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Manufacturing Sector Carbon Dioxide Emissions in Nine OECD Countries 1973–87: A Divisia Index Decomposition to Changes in Fuel Mix, Emission Coefficients, Industry Structure, Energy Intensities, and International Structure

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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Manufacturing Sector Carbon Dioxide Emissions in Nine OECD Countries 1973–87: A Divisia Index Decomposition to Changes in Fuel Mix, Emission Coefficients, Industry Structure, Energy Intensities, and International Structure*

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November 1990

*I acknowledge helpful suggestions and comments from Steinar Strøm, Rich Howarth, Lee Schipper, Stephen Tyler and Ron Ritschard.

This study was carried out during the author's visit to Lawrence Berkeley Laboratory, University of California Berkeley in 1990, building on ongoing research in the International Energy Studies group. *It was made possible through financial support from SAF* Centre of Applied Research, Oslo, and the U.S. Environmental Protection Agency (EPA), through the the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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ABSTRACT

In this paper the reduction in energy-related manufacturing carbon dioxide emissions for nine OECD countries in the period 1973 to 1987 is analyzed. Carbon dioxide emissions are estimated from energy use data. The emphasis is on carbon dioxide intensities, defined as emissions divided by value added. The overall manufacturing carbon dioxide intensity for the nine OECD countries was reduced by 42% in the period 1973-87. Five fuels are specified together with six subsectors of manufacturing. A Divisia index approach is used to sort out the contribution to reduced carbon dioxide intensity from different components. The major finding is that the main contribution to reduced carbon dioxide intensity is from the general reduction in manufacturing energy intensity, most likely driven by economic growth and increased energy prices, giving incentives to invest in new technology and new industrial processes. There is also a significant contribution from reduced production in the most carbon dioxide intensive subsectors, and a contribution from higher efficiency in electricity generation together with a larger nuclear power share at the expense of oil.

1. INTRODUCTION

This paper aims to explain the change in manufacturing carbon dioxide emissions in the period 1973-87 for nine OECD countries. The emphasis is on explaining the change in carbon dioxide intensities, defined as emissions divided by output, measured as value added. Carbon dioxide emissions are estimated from fossil fuel consumption, employing emissions coefficients for gas, oil and solids. In addition, electricity consumption is specified. For electricity use an emission coefficient index is calculated from the shares of fossil fuels, nuclear power and hydro power used to generate electricity, and the efficiency in electricity generation from these energy sources. Non-fuel carbon dioxide sources related to cement production and other production processes (feedstocks) are not included in the study.

Aggregate carbon dioxide intensities may change due to changes in emission coefficients, the share of different fuels, the structure (or output share of different sectors), the energy intensity, and the international structure (the output share of different countries). To disentangle the contribution to the change in intensity from each of these components, a Divisia index approach is employed.

The countries included in the study are Japan (JP), the United States (US), the Federal Republic of Germany (FRG), France (FR), Italy (IT), the United Kingdom (UK), Denmark (DK), Sweden (SW) and Norway (NO). These countries, which will be named the OECD-9, account for over 80% of industrial energy use in OECD. Only the manufacturing sector of industry is considered in this study, meaning that the energy (including petroleum refining), construction, mining, and agriculture sectors are excluded. On average, manufacturing accounts for around 80% of total industrial energy use in these countries. The manufacturing subsectors specified are given in Table 1.1.

TABLE 1.1 Manufacturing subsectors specified

Paper and pulp	ISIC 341
Industrial chemicals	ISIC 351
Stone, clay, and glass	ISIC 36
Ferrous metals	ISIC 371
Nonferrous metal	ISIC 372
Non-raw materials (all other manufacturing activities)	

There are some related previous studies in the area of descriptive industrial analysis. Boyd et al. (1987) and Li et al. (1990) analyse the change in energy use over time in one country employing the Divisia index approach, separating the effects of structural changes from intensity changes. Bending et al. (1987) carry out a comparison of energy use in France, the FRG, Italy and the U.K., with manufacturing industry as one out of five industrial sectors. Duerr et al. (1990) analyse energy use in passenger transport for Japan, the U.S., the FRG, Sweden and Norway in the period 1970 to 1987, using Laspeyres indices and Divisia indices to separate the effects of structural changes and energy intensity changes. However, the study that comes closest to this study is Howarth et al. (1990a), where the same data (excluding Italy) are used to decompose the change in manufacturing energy use to structural changes and energy intensity changes by employing Laspeyres indices and Divisia indices.

A specific feature of the present study is to focus on the development of manufacturing carbon dioxide intensities for the OECD-9 group. In addition to energy intensities, fuel mix and structural components within each country, international structure across countries is accounted for.

The paper is organized as follows. In section 2 the methodology is described. Section 3 describes the data employed and shows the development in energy intensities and structural changes. The carbon dioxide intensities and Divisia indices are reported and discussed in section 4, and a conclusion to the paper is finally given in section 5. The more detailed energy use and value added data description for single OECD-9 countries are included in an appendix.

2. THE METHODOLOGY APPLIED

The emphasis of this paper is on explaining the change in manufacturing carbon dioxide intensity in OECD-9 in the period 1973 to 1987, defined as carbon dioxide emissions divided by value added.

Some notation is needed for the analysis. Let the country index be k (Japan, the U.S., the FRG, France, Italy, the U.K., Denmark, Sweden, Norway); let the fuel index be j (Oil, Gas, Solids, Electricity); and let the sector index be i (Paper & pulp, Industrial chemicals, Stone, clay and glass, Ferrous metals, Nonferrous metals, Non-raw materials). The index for period (year) is left out of the notation when not strictly needed. We will need the following variables:

U_{ijk} : is the carbon dioxide emission coefficient, or emission of carbon dioxide from sector i's use of fuel j, in country k, per unit of fuel j use.

E_{ijk} : is the primary fuel j use, in sector i, and for country k. Primary energy is total fuels consumed for heat and power, counted in terms of it's thermal equivalent at the point of utilization.

E_{ik} : is the sum of primary energy use over fuels, i.e. total energy use for sector i and country k.

Q_{ik} : is the volume of output, measured as value added, in sector i for country k.

Q_k : is the sum of value added over sectors in country k, i.e. manufacturing value added for country k.

Q : is the sum of value added over sectors and countries, i.e. total manufacturing output (value added) for OECD-9.

C_{ijk} : is the emission of carbon dioxide generated by using fuel j in sector i for country k.

C_{ik} : is the emission of carbon dioxide summed over fuels, i.e. emissions from sector i and country k.

C_k : is the emission of carbon dioxide summed over fuels and sectors in country k, i.e. manufacturing emissions from country k.

C : is the emission of carbon dioxide summed over fuels, sectors and countries, i.e. total manufacturing emissions from OECD-9.

Y : is the aggregate carbon dioxide intensity, defined as carbon dioxide emissions divided by value added; Y = C/Q.

W_{ijk} : is the carbon dioxide emissions share of fuel j, sector i and country k; $W_{ijk} = C_{ijk}/C$.

Carbon dioxide emissions from fuel j, in sector i and for country k is found by multiplying primary energy use with the relevant emission coefficient:

$$C_{ijk} = U_{ijk}E_{ijk} \tag{1}$$

Aggregating over fuels, sectors and countries, we find total emissions C:

$$C = \sum_{ijk} C_{ijk} = \sum_{ijk} U_{ijk}E_{ijk} \tag{2}$$

Equation (2) can be expanded to yield:

$$C = \sum_{ijk} \left(U_{ijk}\frac{E_{ijk}}{E_{ik}}\frac{E_{ik}}{Q_{ik}}\frac{Q_{ik}}{Q_k}\frac{Q_k}{Q}\right) Q \tag{3}$$

To facilitate notation, some new variables are defined:

$$\begin{aligned} e_{ijk} &= \frac{E_{ijk}}{E_{ik}} \\ I_{ik} &= \frac{E_{ik}}{Q_{ik}} \\ S_{ik} &= \frac{Q_{ik}}{Q_k} \\ V_k &= \frac{Q_k}{Q} \end{aligned} \tag{4}$$

where e_{ijk} is the fuel j share in sector i and country k, I_{ik} is the energy intensity in sector i and country k, S_{ik} is the structure component of sector i in country k, and V_k is the international structure component of country k in the group OECD-9.

Using the new notation and dividing through equation (3) with Q, we find the aggregate carbon dioxide emission intensity Y:

$$Y = \frac{C}{Q} = \sum_{ijk} (U_{ijk} e_{ijk} I_{ijk} S_{ijk} V_k) \tag{5}$$

Differentiating equation (5) and noting that $C_{ijk}/Q = W_{ijk}C/Q = W_{ijk}Y$, we find the growth rate of Y:

$$\frac{dY/dt}{Y} = \sum_{ijk} \left(\frac{dU_{ijk}/dt}{U_{ijk}} + \frac{de_{ijk}/dt}{e_{ijk}} + \frac{dI_{ik}/dt}{I_{ik}} + \frac{dS_{ik}/dt}{S_{ik}} + \frac{dV_k/dt}{V_k} \right) W_{ijk} \tag{6}$$

Growth rates can alternatively be expressed as the derivative of the logarithms:

$$\frac{dK/dt}{K} = \frac{d\ln K}{dt} \; ; \; K = U_{ijk}, e_{ijk}, I_{ik}, S_{ik}, V_k \tag{7}$$

Integrating both sides of (6) expressed in terms of (7), and taking anti-logarithms yields a continous time Divisia index decomposition of the change in manufacturing carbon dioxide intensity (Hulten (1973), Boyd et al. (1987), Boyd et al. (1988) and Howarth et al. (1990a)). A Divisia index is the exponential of a weighted sum of growth rates, where the weights are each component's share in the aggregate. Thus the weights change over time.

$$\frac{dY/dt}{Y} = \exp\{ \int_t^{t+1} \sum_{ijk} W_{ijk} \frac{d\ln U_{ijk}}{dt} dt \} \exp\{ \int_t^{t+1} \sum_{ijk} W_{ijk} \frac{d\ln e_{ijk}}{dt} dt \}$$

$$\exp\{ \int_t^{t+1} \sum_{ijk} W_{ijk} \frac{d\ln I_{ik}}{dt} dt \} \quad \exp\{ \int_t^{t+1} \sum_{ijk} W_{ijk} \frac{d\ln S_{ik}}{dt} dt \} \qquad \textbf{(8)}$$

$$\exp\{ \int_t^{t+1} \sum_{ijk} W_{ijk} \frac{d\ln V_k}{dt} dt \}$$

or shown with a more compact notation:

$$\frac{dY/dt}{Y} = DU^{*} De^{*} DI^{*} DS^{*} DV^{*} \qquad \textbf{(9)}$$

where the Divisia indices are the right hand side terms of (8). Thus DU^* is the first term, De^* is the second term, DI^* is the third term, DS^* is the fourth term and DV^* is the fifth term of the right hand side of (8).

Since observations are discrete, we need to make a discrete time approximation of (8) and (9). Over short periods of time the intergrals can be approximated by using the mean of the start-point and end-point carbon dioxide shares W_{ijk}, yielding the Divisia index decomposition:

$$\frac{Y_{t+1}}{Y_t} = DU\ De\ DI\ DS\ DV + R \qquad \textbf{(10)}$$

where

$$DU = \exp\{ \sum_{ijk} (\frac{W_{ijk,t+1}+W_{ijk,t}}{2}) \ln (\frac{U_{ijk,t+1}}{U_{ijk,t}}) \}$$

$$De = \exp\{ \sum_{ijk} (\frac{W_{ijk,t+1}+W_{ijk,t}}{2}) \ln (\frac{e_{ijk,t+1}}{e_{ijk,t}}) \}$$

$$DI = \exp\{ \sum_{ijk} (\frac{W_{ijk,t+1}+W_{ijk,t}}{2}) \ln (\frac{I_{ik,t+1}}{I_{ik,t}}) \} \quad (11)$$

$$DS = \exp\{ \sum_{ijk} (\frac{W_{ijk,t+1}+W_{ijk,t}}{2}) \ln (\frac{S_{ik,t+1}}{S_{ik,t}}) \}$$

$$DV = \exp\{ \sum_{ijk} (\frac{W_{ijk,t+1}+W_{ijk,t}}{2}) \ln (\frac{V_{k,t+1}}{V_{k,t}}) \}$$

and R is a residual due to the discrete approximations to continous expressions. DU is the Divisia index decomposition term for carbon dioxide emission coefficients, De is the term for fuel shares, DI is the term for energy intensities, DS is the term for structure (subsector output share), and DV is the term for international structure (national output share).

There may be some problems with applying the Divisia index approach. The Divisia index is a line integral that is path dependent and may cycle and get arbitrarly large. Hulten (1973) shows that the necessary and sufficient conditions for a Divisia index of for example capital stock to be independent of the path of integration is that, (1) an aggregate capital stock, defined on the set S of paths, exists, (2) the aggregate is linear homogenous in the components, and (3) a price exists at every point in S and is unique up to a scalar multiplication. These conditions are restrictive, in particular the second condition of linear homogenity of the aggregate, but Hulten (1973) shows that the homogenity condition can be eliminated in some cases. The other two conditions are analogous to common assumptions in economics. When these conditions are fullfilled, a Divisia index is at least as good as any other index. On the other hand, the Divisia index approach will arbitrarily assign interaction terms to each of the indices (Howarth et al. (1990a)).

A nice feature of the Divisia index approach (and Laspeyres index approach) is that the discrete form index will approach the continous form index when the time period lengths go to zero. In addition the Divisia index is more flexible than for instance the Laspeyres index, since it is employing moving weights compared to the base year weights for the Laspeyres index. On the other hand the Laspeyres index is more readily interpreted. However, Howarth et al. (1990a) in a study decomposing the change in manufacturing energy intensity for the same time period, same countries (with the exception of Italy) and same data, found that there were only minor differences between the Divisia index calculations and the Laspeyres index calculations.

We have chosen to divide the period 1973-87 into only two subperiods, 1973-79 and 1979-87, for the purpose of calculating the Divisia indices. This means that a Divisia index for the whole period is aggregated from the two subperiods. The rationale for not doing a from year to year basis calculation, is that Howarth et al. (1990a) for the same data (excluding Italy) found minor effects on the residual comparing the year to year calculations with the calculation using only the endpoints 1973 and 1987. The year separating the subperiods, 1979, was chosen as a midperiod year, avoiding the more turbulent situation in 1980 due to the second oil price shock in 1979 (OPEC II). With two subperiods it is possible to compare the Divisia indices for the first subperiod 1973-79, the second subperiod 1979-87 and the main period 1973-87.

3. THE DATA

The OECD countries included in this analysis are Japan (JP), the United States (US), the Federal Republic of Germany (FRG), France (FR), Italy (IT), the United Kingdom (UK), Denmark (DK), Sweden (SW), and Norway (NO). This is the OECD-9 group. The period analyzed is 1973 to 1987. The data are for the most part from the the database at Lawrence Berkeley Laboratory (LBL), International Energy Studies group.

The OECD-9 industrial energy use share of OECD was 85% in 1973 and 80% in 1987, and the total industry share of total final energy consumption was 33% in 1973 and 38% in 1987 (OECD and IEA (1984) and (1990)). On average manufacturing accounts for 80% of total industrial energy use. The share of the OECD-9 countries in global energy use was 53% in 1973 and 41% in 1987 (United Nations (1981) and (1989)). Taken together this means that OECD-9 manufacturing energy use accounts for something like 10-12% of total global energy use.

3.1 Carbon dioxide emission coefficients

Carbon dioxide emissions can be estimated from fossil fuels use data since emissions from combustion depends on the carbon content of the fossil fuel type. Physical and chemical characteristics of the fossil fuel type will determine the carbon content. Through combustion carbon is oxidized and released to the atmosphere as carbon dioxide. By multiplying coal, oil and gas use with emission coefficients, carbon dioxide emissions can be estimated. Carbon dioxide emission coefficients in the empirical literature vary somewhat since they typically are calculated from aggregates of fossil fuels with different properties and carbon content (Halvorsen, Kverndokk and Torvanger (1989)). We have chosen the standard emission coefficients in this literature (Marland (1982)), which can be considered as being calculated from the global average fossil fuel composition in the 70s. The coefficients in Table 3.1 show the release of carbon dioxide measured as carbon in the production of a given amount of energy from natural gas, liquids (oil) and solids (coal). Since the coefficients are based on the theoretical energy content, they show total carbon emissions from complete oxidation (combustion) of carbon, and say nothing of what work the energy performs or at what efficiency. The emission coefficients are kept constant in the estimation period 1973-87, thus assuming that there is no major change in fossil fuel composition within each of the fuels groups coal, oil and natural gas in this period that may influence the amount of carbon dioxide released per unit energy produced.

In some countries waste biomass is used as energy source in the manufacturing subsector paper & pulp, and is thus included in solids. To estimate the release of carbon dioxide to the atmosphere from combustion of biomass, the difference in emission from coal and biomass should be accounted for. Steinberg (1985), Table 2 gives a carbon dioxide emission coefficient for biomass (wood and cellulose) equivalent to 21.10 Kt Carbon/PJ (Table 3.1), which is slightly larger than the coefficient for oil. The possible fixation of new carbon dioxide through regrowth of vegetation is a different question, and thus not considered in this study. The national data sources made available to LBL (Howarth et al. (1990b)) include information on the share of biomass and coal in the aggregate solids for paper & pulp. For Denmark and Italy the paper & pulp coal share of solids is 100% in the whole period, whereas the coal share is close to 100% for the U.K. and the FRG (except a biomass share at 8% for the FRG in 1987). For Norway the biomass share is 100% throughout the period, whereas the biomass share for Sweden is reduced from 100% in 1973 and 1979 to 91% in 1987. The biomass share for France is around 90%. For the U.S. the biomass share is reduced from a level of 81-83% in the 70s. to 76% in 1987, whereas the biomass share for Japan is reduced from close to 100% in the 70s to 76% in 1987.

Based on the biomass and coal emission coefficients and the relevant shares in solids, a carbon dioxide emission coefficient index for solids in paper & pulp was constructed for each country and time period.

TABLE 3.1 Carbon dioxide emission coefficients

	Oil	Natural gas	Solids	Biomass (wood,cellulose)
Marland (1982)				
CO_2 as Gt Carbon/TWyr	0.62	0.43	0.75	
CO_2 as Kt Carbon/Mtoe	879.78	610.17	1064.25	
CO_2 as Kt Carbon/PJ	20.80	14.42	25.16	
Steinberg (1985)				
CO_2 as lb CO_2/1000 Btu				0.18
CO_2 as Kt Carbon/PJ				21.10

1 Gt = 10^9 tons
1 Kt = 1000 tons
1 TWyr = 10^{12} Watts for a year
1 Mtoe = 1 mill. metric tons of oil equivalent
PJ = 10^{15} Joule
1 Btu = 1055.056 Joule

In the table carbon dioxide emission coefficients are expressed in Kt carbon per Mtoe and Kt carbon per PJ, in addition to Gt carbon per TWyr from Marland (1982) and lb CO_2 per 1000 Btu from Steinberg (1985). The numerators in the CO_2 emission coefficients expressed as tons of carbon can be changed to CO_2 expressed as tons of carbon dioxide by multiplying with 3.67 (based on the molecule weights of carbon and oxygen).

3.2 Electricity generation carbon dioxide emission coefficients

One of the main fossil fuel using sectors is electricity production, and electricity is one of the major fuels used in manufacturing industries. To estimate manufacturing carbon dioxide emissions, fossil fuel use in electricity production therefore should be included. Table 3.2, based on data from IEA and OECD (1989), shows the fuel shares in electricity generation for OECD-9 countries in 1973, 1979 and 1987.

TABLE 3.2 Fuel shares in electricity generation for OECD-9 countries 1973, 1979 and 1987, percent

		Coal	Oil	Gas	Nuclear	Hydro	Total
Japan	1973	7.9	72.5	2.2	2.1	15.3	100.0
	79	7.5	53.6	12.4	11.9	14.6	100.0
	87	15.3	27.7	19.5	26.1	11.4	100.0
US	1973	46.0	17.0	18.5	4.5	14.0	100.0
	79	47.7	13.8	14.9	11.5	12.2	100.0
	87	57.3	4.6	10.7	17.7	9.7	100.0
FRG	1973	63.7	14.3	11.9	3.9	5.2	100.0
	79	56.5	7.5	18.7	11.4	5.0	100.0
	87	53.1	3.0	6.9	31.2	4.9	100.0
France	1973	19.4	40.2	5.5	8.1	26.4	100.0
	79	29.5	22.0	3.6	16.6	28.1	100.0
	87	8.1	1.6	0.6	70.2	19.3	100.0
Italy	1973	3.6	61.7	3.1	2.2	28.6	100.0
	79	8.3	55.5	6.1	1.5	28.0	100.0
	87	16.5	44.7	15.8	0.1	22.6	100.0
UK	1973	61.9	25.6	1.0	9.9	1.6	100.0
	79	67.7	16.7	1.0	12.8	1.8	100.0
	87	70.4	8.7	0.6	18.3	2.1	100.0
Denmark	1973	35.8	64.1	0	0	0.1	100.0
	79	63.1	36.8	0	0	0.1	100.0
	87	94.8	4.1	0.4	0	0.1	100.0
Sweden	1973	0.6	19.4	0	2.7	76.7	100.0
	79	0.2	13.0	0	22.1	64.3	100.0
	87	1.7	1.5	0.1	45.9	49.5	100.0
Norway	1973	0.0	0.2	0	0	99.8	100.0
	79	0.0	0.1	0	0	99.8	100.0
	87	0.0	0.4	0	0	99.5	100.0
OECD Total	1973	35.5	25.8	12.0	4.5	21.9	100.0
	79	36.4	19.7	11.4	10.9	21.3	100.0
	87	40.8	8.3	9.3	22.4	18.8	100.0

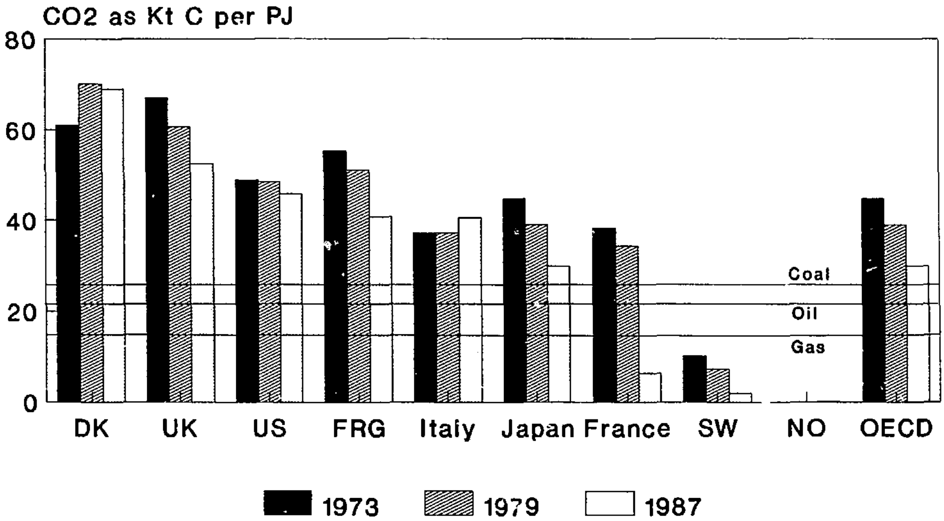
Source: OECD and IEA (1989)

The oil share of electricity production shows a strong decrease in all countries in the period (except for Norway, where the share is minor). For all OECD countries (including countries outside OECD-9), the share is reduced from 25.8% in 1973 to 8.3% in 1987. The coal share, on the other hand, increased for all countries in the group except the FRG and France, where nuclear power is substituted for coal. The increase in the nuclear power share is especially strong in France, but is also found in Japan, the U.S., the U.K. and Sweden. The gas share is down in the U.S., the FRG, France and the U.K., and up in Japan, Italy and Denmark. The hydro power share is down in all countries except the U.K. The importance of the different fuels varies between countries. For all OECD countries coal is most important in 1987, followed by nuclear power and hydro power. Oil is relatively more important in Italy and Japan in 1987, whereas coal dominates in Denmark, the U.K., the U.S. and the FRG. Japan and Italy have larger gas shares than the average, whereas nuclear power dominates in France and is important in Sweden, the FRG and Japan. Hydro power completely dominates in Norway and is relatively important in Sweden.

To find the carbon dioxide emissions related to electricity generation, the efficiency in transformation from fossil fuels to electricity must be accounted for. OECD and IEA (1984) and (1989) give electricity production and energy inputs in electricity generation by fossil fuels, nuclear power, and hydro power and other renewable energy sources for each country and year. From this data the electricity transformation efficiency can be calculated as the quotient between electricity generated and energy inputs. Co-generated heat (which is minor) is not included in the energy output since we only are concerned with the carbon dioxide emissions related to observed electricity use in manufacturing industries. For OECD total the efficiency increases from 0.37 to 0.38 throughout the period 1973-87. There is some variation in efficiency over countries, with for instance higher efficiency in countries with a large hydro power share. For most countries the efficiency is in the range 0.36 to 0.42 in 1987, with a slowly increasing trend in the period 1973-87.

Using electricity generation fuel shares, electricity generation efficiency coefficients and carbon dioxide emission coefficients from Table 3.1, an emission coefficient index can be calculated for each country and year (Figure 3.1). It is assumed that the fuel shares and efficiency coefficients in electricity generation used by manufacturing industries correspond with the aggregate electricity generation fuel shares and the aggregate electricity generation efficiency coefficients.

FIGURE 3.1 Electricity generation CO_2 emission coefficients for OECD-9 countries 1973-87



In Figure 3.1 the emission coefficient index for electricity generation is given in carbon dioxide expressed as 1000 tons C per PJ. The coal, oil and gas emission coefficients from Table 3.1 are included in the figure for comparison, representing carbon dioxide emission in the hypothetical case of 100% efficiency in electricity generation. For OECD total and most countries, the coefficient is reduced due to reduction in the oil share and increase in the nuclear power share. However, in Denmark the coefficient is large and increasing from 1973 to 1979 due to the high and increasing coal share, whereas the small reduction from 1979 to 1987 is due to increased efficiency in electricity generation. The emission coefficient is increased in Italy due to an increased coal share. The reduction is especially strong in France in the 80s due to the fast expansion of nuclear power and the increase in electricity generation efficiency. The emission coefficient is close to zero in Norway due to hydro power and very low in Sweden due to a high hydro power share and a high and increasing nuclear power share.

3.3 Energy use and value added

The energy use data and value added data are from the database at Lawrence Berkeley Laboratory, International Energy Studies (Howarth et al. (1990b)). The data are taken from various national sources and processed to make comparable timeseries.

Energy use is in terms of primary energy, and does not account for losses in generation, transmission and distribution of electricity. Energy is defined as the sum of purchased and self-produced energy, e.g. waste biomass in paper & pulp, whereas feedstocks are excluded. The energy use data are disaggregated by fuel and given at 3- and 2-digit ISIC level, and are expressed in PJ (10^{15} Joule).

The residual sector Non-raw materials is calculated as the difference between Total manufacturing and the sum of the five specified sectors ('The big five' in terms of energy use).

On average The big five use 75% of manufacturing energy and produce only 18% of manufacturing output, whereas the manufacturing share of GDP is 25% (referring to 1987). Change of energy intensities or output shares of The big five will therefore have a disproportionate impact of aggregate manufacturing energy use and energy intensity. More disaggregated data are available for some countries, but previous analyses indicate that this aggregation level is sufficient for capturing the main effects of energy intensity changes and structural changes on manufacturing energy use (Howarth et al. (1990b)). Due to the carbon dioxide emission estimation method employed, the level of aggregation should make it possible to capture the main components of the change in aggregate carbon dioxide emissions.

Real value added is expressed in billion 1980 US dollars, calculated from real 1980 national currencies with the help of 1980 purchasing power parities (ppp) for GDP (OECD (1989)). We have chosen value added as the output indicator instead of gross output, since employing gross output would lead to double counting problems due to production and use of intermediate products, and since value added data are comparable over countries. Howarth et al. (1990a) gives a further discussion of real value added measurement.

Taking the quotient between energy use and value added yields energy intensities. Structure is calculated as the subsector's share of manufacturing value added.

There are some problems with some of the data employed. The value added data for Denmark 1987 are estimated from a gross production index taken from Nordic Council of Ministers and the Nordic Statistical Secretariat (1990). For the U.S. and Denmark, energy use figures are interpolated for the years 1986 and 1987. For Italy there are some aggregation problems. Paper & pulp includes printing and publishing, and Industrial chemicals includes chemical products, which should have been separated from basic chemicals (ISIC 351). However, we chose to include Italy in the analysis since the data should approximately represent the energy intensive industries.

The next section of tables, Table 3.3 to 3.5, shows the development of energy use and output for the group OECD-9. Similar tables with manufacturing subsector data for individual countries are given in the Appendix.

TABLE 3.3 OECD-9 - manufacturing energy use, value added, intensity and structure by country 1973 - 87

	Energy use		Value added		Intensity		Structure, VA	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Japan	6432.2	-1.3	228.2	3.0	28.2	-4.2	18.3	20.7
US	15013.7	-1.6	504.7	2.6	29.7	-4.1	40.4	43.2
FRG	2774.2	-1.7	153.1	1.0	18.1	-2.6	12.3	10.5
France	1905.9	-2.2	92.7	0.9	20.6	-3.1	7.4	6.3
Italy	1674.6	-1.4	117.9	2.6	14.2	-3.8	9.4	10.1
UK	2813.0	-2.7	124.9	-0.3	22.5	-2.4	10.0	7.2
Denmark	151.7	-1.2	6.3	1.7	24.2	-2.9	0.5	0.5
Sweden	570.2	-1.0	15.4	1.3	37.1	-2.2	1.2	1.1
Norway	259.8	-0.1	6.1	0.6	42.9	-0.7	0.5	0.3
OECD-9	31595.4	-1.6	1249.1	2.1	25.3	-3.7	100.0	100.0

Energy use is down by 1.6% per year in the period 1973-87 for OECD-9, whereas output is up 2.1% per year. Consequently energy intensity is down 3.7% per year. The U.K. and France have the largest energy use reduction, and Norway the smallest energy use reduction. The U.K. is the only country with a reduced output in the period. Japan, the U.S. and Italy have the largest output growth. Thus, energy intensity shows strongest reduction in Japan, the U.S., Italy and France, and weakest reduction in Norway. The output share of Japan, the U.S. and Italy is increased, while it is reduced for the other countries in OECD-9, except Denmark, where the share is constant.

TABLE 3.4 OECD-9 - Manufacturing energy use 1973 and 1987 by fuel, PJ

	1973	1987	%/yr 1973-87
Total energy use	31595.4	25082.6	-1.6
Oil	10698.3	4814.6	-5.5
Gas	8009.0	7109.7	-0.8
Solids	8159.8	7749.2	-0.4
Electricity	4686.5	5352.1	1.0

Oil use is heavily reduced in the period 1973-87. There is some reduction in the gas and solids use, and 1.0% per year increase in electricity use. Altogether energy use is down by 1.6% per year.

TABLE 3.5 OECD-9 - Manufacturing energy use by country 1973 and 1987 as percentage of group

	Oil		Gas		Solids		Electricity		Total energy	
	1973	1987	1973	1987	1973	1987	1973	1987	1973	1987
Japan	35.2	49.2	1.2	2.0	19.7	22.0	20.5	21.2	20.4	21.3
US	21.5	15.9	75.9	67.2	55.5	53.8	44.9	42.2	47.5	47.7
FRG	10.3	8.2	8.4	9.6	5.9	6.4	10.2	10.6	8.8	8.7
France	8.9	7.1	3.7	5.0	4.4	4.4	6.5	6.8	6.0	5.6
Italy	8.5	7.6	4.1	6.5	1.9	2.5	5.9	6.6	5.3	5.5
UK	11.2	8.1	6.7	9.4	9.6	7.0	6.1	5.9	8.9	7.7
Denmark	1.1	1.1	0	0.2	0.2	0.4	0.3	0.5	0.5	0.5
Sweden	2.5	2.1	0	0	2.1	2.6	2.8	3.3	1.8	2.0
Norway	0.8	0.7	0.0	0.0	0.6	0.8	2.7	2.9	0.8	1.0
OECD-9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

In Table 3.5 manufacturing energy use by type is shown as percentage of the group OECD-9. We note that Japan's oil share is going up, whereas the oil share of the other countries is reduced or stable. The gas share is down for the U.S. and up for all the other countries, except for Sweden and Norway, where it is stable close to zero. The solids share is down for the U.S. and the U.K., and up for the rest of the group except for France, where it is constant. The electricity share is also down for the U.S. and the U.K., and up for the other countries. For total energy, the share is increased for Japan, the U.S., Italy, Sweden and Norway, and reduced for the FRG, France and the U.K. Japan and the U.S. dominates all the fuel uses, except for gas, where the U.S. dominates alone.

4. DISCUSSION OF RESULTS

In Table 4.1 manufacturing carbon dioxide emissions are given as estimated from energy use and composition, including electricity production, for the OECD-9 group by country. The overall picture is an annual carbon dioxide emissions decrease for OECD-9 of 0.7% in the period 1973-79 and 1.7% in the longer period 1973-87. This is equivalent to a total reduction of 3.9% for the period 1973-79 and 21.8% for the period 1973-87. Thus the emissions reduction was much stronger in the 80s than in the 70s.

TABLE 4.1 Manufacturing CO_2 emissions in 1973, 1979 and 1987 for OECD-9 countries, expressed as Mt carbon

	1973	1979	1987	%/yr 1973-79	%/yr 1973-87	Percent of OECD-9 1973	1979	1987
Japan	157.4	146.6	125.6	-1.2	-1.6	21.0	20.4	21.4
US	348.8	346.0	288.1	-0.1	-1.4	46.6	48.1	49.2
FRG	71.1	68.3	53.7	-0.7	-2.0	9.5	9.5	9.2
France	44.6	41.5	23.1	-1.2	-4.6	6.0	5.8	3.9
Italy	38.0	37.3	33.6	-0.3	-0.9	5.1	5.2	5.7
UK	71.8	63.7	48.2	-2.0	-2.8	9.6	8.9	8.2
Denmark	3.9	3.9	4.0	0	0.2	0.5	0.5	0.7
Sweden	10.7	9.6	7.1	-1.8	-2.9	1.4	1.3	1.2
Norway	2.9	2.9	2.3	0	-1.7	0.4	0.4	0.4
OECD-9	749.2	719.8	585.6	-0.7	-1.7	100.0	100.0	100.0

Comparing the contribution of different countries, we find that France had the strongest reduction of 4.6% per year for 1973-87, followed by Sweden at 2.9%, the U.K. at 2.8% and the FRG at 2.0% per year. In Denmark emissions increased with 0.2% per year in the period 1973-87. For Italy emissions were reduced with 0.9% per year, whereas the U.S. emissions reduction was 1.4% per year in the period 1973-87. An interesting observation is that the carbon dioxide emissions reduction is stronger in the 80s than the 70s for all countries except Denmark. The difference is especially pronounced for France. The changes in carbon dioxide emission shares within the group OECD-9 are modest. The emission shares of Japan, the U.S., Italy and Denmark are increased, whereas the emission shares of France, the FRG, the U.K. and Sweden are reduced.

In Table 4.2 the average carbon dioxide emission contribution in 1979 and 1987 from different fuels are compared. Emissions pertaining to fossil fuel use in electricity generation are counted as electricity emissions.

TABLE 4.2 Carbon dioxide emission contribution from different fuels as percentage of national emissions in OECD-9 countries - average for 1979 and 1987.

	Oil	Gas	Solids	Electricity[1]	Total
Japan	42.4	2.0	29.8	25.8	100.0
US	8.2	24.3	33.1	34.4	100.0
FRG	20.1	17.4	20.9	41.7	100.0
France	34.9	18.3	27.6	19.1	100.0
Italy	31.2	18.0	12.7	38.0	100.0
UK	23.1	17.9	26.6	32.3	100.0
Denmark	36.8	2.6	18.9	41.6	100.0
Sweden	37.2	0	55.1	7.8	100.0
Norway	40.9	1.6	56.8	0.7	100.0

[1] Includes emissions from fossil fuels used for electricity generation.

We find substantial variation between countries. Due to the dominating share of hydro power in electricity generation, the electricity share is lowest in Norway at 0.7% of national emissions. Sweden and France also have a relatively low electricity share due to large nuclear and hydro power shares, whereas the FRG and Denmark have the highest shares at 41-42%. The emission shares from solids (excluding solids in electricity generation) show less variation, with Italy lowest at 12.7% and Norway highest at 56.8%. For gas the emission shares range from 0% in Sweden to 24.3% in the U.S. Finally, for oil the emission shares range between 8.2% for the U.S. to 42.4% for Japan.

By dividing the carbon dioxide emissions (from Table 4.1) with value added, carbon dioxide intensities can be calculated. Table 4.3 shows the average annual carbon dioxide intensity percentage change for OECD-9 countries 1973-87 broken down to carbon dioxide emission percentage change and value added percentage change. The carbon dioxide intensity growthrate (percentage change) is approximately equal to the carbon dioxide emission growthrate minus the value added growthrate.

TABLE 4.3 Average annual manufacturing carbon dioxide intensity percentage change 1973-87 for OECD-9 countries - breakdown to carbon dioxide emission percentage change and value added percentage change

	CO_2 emissions %/yr	Value added %/yr	CO_2 intensities %/yr
Japan	-1.6	3.0	-4.5
U.S.	-1.4	2.6	-3.9
FRG	-2.0	1.0	-2.9
France	-4.6	0.9	-5.5
Italy	-0.9	2.6	-3.4
U.K.	-2.8	-0.3	-2.6
Denmark	0.2	1.7	-1.5
Sweden	-2.9	1.3	-4.1
Norway	-1.7	0.6	-2.3
OECD-9	-1.7	2.1	-3.8

The carbon dioxide intensity for OECD-9 is reduced by 3.8% per year, caused by a carbon dioxide reduction of 1.7% and an output increase of 2.1% per year. France has the largest reduction in carbon dioxide intensity, mostly due to a large reduction in carbon dioxide emissions caused by the expansion in nuclear power generation. Japan is second in reduction of carbon dioxide intensity, but increased output is more important than reduced emissions. The medium reduction in intensity is represented by Sweden, the U.S. and Italy, where emission reduction is largest in Sweden due to expansion of nuclear power. The smallest carbon dioxide intensity reduction is found for Denmark, mostly caused by increased emissions, followed by Norway, the U.K. and the FRG. The U.K. is the only country in the group with a negative output growthrate.

Figure 4.1a shows manufacturing carbon dioxide intensities for OECD-9 countries in 1973 and 1987, and the share pertaining to electricity generation in total manufacturing intensity is shown in Figure 4.1b. Figure 4.2 a-f show the intensities broken down to subsectors. The sectors are Ferrous metals, Paper & pulp, Stone, clay and glass, Industrial chemicals, Nonferrous metals and Non-raw materials.

FIGURE 4.1a Manufacturing CO2 intensities for OECD-9 countries 1973 and 1987

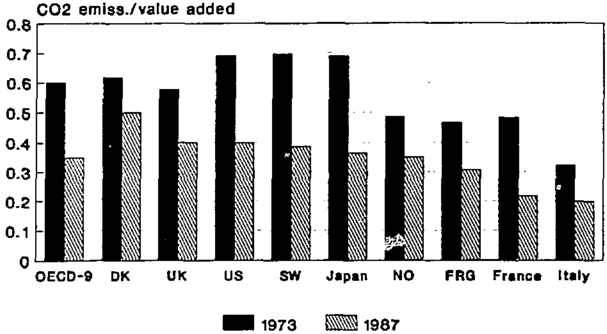


FIGURE 4.1b Manufacturing CO2 intensities with electricity share for OECD-9 countries 1973 and 1987

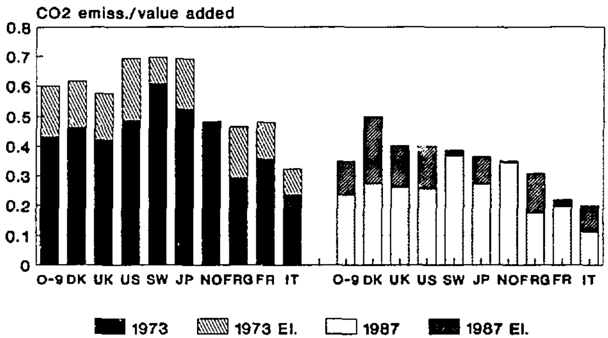


FIGURE 4.2a CO2 intensities 1973, 1987 for OECD-9 countries, Ferrous metals

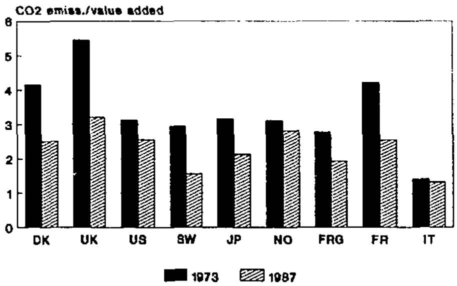


FIGURE 4.2b CO2 intensities 1973, 1987 for OECD-9 countries, Paper & pulp

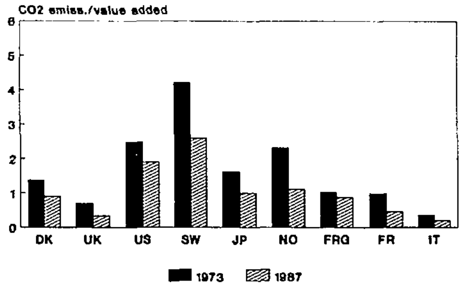


FIGURE 4.2c CO2 intensities 1973, 1987 for OECD-9 count., Stone, clay and glass

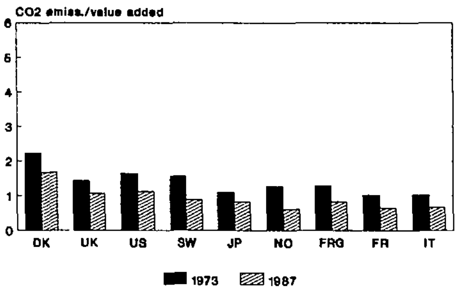


FIGURE 4.2d CO2 intensities 1973, 1987 for OECD-9 count., Industrial chemicals

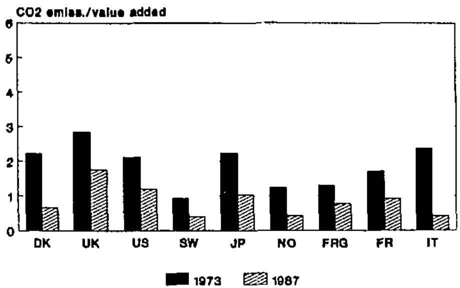


FIGURE 4.2e CO2 intensities 1973, 1987 for OECD-9 countries, Nonferrous metals

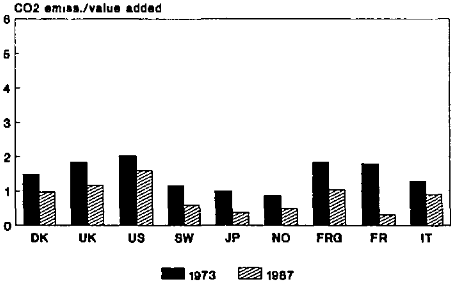
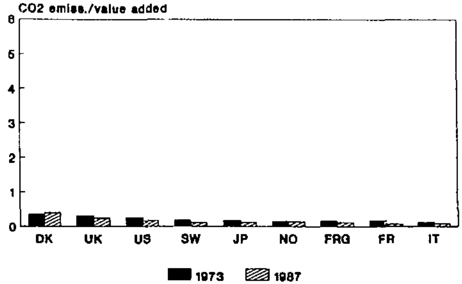


FIGURE 4.2f CO2 intensities 1973, 1987 for OECD-9 countries, Non-raw materials



Comparing total manufacturing intensities in 1987 from Figure 4.1a, we find that Denmark has the highest intensity, followed by the U.K., the U.S., Sweden and Japan. All these countries have a higher intensity than the aggregate OECD-9 group, whereas the FRG, France and Italy have a lower intensity. The situation in 1973 was somewhat different, with overall higher intensities. In 1973 Sweden had the highest intensity, followed by the U.S., Japan and Denmark. The countries with lower intensity than OECD-9 were the U.K., Norway, France, the FRG and Italy.

The electricity generation component of the carbon dioxide intensity from Figure 4.1b is 28.2% in 1973 for OECD-9 (O-9), and increased to 33.2% in 1987. The variation between countries is large. Norway is lowest in both years (0.4% in 1973 and 1.1% in 1987) due to the dominating share of hydro power, whereas the FRG is highest in 1973 (37.0%) and Denmark in 1987 (45.2%). The share is increased from 1973 to 1987 for all countries except France and Sweden, where the share is reduced by almost 2/3, mostly due to nuclear power expansion. In Denmark the share is almost doubled.

A higher intensity for one country can be caused by higher intensity in one or more sectors, or a larger output share of carbon dioxide intensive sectors.

For most countries Ferrous metals is the most carbon dioxide intensive sector, followed by Paper & pulp, Stone, clay and glass, Industrial chemicals and Nonferrous metals. Non-raw materials is the least intensive sector. However, there are individual variations between countries and over time.

In Denmark stone, clay and glass is more intensive than paper & pulp, and nonferrous metals is more intensive than industrial chemicals in 1987. In the U.K. paper & pulp is the least intensive raw materials sector, and industrial chemicals is more intensive than stone, clay and glass (and paper & pulp in 1973). The U.S. industrial chemicals intensity is larger than the stone, clay and glass intensity, whereas the 1987 nonferrous metals intensity is larger than the industrial chemicals intensity. The Swedish paper & pulp intensity is higher than the ferrous metals intensity, and nonferrous metals is higher than industrial chemicals. In Japan industrial chemicals is more intensive than stone, clay and glass. In Norway nonferrous metals is higher than industrial chemicals in 1987. In the FRG nonferrous metals is second highest in intensity, and stone, clay and glass and industrial chemicals are more intensive than paper & pulp in 1973. In France industrial chemicals is more intensive than paper & pulp and stone, clay and glass. Comparing the two latter sectors, stone, clay and glass is more intensive than paper & pulp. For 1973 nonferrous metals is second highest in intensity. In Italy paper & pulp has the second lowest intensity after non-raw materials. Industrial chemicals has highest intensity in 1973, whereas nonferrous metals has the second highest intensity in 1987.

The aggregate carbon dioxide intensity in manufacturing industry for OECD-9 is 0.600 in 1973, 0.504 in 1979 and 0.350 in 1987, equivalent to a total reduction of 16.0% for 1973-79 and 41.7% for 1973-87. Applying the Divisia index method to decompose the change in carbon dioxide intensity in the period yields the results in Table 4.4, Table 4.5 and Figure 4.3. In Figure 4.3 the change in carbon dioxide intensities is included, and 1 is subtracted from the Divisia indices to make the figure easier to read. To make the presentation consistent, the sign of the residuals is changed.

TABLE 4.4 Divisia index decomposition of OECD-9 manufacturing carbon dioxide intensities 1973 - 87, defined as carbon dioxide emissions divided by value added.

	1973-79	1979-87	1973-87
CO_2 intensity change	0.841	0.695	0.584
Emission coefficient[1]	0.983	0.948	0.932
Fuel mix[2]	1.021	1.029	1.051
Manufacturing structure	0.973	0.912	0.887
Energy intensity	0.901	0.836	0.753
International structure	0.998	1.009	1.008
Residual	-0.04	-0.06	-0.07

[1] Changes in the emission coefficients are only due to changes in the fuel mix in electricity generation and changes in electricity generation efficiency, in addition to changes in the mix of coal and waste biomass in the aggregate solids for the manufacturing subsector paper & pulp. The emission coefficients for coal, oil and natural gas are constant over countries and time.

[2] The Divisia index related to substitution between solids (coal), oil, gas and electricity, exclusive of changes in the fuel mix and efficiency in electricity generation, and exclusive of changes in the coal and waste biomass mix in paper & pulp.

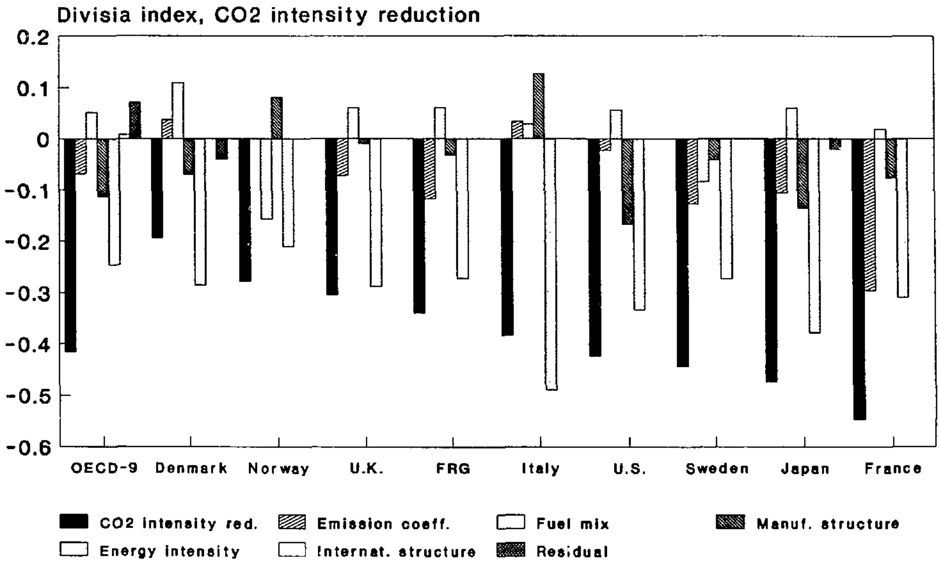
TABLE 4.5 Divisia index decomposition of manufacturing carbon dioxide intensities for OECD countries 1973-87, defined as carbon dioxide emissions divided by value added.

	CO_2 intensity change	Emission coefficient[1]	Fuel mix[2]	Manufac. structure	Energy intensity	Residual
Denmark						
1973-79	0.902	1.045	1.113	0.983	0.791	-0.00
1979-87	0.894	0.993	0.996	0.946	0.902	0.05
1973-87	0.806	1.037	1.109	0.930	0.714	0.04
Norway						
1973-79	0.993	1.000	0.949	1.038	1.010	-0.00
1979-87	0.727	1.000	0.888	1.042	0.781	0.00
1973-87	0.722	1.000	0.843	1.081	0.789	0.00
U. K.						
1973-79	0.925	0.972	1.013	0.993	0.945	0.00
1979-87	0.751	0.954	1.046	0.998	0.753	0.00
1973-87	0.695	0.928	1.060	0.991	0.712	0.00
FRG						
1973-79	0.898	0.970	1.011	1.015	0.902	0.00
1979-87	0.735	0.910	1.049	0.954	0.807	0.00
1973-87	0.661	0.883	1.061	0.968	0.728	0.00
Italy						
1973-79	0.776	1.001	1.013	1.045	0.732	0.00
1979-87	0.795	1.033	1.016	1.078	0.699	0.00
1973-87	0.617	1.034	1.029	1.127	0.511	0.00
U. S.						
1973-79	0.836	0.996	1.026	0.942	0.868	0.00
1979-87	0.690	0.982	1.029	0.885	0.769	0.00
1973-87	0.577	0.978	1.056	0.833	0.667	0.00
Sweden						
1973-79	0.868	0.961	1.000	1.002	0.905	-0.00
1979-87	0.641	0.909	0.916	0.957	0.804	0.00
1973-87	0.557	0.874	0.916	0.959	0.727	-0.00
Japan						
1973-79	0.821	0.962	1.027	0.987	0.834	0.01
1979-87	0.643	0.930	1.032	0.876	0.748	0.01
1973-87	0.527	0.894	1.060	0.865	0.623	0.02
France						
1973-79	0.800	0.971	0.993	1.009	0.824	-0.00
1979-87	0.567	0.725	1.026	0.915	0.838	-0.00
1973-87	0.454	0.705	1.019	0.924	0.690	-0.00

[1] Refer to note 1 in Table 4.4.

[2] Refer to note 2 in Table 4.4.

FIGURE 4.3 Manufacturing CO2 intensity Divisia index decomposition for OECD-9 countries 1973-87



From Table 4.4, third column, and the left group of bars in Figure 4.3 we see that three out of five components (indices) contribute to the 41.7% reduction of carbon dioxide intensity for OECD-9 in the period 1973-87. These are the emission coefficient component (which has changed due to the change in efficiency and fuel mix in electricity generation, and the change in coal and waste biomass mix in the aggregate solids for paper & pulp), the manufacturing structure component and the energy intensity component, whereas the fuel mix component and the international structure component contribute to an increased carbon dioxide intensity. However, the international structure index is low (close to one). The energy intensity index is lowest at 0.753 followed by the structure index at 0.887 and the emission coefficient index at 0.932, whereas the fuel mix index is highest at 1.051. The residual is acceptably low at -0.07.

In Table 4.5 and Figure 4.3 national Divisia indices are given for the two subperiods (only Table 4.5) and the main period 1973-87 together with the change in carbon dioxide intensity. The intensity reduction for the period 1973-87 is smallest in Denmark at 19.4% and largest in France at 54.6%.

We can see some effect of the reduction in oil share and increase in nuclear power share in electricity generation through the emission coefficient index. This is the case for 6 out of the 9 OECD-9 countries. The exceptions are Denmark, Norway and Italy, where the nuclear power share is constant (zero) or reduced. In Denmark there is a strong increase in the coal share, whereas the coal share and gas share is up and hydro power share down in Italy. The emission coefficient is also lowered by the increase in electricity generation efficiency in the period 1973-87, which is found for 5 of the OECD-9 countries (the U.S., Japan, France, Italy and the U.K.) and for OECD total. However, there is a weak contribution towards a larger coefficient from the increased share of coal in solids in paper & pulp, which is found for the U.S., Japan and Sweden.

The fuel mix index is larger than one for OECD-9, indicating that the reduction in fossil fuels (especially oil) use is dominated by the increased electricity use, where a large share is generated through fossil fuels combustion at a typical efficiency of 0.37, giving rise to substantial carbon dioxide emissions. The only exceptions are Sweden and Norway, where electricity generation is dominated by nuclear power and hydro power at high generation efficiency. This is also indicated in Figure 3.1, where the electricity generation carbon dioxide coefficients are larger than the 100% generation efficiency coefficients for coal, oil and natural gas for all countries except Sweden and Norway (and France in 1987).

The stronger effect seen from the structure index is caused by reduction in the output share of the most carbon dioxide intensive manufacturing subsectors, which typically are Ferrous metals and Paper & pulp, and an increase in the least carbon dioxide intensive subsectors, which typically are Non-raw materials and Nonferrous metals. In Norway and Italy the national Divisia indices are larger than one, indicating that the more carbon intensive subsectors in these countries, which are Ferrous metals and Nonferrous metals for Italy, have an increased output share (Figure 4.2a - f).

The most significant contribution to reduced carbon dioxide intensity in manufacturing industries in the period 1979-87 is from the general reduction in (primary) energy intensity, which can be seen for all countries, but most pronounced for Japan, the U.S., France and Italy. This increased efficiency trend is most likely driven by increasing energy prices and economic growth resulting in technological progress, more efficient capital equipment and new industrial processes. The contribution from reduced energy intensity over time in manufacturing sectors, as represented by the change in the energy intensity index, is supported by findings from other studies (e.g. Howarth et al. (1990a) and Li et al. (1989)).

There is a weak contribution towards increased carbon dioxide intensity from the international structure Divisia index, indicating a larger manufacturing industries output share in the aggregate OECD-9 output from the most carbon dioxide intensive countries. In 1987 Denmark, the U.K. and the U.S. are the most carbon dioxide intensive countries. Alternatively, there is a small reduction in the output of the least carbon dioxide intensive economies, which are the FRG, France and Italy. Checking the output shares in Table 3.3 and manufacturing intensities from Figure 4.1a we find an increased output share for the U.S. and a reduced output share for the FRG and France.

Comparing the two subperiods and the main period 1973-87, we find that the contribution towards a lower aggregate carbon dioxide intensity from reduced manufacturing energy intensity, as seen from the intensity index, is stronger in the 80s than the 70s. The same goes for the manufacturing structure index and the emission coefficient index. The contribution towards larger aggregate carbon dioxide intensity, as seen from the fuel mix index, is also stronger in the 80s than the 70s. The international structure index is slightly smaller than one in the first subperiod and slightly larger than one in the second subperiod, making the Divisia index slightly larger than one for the main period 1973-87.

5. CONCLUSIONS

Based on the energy use data, the manufacturing carbon dioxide emissions estimates for OECD-9 show a reduction of 21.8% in the period 1973 to 1987, equivalent to -1.7% per year. The reduction was strongest in the 80s. Comparing the countries in the OECD-9 group, France had the largest emissions descrease, whereas Denmark had a small increase in emissions.

When it comes to manufacturing carbon dioxide intensities, Denmark had the highest intensity in 1987 and Sweden had the highest intensity in 1973, whereas Italy had the lowest intensity in both years. In 1987 the U.K. had the second highest intensity, followed by the U.S., Sweden, Japan, Norway, the FRG and France. For Japan, the U.S. and Italy the output growth is large and important for reducing the carbon dioxide intensity, whereas the emission reduction is the most important factor for reduced intensities in France, Sweden and the U.K.

Ferrous metals had the highest maufacturing subsector intensity, followed by Paper & pulp, Stone, clay and glass, Industrial chemicals and Nonferrous metals. Non-raw materials had the lowest intensity. However, there is some variation between countries, sectors and years. The overall reduction in intensity for OECD-9 in the period 1973-87 is 41.7%.

Employing the Divisia index approach to explain the reduction in aggregate manufacturing carbon dioxide intensity for OECD-9, we find that the strongest contribution comes from the general reduction in energy intensity most likely driven by increasing energy prices and economic growth resulting in technological progress, more efficient capital equipment and new industrial processes. The second strongest contribution comes from structural changes, meaning that a larger output share is produced in less carbon dioxide intensive manufacturing subsectors. There is also a contribution from reduced emission coefficients in electricity production caused by more use of nuclear power at the expense of oil, and increased efficiency in electricity generation. A contribution towards increased carbon dioxide intensity is found for the mix of fossil fuels and electricity, where the increased carbon dioxide emissions from a larger electricity share is felt, to a large extent generated from fossil fuel combustion at a typical 37% efficiency. The international structure index is close to but larger than one, indicating that there is no pronounced effect of change in the output share of the most carbon dioxide intensive countries Denmark, the U.K. and the U.S.

The policy implications from this analysis in terms of reducing carbon dioxide emissions to limit greenhouse warming would be to stimulate technological improvements, more efficient capital equipment and new industrial processes, where energy prices play an important role. The other option would be to stimulate fuel switching to natural gas, hydro power and other renewable energy sources, especially in electricity generation, assuming that nuclear power is not an environmentally acceptable energy source. Another important factor is the output share of the most carbon dioxide intensive manufacturing subsectors, which will depend on market development (product prices, input prices and energy prices) in addition to product substitution possibilities and technological development.

One interesting follow-up analysis of the present paper would be to find the optimal allocation of output over OECD-9 countries and sectors that minimizes carbon dioxide emissions given total output and labour input. Since carbon dioxide emission coefficients may vary between countries and over time (especially for solids/coal), national and time-specific emission coefficients could be included in a more detailed analysis to the extent that these coefficients are available. If more disaggregated fuel use data were available, more disaggregated emission coefficients could be used. Another idea is to include carbon dioxide emissions from cement production in the manufacturing subsector stone, clay and glass. The methodology employed in this paper could be employed on other sectors, for instance transportation.

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APPENDIX: ENERGY USE DATA AND VALUE ADDED DATA FOR OECD-9 COUNTRIES

Tables A.1 to A.9 show energy use by fuel, value added, intensity and structure by sector 1973-87 for each country in the OECD-9 group. The change in energy use, value added and intensity in the period is given as annual percentage change. The data are taken from the database at Lawrence Berkeley Laboratory, International Energy Studies group (Howarth et al. (1990b)), taken from various national sources.

TABLE A.1 Japan - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	6432.2	-1.3	228.2	3.0	28.2	-4.2	100.0	100.0
Paper & Pulp	414.1	-0.7	6.5	2.2	63.9	-2.9	2.8	2.5
Indust. chemicals	1730.6	-1.2	18.1	3.9	95.8	-4.9	7.9	8.9
Stone, clay, glass	614.5	-2.3	13.1	0	47.0	-2.3	5.7	3.8
Ferrous metals	2281.7	-2.4	19.0	0.1	120.1	-2.6	8.3	5.6
Nonferrous metals	196.5	-3.5	6.8	1.2	28.9	-4.6	3.0	2.3
Non-Raw materials	1194.9	0.8	164.7	3.5	7.3	-2.7	72.2	76.8
Total energy	6432.2	-1.3						
Oil	3765.4	-3.3						
Gas	96.3	2.9						
Solids	1609.4	0.4						
Electricity	961.1	1.2						

TABLE A.2 The United States - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	15014	-1.6	504.7	2.6	29.7	-4.1	100.0	100.0
Paper & Pulp	2248	0.6	19.7	2.8	113.9	-2.2	3.9	4.0
Indust. chemicals	2654	-1.5	27.6	2.8	96.3	-4.1	5.5	5.6
Stone, clay, glass	1342	-2.0	16.1	1.6	81.0	-3.5	3.3	2.9
Ferrous metals	3610	-5.0	26.9	-3.6	134.2	-1.5	5.3	2.2
Nonferrous metals	878	-2.4	12.0	-0.3	73.4	-2.1	2.4	1.6
Non-Raw materials	4281	-0.5	402.0	3.0	10.6	-3.3	79.7	83.7
Total energy	15014	-1.6						
Oil	2302	-7.6						
Gas	6079	-1.7						
Solids	4529	-0.6						
Electricity	2104	0.5						

In Japan energy use is reduced in all sectors except non-raw materials. The energy use is especially down for nonferrous metals. By fuel the reduction is strongest for oil, whereas gas use is increased. The sectors with largest output growth are industrial chemicals and non-raw materials. Consequently the energy intensity is strongly reduced for industrial chemicals and non-raw materials. The main structural change is reduction in stone, clay and glass, and ferrous metals, and increase in non-raw materials.

For the U.S., energy use is heavily down for ferrous metals and slightly up for paper & pulp. Oil use is strongly reduced in the period analyzed. Output (value added) is reduced for metals (ferrous and nonferrous). When it comes to energy intensity, the reduction is most marked for industrial chemicals, stone, clay and glass and non-raw materials. Structural changes are relatively small, with a decreasing share for ferrous metals and and increasing share for non-raw materials.

TABLE A.3 The Federal Republic of Germany - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	2774.2	-1.7	153.1	1.0	18.1	-2.6	100.0	100.0
Paper & Pulp	118.6	0.5	3.2	1.2	36.8	-0.7	2.1	2.2
Indust. chemicals	380.8	0.2	9.0	2.7	42.3	-2.4	5.9	7.4
Stone, clay, glass	432.5	4.0	7.6	-0.9	57.2	-3.2	5.0	3.8
Ferrous metals	981.1	-3.4	8.1	-0.8	120.9	-2.5	5.3	4.1
Nonferrous metals	96.0	0.7	1.9	3.8	50.5	-3.0	1.2	1.8
Non-Raw materials	765.2	-0.6	123.2	1.0	6.2	-1.5	80.5	80.6
Total energy[1]	2774.2	-1.7						
Oil	1104.6	-7.1						
Gas	671.4	0.1						
Solids	483.3	0.2						
Electricity	475.9	1.3						

[1] Total energy includes other fuels (district heating), amounting to 39.0 PJ in 1973 and 40.3 PJ in 1987.

The FRG energy use for ferrous metal production is strongly reduced, whereas the energy use for stone, clay and glass production is strongly increased. Value added shows a marked increase for nonferrous metal production. Due to this, energy intensity is more strongly reduced for stone, clay and glass, and nonferrous metal than in the other sectors. The most marked structural changes are a relative growth of industrial chemicals and a relative reduction of stone, clay and glass, and ferrous metal subsectors.

TABLE A.4 France - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	1905.9	-2.2	92.7	0.9	20.6	-3.1	100.0	100.0
Paper & Pulp	97.7	-0.8	2.4	0.8	41.4	-1.8	2.6	2.6
Indust. chemicals	314.6	-0.5	4.4	0.8	72.0	-1.3	4.7	4.6
Stone, clay, glass	277.0	-2.4	5.8	-0.4	47.8	-2.0	6.3	5.2
Ferrous metals	554.2	-4.4	3.0	-1.3	186.0	-3.3	3.2	2.4
Nonferrous metals	89.8	-2.0	1.4	4.5	62.3	-6.0	1.5	2.5
Non-Raw materials	572.7	-1.6	75.7	1.0	7.6	-2.7	81.7	82.8
Total energy	1905.9	-2.2						
Oil	947.3	-7.0						
Gas	295.2	1.3						
Solids	360.0	-0.4						
Electricity	303.5	1.3						

In France energy use for ferrous metal production is strongly reduced, whereas output is strongly up for nonferrous metals. The reduction in oil use is very marked. Intensity is heavily down for nonferrous metals, and somewhat less down for ferrous metals. There are only smaller structural changes.

TABLE A.5 Italy - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	1674.6	-1.4	117.9	2.6	14.2	-3.8	100.0	100.0
Paper & Pulp	78.8	-1.2	5.2	3.1	15.3	-4.2	4.4	4.7
Indust. chemicals	436.7	-3.5	4.2	9.4	105.1	-11.9	3.6	8.8
Stone, clay, glass	370.7	-1.9	7.4	1.6	50.2	-3.4	6.3	5.4
Ferrous metals	303.4	0.2	5.0	1.2	60.7	-1.0	4.2	3.5
Nonferrous metals	36.4	-1.4	0.8	2.3	45.0	-3.6	0.7	0.7
Non-Raw materials	448.6	-0.5	95.4	2.2	4.7	-2.7	80.9	76.9
Total energy	1674.6	-1.4						
Oil	914.1	-6.3						
Gas	325.5	2.5						
Solids	157.0	1.6						
Electricity	278.0	1.8						

TABLE A.6 The United Kingdom - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use 1973 PJ	Energy use 73-87 %/yr	Value added 1973 bill.80$	Value added 73-87 %/yr	Intensity 1973	Intensity 73-87 %/yr	Structure 1973 %	Structure 1987 %
Total manufacturing	2813.0	-2.7	124.9	-0.3	22.5	-2.4	100.0	100.0
Paper & Pulp	107.1	-5.9	3.6	-0.8	29.8	-5.2	2.9	2.7
Indust. chemicals	379.7	-1.2	3.3	2.1	113.6	-3.1	2.6	3.7
Stone, clay, glass	278.7	-3.6	4.8	-1.7	58.5	-2.1	3.8	3.2
Ferrous metals	637.1	-5.4	3.1	-1.8	207.2	-3.7	2.5	2.0
Nonferrous metals	77.5	-0.7	1.5	0.9	50.8	-1.6	1.2	1.4
Non-Raw materials	1333.0	-1.9	108.6	-0.2	12.3	-1.6	86.9	87.1
Total energy	2813.0	-2.7						
Oil	1201.6	-7.7						
Gas	539.0	1.6						
Solids	784.2	-2.6						
Electricity	288.2	0.7						

In Italy industrial chemicals has the strongest reduction in energy use. Similar to the other countries in the group, oil use shows a major reduction. Output is strongly increased for industrial chemicals, and is somewhat less increased for paper & pulp. Consequently, energy intensity is heavily down from the initial high figure for industrial chemicals. The reduction in intensity is also marked for paper & pulp, nonferrous metals and stone, clay and glass. The most marked structural change is a pronounced relative growth of industrial chemicals.

In the United Kingdom energy use is heavily reduced for paper & pulp and ferrous metals. It is noteworthy that output is down in all sectors except industrial chemicals and nonferrous metals. Due to this, energy intensity is heavily down for paper & pulp and ferrous metals. There is no pronounced structural change, except some increase for industrial chemicals.

TABLE A.7 Denmark - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use 1973 PJ	Energy use 73-87 %/yr	Value added 1973 bill.80$	Value added 73-87 %/yr	Intensity 1973	Intensity 73-87 %/yr	Structure 1973 %	Structure 1987 %
Total manufacturing	151.7	-1.2	6.3	1.7	24.2	-2.9	100.0	100.0
Paper & Pulp	7.2	-1.2	0.1	2.9	52.6	-3.9	2.2	2.5
Indust. chemicals	17.0	-7.4	0.2	4.6	90.5	-11.5	3.0	4.4
Stone, clay, glass	46.3	-5.0	0.5	-2.3	91.6	-2.7	8.1	4.6
Ferrous metals	7.8	-3.9	0.0	3.4	162.7	-7.1	0.8	1.0
Nonferrous metals	1.2	-7.5	0.0	-1.8	55.6	-5.8	0.4	0.2
Non-Raw materials	72.3	1.4	5.4	1.9	13.4	-0.4	85.7	87.3
Total energy	151.7	-1.2						
Oil	118.4	-5.6						
Gas	0	1)						
Solids	17.5	5.0						
Electricity	15.8	3.6						

1) Gas use increased from 0 in 1973 to 14.5 PJ in 1987

In Denmark energy use shows a strong reduction for the production of nonferrous metals, industrial chemicals and stone, clay and glass. Breaking down by fuel, solids has almost as strong an increase as the reduction in oil use. Output shows marked increase for the subsectors industrial chemicals and ferrous metals. Due to this, intensity is strongly reduced for industrial chemicals and ferrous metals, and somewhat less reduced for nonferrous metals and paper & pulp. The most pronounced structural changes are the decrease for stone, clay and glass, and the increase for industrial chemicals and non-raw materials.

TABLE A.8 Sweden - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973 PJ	73-87 %/yr	1973 bill.80$	73-87 %/yr	1973	73-87 %/yr	1973 %	1987 %
Total manufacturing	570.2	-1.0	15.4	1.3	37.1	-2.2	100.0	100.0
Paper & Pulp	249.6	-0.9	1.1	1.1	221.4	-1.9	7.3	7.1
Indust. chemicals	28.8	-0.1	0.5	2.2	62.9	-2.2	3.0	3.4
Stone, clay, glass	48.3	-4.5	0.6	-1.0	76.8	-3.5	4.1	3.0
Ferrous metals	105.0	-2.8	0.7	0.8	143.0	-3.5	4.8	4.5
Nonferrous metals	13.2	0.3	0.2	0.9	79.2	-0.6	1.1	1.0
Non-Raw materials	125.4	0.6	12.3	1.4	10.2	-0.7	79.8	81.0
Total energy[1]	570.2	-1.0						
Oil	263.7	-6.7						
Gas	0	0						
Solids	171.2	1.3						
Electricity	132.4	2.0						

[1] Total energy includes other energy sources (district heating), amounting to 2.9 PJ in 1973 and 16.0 PJ in 1987.

In Sweden energy use is mostly reduced for stone, clay and glass, and ferrous metals. Consequently, energy intensity reduction is more pronounced for these two sectors. There are only minor structural changes, with some reduced size for stone, clay and glass, and some increased size for non-raw materials.

In Norway energy use is heavily down for stone, clay and glass. For nonferrous metals, on the other hand, energy use is up, and more so than for any other country. For most other countries energy use in this sector is down. The output increase is largest for industrial chemicals. Thus energy intensity is heavily reduced for industrial chemicals and stone, clay and glass. The main structural changes are growth for industrial chemicals and nonferrous metals, and decrease for non-raw materials.

TABLE A.9 Norway - manufacturing energy use, value added, intensity and structure by sector 1973 - 87

	Energy use		Value added		Intensity		Structure	
	1973	73-87	1973	73-87	1973	73-87	1973	1987
	PJ	%/yr	bill.80$	%/yr		%/yr	%	%
Total manufacturing	259.8	-0.1	6.1	0.6	42.9	-0.7	100.0	100.0
Paper & Pulp	41.9	-0.6	0.3	2.3	165.4	-2.8	4.2	5.3
Indust. chemicals	29.5	-1.2	0.2	6.2	154.4	-7.0	3.2	6.8
Stone, clay, glass	20.7	-4.9	0.3	-0.5	68.8	-4.4	5.0	4.3
Ferrous metals	59.7	-0.4	0.2	0.2	254.3	-0.6	3.9	3.7
Nonferrous metals	60.4	1.0	0.3	2.7	186.5	-1.6	5.4	7.1
Non-Raw materials	47.7	1.0	4.7	0.1	10.0	1.0	78.5	72.9
Total energy[1]	259.8	-0.1						
Oil	81.1	-5.8						
Gas	2.7	0.3						
Solids	48.1	1.8						
Electricity	127.9	1.4						

[1] Total energy includes other fuels (district heating) in 1987, amounting to 0.7 PJ.