiency indicators

#### Methodology

For this sector it was possible to calculate indicators which describe the energy use per production in tonnes because the products of iron and steel manufacturing are rather homogenous. Specific energy uses for different processes were available in International Iron and Steel Institute data (IISI, 1996), but only for a few European countries and Japan. Unfortunately time series cannot be introduced because statistics were available only for a couple of years. Refining of crude steel, for example rolling, is not taken into account because its energy use depends on the level of refining, which is different in various countries.

There were a few shortcomings in the IISI data. Specific energy uses for the BOF and EAF processes were not available for Japan and Spain. Therefore, indicators for production routes could not be calculated for these countries. However, Japan and Spain have been taken into account when calculating an efficiency index for iron and steel manufacturing in various countries. This comparison has been done by using Finnish specific energy uses for both routes. These numbers have been multiplied with BOF and EAF steel production of each country. The calculated amount of primary energy has been compared with the amount of primary energy from the IISI data. If the calculated amount is smaller than the amount from the IISI data then the Finnish specific energy uses are on an average lower than the ones of the country compared and vice versa. The comparison is made for three different years that annual fluctuations can be seen.

The specific energy use of ore-based steel production in 1994 is shown in Figure 25 A for six European countries. In this comparison Sweden obtains the lowest value but this is due to the inaccuracy of IISI data. In Sweden ore preparation is mostly done in the mining areas and is not taken into account in the steel production sector. If the specific energy use of ore preparation were on the same level as in other countries, the histogram for Sweden would be slightly higher than Finland's. The Netherlands obtains a very good value, which is based on efficient processes; in particular the BOF process is very efficient because of a good recovery of converter gases. In Finland there is no recovery in

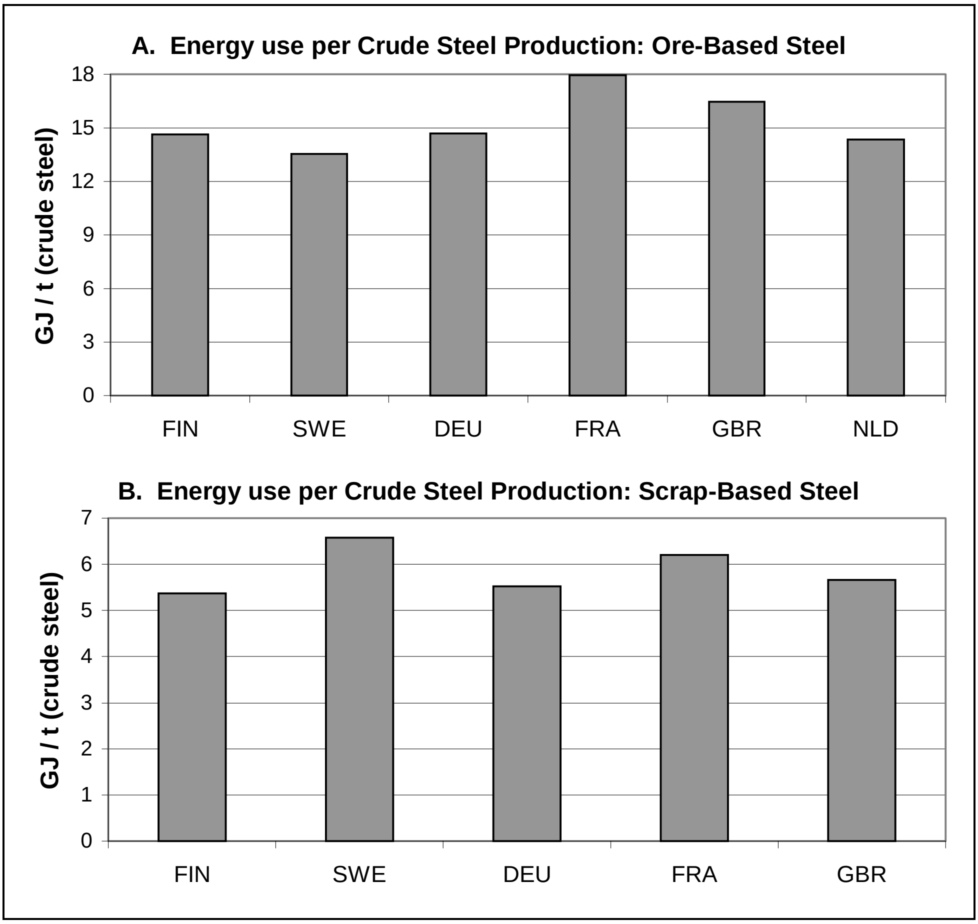



*Fig. 25. Specific energy use in 1994 for ore-based steel production (A) and scrap-based steel production (B) in selected European countries.*

the BOF-process, but very efficient blast furnaces compensate for this shortcoming. The higher values for France and UK are due to less efficient blast furnaces.

The specific energy use of scrap-based steel production in 1994 is shown in Figure 25 (B) for five European countries. The Netherlands is out of this comparison because no scrap-based steel is produced there. In this comparison Finland obtains the lowest value, which might be partly explained by the fact that the process in the town of Imatra is only a partial EAF process, with a supply of intermediate billets from elsewhere.

The energy-efficiency index of steel industry in various countries is shown in Figure 26 for eight countries and for three different years. The indexes calculated show the same results that were already obtained earlier. Fluctuations between various years and various countries are quite small. For the same reasons as mentioned above, the histograms for Sweden are also in this comparison too low, and probably Sweden should be at the same level as Finland and Germany in the year 1994. The histograms for Japan are possibly too high. When compared to other countries more pig iron is produced in Japan for other purposes than BOF-steel production. For this reason the energy use of blast furnaces per BOF-steel production is somewhat too high.

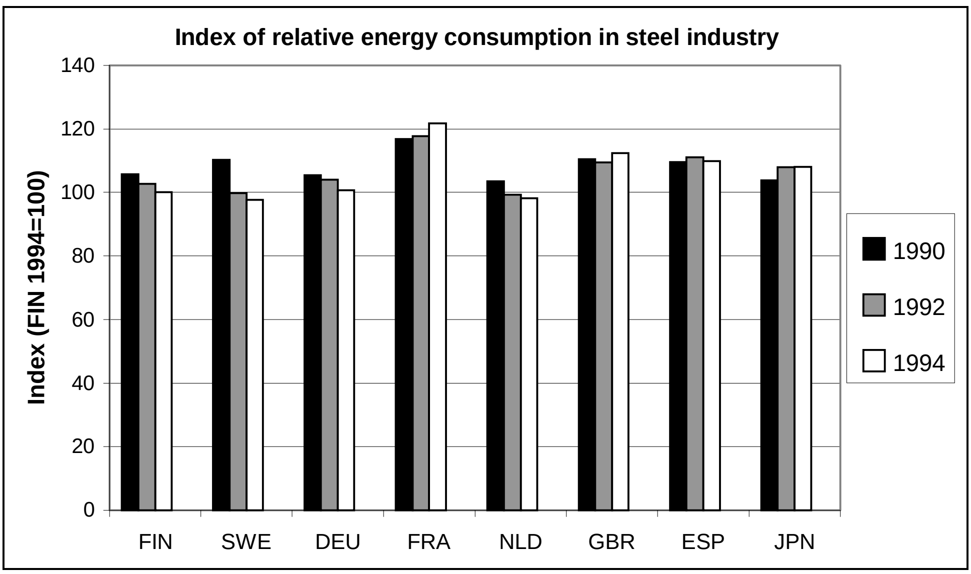



*Fig. 26. Index of relative energy consumption in steel industry in selected European countries and Japan.*

# 6 Other energy use and emissions

## 6.1 The residential sector

### 6.1.1 Components of residential energy use

The residential sector includes all the energy used in residential buildings. It consists of space heating, water heating, the use of cooking appliances, lighting, and various other household appliances. The use of private passenger cars is not included in the residential sector, but in the transport sector. Due to space heating activities, energy use in the residential sector is significantly affected by climatic conditions.

It is important to see that the residential heating, hot water, lighting, and appliance energy uses interact with each other. The heating and hot water systems are in centrally heated houses usually closely interlocked. Moreover, a large part of the total heat requirements can actually be provided by free or residual heat from lighting and appliances, hot water and ventilation systems, and from circulation system losses. Therefore, additional insulation and heat recovery measures can considerably reduce the need for external heating energy. Figure 27 illustrates the heating and hot water energy balance of an average single family house today in Finland, and that of a low-energy house which is projected to represent the level of standards in new houses within the next few decades. According to the projection, the requirements for heat production could be reduced by about 75% in the new low-energy houses, and the need for external purchased energy could be even further reduced by using heat pumps and solar collectors for the production.

### 6.1.2 Energy efficiency indicators

#### Methodology

In general, the methodology for the calculation of the total energy use and $CO_2$ emissions in the residential sector is similar to the methodology used for the manufacturing sector. Accordingly, the direct fuel consumption in residential buildings is counted as such, and the electricity and heat are converted to

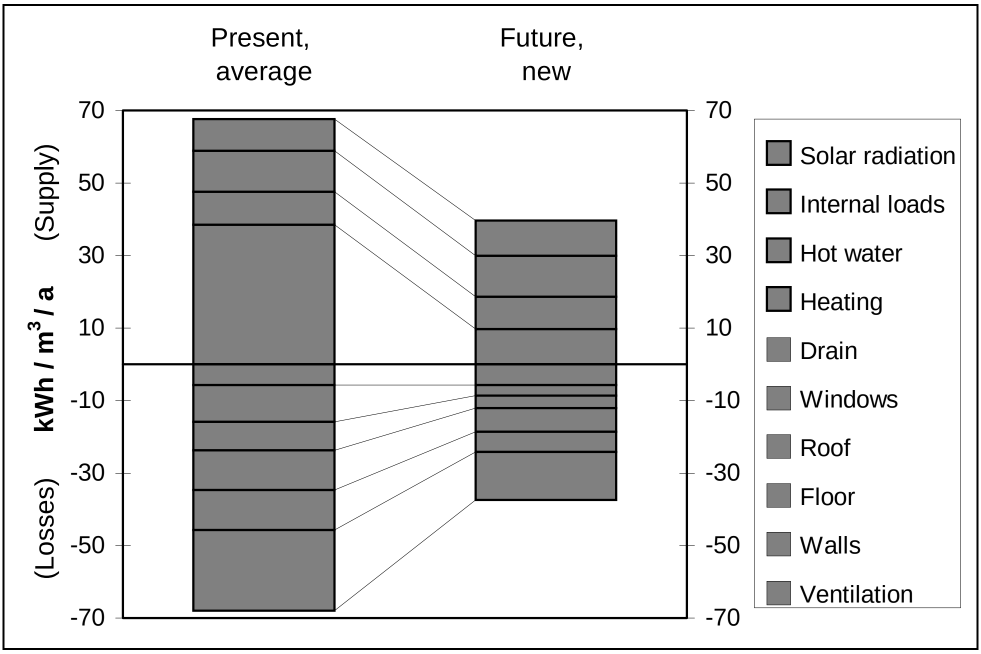



*Fig. 27. Heating and hot water energy balance in present and projected future single family houses in Finland (adapted from Saarimaa et al. 1994).*

primary energy equivalents by using the average efficiencies of public electricity and heat generation and distribution.

As already described in Section 2, the primary activity level used for calculating the intensities of energy use and emissions is the total population in each country considered. Nevertheless, it should be borne in mind that the average per capita living area in dwellings varies considerably from one country to another, as shown in Figure 28. Consequently, besides the climatic conditions, insulation, and heating practices, the average size of dwellings undoubtedly is a major factor affecting the residential energy use. In Finland the average living area is considerably smaller than in the other Nordic countries, but is close to that in Germany, France, UK, and Italy. In all countries the area has been steadily increasing, which is reflected in the space heating energy consumption. In order to take into account also the impact of dwelling sizes on the energy use, indicators for energy use and $CO_2$ emissions have been calculated on the basis of the total dwelling floor area as well. The two approaches together should give a sufficiently good perception of residential energy use.

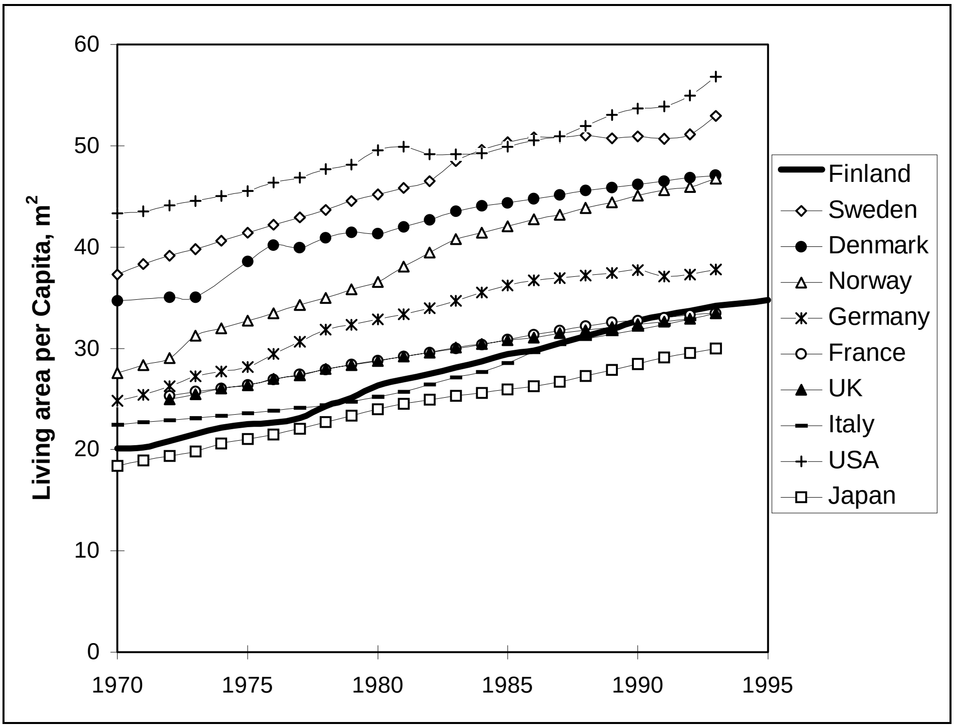



*Fig. 28. Average living floor-area in dwellings in selected OECD countries.*

The large differences in climatic conditions should be accounted for when making inter-country comparisons of space heating energy use. Data on the average heating degree-days in each country are widely used for the adjustment of heating energy use for better comparison. This method was followed also in the present study. The estimates used for the average heating degree-days are presented in Figure 29. As adequate data on energy use for cooling were not available, corrections based on cooling degree-days were not considered.

The adjustments based on the degree-days should basically be applied only to the energy use attributable to heating, not to appliance or lighting energy use. Sufficiently good data on the split of the residential energy use between heating and other uses were available from the LBL databases for most of the countries studied. For Finland, however, estimates based on national sources were used. For the remaining two countries (Belgium and The Netherlands), estimates were derived on the basis of the average per capita non-heating energy use in major EU-countries (Germany, France, UK, and Italy) between 1970 and 1992.

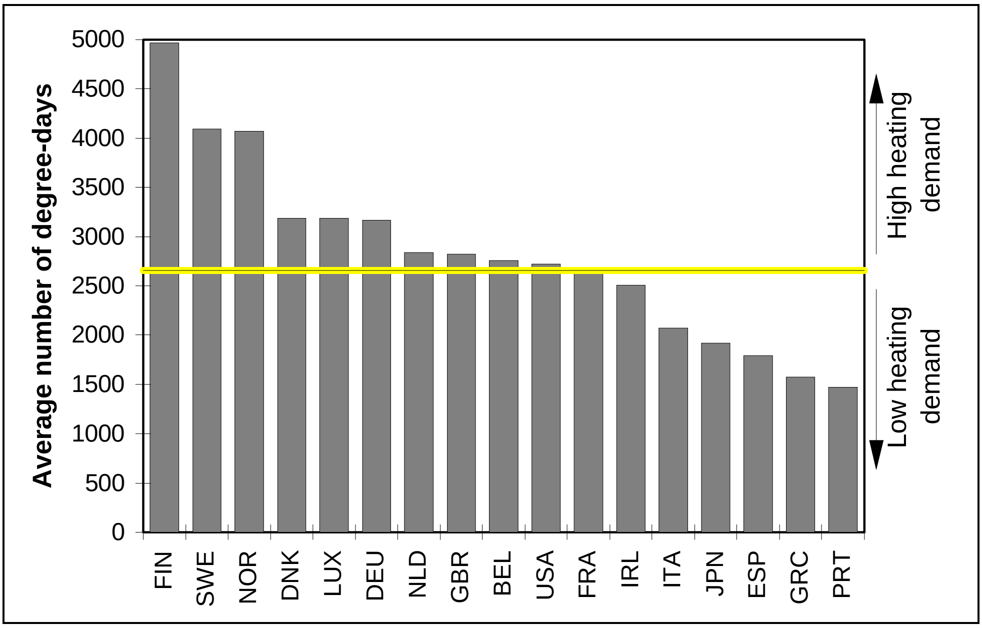



*Fig. 29. Estimates for the average population-weighted heating degree-days in selected countries, and the average (2660 DD) used as a basis for the DD-adjustment.*

In the degree-day correction the energy consumption attributable to space heating is adjusted for each country on the basis of the estimated average (population weighted) degree-days in the European Union and Norway. The estimate used for this average is 2660 degree-days. For example, as the average (population weighted) degree-days in Finland were calculated to be 4965, the heating energy in Finland is multiplied with 2660/4965.

## Indicator results

The development of the total residential energy use per capita (unadjusted) is shown in Figure C:1 for selected OECD countries. The intensities of energy use vary considerably from country to country. The intensities are lowest in Italy, France, and Japan, and the highest in the USA, Canada, and Norway. In the case of France it should be pointed out, however, that a large share of the residential use of wood has not been included in the French statistics before 1992. Consequently, the energy use in France prior the year 1992 should probably be notably larger than what is shown in Figure C:1.

The increasing per capita living areas have clearly been affecting the development of the energy use. A clear decreasing trend in the energy use per capita can not be identified for any other country than possibly The Netherlands, where high population density tends to limit increases in living area and therefore in energy use. On the contrary, the intensities have been steadily increasing in many countries. Apart from the reductions achieved in the Netherlands, in some of the countries with the highest intensities the per capita energy use appears to have become stabilized (Sweden, the USA, and Canada).

Finland has by far the coldest climate of the countries considered. Despite this, the unadjusted residential energy intensity in Finland is close to the average of the countries. The impact of the degree-day correction on the average energy intensities in 1990–1994 is shown in Figure 30, and in Appendix B time series are shown for the whole period 1970–1994 (Figure C:2). After the adjustments the variations among countries are much smaller, as one would expect. The adjustment made with the average degree-days of a normal year does not affect the variations between years.

After adjustments for climate, the intensity of residential energy use in Finland is among the lowest of all the countries considered. Only in Japan the intensity appears to be clearly at a yet lower level. The energy use attributable to space heating is found to be particularly low in Finland compared to other EU countries. The very low intensities in Finland can be explained by a very effective insulation of buildings (triple glazing, etc.), efficient heating systems, as well as by the relatively small living areas.

In Figure 30 the energy intensities are also shown based on the total living floor area of dwellings. Bearing in mind that the per capita floor area should only have a weak correlation with the appliance energy use, the results well confirm the conclusion on low residential energy use in Finland compared to most other countries. Appendix B includes results for the whole period studied (Figure C:6).

The development of residential electricity use is shown in Figure C:3. Intensities of electricity use have been increasing in all countries, particularly in the Nordic countries, the USA and Canada. The rapid growth is explained by the increases in the ownership of various household appliances, as well as electric heating.

Emissions of carbon oxide from residential energy use are shown in Figure C:4 on the per capita basis. The corresponding DD-corrected specific emissions are presented in Figure C:5. Unlike with the energy intensities, the $CO_2$ emission intensities show a distinctively decreasing trend in many countries. This is due to a shift into less carbon intensive energy forms, such as hydro and nuclear power, and natural gas.

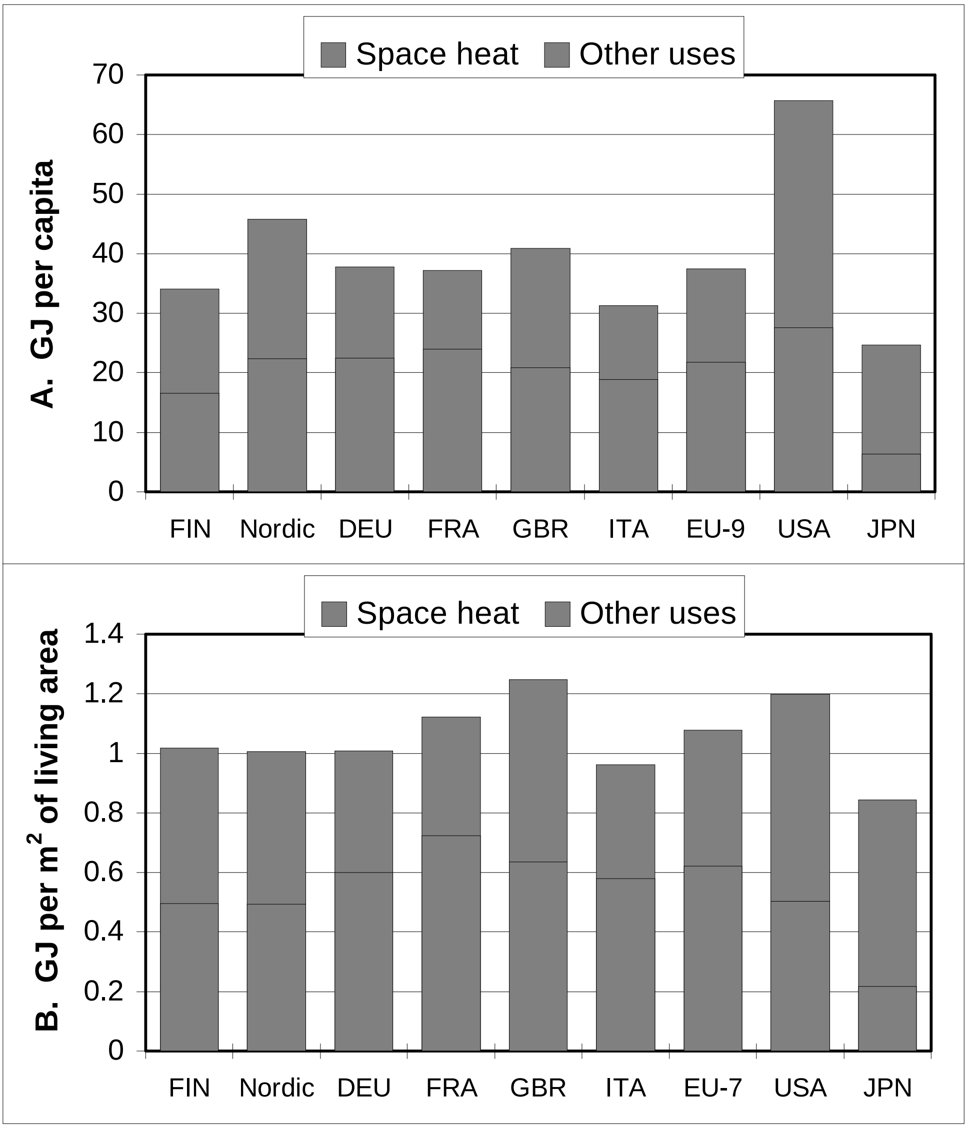



*Fig. 30. Degree-day corrected average residential energy use (A) per capita and (B) per living floor-area of dwellings during 1990–1994.*

The DD-adjusted per capita emissions are the smallest in Norway, Sweden, France, Finland, and Japan. In the first three countries the low emissions are largely explained by the abundant hydro and nuclear power resources. In the Finnish case, however, the efficient insulation and heating systems (including district heating systems) have a major contribution to the low emission level.

## 6.2 Transportation

### 6.2.1 Methodology

The transportation sector is in many ways the most transparent sector in terms of energy consumption. Data on fuel consumption should be reasonably reliable because of the particular characteristics of transport fuels. Additionally, thus far electricity has played only a very minor role in transportation, and merchandised heat has practically no role at all.

The basic indicators calculated for the transport sector are similar to those for the other sectors considered, with the exception that separate indicators are calculated for passenger and freight transport. The total amounts of energy consumed and emissions in passenger and freight transport are divided by the activity levels (passenger-kilometers and tonne-kilometers). The consumption of electricity is converted into primary energy and $CO_2$ emissions in a similar manner as for manufacturing (see Section 5.1).

As mentioned before, the split of energy consumption between passenger and freight transport is based on LBL data (LBL 1997). However, for a few countries the total fuel consumption amounts, e.g. in road transport, were considerably higher according to the IEA compared to the LBL estimates. If in such cases the IEA data could not be deemed to be incorrect, the total consumption was based on IEA data, and only the proportional split between passenger and freight transport was based on LBL data. For example, the IEA and LBL estimates for road transport fuels in Sweden differed from each other by 5–10%. After consulting also a few national estimates (SWE 1994, Nutek 1996), the IEA totals were assessed to be the more satisfactory of the two. Apart from Sweden, the only other country for which significant differences between the IEA and LBL data could not be resolved was France. For Australia, Japan, The Netherlands, Norway, the UK, and the USA the data used for the indicators were fully or with very small disparities consistent with the LBL data.

In the case of Germany the LBL data for West-Germany were used as such until 1990, but for 1991–1993 the IEA data for the united Germany were used, as for the most recent years the IEA energy data appeared to consistent with the ECMT energy and activity data.

### 6.2.2 Indicator results

Some characteristics of passenger car transport in various countries are presented in Figures D:1 and D:2. The average annual distance travelled with passenger cars has been relatively high in Finland compared to many other countries. This is largely explained by sparse population, and a relatively low ownership of more than one car per household. Moreover, the average number of passengers in cars is among the lowest of the countries studied (Finnra 1996, Fig. D:2). The number of cars per capita was in Finland still low in the 1970s, but has been raised to the average level in Europe. Combining all these factors, the passenger kilometers per capita are at present close to the average in Europe, as shown in Figure 31.

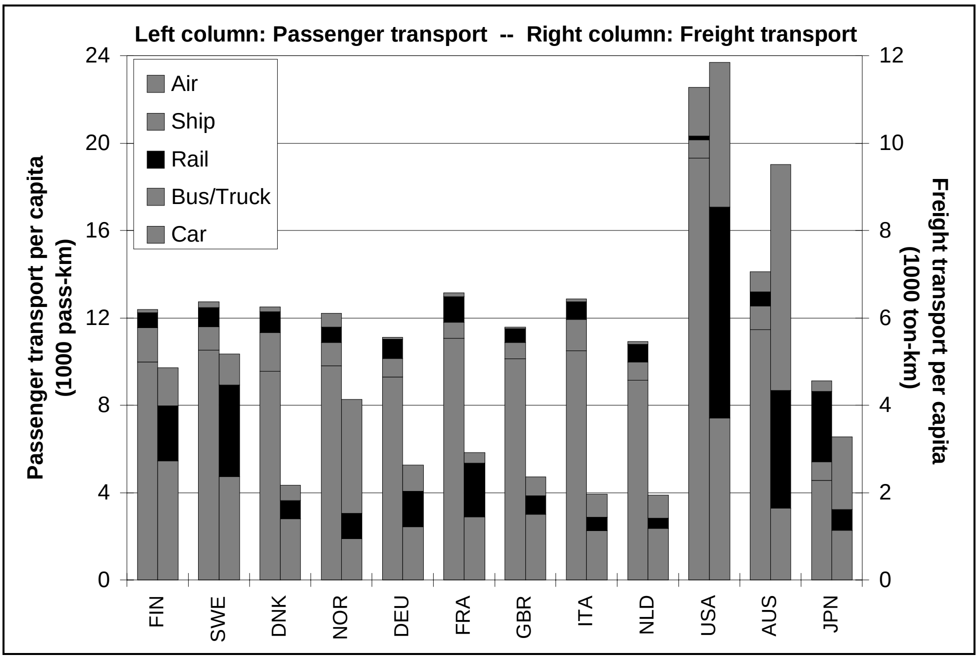



*Fig. 31. Total passenger and freight transport volume per capita in selected OECD countries.*

Differences in the modal split of passenger transport among countries are generally small. Passenger cars clearly dominate the total transport activity in all countries except Japan. Rail transport typically constitutes a 5–8% proportion of total passenger transport, but in Japan the share is as high as 35%. The overall contribution of public transport is typically 15–20%, but in Japan it is about 50%. In freight transport the differences in total per capita volume are strikingly large. While in Italy and The Netherlands the amount is about 2000 tonne-km, in the USA it is almost 12 000 tonne-km. Finland is around the average with about 5000 tonne-km per capita. In general, the freight transport volumes are high in sparsely populated countries.

The modal shares of the volume and energy use in passenger and freight transport are shown in Figures D:3 and D:4 for the years 1973 and 1993 (for some countries the years are different due to data availability, as indicated in the Figures). In Finland and the UK the public transport systems have lost a significant part of their market share during the two decades. On the other hand, particularly in Denmark but also in USA public transport has gained some market share. However, in USA this is explained by increased air transport, which has little contribution to improved energy efficiency.

In goods transport rail has a significant market share in many countries. The share of energy consumption, however, is much smaller, as shown in Figure D:4. As in passenger transport, road transport dominates the energy consumption in almost all countries.

The development of the intensity of energy use in passenger transport is illustrated in Figure D:5, and the intensity in road transport in Figure D:6. The intensities for the year 1993 are summarized also in Figure 32. The variation in total energy use per passenger-kilometer among countries is relatively small within Europe. In Finland the specific energy use increased notably during the late 1980s, which is explained by the decreasing market share of public transport and larger passenger cars. Despite this, the energy intensity in Finland is at the good average level of the European countries considered. As could be expected, the intensities in the United States and Australia are at a much higher level than in Europe, due to the predominating passenger car transport and large cars, which, in turn, are related to the long travel distances in these two countries.

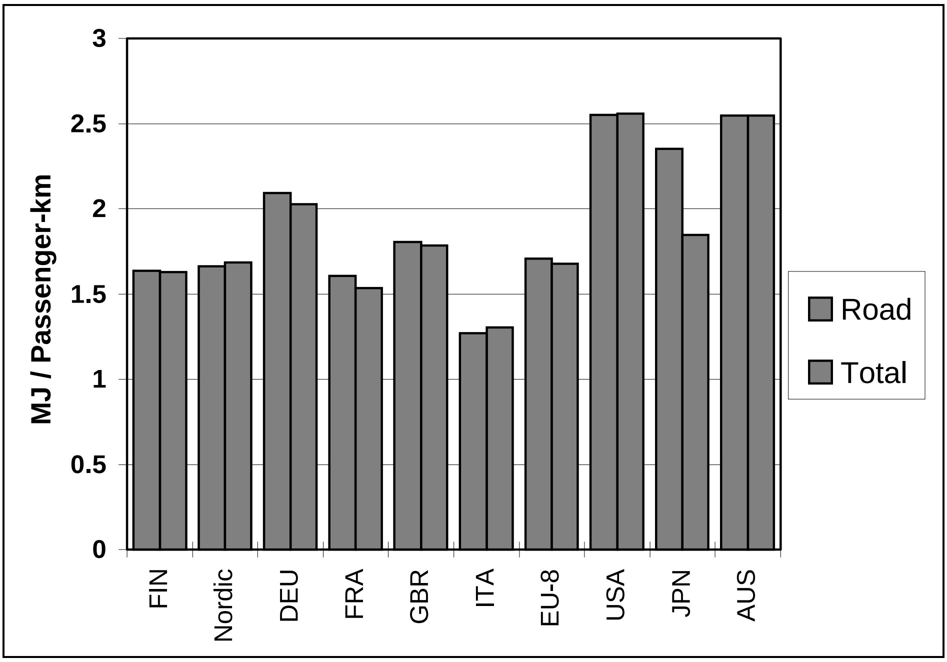



*Fig. 32. Energy use in passenger transport per person-kilometer in 1993. Total passenger transport, and passenger transport on roads.*

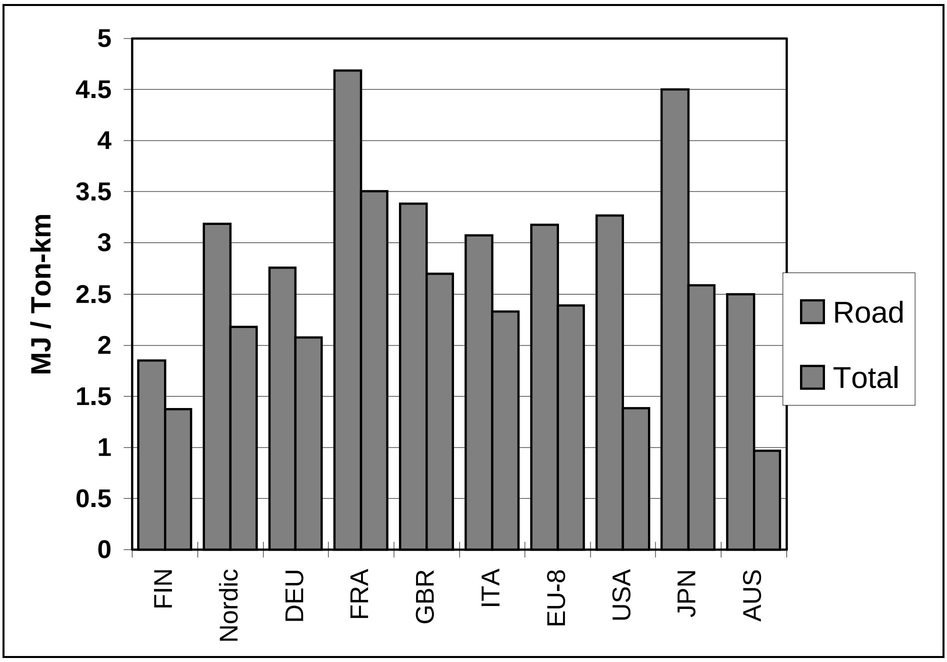



*Fig. 33. Energy use in freight transport per tonne-kilometer in 1993. Total freight transport, and freight transport on roads.*

According to the calculations, in Japan the intensity also appears to be high, due to the relatively high fuel consumption of passenger cars, a low load factor, and probably traffic congestion. Similar results for Japan have been obtained in LBL studies (Schipper & Perälä 1995, IEA 1997).

In freight transport the average intensities vary considerably among countries, as depicted in Figures D:7 and D:8. The intensities for the year 1993 are summarized also in Figure 33. In Finland the energy intensity of total freight transport is the lowest among the European countries considered. The intensity in the USA is approximately at the same level as in Finland, and Australia is the only country with distinctively lower average intensity.

When examining goods transport on roads only, Finland stands out from all other countries with the lowest energy intensity. In Denmark and Norway, on the other hand, the intensity appears to be surprisingly high compared with Sweden and Finland. In general, in countries with high population density energy intensities tend to be high, apparently because of the large share of short-distance transportation with small batch size and in small trucks and vans.

The development of the $CO_2$ emission intensity from passenger and freight transport energy use is shown in Figure D:9. The results for the emissions are very similar to the energy results. The reasons for the similarity are obvious: almost all the fuels used within the transport sector are oil-based fuels with nearly the same $CO_2$ emission factors, and electricity is not yet anywhere used to power cars on a large scale.

Finally, in Figure D:10 a simple analysis on the relation of transport energy use to the sparsity of the population is presented. The longer the distances are within a country, the larger one would expect the per capita energy consumption to be. Therefore, the energy consumption is plotted against the square root of the per capita area for each country (the square root of the area represents a model for the impact of the sparsity of population to transportation distances). The results of this simplistic analysis show that there is a weak dependence of the energy consumption on the sparsity. In light of the results, the per capita energy consumption in Finland appears to be among the lowest of all the countries both in passenger and freight transport.

# 7 Energy technology research in Finland

Extensive research in energy technology is carried out in Finland by engineering and manufacturing companies and research institutes. The Finnish government supports many activities in basic R & D of energy technology, and also provides funding for technology development and participates in the most expensive technology demonstration projects. Currently, the national energy technology research programmes for 1993–1998 are the main framework for the research funded by government. The research projects in the framework of the EU research programmes are assuming an increasing percentage; and the activities in the OECD/IEA programmes are also considerable. The non-nuclear research programmes are funded and co-ordinated by the Technology Development Centre of Finland (TEKES).

The overall objective of the Finnish national energy research programmes is to promote economic and environmentally friendly energy technology in Finland, for use in Finland and for export to other countries. The programmes covering the development of energy production systems include combustion and gasification technologies, bioenergy, and advanced energy systems and technologies. Although all programmes contribute to the lowering of emissions to the environment, the environmental aspects of energy technology also have a special programme. Furthermore, two programmes concentrate on energy distribution, namely automation of electricity distribution and district heating. The programmes for energy end-use cover transportation, manufacturing of basic metals, pulp and paper, and energy use in buildings. Table 3 lists the ongoing research programmes.

The total funding of energy research in Finland is about USD 300 million, and the amount funded by public sources was about USD 60 million in 1995. The total budget of the programmes is about USD 200 million, half of which is provided by the government.

Finland's energy technology priorities have focused on areas where they can exploit existing skills and knowledge to gain an international advantage in advanced equipment markets. As an indication of the scale involved, its annual energy equipment exports are greater than the value of its oil imports.

*Table 3. Finnish national energy research programmes 1993–1998.*

| Programme | Objectives |
|---|---|
| **Energy Production** | |
| LIEKKI2 Combustion and gasification technology<br>• Biomass combustion and gasification | To develop new production technology to reduce emissions and improve efficiency |
| BIOENERGIA Bioenergy<br>• Wood fuel production and handling<br>• Small-scale combustion of solid biomass<br>• Peat production<br>• Liquid biofuel production | To develop technologies to achieve a competitive price level for bioenergy and peat production |
| NEMO2 Advanced energy systems and technologies<br>• Solar and wind energy | To develop technologies for the use of wind and solar energy |
| FFUSION Finnish fusion energy research programme | To carry out high-level scientific and technological research in support of the European Fusion Programme and International Thermonuclear Experimental Reactor (ITER) project |
| **The Environment** | |
| SIHTI2 Energy and environmental technology<br>• Environmental research includes biomass and wastes | To develop technologies to reduce the emissions of harmful substances, to recycle raw materials, and to limit the amount of wastes and utilize them in the energy sector |
| **End-use of Energy** | |
| MOBILE Energy and the environment in transportation<br>• Utilization of liquid biofuels | To develop technologies to reduce emissions from the transport sector |
| SULA2 Energy in steel and base metal production | Development of processes to achieve the world's lowest specific consumption of energy |
| SUSTAINABLE PAPER Energy in paper and board production | Development of processes to achieve the world's lowest specific consumption of energy |
| RAKET Energy use in buildings<br>• Wood fuel utilization in space heating | To create technologies for halving the energy consumption of new buildings compared with present levels |
| EDISON Electric distribution automation | To develop an integrated distribution automation concept |
| TERMO District heating | To develop technologies to increase the efficiency and economy of district heating |

# 8 Discussion and conclusions

Calculation of energy efficiency indicators is a complicated task that involves many difficulties from the selection of calculation methodologies to the interpretation of extensive databases, and finally to the interpretation of results. At least two large international programmes are being undertaken by the OECD/IEA and EU in this field (Bosseboeuf et al. 1996, IEA 1997). Similar indicators have also been calculated in an earlier national study (Schipper & Perälä 1995).

In the present study, several important sources of international energy data have been used. At the level of national energy balances, the IEA basic energy statistics were considered to be the best available international source and were used for the indicators on energy supply and power and heat generation. At the level of end-use sectors, however, the IEA data contain a considerable amount of severely misallocated data, for some countries even for the most recent years. Consequently, the use of IEA data can, for some countries, lead to significantly biased sectoral results. To avoid these serious pitfalls, other data sources of higher quality should also be used.

One of the foremost pioneers in international sectoral energy analyses is the International Energy Studies group of the Lawrence Berkeley National Laboratory (LBL). Of their extensive databases, data on residential and transport sectors were available for the present study. When the IEA data were found to be far from correct, the LBL data were used instead. The LBL data also included activity data for the residential and transport sectors, which were extensively used for the indicator calculations. It can be assessed that the combined use of IEA and LBL data makes the indicators much more reliable than with IEA data alone.

For the manufacturing sector, an attempt was made to separate out the impact of structural changes on the development of energy intensity. However, due to lack of data, this could be done only on the rather aggregate level of about 10 manufacturing subsectors. Structural changes within the subsectors could not be captured by the analysis. The results on intensity changes should, therefore, be interpreted with caution, bearing in mind that the general trend in most branches has been towards products with higher value added and less energy or raw material use.

With respect to comparisons of the Finnish energy economy with other countries, the results from the present study are generally in good agreement with other studies. Improvements in the Finnish manufacturing industries in terms of energy and emission intensities, however, appear to be greater than indicated by some earlier studies.

The structure of the primary energy supply in Finland is less carbon-intensive than the average for the EU or OECD countries. The low specific carbon emissions are explained by the high percentage of renewable energy, as well as nuclear power. Of the renewable energy sources, the utilization of biomass for energy in Finland is the highest among the OECD countries.

The market share of combined heat and power production (CHP) of the total electricity generation is at present highest in Denmark and Finland among the OECD countries. In these countries the market share is three to four times as high as the EU average. In consequence, the overall efficiency of power and heat generation is relatively high in these countries. Finland differs from Denmark by having extensive CHP generation both for industry and for the residential and commercial sectors. The high energy efficiency of CHP production lowers the average specific $CO_2$ emissions from electricity generation, which are particularly low in Finland.

In comparison to average levels within the OECD countries, the use of non-fossil energy sources is extensive in Finland: hydropower resources are used at nearly practical maximum levels, nuclear power is utilized to a large extent, and biomass is used by modern methods for cogeneration of power and heat both in industry and district heating. In particular, the use of biomass for electricity generation has penetrated much further in Finland than in any other OECD country. Furthermore, most of the biomass is utilized efficiently in combined heat and power production.

With regard to the end-use sectors, the results indicate that in the manufacturing industries the average intensities of energy use and $CO_2$ emissions are high in Finland compared with most other OECD countries. The high levels of the intensities are explained by the structure of manufacturing, especially the large pulp and paper exporting industries. The improvements achieved in the intensities, however, have been approximately at the average level among the countries studied.

As a general conclusion, it was found that the relative decreases in energy and $CO_2$ intensity of manufacturing industries have been considerably large in most of the countries considered. However, differences in the absolute level of energy intensity in the specific energy intensive branches studied (pulp and paper, iron and steel) were found to be relatively small between countries. Therefore, it was concluded that the manufacturing structure, which is much more energy intensive than the average within the European Union, is causing high average energy intensity in Finland, instead of inefficient use of energy.

Regarding the pulp and paper industries, which are in Finland by far the largest energy-consuming industrial sector, about half of the total energy requirements both in Finland and Sweden are satisfied by renewable by-product and waste fuels. Among the major exporting countries of pulp and paper products the Finnish pulp and paper industries were found to be fairly energy-efficient, but the differences among these countries appear to be small. A similar conclusion could be drawn for the iron and steel manufacturing: differences in specific energy consumption are small among major countries producing raw iron and steel, but energy use in Finland is clearly on the lower end of the scale.

Per capita energy consumption and emissions in the residential sector appear to be very low in Finland, when the cold climate is taken into account. The energy use attributable to space heating especially appears to be very low, both in per capita terms and in proportion to the total floor area of dwellings. Good insulation of buildings, efficient heating systems, and large penetration of district heating can be identified as major factors contributing to the low primary energy requirements of the Finnish residential sector. Relatively small dwelling sizes represent an additional explanation for the low per capita consumption.

As for the transport sector, the energy intensity of total freight transport in Finland is the lowest in Europe, Sweden being at a similar level. Moreover, freight transport on roads appears to be more energy-efficient in Finland than in any other country considered in the study. Finland is also one of the few countries where notable improvements have been achieved in the energy intensity of road transports during 1970–1994. The energy use in passenger transport, on the other hand, is at present at the average European level in Finland.

On the basis of the results obtained in the study, countries can be seen to have very different possibilities for utilizing the generic technology options proposed by the IPCC. This would mean that emission reductions of equal percentages would lead to very different costs in various countries. The actions widely recommended as policies and measures for reducing emissions in industrialized countries appear to be already implemented to a large extent in Finland. The carbon intensity of the Finnish energy supply is low, due to extensive use of indigenous renewable energy resources as well as nuclear power, and the efficiency of the energy conversion sector is in general outstanding. Furthermore, the energy intensities in many of the end-use sectors were found to be among the lowest of the countries studied, including the residential, transport, and two of the most energy-intensive manufacturing sectors.

A large part of the generic technology options proposed by the IPCC for $CO_2$ emission reductions have thus been well put into practice in Finland. The considerable utilization of these options has been mainly inherently achieved, through self-regulation of the energy and manufacturing industries.

The incentives behind the advances have included the energy-intensive structure of manufacturing, cold temperatures, and sparse population, which all have influenced the establishment of energy-efficient practices. The marginal costs of additional emission-reduction measures can therefore be expected to be higher in Finland than in many other countries. Nevertheless, along with continuing efforts to maintain the good results obtained thus far, it is important to recognize what can still be done in Finland, even if the prospects are limited in the short term. Notable potential for additional emission reductions can be identified at least in further extending the use of low-carbon and carbon-free energy sources (biomass, wind, solar, and nuclear, when possible), raising the power to heat ratios in cogeneration, low-energy housing solutions, and, as in virtually any country, intensified efforts to remove the barriers still preventing the utilization of cost-efficient energy conservation options in the end-use sectors.

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# References

AGFW 1996. District Heating Combined Heat and Power in the Federal Republic of Germany. AGFW Position Paper, Statement of Principles. Arbeitsgemeinschaft Fernwärme e.V. (AGFW). Online WWW-page: http://www.energy.rochester.edu/de/agfw/chp.htm.

Bosseboeuf, D., Lapillone, B. & Chateau, B. 1996. Cross country comparison on energy indicators: the on-going European effort towards a common methodology. Service Economie Prospective, Ademe.

Cogen 1997. European Cogeneration Review 1997. A study co-financed by the SAVE Programme of the European Commission. Brussels: Cogen Europe. 182 p.

EC 1996. Renewable Energy Sources Statistics 1989–1994. Brussels: European Commission, Statistical Office of the European Communities.

ECMT 1995. Trends in the Transport Sector 1970–1994. Paris: European Conference of Ministers of Transport. Statistical brochure.

ECMT 1997. Statistical Trends in Transport 1965–1992. Paris: European Conference of Ministers of Transport, OECD Publications. 256 p.

Euroheat 1996. 1995 Euroheat District Heating Statistics. Prepared by Euroheat & Power study committee for nomenclature and statistics. Online data at WWW server: http://www.energy.rochester.edu/euroheat/1995.htm.

Euroheat 1997. Euroheat & Power, Yearbook 1997. Brussels/Frankfurt am Main: Euroheat & Power, Unichal, Arbeitsgemeinschaft Fernwärme e.V. 126 p.

FAO 1997. FAOSTAT Statistic Database. Online Database available at WWW server: http://apps.fao.org.

Finnra 1996. Liikenteen vertailutietoja eri maista [Comparative data on transport in various countries]. Helsinki: Finnish National Road Administration (Finnra), Tielaitoksen selvityksiä 27/1996. 80 p. + app. (In Finnish)

Finnra 1997. Finnish Road Statistics 1996 [Tietilasto 1996]. Helsinki: Finnish National Road Administration (Finnra), Finnra Statistical Reports 3/1997. 80 p.

Forest Research Institute 1996. Statistical Yearbook of Forestry. Helsinki: The Finnish Forest Research Institute. SVT Agriculture and forestry 1996:3. 351 p.

Greening, L. A., Davis, W. B., Schipper, L. & Khrushch, M. 1997. Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries. Energy Economics 19, p. 375–390.

Heston, A., Summers R., Nuxoll, D., A. & Aten, B. 1995. Penn World Tables: An Expanded Set of International Comparisons, 1950–1992, Mark 5.6. Online data at: `http://datacentre.epas.utoronto.ca:5680/pwt/pwt.html`.

IEA 1995. Energy Policies of IEA Countries. Paris: International Energy Agency, OECD. 652 p.

IEA 1996a. Energy Statistics and Balances. OECD (1960–1994), Non-OECD (1971–1994). Diskette Service Documentation. Paris: International Energy Agency, OECD. 33 p. + 7 diskettes.

IEA 1996b. IEA/AFIS Raw materials and conversion. Automotive fuels survey. December 1996. Paris: International Energy Agency, Organization for Economic Co-operation and Development. 172 p.

IEA 1997. Indicators of Energy Use and Efficiency. Understanding the link between energy and human activity. Paris: International Energy Agency, Organization for Economic Co-operation and Development. 330 p.

IISI 1996. Statistics on Energy in the Steel Industry (1996 Update). Brussels: International Iron and Steel Institute. Committee on Economic Studies. 15 p. + app. 120 p.

IPCC 1995. IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 1–3. Bracknell: Intergovernmental Panel on Climate Change. Available online in PDF format at: `http://www.iea.org/ipcc/general/invs1.htm.`

IPCC 1996a. IPCC second assessment synthesis of scientific-technical information relevant to interpreting Article 2 of the UN Framework Convention on Climate Change. `http://www.unep.ch/ipcc/synt.htm.`

IPCC 1996b. Climate change 1995 – economic and social dimensions of climate change, contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. 448 p.

Kanninen, M., Korhonen, R., Savolainen, I. & Sinisalo, J. 1993. Comparison of the radiative forcings due to the $CO_2$ emissions caused by fossil fuel and forest management scenarios in Finland. In: Kanninen, M. (ed.) Carbon Balance of the World's Forested Ecosystems: Towards a Global Assesment. IPCC/AFOS workshop, held in Joensuu, Finland, 11–15 May 1992. Publ. Acad. of Finland 3/93. Pp. 240–251.

LBL 1997. International datasets for residential and transport energy use. Lawrence Berkeley National Laboratory, Energy Analysis Program, International Energy Studies, Electronic Database.

Lehtilä, A. 1995. Uusien energiatekniikoiden ja päästönvähennyksen potentiaali Suomessa [New energy technologies and emission reduction potential in Finland]. Espoo: Technical Research Centre of Finland, VTT Research Notes 1697. 73 p. + app. 8 p. (In Finnish)

Lehtilä, A., Savolainen, I. & Sinisalo, I. 1997. Indicators Describing the Development of National Greenhouse Gas Emissions. Espoo: VTT Energy, Technical Report ENE6/09/96. 18 p. + app. 48 p.

Marland, G., Andres, R. J., & Boden, T. A. 1994. Global, regional, and national $CO_2$ emissions. In: Boden, T. A., Kaiser, D. P., Sepanski, R. J. & Stoss, F. W. (eds.). Trends '93: A compendium of data on global change. Oak Ridge: Carbon Dioxide Analysis Center, Oak Ridge National Laboratory (ORNL/CDIAC-65). Pp. 505–585. Online data at: `ftp://cdiac.esd.ornl.gov`.

MoE 1997. Finland’s second report under the Framework Convention on Climate Change. Helsinki: Ministry of Environment. 63 p.

Mäenpää, I. & Tervo, H. 1994. Suomen talouden energiankulutuksen ja ilmapäästöjen rakenteet vuonna 1990. Panos-tuotos-analyysi. [Structures of the atmospheric emissions and energy consumption in Finland’s economy]. Oulu, Finland: University of Oulu. Discussion papers in economics and business studies, Nr. 15. 55 p. (In Finnish)

Mäkelä, K., Kanner, H. & Laurikko, J. 1996. Suomen tieliikenteen pakokaasupäästöt – Liisa 95 -laskentajärjestelmä [Road traffic exhaust gas emissions in Finland – Liisa 95 calculation software]. Espoo: Technical Research Centre of Finland, VTT Research Notes 1772. 45 p. + app. 51 p. (In Finnish)

Nippala, E., Heljo, J., Jaakkonen, L. & Lehtinen, E. 1995. Rakennuskannan energiankulutus Suomessa [Energy consumption of the building stock in Finland]. Espoo: Technical Research Centre of Finland, VTT Research Notes 1625. 61 p. + app. 14 p.

Nordvärme 1995. Nordvärme Bulletin. Statistik 1994 [Statistics 1994]. Stockholm: Nordvärme (Cooperative body for Nordic district heating associations). 4 p. (In Swedish)

Nutek 1996. Energy in Sweden: Facts and Figures 1996. Stockholm: Swedish National Board for Industrial and Technical Development (Nutek), Info 334–96. 24 p.

OECD 1997a. OECD International Sectoral Database. Online Database available at WWW-server: `http://www.etla.fi`.

OECD 1997b. Industrial Structure Statistics 1970–1994. Paris: OECD Economic Analysis and Statistics Division, Electronic Publication (5 diskettes).

Pingoud, K., Savolainen, I., Seppälä, H. 1996. Greenhouse impact of the Finnish forest sector including forest products and waste management. Ambio, Vol. 25, No. 5, pp. 318–326.

Saarimaa, J., Hyttinen, R. & Immonen, K. 1994. ETRR Energy-efficient buildings and building components. Final report on the energy research programme 1988–1992. Helsinki: Ministry of Trade and Industry, Reviews B:163. 197 p.

Salokoski, P. & Äijälä, M. 1996. Kasvihuonekaasupäästöjä vähentävien energiatekniikoiden tilanne ja kehitysnäkymät Suomessa [The Status of Development of Energy Technologies to Reduce Greenhouse Gas Emissions in Finland]. Helsinki: Ministry of Trade and Industry, Studies and Reports 19/1996. 70 p. (In Finnish)

Schipper, L. & Perälä, L. 1995. Energy Use in Finland: An International Perspective. Berkeley: Lawrence Berkeley National Laboratory.

Solomon 1995. Europe, Africa, and the Middle East Fuels Refinery Performance Analysis for Operating Year 1994. Reference Manual. Windsor, UK: Solomon Associates.

Statistics Finland 1995. Rakennukset ja asunnot 1994 [Buildings and dwellings 1994]. Helsinki: Statistics Finland, SVT Asuminen 1995:9. 108 p. (In Finnish)

Statistics Finland 1996a. Energy statistics 1995. Helsinki: Statistics Finland, SVT Energy 1996:1. 126 p.

Statistics Finland 1996b. Energy and Emissions. Helsinki: Statistics Finland, SVT Environment 1996:2. 135 p.

Statistics Finland 1996c. Statistical Yearbook of Finland 1996. Helsinki: Statistics Finland.

Statistics Finland 1996d. Yearbook of Industrial Statistics 1996, Volume 1. Helsinki: Statistics Finland. SVT Teollisuus 1996:6.

Statistics Finland 1996e. Construction and Housing, Yearbook 1996. Helsinki: Statistics Finland. SVT Housing construction 1996:24.

Statistics Finland 1996f. Transport and Communications Statistical Yearbook for Finland. Helsinki: Statistics Finland. SVT Transport and Tourism 1996:20.

SWE 1994. Sweden's National Report under the United Nations Framework Convention on Climate Change. Stockholm: Ministry of the Environment and Natural Resources (Sweden). 119 p.

Timonen, L. 1995. Teollisuuden energiatehokkuuden seuranta [Follow-up of the energy-efficiency in manufacturing]. Helsinki: Teollisuuden Energialiitto, huhtikuu 1995. 45 p. + app. 27 p. (In Finnish)

UN 1995. United Nations Secretariat, Population Division, Department for Economic and Social Information and Policy Analysis. Data available online at the World Wide Web server: `http://www.undp.org/popin/popin.htm`.

Vainikka, P. 1997. Combined heat and power in industry – Benefits, potential, and case examples. Paper presented at the seminar "Energy Efficiency – Experiences and New Technologies" at AGBM Bonn, August 6th, 1997. 5 + 6 p.

# Appendix A: List of figures

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## (Indicators for the Residential Sector)

# List of Figures in Appendix D:
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# Appendix B:
# Indicators for the manufacturing sector

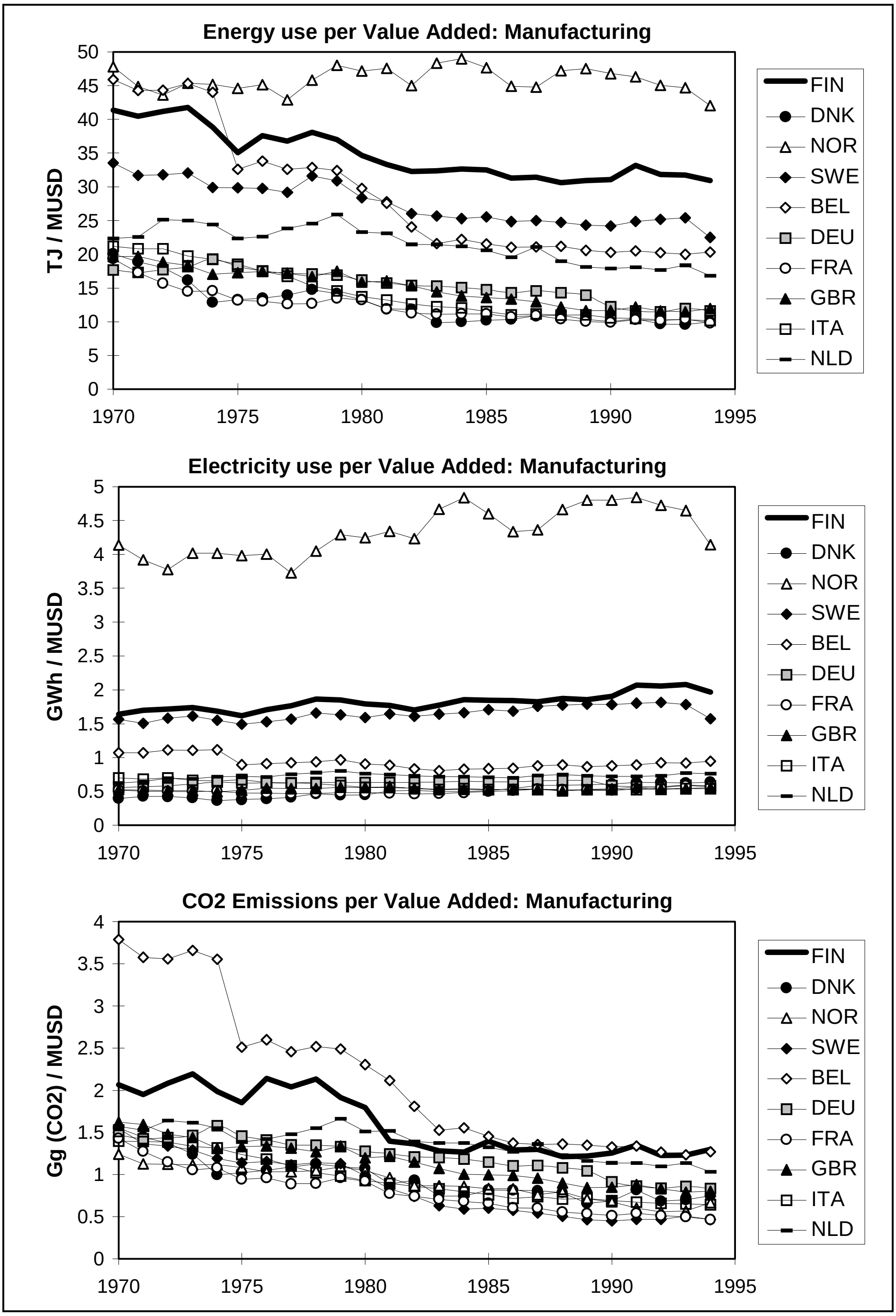



*Fig. B:1. Ratio of total energy requirements (A), electricity use (B), and $CO_2$ emissions (C) to total value added in the manufacturing industries of selected European OECD countries.*

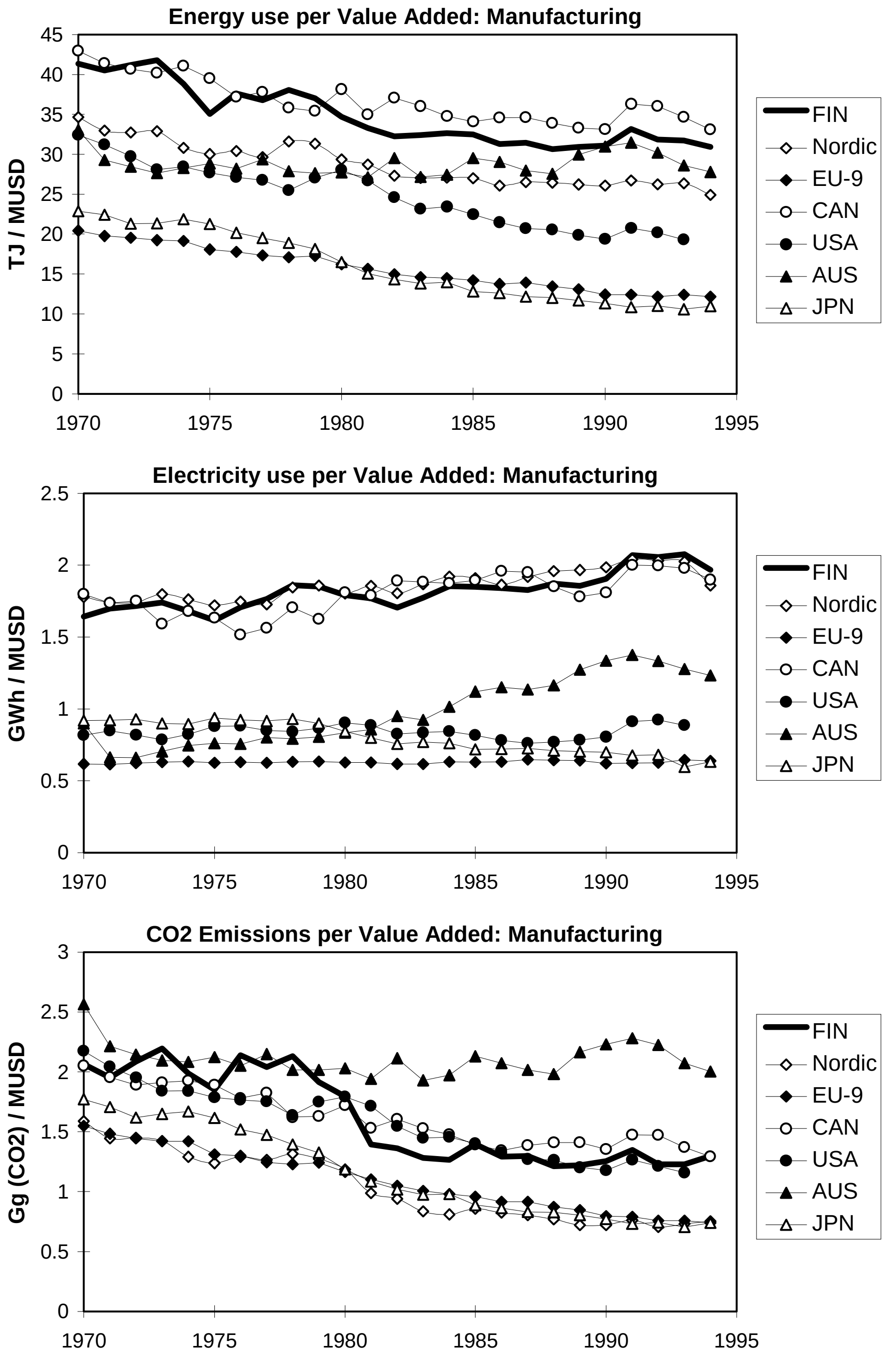



*Fig. B:2. Ratio of total energy requirements (A), electricity use (B), and $CO_2$ emissions (C) to total value added in the manufacturing industries of Finland, EU, and selected non-European OECD countries.*

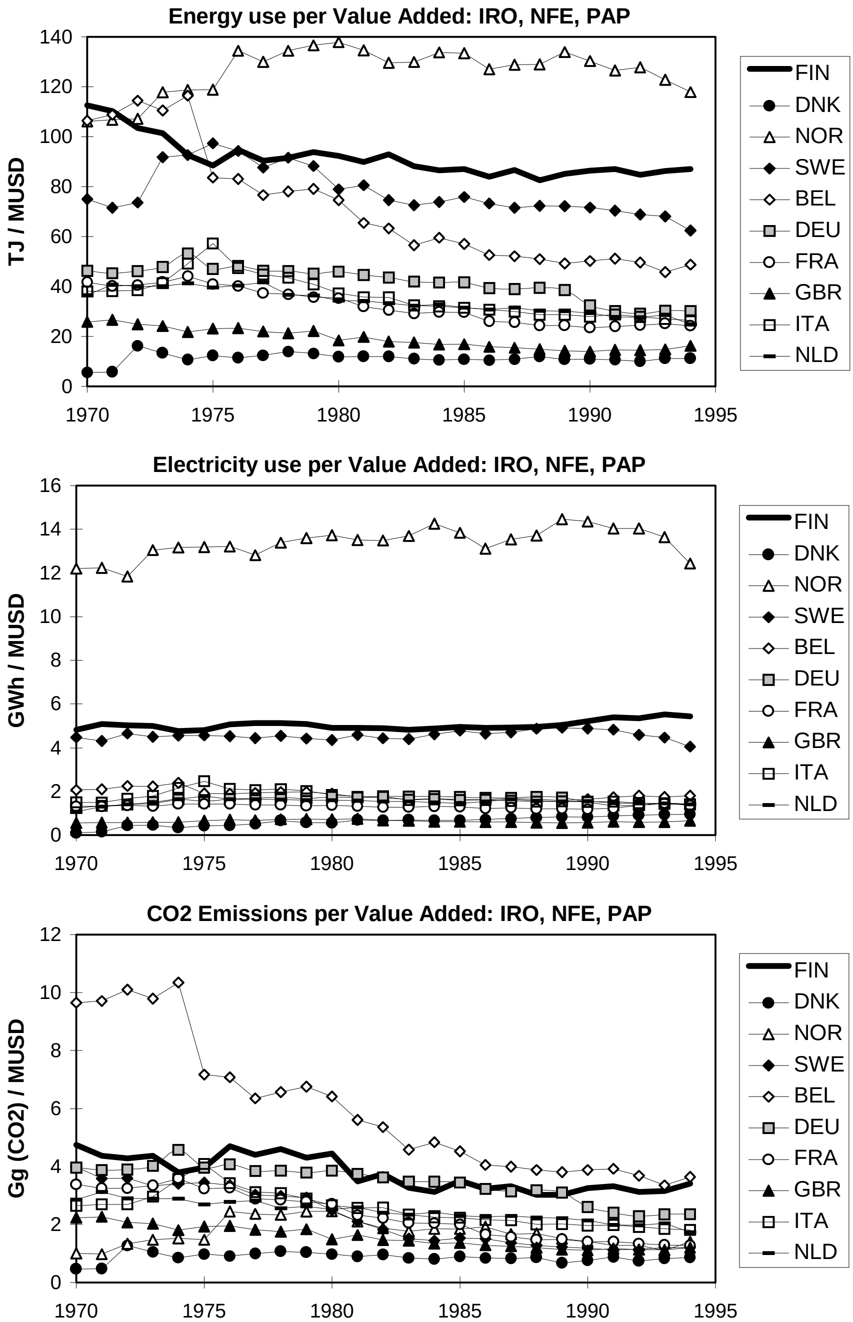



*Fig. B:3. Ratio of total energy requirements (A), electricity use (B), and $CO_2$ emissions (C) to total value added in the iron and steel, non-ferrous metal, and pulp, paper and printing industries of selected European OECD countries.*

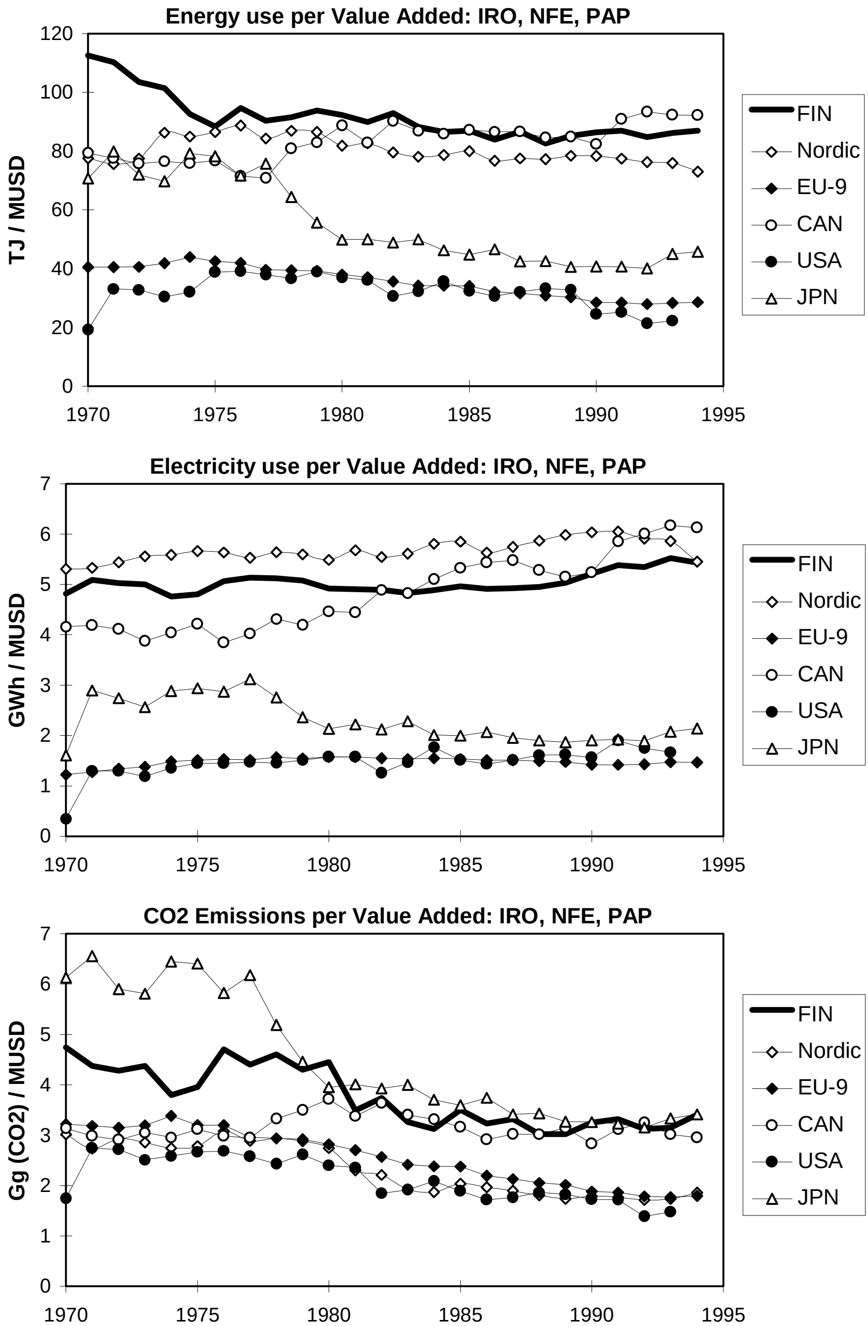



*Fig. B:4. Ratio of total energy use (A), electricity use (B), and $CO_2$ emissions (C) to total value added in the iron and steel, non-ferrous metal, and pulp, paper and printing industries of Finland, EU and selected non-European OECD countries.*

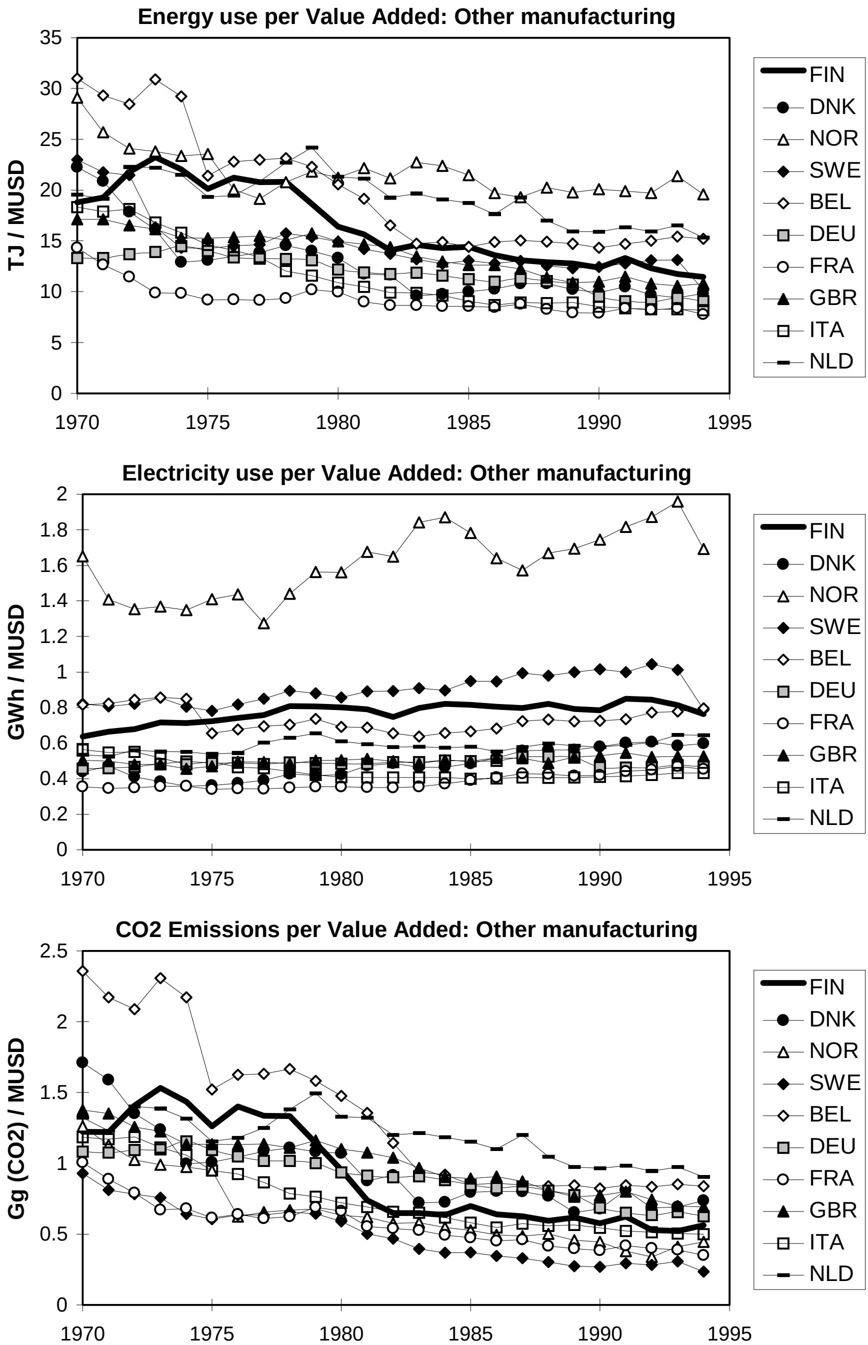
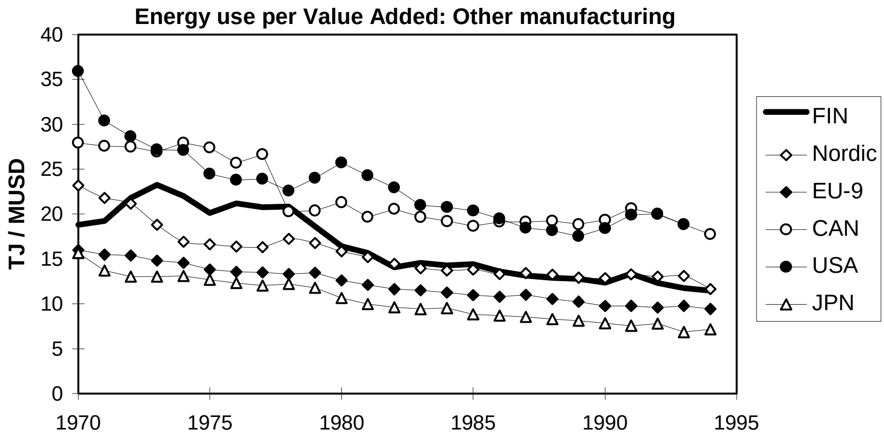
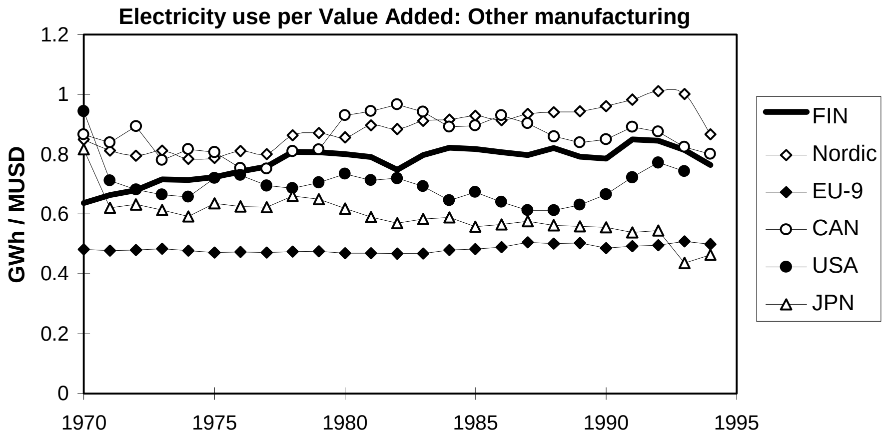



*Fig. B:5. Ratio of total energy requirements (A), electricity use (B), and $CO_2$ emissions (C) to total value added in other manufacturing (cf. Fig. 3) of selected European OECD countries.*



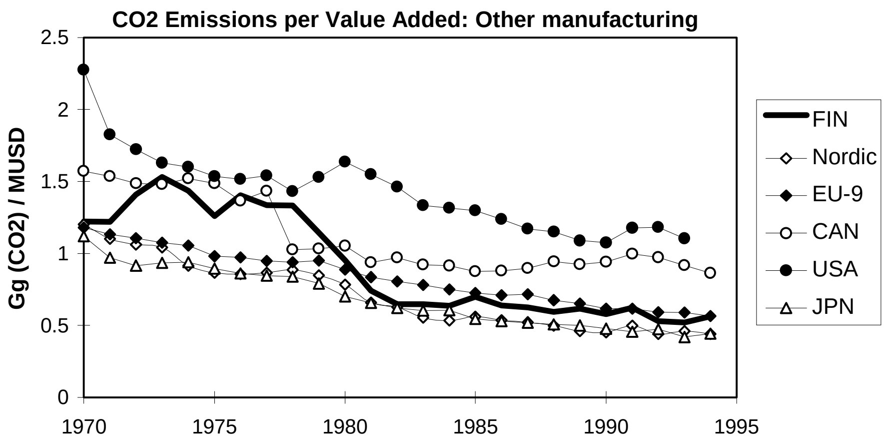




*Fig. B:6. Ratio of total energy use (A), electricity use (B), and $CO_2$ emissions (C) to total value added in other manufacturing (cf. Fig. 4) of Finland, EU and selected non-European OECD countries.*

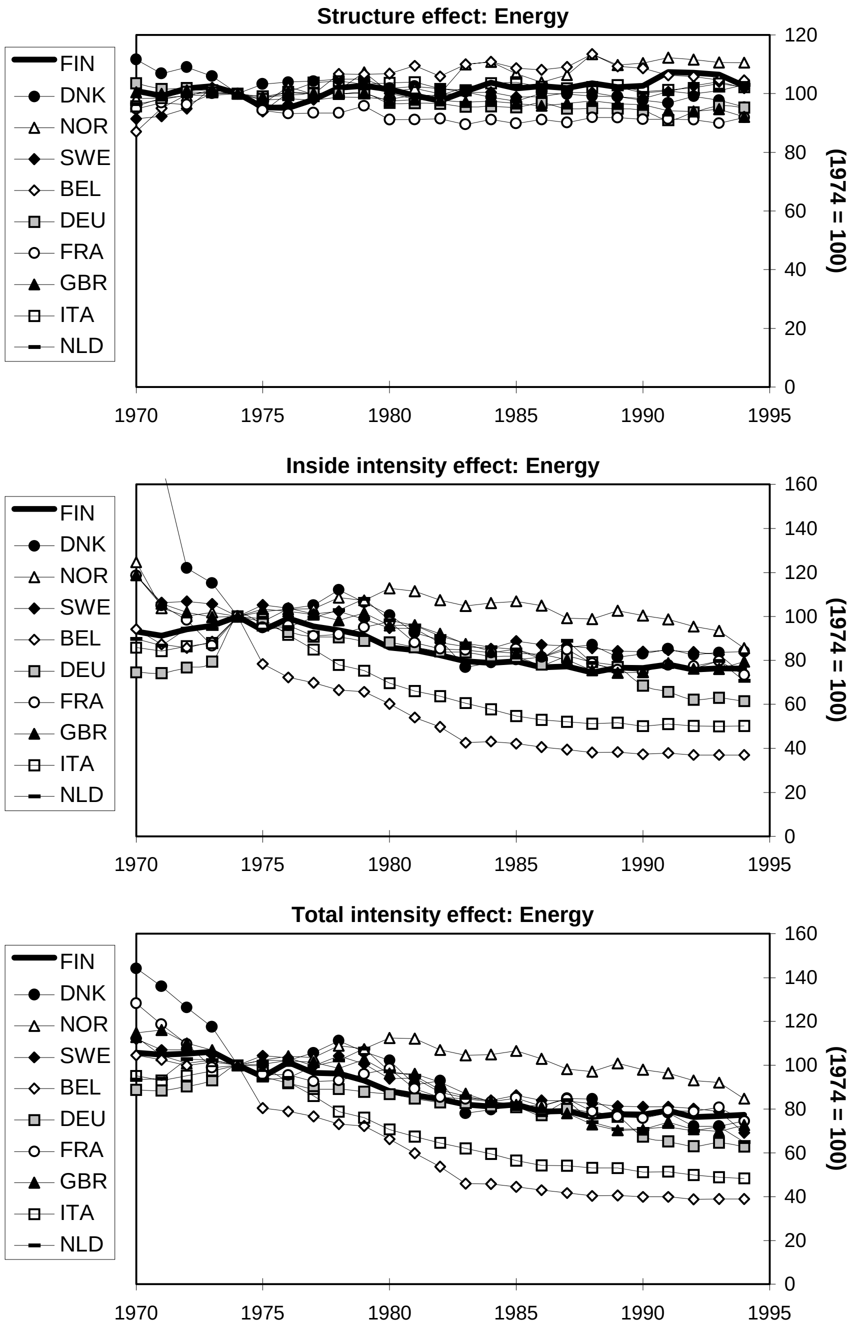



*Fig. B:7. Effects of changing industrial top-level structure (A), intensity of energy use within industry (B), and intensity of energy use within and outside industry (C) on industrial energy use in selected European OECD countries.*

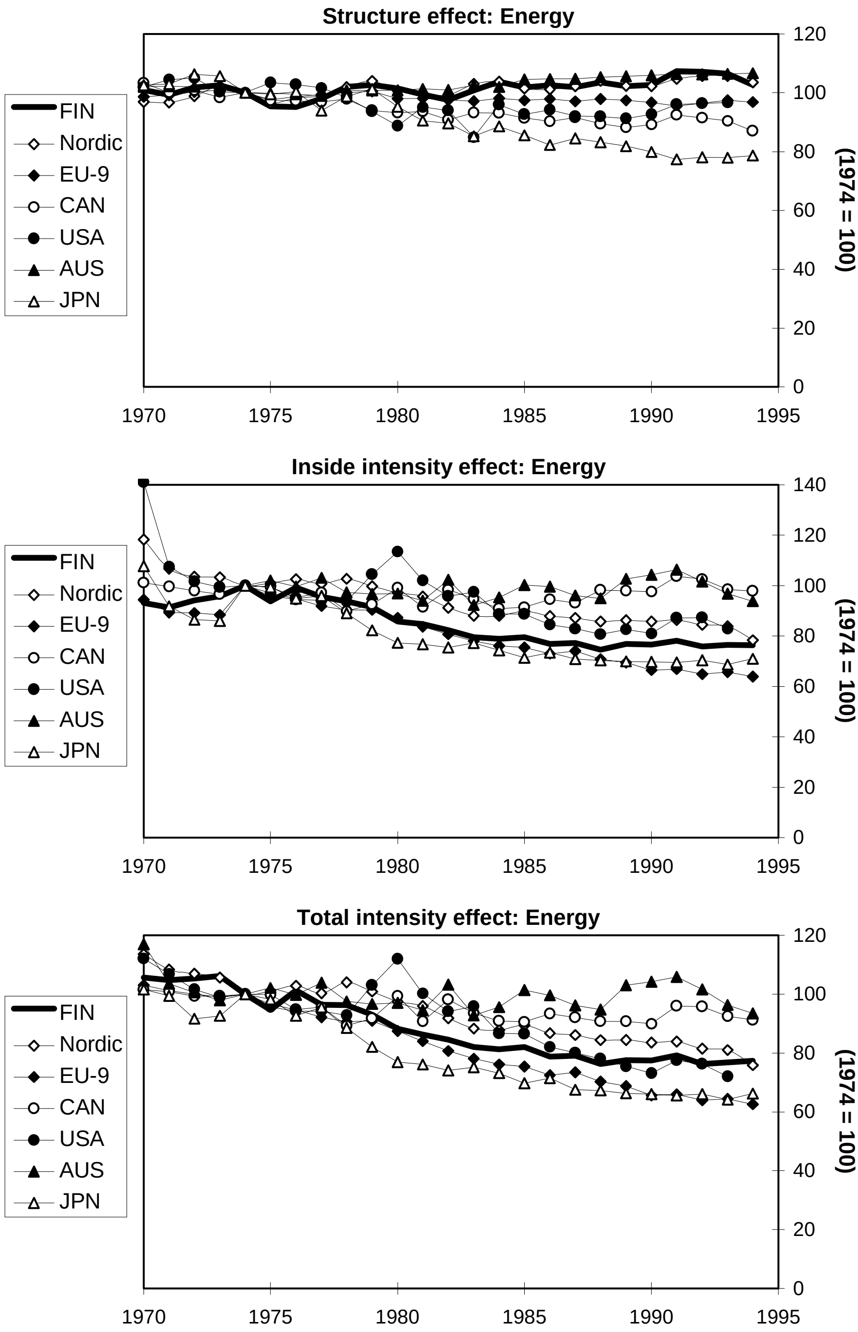



*Fig. B:8. Effects of changing industrial top-level structure (A), intensity of energy use within industry (B), and intensity within and outside industry (C) on industrial energy use in Finland, EU, and selected non-European OECD countries.*

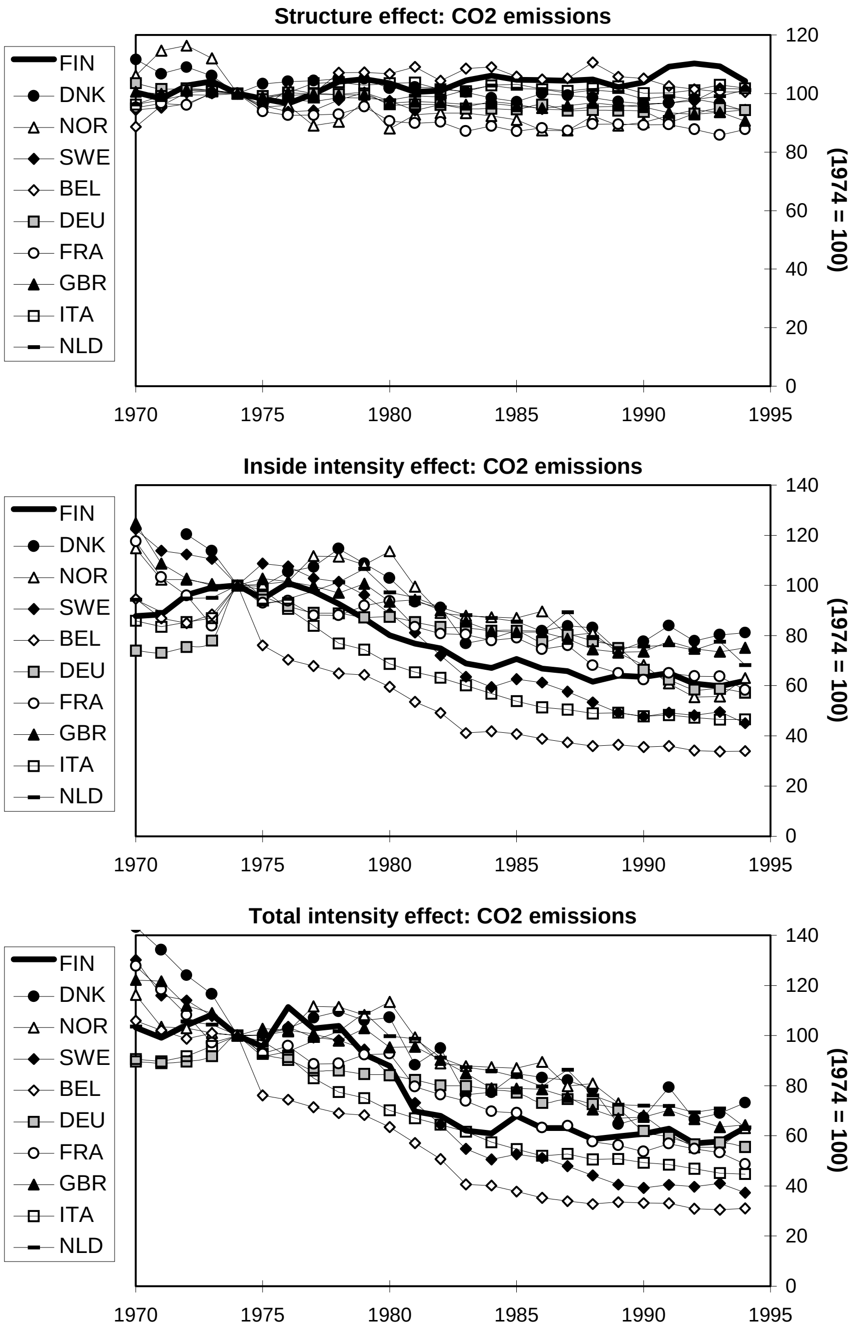



*Fig. B:9. Effects of changing industrial top-level structure (A), energy and carbon intensity within industry (B), and intensity of energy use within and outside industry (C) on industrial $CO_2$ emissions in selected European OECD countries.*

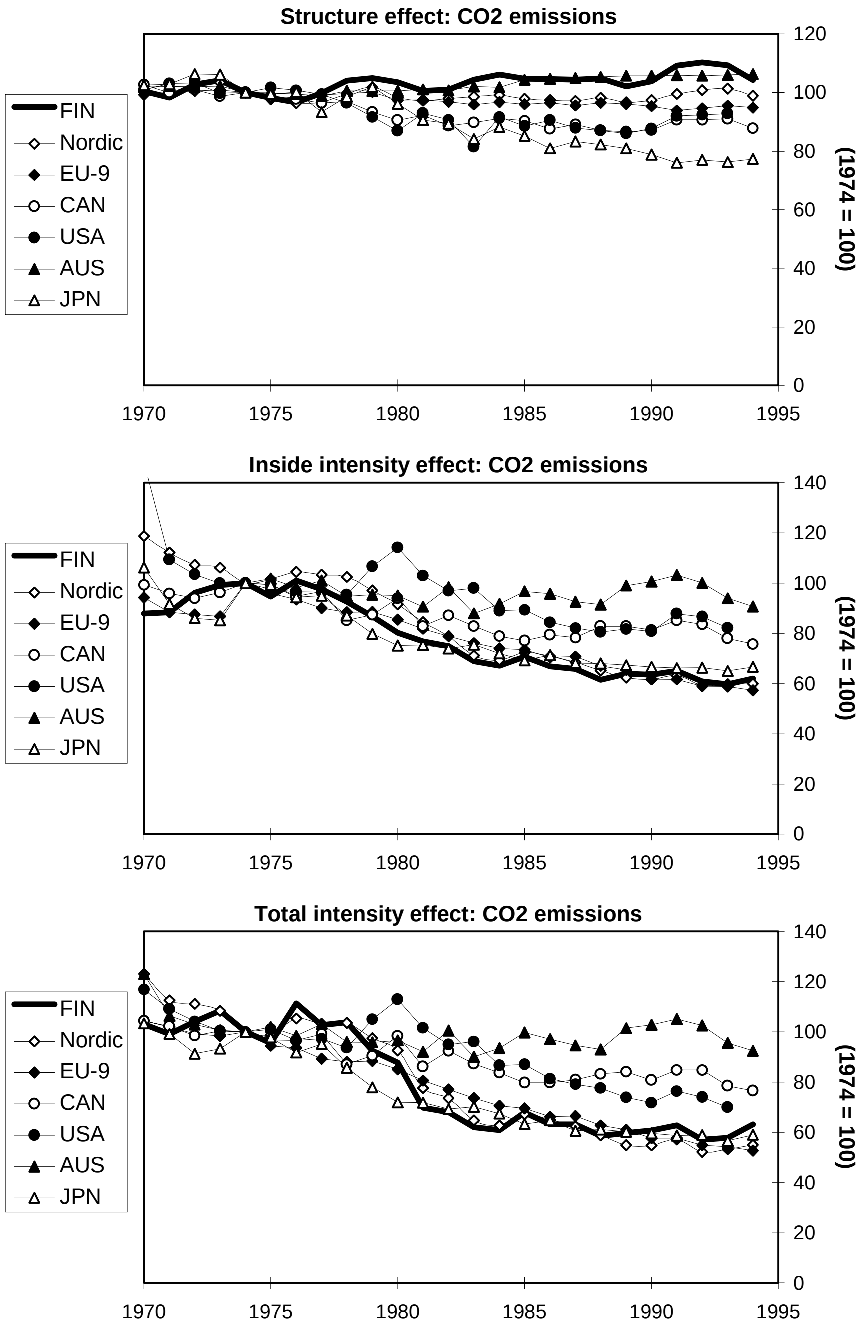
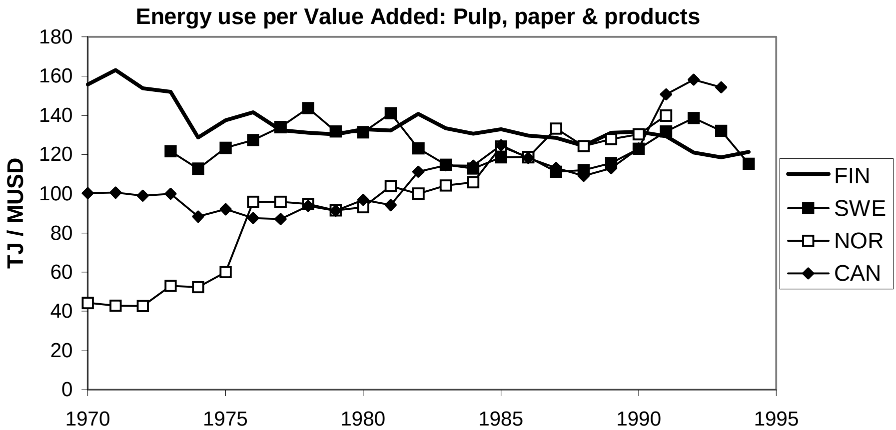
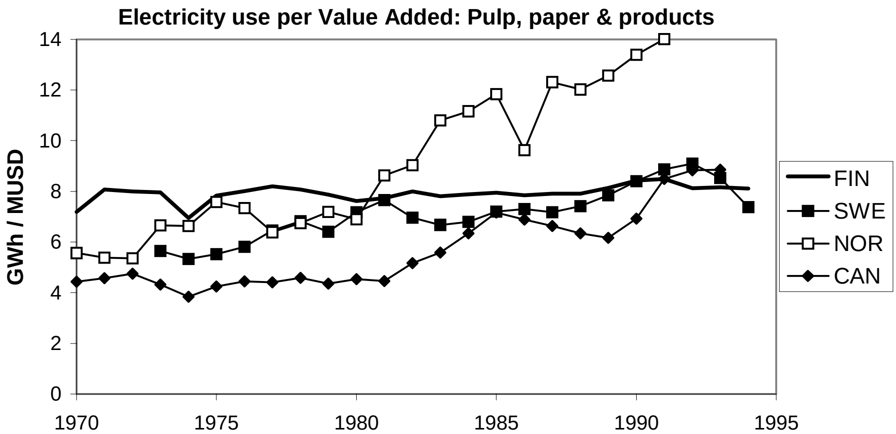



*Fig. B:10. Effects of changing industrial top-level structure (A), energy and carbon intensity within industry (B), and intensity within and outside industry (C) on industrial $CO_2$ emissions in Finland, EU, and selected non-European OECD countries.*



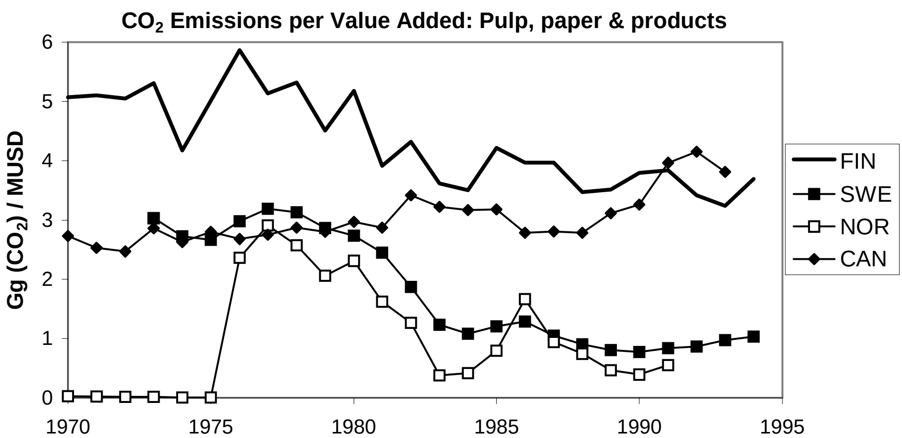




*Fig. B:11. Ratio of total energy requirements (A), electricity use (B), and $CO_2$ emissions (C) to total value added in pulp, paper, and paper products industries of selected OECD countries.*

# Appendix C:
# Indicators for the residential sector

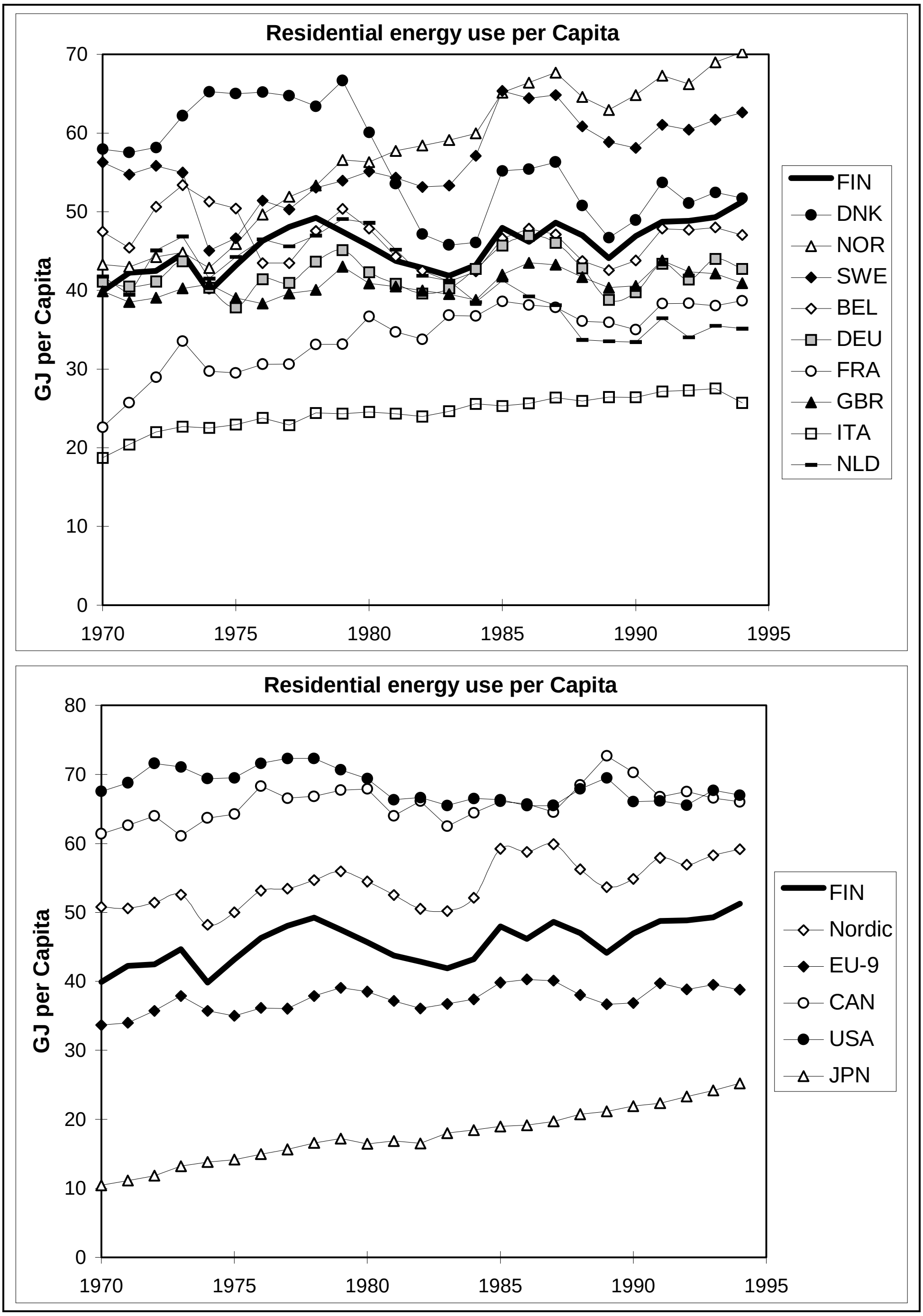
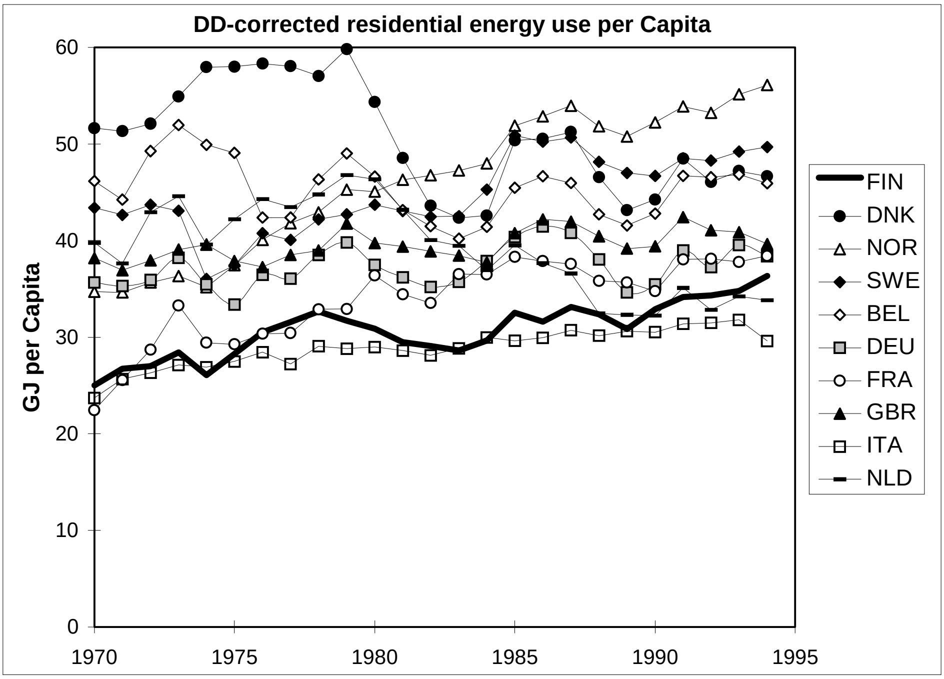



*Fig. C:1. Residential heating and other energy use per capita in selected OECD countries, and the average use in Nordic and nine EU countries. Energy use in primary energy terms.*



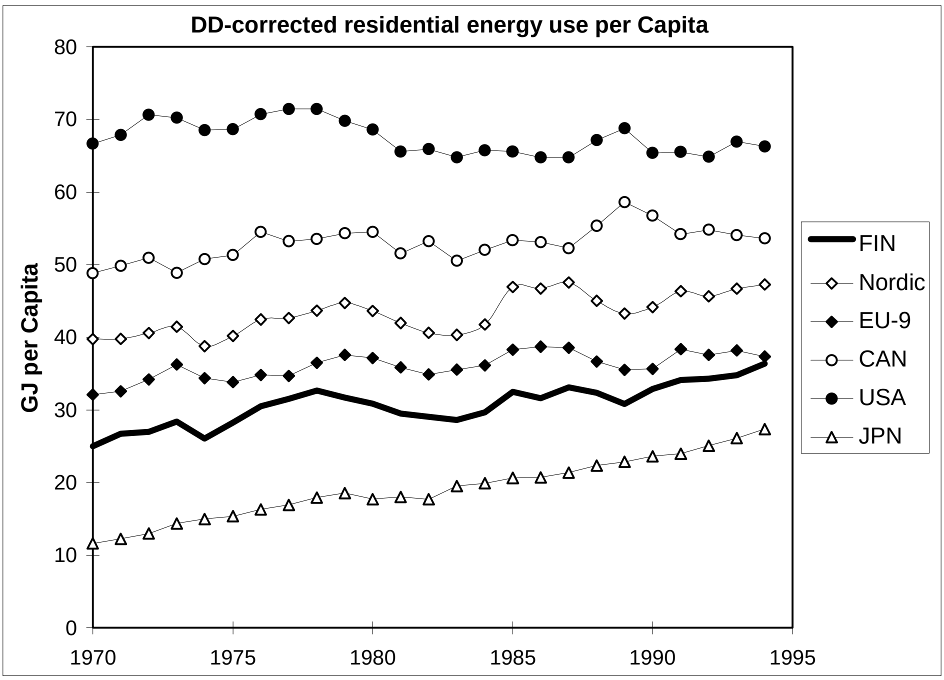
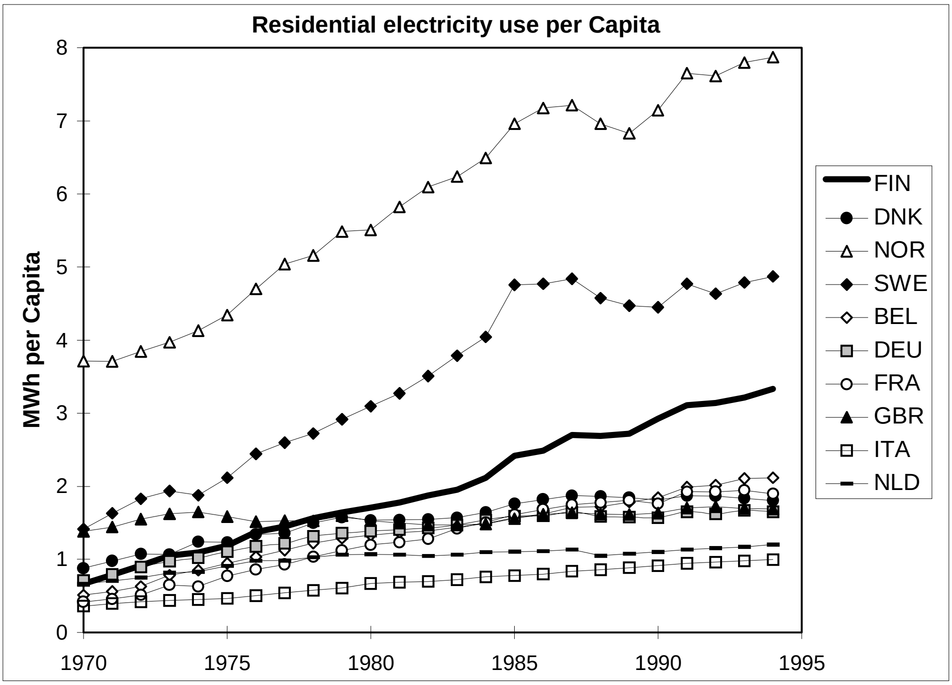




*Fig. C:2. Residential heating and other energy use per capita, adjusted to 2660 degree-days, in selected OECD countries, and the average use in Nordic and nine EU countries. Energy use in primary energy terms.*



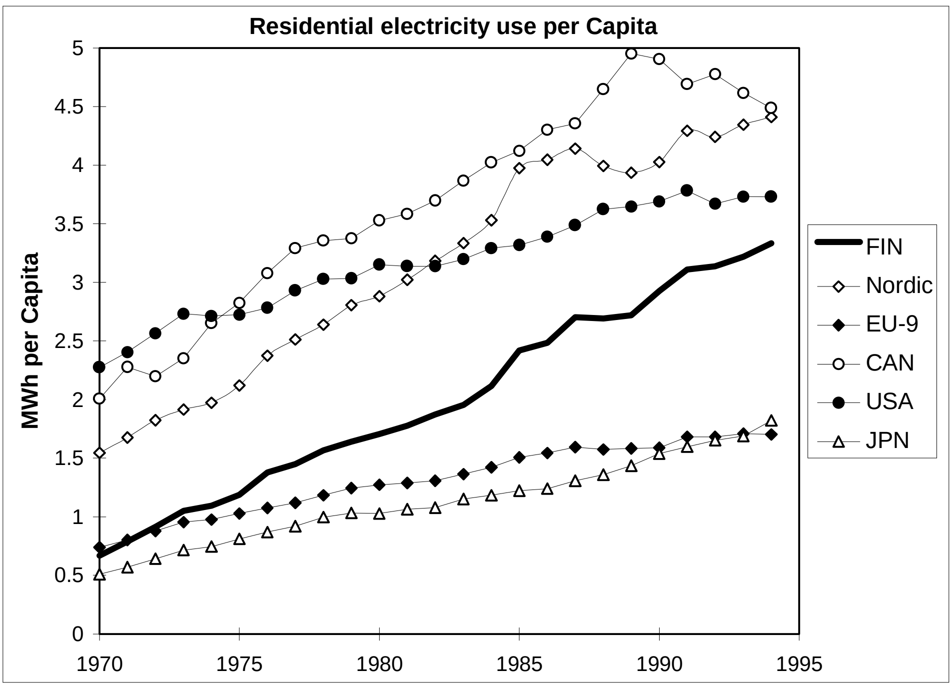
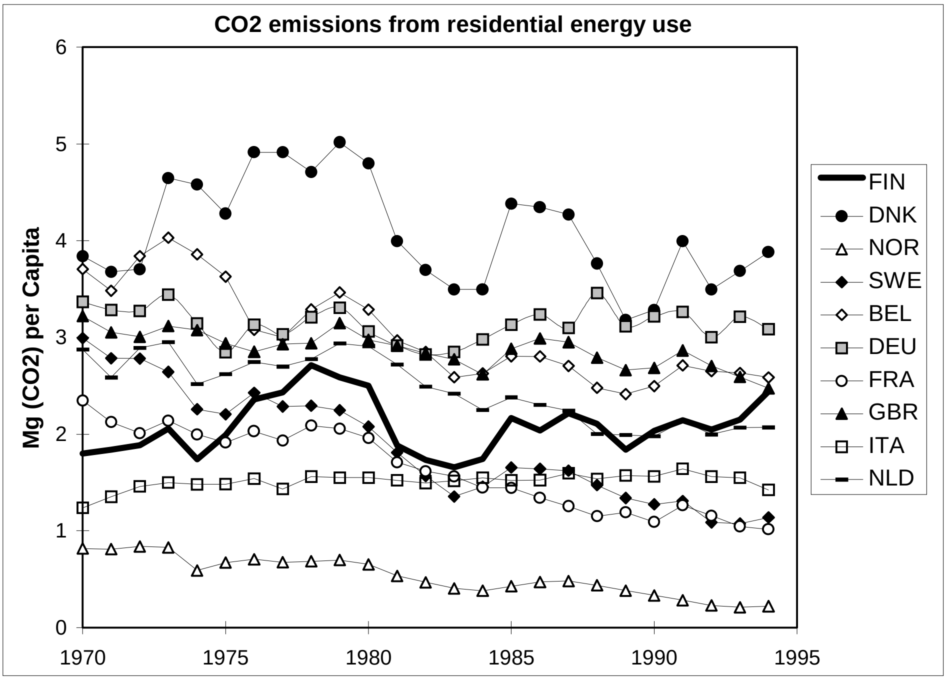




*Fig. C:3. Residential heating and other electricity use per capita in selected OECD countries, and the average use in Nordic and nine EU countries.*



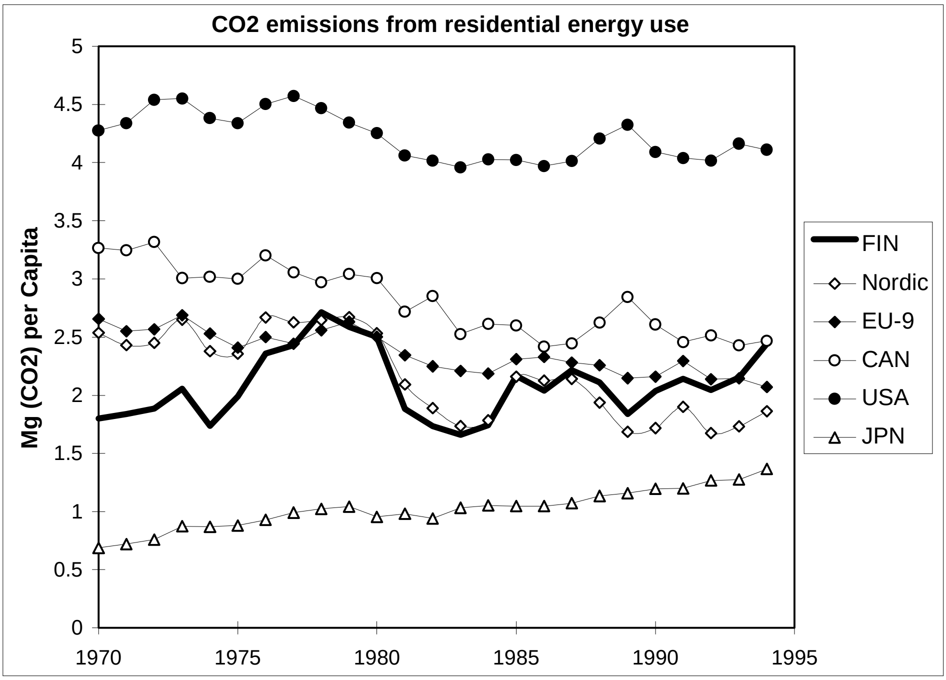
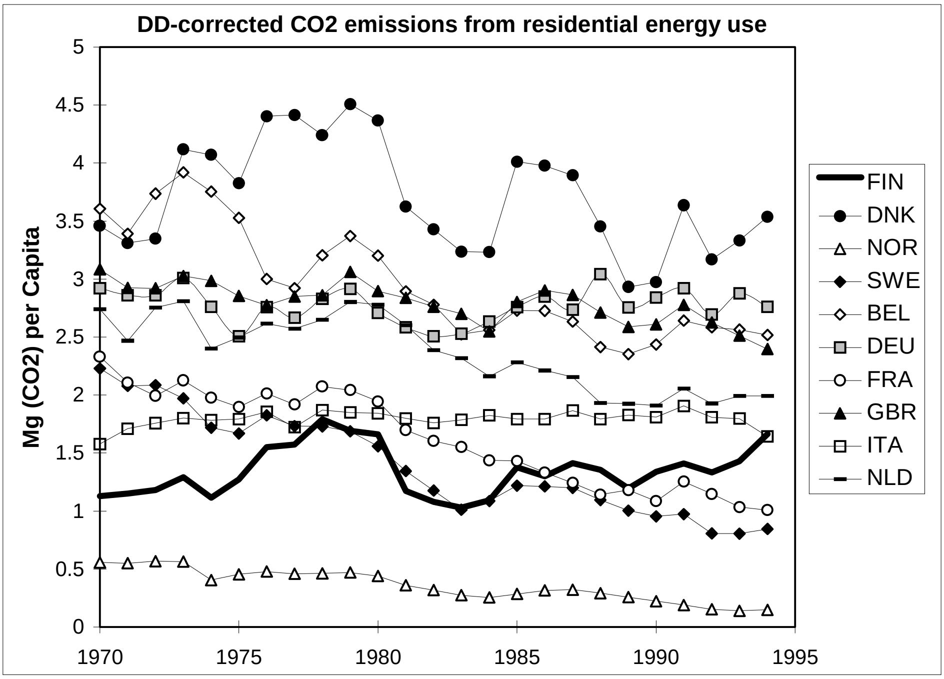




*Fig. C:4. $CO_2$ emissions per Capita from residential energy use in selected OECD countries, and the average use in Nordic and nine EU countries. Emissions from electricity and heat generation included.*



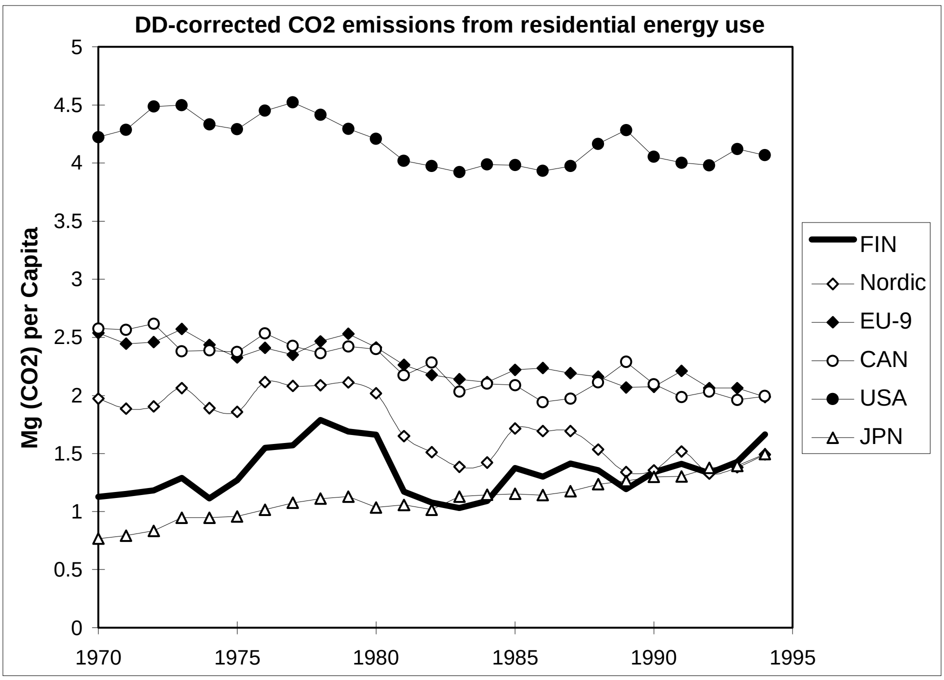
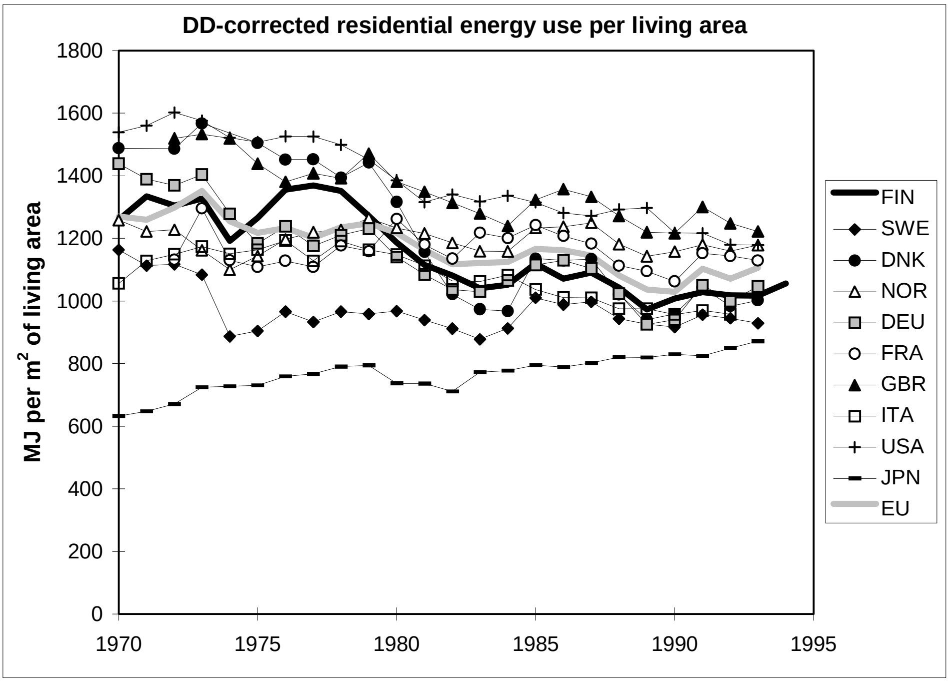




*Fig. C:5.* *$CO_2$ emissions per capita from residential energy use, adjusted to 2660 degree-days, in selected OECD countries, and the average use in Nordic and nine EU countries. Emissions from electricity and heat generation included.*



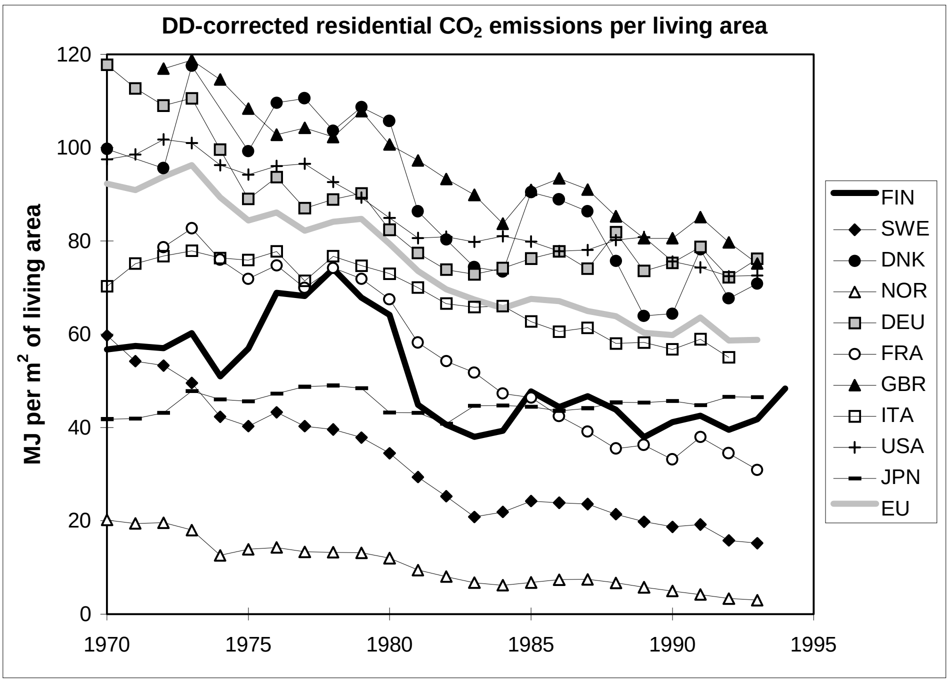




*Fig. C:6. Residential energy use and $CO_2$ emissions per living area of dwellings, adjusted to 2660 degree-days, in some OECD countries and the average in EU. Emissions from electricity and heat generation included.*

# Appendix D:
# Indicators for the transport sector

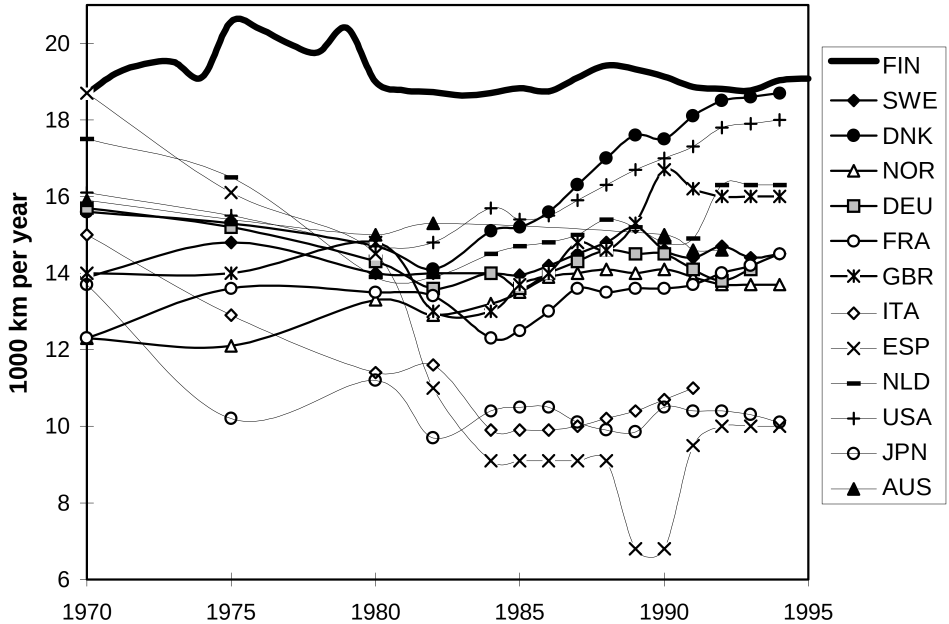



*Fig. D:1.* *Average annual distance traveled per passenger car in selected OECD countries.*

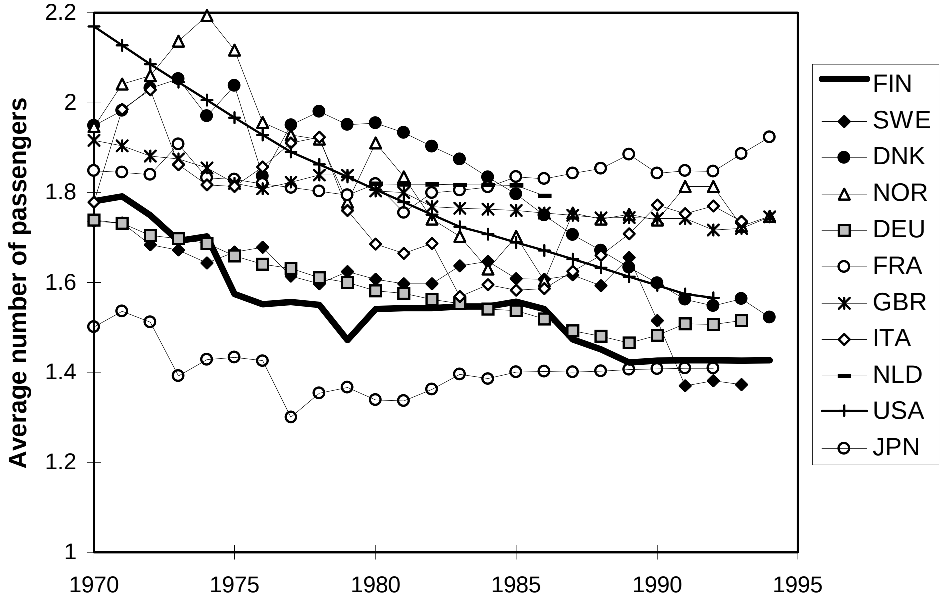
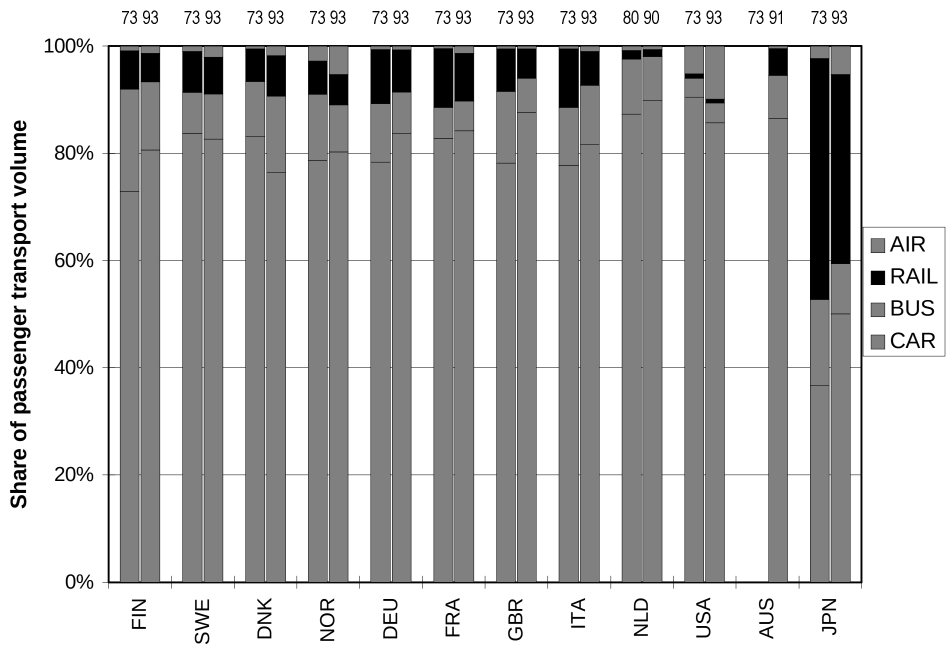



*Fig. D:2.* *Average number of passengers (including driver) in passenger cars in selected OECD countries.*



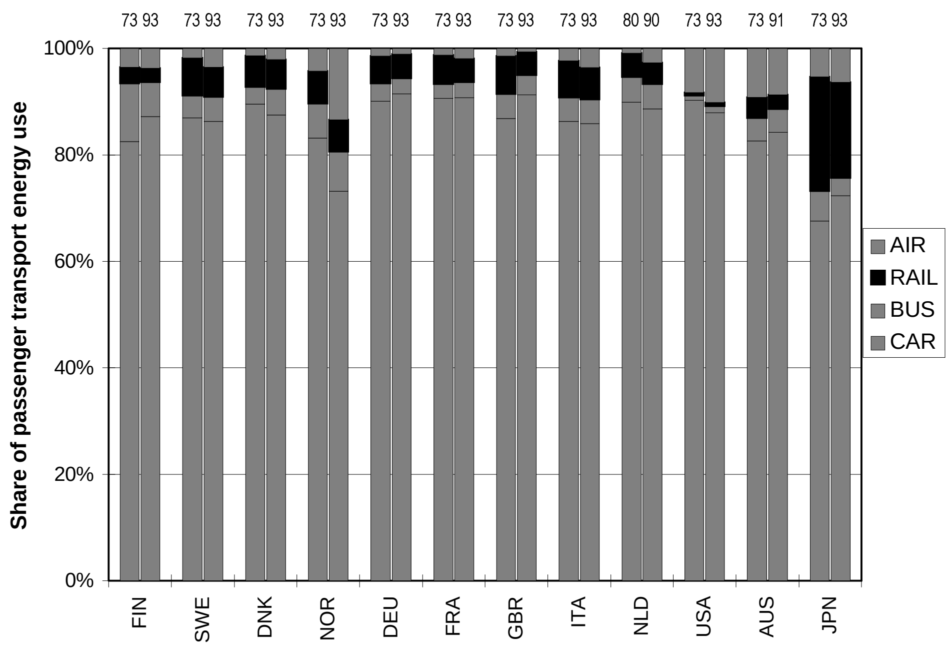




*Fig. D:3. Modal shares of passenger transport volume and energy use in selected OECD countries.*

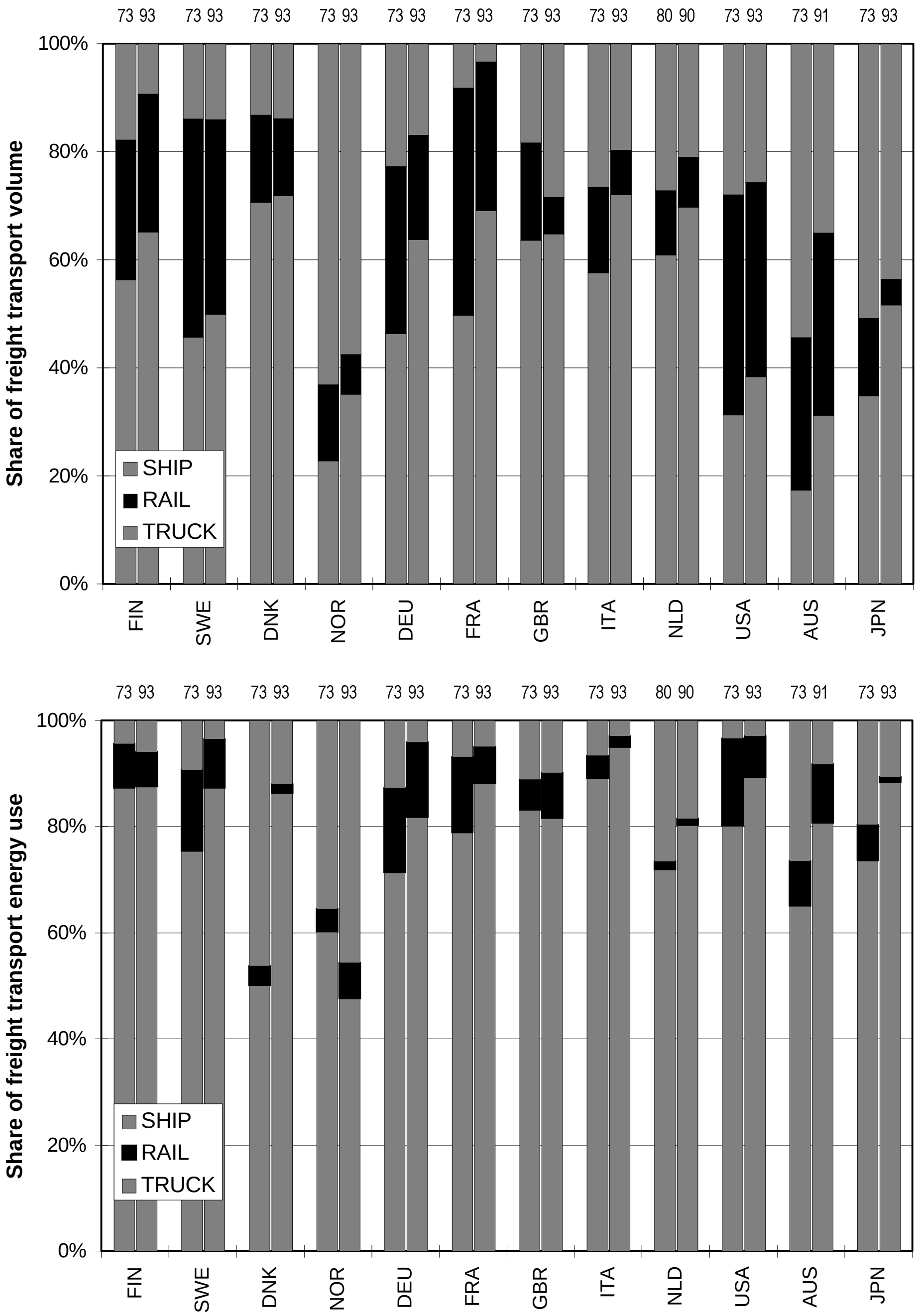
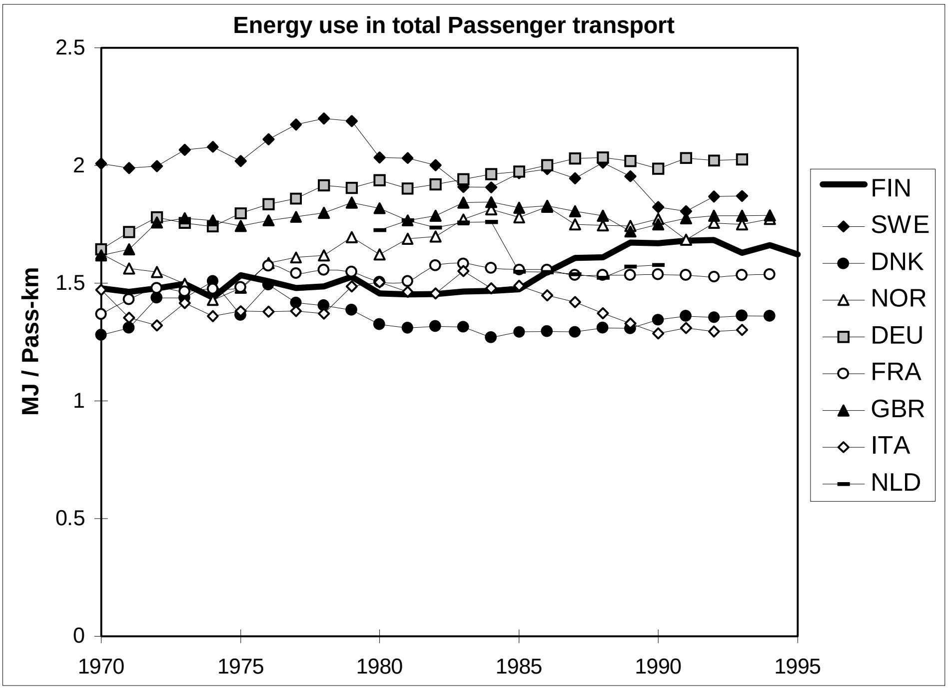



*Fig. D:4. Modal shares of freight transport volume and energy use in selected OECD countries.*



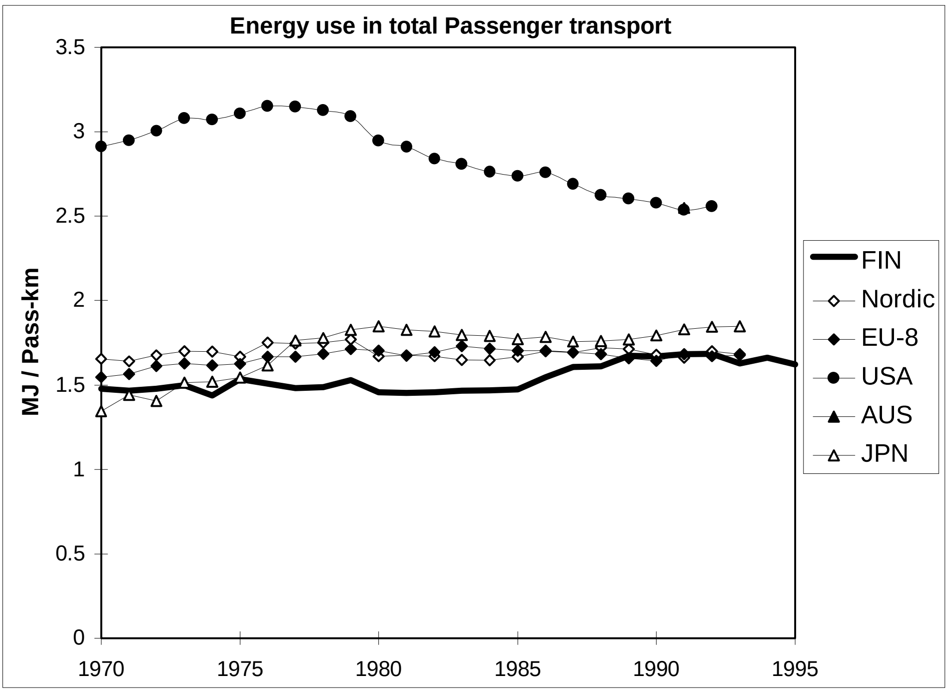
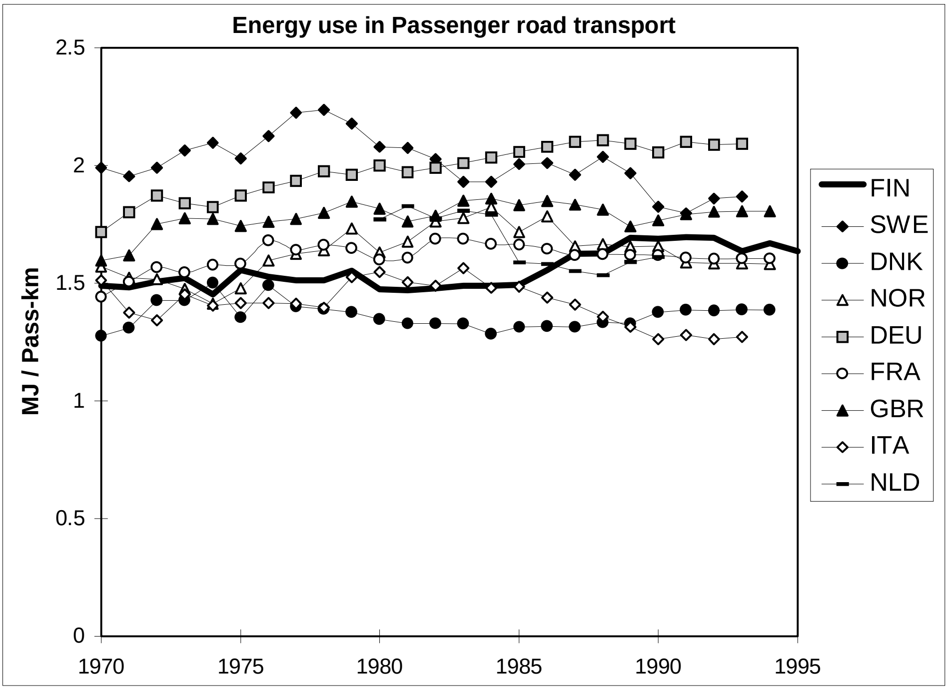




*Fig. D:5. Specific energy use in total passenger transport in selected European and non-European OECD countries and country groups.*



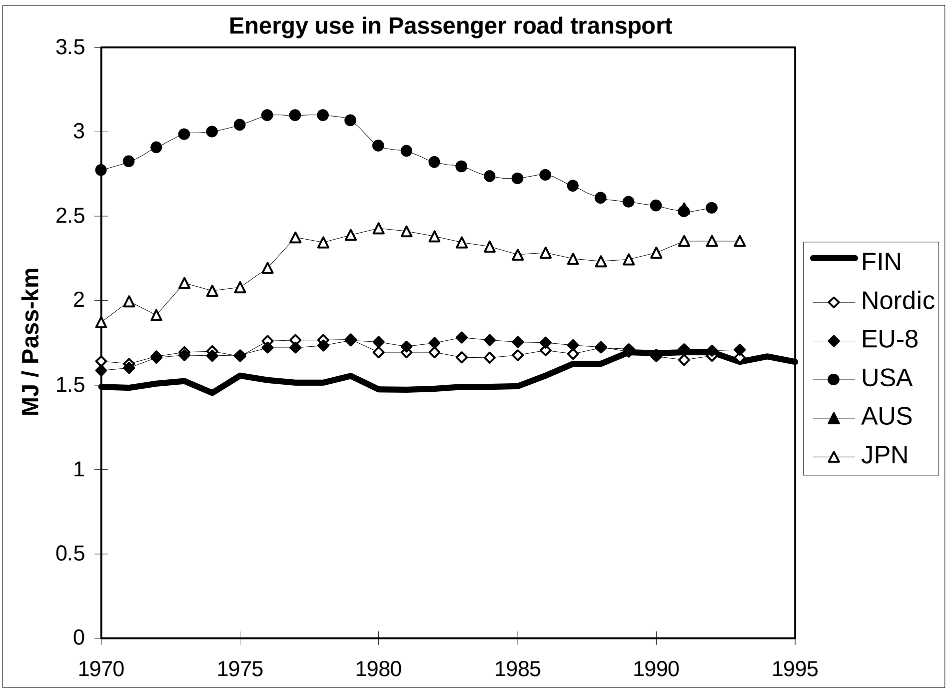
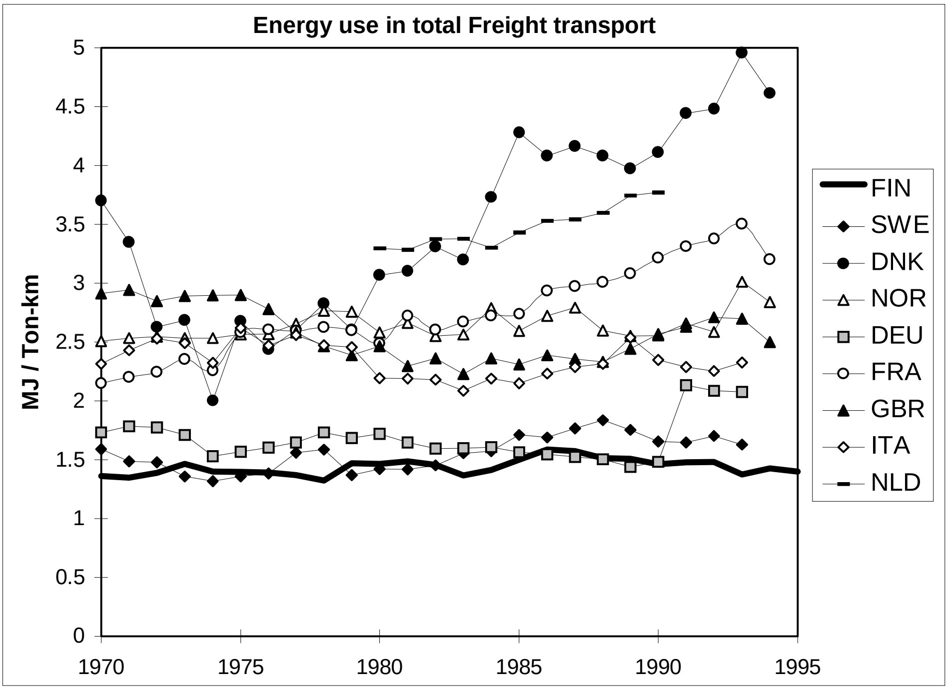




*Fig. D:6. Specific energy use in passenger transport on roads in selected European and non-European OECD countries and country groups.*



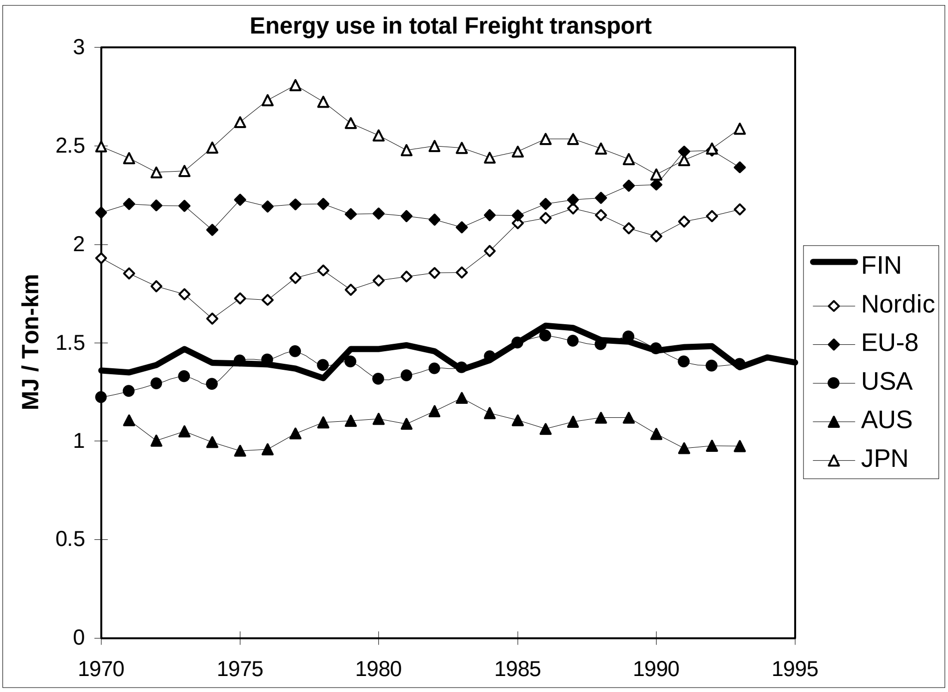
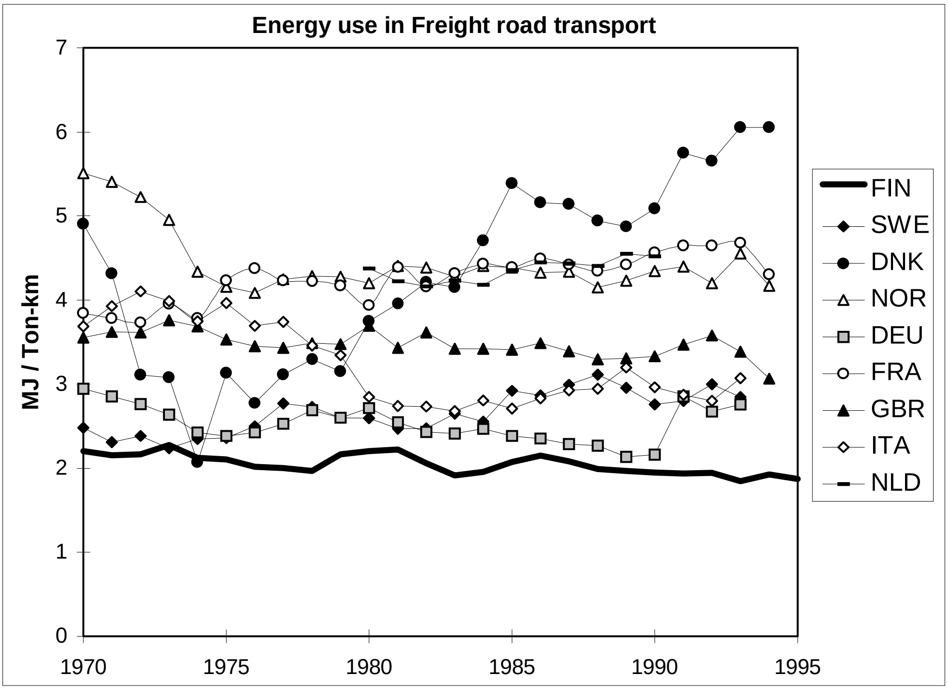




*Fig. D:7. Specific energy use in total freight transport in selected European and non-European OECD countries and country groups.*



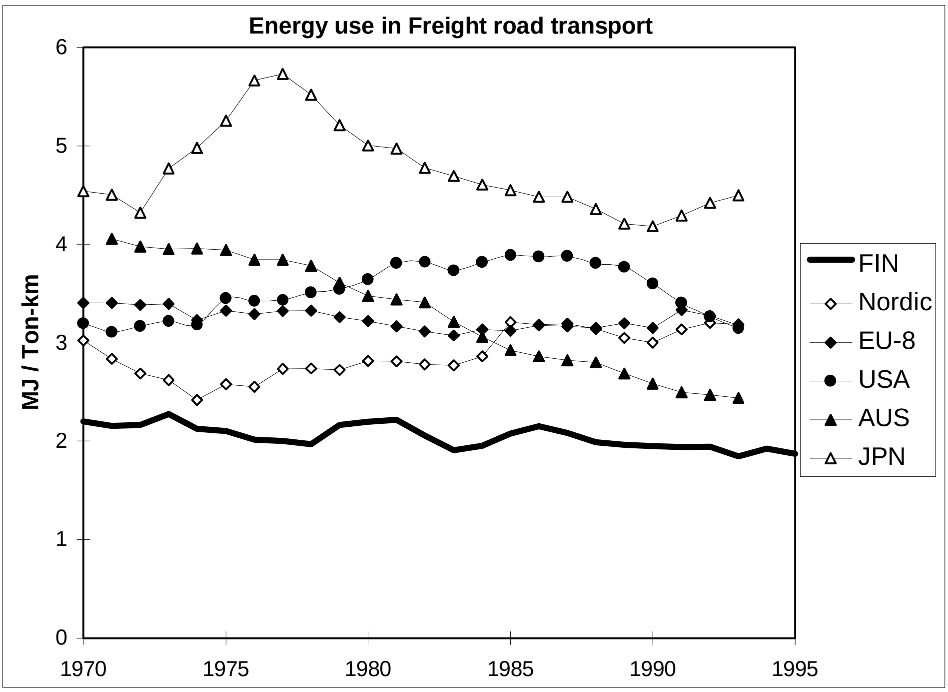
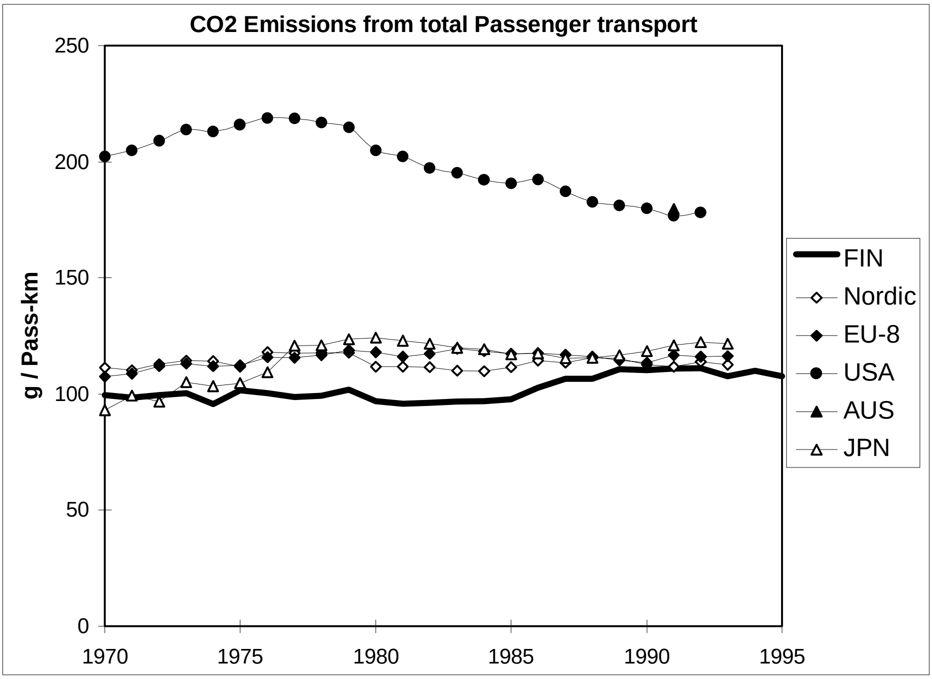




*Fig. D:8. Specific energy use in freight transport on roads in selected European and non-European OECD countries and country groups.*



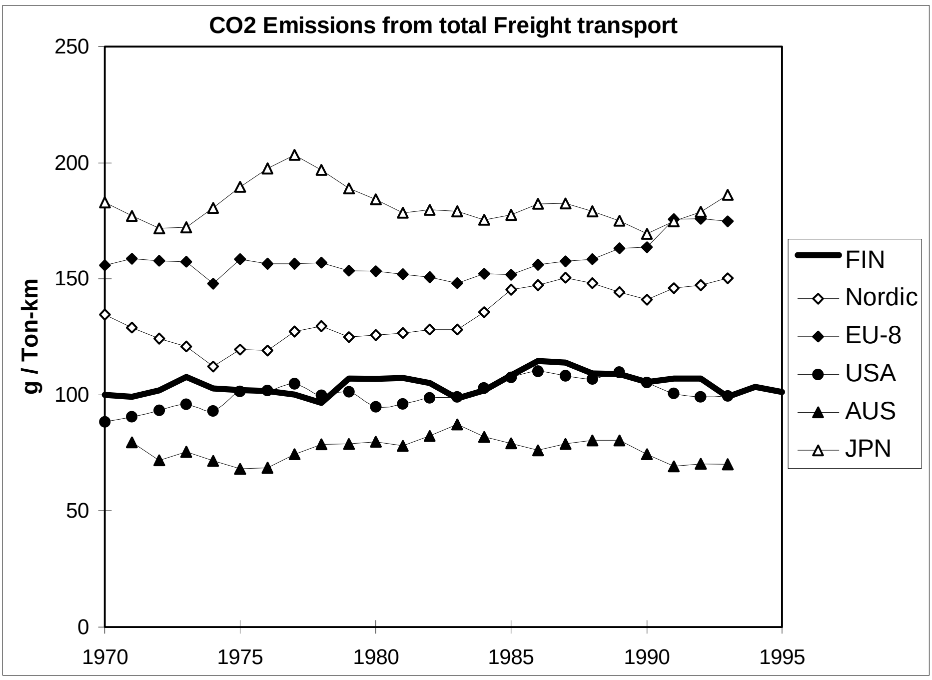
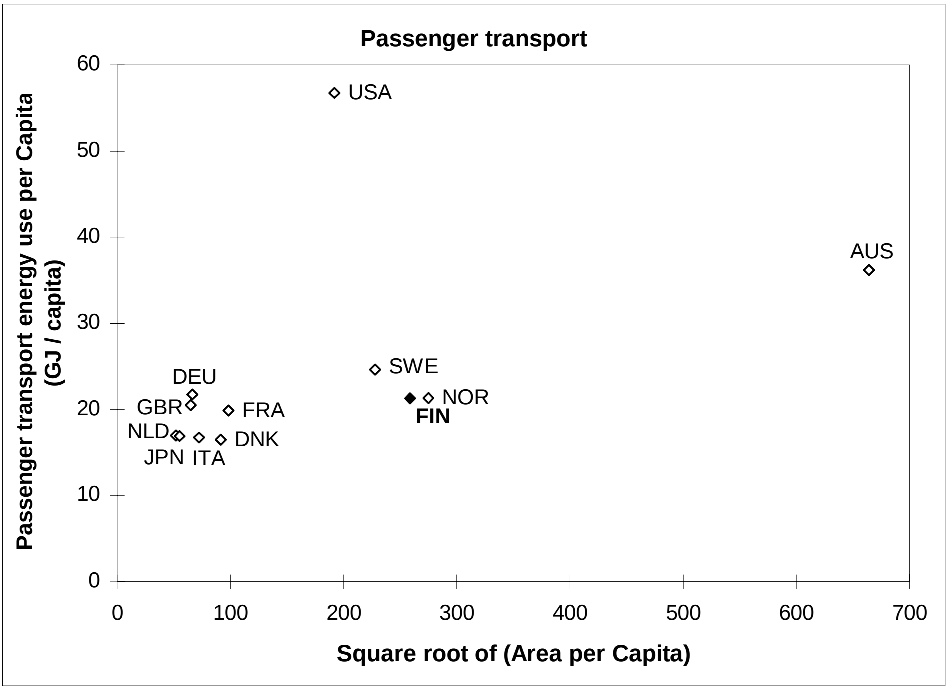




*Fig. D:9. Specific $CO_2$ emissions from total passenger and freight transport energy use in selected European and non-European OECD countries and country groups.*



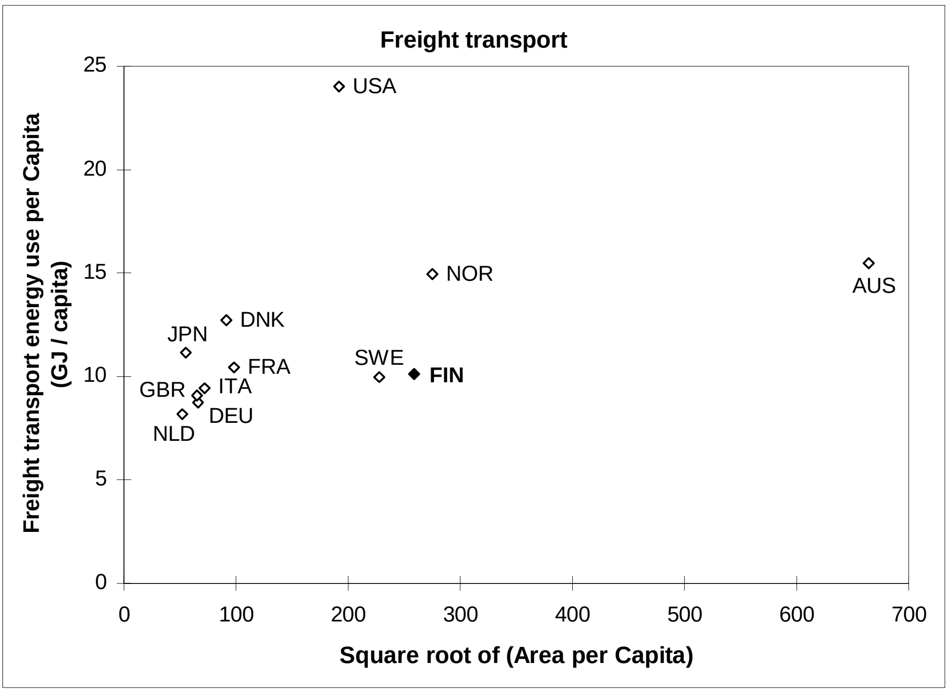




*Fig. D:10. Per capita energy use in passenger and freight transport plotted against square root of inverse population density.*