The Road from Kyoto: The Evolution of Carbon Dioxide Emissions from Energy Use in IEA Countries

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ABSTRACT

Building on earlier analysis of energy use and CO_2 emissions in 13 member countries of the International Energy Agency (IEA), we quantify energy use and carbon emissions for nearly three dozen activities and economic branches from the early 1970s to the mid 1990s. We show how lifestyles, economic structure, and overall economic growth affect the structure and rate of CO_2 emissions. Similarly we show how energy intensities, final fuel mixes, and utility fuel mixes shape emissions. Using Laspeyres indices, we calculate the relative importance of each of these factors in affecting sectoral and total emissions over time. We focus on consumer sectors, homes and personal travel, but extend the analysis to all sectors of the economies studied. We find that emissions reductions in all sectors after 1990 have been slower than in the previous fifteen years, a period that saw emissions reductions in spite of economic growth. Manufacturing and households led the reductions in most cases, but progress has slowed markedly. In almost all cases, emissions from the transportation sector showed the least reduction and indeed some increases.

Our findings do not give an optimistic view of the recently concluded accords at the Third Conference of Parties (COP-3) in Kyoto, Japan. We conclude that the current rate of energy saving and fuel switching must be greatly accelerated if the IEA countries studied here are to affect reductions in CO_2 emissions to meet their Kyoto targets.

Introduction

There has been much attention drawn to plans for reductions or restraint of future CO_2 emissions since the recent COP-3 meeting in Kyoto. Yet little analysis of the recent history of those emissions by end-use or economic activity has occurred in conjunction with the formulation of those plans. Understanding components of CO_2 emissions, particularly those related to combustion of fossil fuels, is important for judging the likely success of plans to restrain emissions. Knowing how fuel switching, changes in economic activity and its structure, and changes in energy efficiency affected emissions in the past, we can better judge both the realism of national proposals to restrain future emissions and the outcomes as well. Building on previous work, this study presents the next step in establishing such an understanding by contrasting the period before 1990 with that after 1990, the base year chosen for climate change-related agreements.

Background

A detailed review of CO_2 emissions from energy end uses[1] (including primary energy for power and heat generation) showed that for as many as 13 IEA countries, emissions between the early 1970s and 1991 declined relative to GDP in all 13 countries, relative to population in all but three countries, and fell in absolute terms in half of them (Schipper *et al.* 1997a). Since 1990, however, the trends have changed and do not suggest that such declines are about to recur without changes in current policies. Fossil fuels are inexpensive compared to the late 1970s and early 1980s, economies are growing, and the transportation sector, which is almost completely reliant upon petroleum, is growing strongly. In this paper we will compare the underlying components of the 1990-1994 change those from the previous 17 years. Although this study will make no predictions about the future, we will discuss the underlying components of current changes in CO_2 emissions and what they imply about likely trends in the near future.

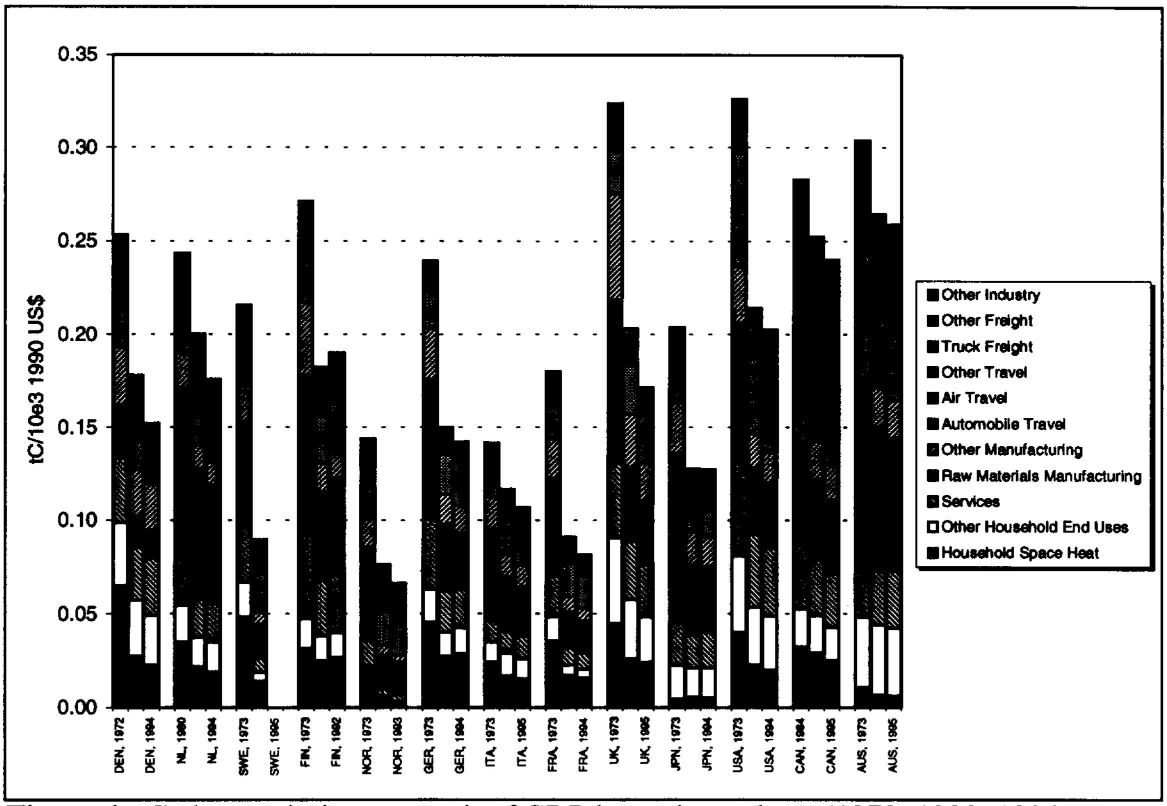

Figure 1. Carbon emissions per unit of GDP by major end use (1973, 1990, 1994)

Decomposing Energy Use and CO_2 Emissions

Figure 1 shows the ratio of emissions to GDP for 13 countries. We display 1973 (or the earliest year for which data were available), 1990 (the base year for climate-related agreements), and the latest

[1] Our data and methodology are described in detail in Schipper & Meyers (1992), Howarth, Schipper & Andersson (1993), and Schipper *et al.* (1997a) as well as in IEA (1997a, 1997b). The latter book, as well as more recent work at the IEA, extends the original analysis to three additional countries and to 1994 or even 1995. Sectoral analyses are presented in Schipper, Scholl & Price (1997) for freight; Schipper, Haas & Sheinbaum (1996) for households; Scholl, Schipper & Kiang (1996) for travel; and Greening, Davis & Schipper for manufacturing (1998).

year for which complete data are available[2]. The drop in emissions per unit of GDP surprises many. What has accounted for these changes? Why has so little change apparently occurred since 1990?

To answer the questions, we decompose carbon emissions from energy use into terms representing the carbon intensity and the "energy services" of each activity. Carbon intensity is the product of three terms: energy intensity (energy use per unit of activity *i* or *Ei/Yi*), final fuel mix (share of each fuel *j* in the total energy used for activity *i* or *Eij/Ei*), and the carbon intensity of each fuel (*Cij/Eij*). We assume that the carbon intensities of primary fuels (oil, gas, etc.) are constant over time, thus the *Cij/Eij* term varies only for electricity and district heat. Since changes in the *Cij/Eij* term represent changes in the primary fuel mix used to generate electricity and district heat, we call this term "utility fuel mix". "Energy services" is the product of two terms: sectoral activity (*Y*) and sectoral structure (share of each activity *i* in total sectoral activity or *Yi/Y*). The units of the *Y* and *Yi* terms are value added for manufacturing[3], GDP for services, population for households[4], passenger-km's traveled for passenger transportation, and tonne-km's hauled for freight transportation. While energy services and energy intensities are not independent of each other, the interaction (also called the "rebound effect") is in general small (Greening & Greene 1997; Berkhout & Velthuisen 1997). The full equation decomposing carbon emissions is shown below where the products are summed across all fuels (*j*) and activities (*i*) for each sector of the economy[5].

$$C = Y\sum_{ij}\left(\frac{C_{ij}}{E_{ij}}\right)\left(\frac{E_{ij}}{E_i}\right)\left(\frac{E_i}{Y_i}\right)\left(\frac{Y_i}{Y}\right)$$

Using this identity, we apply Laspeyres indices to calculate the relative impact of each term on total carbon emissions from a given sector over time. The indices are constructed by choosing a base year, taking the ratio of the above identity to itself, and then allowing one term in the numerator to vary over time while holding all other terms in the numerator and denominator at their base year values. The result is an index that measures the relative impact of the varying term (e.g., final fuel mix) on carbon emissions over time. The results can literally interpreted as "how emissions would have evolved if only one term had changed over time and all other terms remained the same". The benefits of this approach are that the indices are simple to obtain and the results are easy to interpret since everything is expressed relative to a single base year. Other, more sophisticated decomposition indices can be used, notably Adaptive Weighting Divisia indices (see Greening, Davis & Schipper 1998), but these are more complex to obtain and more difficult to interpret due to their rolling base year framework and the varying weights applied to the base and study year.

We calculate an index for each term the identity – the results of which we denote respectively as the utility fuel mix effect, the final fuel mix effect, the energy intensity effect, the structure effect, and the activity effect. As noted above, we can multiply the utility fuel mix, final fuel mix, and energy intensity terms to give an aggregate carbon intensity term, and combine the structure and activity terms to give an energy services term. Similarly we multiply the Laspeyres indices for the components of

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2 Due to lack of available data, Australia starts in 1974, Canada starts in 1984, the Netherlands start in 1981, and Norway ends in 1993.

3 in constant 1990 US dollars converted at purchasing power parity.

4 Secondary activity terms such as floor area and household occupancy are also used to measure changes in "energy services" within the household sector. These secondary activity terms are discussed in the next section.

5 Excluded from the analysis are bunkers and international air travel, as well as an aggregate we label "other industry", consisting of agriculture, construction, and mining, because energy data for the United States and other countries covering these sectors are not available.

carbon intensity and energy services to give a carbon intensity "effect" and an energy services "effect".

For this study, we chose 1990 as the base year. Our reasoning is both technical and analytical. Primarily we wish to examine changes relative to the reference year chosen for the major global climate change agreements – the United Nations Framework Convention on Climate Change and the recent Kyoto Protocol – in order to establish a historical perspective of how energy use and emissions have changed before and after that reference year. However, the choice of 1990 as the reference year proves to make comparative analysis difficult since it was extremely warm year in Europe and many countries were in the midst of economic recessions. Both of these factors make interpretation of changes since 1990 difficult and make comparisons with "target" years difficult, since any country can claim it needs to adjust 1990 upwards to reflect a normal year for heating or for manufacturing. Whatever the difficulties, we use this year as long as it remains the key "base year" for climate negotiations. Secondarily, we wish to improve the accuracy of our index results in the late 1980s and 1990s. Because we use a fixed base year approach, the error term increases as one proceeds farther away from the base year (see Greening *et al.* 1997). In previous studies, we used 1973 as the base year in order to examine changes in energy use over the 1970s and 1980s, thus our results for the 1990s carried the largest error terms. By using 1990 as our base year for this study, we minimize that error term for the late 1980s and 1990s.

Results of Sectoral Decomposition Analyses

Households

We measure the "structure" of household energy consumption using physical proxies for changes in energy services, including floor area per capita (to measure area heated or lit), household occupancy (to measure cooking and water heating services), and appliance ownership per capita. While more accurate indicators would measure quantities like hours and temperature of heating, appliance sizes and utilization, and lumens of light provided, most of these measures are simply unavailable for more than a limited sample of households. Even with such limitations, our structural measures give a reasonable answer to the question "how much does energy use change on the average because there is more or less equipment".

The results in Table 1 show that since the early 1970s, total household carbon intensity fell in almost every country, led by declining energy intensities and improvements in the utility fuel mix. In all but Japan, reduced energy intensities for space and water heating alone cut emissions with Denmark, W. Germany, and the U.S. showing the greatest savings. The household fuel mix generally moved towards gas, which lowered emissions, but the increased penetration of electrical end uses tended to increase emissions slightly in about half the study countries. In the "nuclear" and "hydro" countries where electricity was not carbon-intensive (France, Norway, Sweden) this component pushed household emissions down even more.

Since 1990, the rate of energy savings has slowed in 9 of 13 countries, due primarily to flat trends in space heating energy intensity. The energy intensities of appliances continue to fall, but only slowly. Household fuel mixes also continued to wander towards lower carbon intensity, but the increasing share of electricity in the non-nuclear countries has kept this trend gradual. Energy services, on the other hand, are steadily increasing due to structural changes such as growth in per capita floor area (which bolsters space heating and lighting demand) and increased appliance penetration. With carbon intensities decreasing slowly and energy services growing steadily at the about same rate as in the pre-1990 period, it is clear that household decarbonization has slowed in 7 of 13 countries.

Table 1. Decomposition results for the household sector (annual average rates of change)

	Actual Emissions	Activity	Structure	Carbon Intensity	Energy Intensity	Final Fuel Mix	Utility Fuel Mix
				1973-1990			
Denmark (72)	-1.2%	0.2%	1.3%	-2.9%	-2.6%	-0.1%	-0.2%
Norway	-4.0%	0.4%	-2.8%	-2.5%	-0.2%	-2.2%	-0.2%
Sweden	-5.4%	0.3%	1.4%	-7.1%	-2.4%	-3.9%	-3.4%
Finland	1.7%	0.4%	2.4%	0.4%	-2.5%	0.4%	-1.4%
Holland (81)	-0.5%	0.5%	0.9%	-2.7%	-3.2%	0.6%	-0.1%
France	-2.0%	0.5%	2.0%	-4.6%	-1.6%	-3.4%	-3.0%
W. Germany	-0.5%	0.1%	2.7%	-3.1%	-2.2%	-0.1%	-1.1%
Italy	1.6%	0.2%	1.0%	0.0%	-0.4%	0.2%	0.3%
UK	-0.7%	0.1%	1.0%	-1.4%	-1.0%	0.2%	-0.7%
USA	0.2%	1.0%	1.6%	-2.6%	-2.3%	0.2%	-0.6%
Japan	3.4%	0.7%	2.3%	-0.1%	0.7%	0.1%	-1.2%
Australia (74)	2.9%	1.4%	1.7%	-0.4%	-0.2%	0.4%	-0.6%
Canada (84)	1.9%	1.3%	0.2%	0.4%	-0.6%	1.1%	-0.2%
				1990-1994			
Denmark	-2.3%	0.3%	0.9%	-3.3%	-1.5%	-0.2%	-1.6%
Norway (93)	-16.5%	0.5%	-10.8%	-7.4%	-4.1%	-3.4%	-0.1%
Sweden	1.8%	0.6%	1.1%	0.0%	-2.4%	-0.5%	2.8%
Finland	0.8%	0.5%	1.5%	0.0%	-0.9%	0.0%	-1.7%
Holland	0.4%	0.7%	1.0%	-0.9%	-2.2%	1.3%	0.1%
France	-1.6%	0.5%	1.3%	-3.3%	-0.5%	-2.8%	-1.7%
W. Germany	3.3%	0.7%	1.9%	0.7%	0.9%	-0.3%	0.1%
Italy	-0.9%	0.2%	-2.0%	5.0%	0.1%	5.6%	-1.0%
UK	-1.9%	0.4%	1.0%	-3.0%	-0.8%	0.6%	-2.8%
USA	0.0%	1.1%	2.1%	-2.5%	-1.7%	0.2%	-0.9%
Japan	2.3%	0.3%	3.1%	-1.1%	-0.5%	0.0%	-0.5%
Australia	1.4%	1.1%	0.6%	-0.3%	0.0%	-0.3%	0.1%
Canada	-1.0%	1.3%	-1.2%	-3.4%	-1.9%	-0.2%	-1.4%

Examining households at the end-use level reveals some surprising differences among countries (see Figure 2). Improvements in building insulation and heating equipment efficiency have led to lower space heating energy intensity in the Nordic countries than in North America or the other European countries. Additionally, the availability of low-carbon electricity in both Sweden and Norway lowers their space heating emissions even further. In contrast, the low average indoor temperatures of Japanese homes is the primary reason behind Japan's extremely low space heating emissions. Note that there is still a slow decline in per capita space heating emissions in a few countries. However, floor area is still growing slowly, so the outlook for space heating emissions is one of weak growth.

With the major appliances nearing saturation in most of our study countries, per capita energy use for appliances in the U.S. remains far higher than elsewhere both because appliances are larger and, to some extent, less efficient than elsewhere (although new U.S. appliances are now among the most efficient in the world) and because ownership of "miscellaneous appliances" (televisions, computers, etc.) is rising rapidly. It is possible that improvements in appliance efficiency in the U.S. and elsewhere will almost balance increases in ownership in the next few years.

Overall, with the winter climate (measured in heating degree-days) in the U.S. being close to the average of all countries, it is the size of U.S. homes and the number of appliances, then, that are the most important factors differentiating emissions in the U.S. from other countries, with utility fuel mix in the Nordic countries (save Denmark) and France offering important low-carbon power there. Since the electricity fuel share in this sector has risen everywhere, both the efficiency of electricity use and the resulting emissions from the utilities sector will play key roles in future emissions. Similarly, as space heating energy efficiency is now only changing slowly, the overall fuel mix in households, which tends to favor natural gas except where electricity is very cheap, will also play a key role in determining future emissions from this sector.

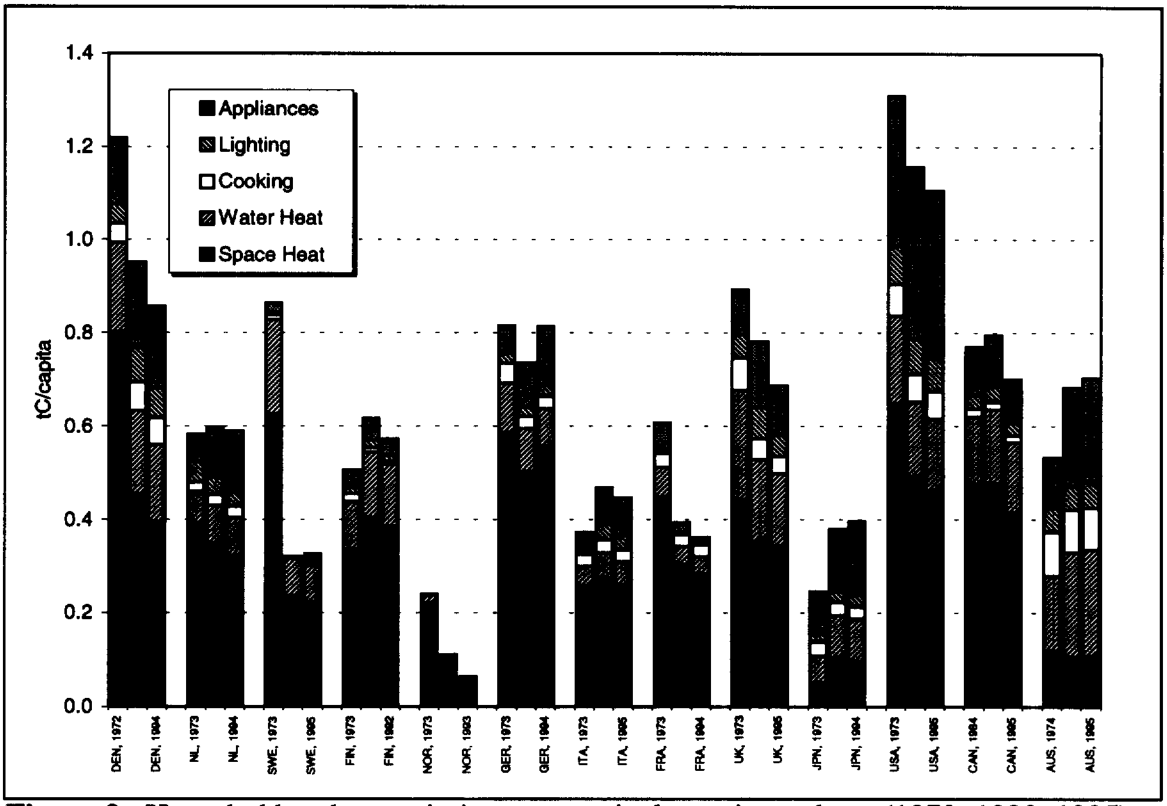

Figure 2. Household carbon emissions per capita by major end use (1973, 1990, 1995)

Travel

As the results in Table 2 show, only the U.S. showed a major reduction in the carbon intensity of passenger transportation (1.4% per year), which alone reduced cumulative emissions by 25-30% through 1990[6]. Here and elsewhere, modal shifts towards cars and air travel raised emissions, by enough to offset small reductions in intensities in most European countries and Japan. The growing volume of domestic travel, led by cars and air, boosted emissions in all countries, although the U.S. and Canada only passed their per capita 1973 levels in the early 1990s. Fuel mix had almost no effect here since the various oil products used have nearly the same emissions per unit of energy and the share of alternative fuels remains insignificant.

After 1990, U.S. and Japanese energy intensities rose slightly, led by those of cars and light trucks, and per capita emissions started upward in the former country. Modal shifts continue to boost emissions slightly. As the world climbed out of its deep recession, travel grew strongly so that by 1995 travel-related emissions were rising in 9 of 13 countries. As the fuel intensities of new cars are now falling only very slowly, emissions in this sector should continue to rise unless dramatic changes in new-car fuel economy and the rate of stock turnover are achieved.

At the end-use level, the story is somewhat the same as that for households: energy efficiency per se plays an even less striking role in differentiating the countries. To be sure the fuel intensity of North American vehicles (nearly 12 liters/100 km in the U.S. and slightly lower in Canada) is higher than in Europe, where intensities range from around 7.5-8 liters/100 km in Denmark, France or Italy to

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6 Since complete data prior to 1984 are missing for Canada we can not estimate this effect here. However, data for car use alone indicate that a similar trend can be also be observed in Canada.

Table 2. Decomposition results for the travel sector (annual average rates of change)[7]

	Actual Emissions	Activity	Structure	Carbon Intensity	Energy Intensity	Final Fuel Mix
			1973-1990			
Denmark (72)	1.1%	1.2%	-0.2%	0.0%	-0.1%	0.1%
Norway	3.3%	2.9%	-0.1%	0.4%	0.5%	-0.1%
Sweden	1.8%	1.3%	-0.1%	0.4%	0.5%	0.0%
Finland	3.6%	2.8%	0.2%	0.4%	0.1%	0.3%
Holland (81)	-0.5%	2.4%	0.2%	-0.5%	-0.7%	0.2%
France	2.5%	2.5%	0.1%	-0.2%	-0.1%	-0.1%
W. Germany	2.8%	2.2%	0.2%	0.4%	-0.1%	0.5%
Italy	3.5%	3.8%	0.0%	-0.3%	-0.5%	0.2%
UK	2.4%	2.7%	0.2%	-0.5%	-0.6%	0.0%
USA	0.5%	1.7%	0.0%	-1.4%	-1.4%	0.0%
Japan	3.7%	2.9%	1.0%	-0.5%	-0.4%	0.0%
Australia (74)	2.8%	3.3%	-0.3%	-0.2%	-0.3%	0.0%
Canada (84)	1.3%	3.6%	0.1%	-2.3%	-2.2%	-0.1%
			1990-1994			
Denmark	0.9%	1.1%	0.0%	-0.1%	-0.2%	0.0%
Norway (93)	0.1%	0.4%	-0.4%	0.1%	0.1%	0.0%
Sweden	-0.1%	-0.2%	0.1%	0.0%	0.0%	0.0%
Finland	-1.5%	-1.0%	0.1%	-0.5%	-0.4%	-0.1%
Holland	3.6%	2.4%	-0.1%	1.3%	0.0%	1.2%
France	1.6%	2.1%	0.4%	-0.9%	-0.9%	0.1%
W. Germany	-0.8%	-0.1%	0.0%	-0.6%	-0.9%	0.3%
Italy	3.7%	3.5%	0.4%	-0.6%	-0.5%	-0.2%
UK	-0.3%	0.0%	0.1%	-0.4%	-0.2%	-0.1%
USA	2.1%	1.9%	0.0%	0.2%	0.2%	0.0%
Japan	4.9%	2.3%	0.9%	1.7%	1.6%	0.0%
Australia	2.1%	2.2%	1.3%	-0.7%	-0.8%	0.0%
Canada	1.5%	2.7%	-0.1%	-1.1%	-1.0%	-0.1%

about 9.5 liters/100 km in Sweden and Germany. Surprisingly, Japan lies at above 10 liters/100 km, with Australia at nearly the same level as the U.S. But it is the total distance traveled, particularly in cars, that provides a much sharper element distinguishing emissions, as noted above. And while domestic air travel is large in a few countries, the energy intensity of that mode is close to that for autos in most countries where it is important (U.S., Canada, Japan, Australia, Sweden). Thus air travel per se is not a high-carbon mode, but it is a high-distance mode because of its speed. By contrast, rail and bus travel are associated with fewer emissions/pass-km than other modes. An important exception are city buses in the U.S., which on average release more carbon/pass-km than cars. Clearly as relative utilization and vehicle efficiencies keep changing, it will be important to monitor where the real carbon savings lie.

Looking at changes in emissions from travel over time, increasing activity and shifts towards cars and air travel have all boosted emissions since the early 1970s (see Table 2). The ratio of fuel used to car power or weight has fallen steadily, a sure sign of improved technological efficiency. However, both the average weight and power of vehicles have increased steadily. In Europe, efficiency moved faster, resulting in a slow decline in fuel intensity even in the 1990s, while U.S. fuel intensity, which declined dramatically over the 1970s and 1980s, stopped its decline as "urban assault vehicles" increased their popularity. But in all countries, the average occupancy of cars fell from over 2 persons/vehicle in the early 1970s to 1.5-1.6 persons/vehicle, increasing energy and carbon intensity of car travel. By contrast, aircraft fuel intensity fell by 40% and the share of seats filled increased by roughly 20%, resulting in a more than 50% drop in energy and emissions per passenger-km flown.

[7] We do not explicitly measure utility fuel mix effects in either of the transportation sectors since electricity accounts for only a very small share of total energy.

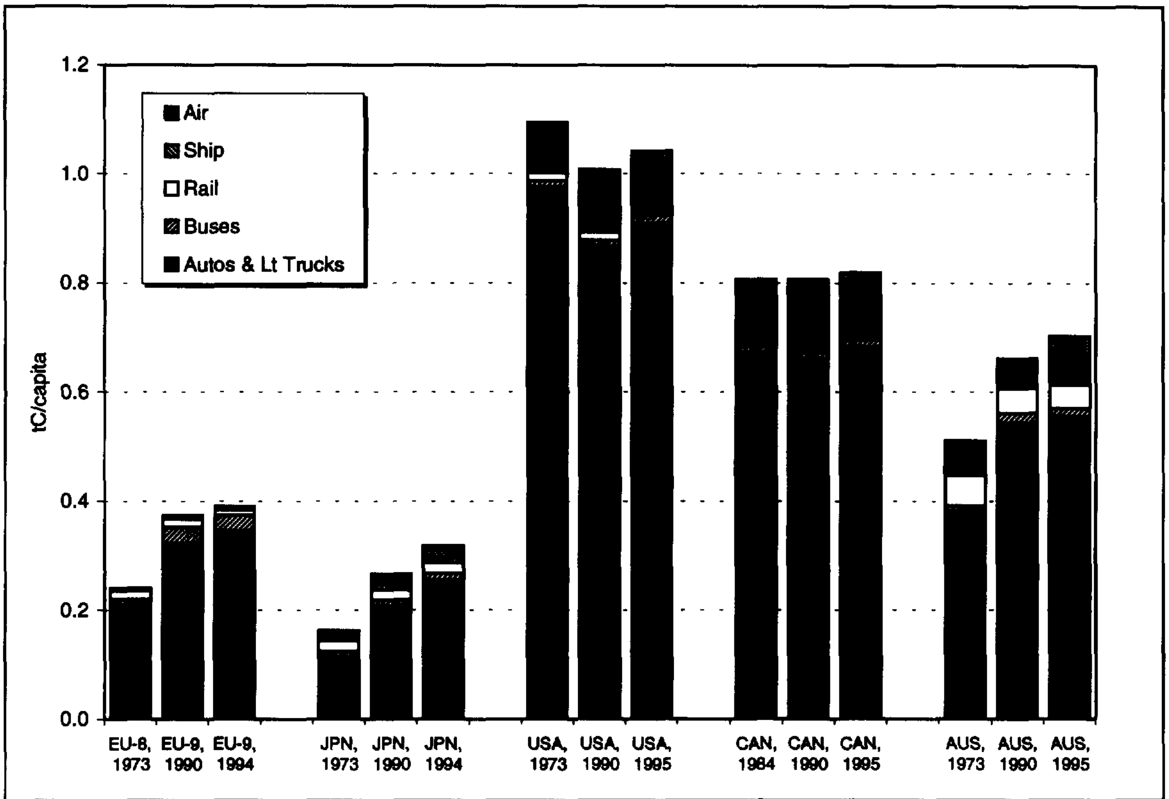

Figure 3. Travel carbon emissions by mode (1973, 1990, 1995)[8]

Diesels have become popular in some countries in Europe, principally because diesel fuel is cheaper than gasoline. Since buyers of diesels tend to choose somewhat larger engines than in corresponding gasoline models, only some of the potential energy and carbon savings benefits of diesel have been utilized. Diesels are also driven more than gasoline models (Hivert 1996). Although the exact carbon content of diesel is higher than that of gasoline, refining losses may be less. Nevertheless, the overall picture suggests that diesel fuel as used today offers few carbon benefits.

The past savings notwithstanding, the trends of these two consumer sectors combined have turned since 1990. As noted above, the slow-down in energy savings in heating is the most important reason, followed by the stagnation of vehicle fuel economy in North America. Fuel economy elsewhere is improving slowly with stock turn-over, as is home heating efficiency and the efficiency of electric appliances. But while the energy efficiency gap between new and existing home heating systems and appliances is still about 30%, that gap for cars is very small (Schipper *et al.* 1997b). And while most household energy uses, particularly heating and major appliances, are growing slower relative to incomes than before 1990, car use and travel in general shows much weaker signs of saturation. And in each sector, the rate of energy and carbon savings now is less than the rate at which energy services are driving emissions upward. Hence neither sector appears poised to contribute to emissions reductions in the majority of our study countries.

Manufacturing

[8] We aggregate the western European countries when comparing the transportation sectors because land areas, vehicle ownership and driving patterns are very similar across countries. Additionally, Europe experiences heavy volumes of inter-country travel and freight haulage, so in many ways it is more accurate to compare the aggregate than individual countries.

In manufacturing, emissions per unit of manufacturing GDP fell in all countries, and emissions per capita in 1990 were below those in 1973 in most. The greatest drop occurred in Sweden, led by fuel switching at both the final-user and utility levels, bolstered by lower energy intensities. In all other countries, falling energy intensities had the largest downward effect on emissions from 0.8% per year in Australia to 2.9% per year in France. Structural change reduced emissions further in 8 of 13 countries, most notably W. Germany, the U.S., and Japan, as countries shifted away from energy-intensive raw materials production. Changes in utility fuel mix also contributed to lower emissions as oil and coal were gradually replaced with gas, but the largest reductions occurred in Sweden and France where nuclear power became particularly prevalent. Changes in final fuel mix had varied effects because some countries favored coal as a substitute for oil products and actually increased emissions slightly in half the countries.

Since 1990, the rate of energy intensity declines has slowed in all countries, and in a few countries, notably Japan, energy intensities have increased. Some of this change is a consequence of the recession in the early 1990s. Structural change has slowed, in part due to shifts towards some energy-intensive branches in Denmark, the Netherlands, W. Germany, and Australia. Only three countries maintained rates of decarbonization close to those of the pre-1990 period – the U.K., Canada, and France – and in cases, even though energy intensities did decline, their decarbonization was augmented by significant fuel switching away from oil and coal in the power sector. Unquestionably, decarbonization in the manufacturing sectors of our study countries has slowed in the 1990s.

Services

Reduced energy intensities for space heating contributed to great reductions in emissions per unit of GDP and emissions per square meter of floor area in this sector. The growth rate of both sectoral output and floor area offset much of this trend, however, so that by 1990 emissions per capita were about what they were in 1973 and growing. Electricity steadily gained share in the fuel mix of all countries, and those countries with low-carbon electricity consequently showed the biggest emissions reductions in the services sector. Overall services carbon intensity fell in 12 of 13 countries. It rose only in Australia, primarily because energy intensity increased and fuel mix had a similar effect.

Since 1990 the energy savings rate in the services sector has slowed. Indeed, energy and carbon intensities are rising in half the countries. Fuel use now accounts for less than 50% of emissions on average, the rest coming from heat and electric utilities. Broad exceptions are those countries with very low electricity penetration (Denmark and the Netherlands) or those with very low-carbon electricity. Thus future emissions depend very much on the growth of electricity use and the future of appliance and space heating energy intensities.

Freight

In many ways this sector showed the strongest relative growth in emissions of all. Between 1973 and 1990, strong growth in activity driven by rising GDP and steady shifts towards trucking raised emissions 2-3% per year in every country, enough to keep pace with GDP. In six countries, the energy intensities of trucking (the dominant source of emissions) were falling enough to cut into this growth, but emissions per capita in every country were higher in 1990 than in 1973.

Although recession cut into the growth rate of freight volume and emissions after 1990, these trends continued. However, eight countries showed falling carbon intensities, again driven by lower trucking energy intensities. These include the U.S., Australia, Canada and a few European countries.

Increases in trucking activity continued to lead emissions upward. Longer-term trends will only be clear when the full effects of recession have worn off. Freight remains a source of growth in emissions that is hardly mentioned in policy contexts.

Integration of Sectoral Analyses: Economy-Wide Changes in Emissions

To summarize the changes in emissions by country, we use the following procedure. Using the indices calculated for the different "effects" at the sectoral level, we multiply each index by the base year quantity of carbon emissions (in MtC) in that sector. The analogous effects from each sector are then summed to give a "total" effect, which is weighted by each sector's contribution to total emissions. In order to compare these total effects across countries, we convert each series back to an index by dividing each series by total emissions in the base year. Comparing the rates of change in the period before 1990 with those after 1990 shows whether the trends identified in Schipper *et. al* (1997a) have changed significantly in the 1990s. We show key results in Table 3 along the growth rates of GDP and emissions per GDP over the same time periods.

Table 3. Decomposition results for all sectors plus GDP and emissions/GDP trends (annual average rates of change)[9]

	Actual Emissions	Activity	Structure	Carbon Intensity	Energy Intensity	Final Fuel Mix	Utility Fuel Mix	Energy Services	GDP	Emissions/ GDP
					1973-1990					
Denmark (72)	-0.1%	1.1%	0.3%	-1.9%	-2.3%	0.5%	-0.1%	1.5%	1.8%	-1.9%
Norway	-0.9%	1.4%	-0.1%	-2.1%	-0.6%	-1.7%	-0.1%	1.3%	3.3%	-4.2%
Sweden	-3.3%	1.1%	0.2%	-4.8%	-1.4%	-2.5%	-2.0%	1.3%	1.9%	-5.4%
Finland	0.5%	2.3%	0.6%	-2.3%	-2.0%	-0.4%	-1.1%	2.9%	2.9%	-2.4%
Holland (81)	0.8%	1.9%	0.5%	-1.6%	-2.0%	0.4%	-0.1%	2.4%	2.5%	-1.6%
France	-1.6%	1.5%	0.5%	-3.9%	-1.7%	-1.4%	-2.2%	2.0%	2.4%	-4.1%
W. Germany	-0.6%	1.4%	0.6%	-2.8%	-2.2%	0.3%	-1.1%	2.0%	2.2%	-2.9%
Italy	1.6%	2.6%	0.1%	-2.0%	-2.4%	0.2%	0.3%	2.7%	2.8%	-1.2%
UK	-0.7%	1.0%	0.2%	-1.8%	-1.8%	0.4%	-0.5%	1.2%	2.0%	-2.8%
USA	0.2%	1.9%	0.1%	-2.0%	-1.8%	0.1%	-0.4%	2.0%	2.7%	-2.5%
Japan	0.9%	2.7%	0.0%	-2.1%	-1.8%	0.3%	-0.8%	2.7%	3.7%	-2.9%
Australia (74)	2.5%	2.0%	1.0%	-0.5%	-0.7%	0.5%	-0.4%	3.0%	3.0%	-0.4%
Canada (84)	1.3%	2.2%	0.1%	-1.2%	-1.2%	-0.1%	-0.1%	2.3%	3.1%	-1.8%
					1990-1994					
Denmark	0.0%	0.6%	0.4%	-0.8%	0.3%	0.0%	-1.2%	1.0%	1.6%	-1.6%
Norway (93)	-1.1%	0.7%	-0.8%	-0.8%	-0.5%	-0.5%	0.0%	-0.1%	3.0%	-4.0%
Sweden	1.5%	0.5%	1.1%	0.0%	-1.6%	-0.1%	1.8%	1.5%	-0.6%	2.0%
Finland	-3.1%	-2.8%	1.8%	-1.4%	1.8%	-0.9%	-3.6%	-1.1%	-5.3%	2.4%
Holland	1.0%	1.1%	0.8%	-0.8%	-1.2%	0.5%	0.0%	1.9%	2.1%	-1.1%
France	-0.8%	0.6%	0.5%	-1.9%	-0.2%	-0.9%	-1.1%	1.1%	0.9%	-1.7%
W. Germany	0.6%	0.3%	1.0%	-0.6%	-0.3%	0.0%	-0.3%	1.3%	1.8%	-1.2%
Italy	-0.2%	1.0%	-0.2%	0.2%	-0.7%	1.8%	-1.0%	0.7%	0.7%	-0.9%
UK	-2.4%	0.3%	0.2%	-2.7%	-0.6%	0.2%	-2.3%	0.5%	0.9%	-3.2%
USA	0.9%	1.8%	0.7%	-1.3%	-0.8%	0.1%	-0.6%	2.5%	2.3%	-1.3%
Japan	1.6%	-0.4%	0.8%	1.2%	1.5%	0.1%	-0.3%	0.4%	1.4%	0.2%
Australia	1.5%	1.4%	0.5%	-0.3%	-0.4%	0.1%	0.0%	2.0%	3.3%	-1.7%
Canada	-0.2%	2.0%	0.6%	-2.6%	-1.5%	0.3%	-0.9%	2.6%	1.3%	-1.4%

Table 3 shows that increased energy services led to increased emissions in all countries. The growth in emissions through 1990 from increased activity ranged from 1.2% per year in the U.K. to 3% per year in Australia. Japan saw 2.7% per year growth, but GDP grew by a greater amount. Indeed, for most countries, energy services in most sectors grew *less* rapidly than GDP, although the

9 In calculating a total structure effect, we hold the structure term for services at 100% over the whole time series. Similarly for the total utility fuel mix effect, we hold those terms for travel and freight at 100% over the entire time period.

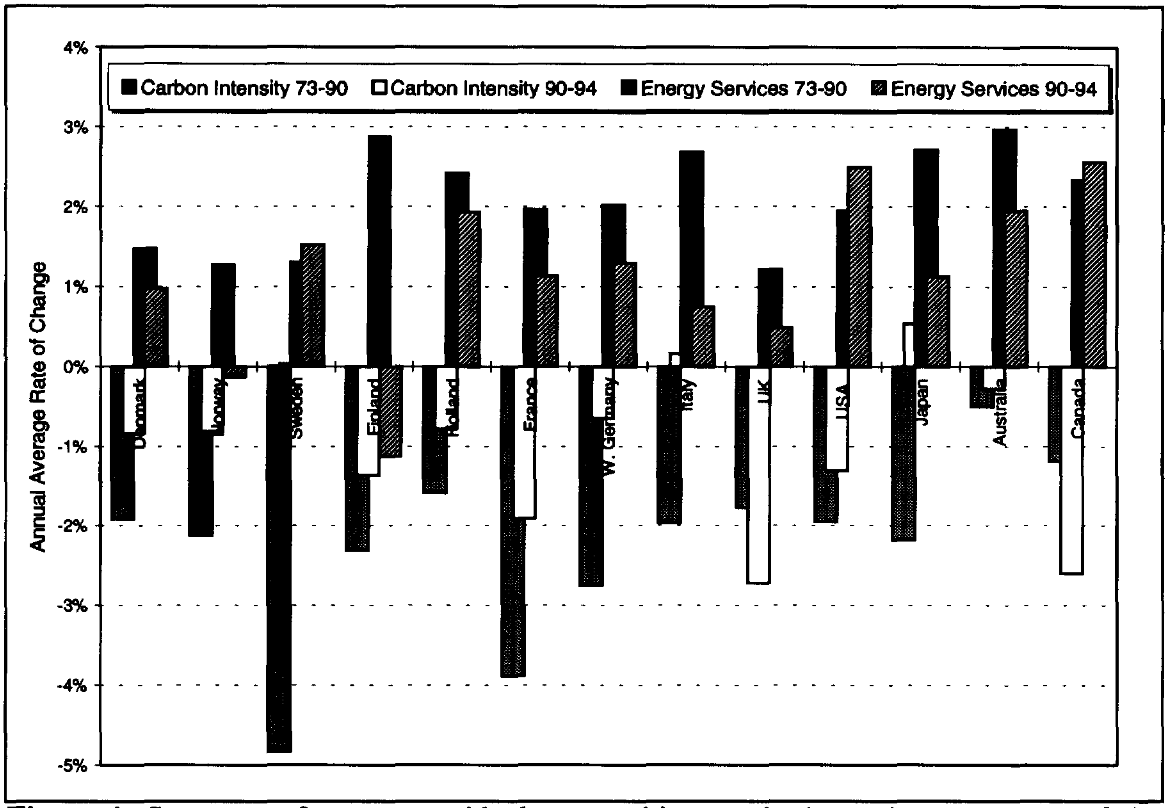

Figure 4. Summary of economy-wide decomposition results (annual average rates of change)

gap in the Netherlands, Finland, and Australia was very small. There, shifts towards energy-intensive industries, and an increase in consumer amenities (car ownership and use, heating demand, appliance ownership) vaulted energy services upward at nearly the same pace as GDP. In the other countries, the ratio of CO_2 to GDP fell "without anyone trying" from these structural changes alone.

After 1990, GDP grew erratically, recovering strongly in the U.S. and a few other countries, but only weakly in others. Sectoral activity that followed GDP closely (freight, manufacturing, and services) tended to follow these patterns. Structural changes continued slowly, mostly to raise emissions. Overall, energy services, the combined effect of these two components, raised emissions in all countries, but at a slower rate than before. This is mostly because GDP grew more slowly.

Changes in final energy intensities reduced emissions in every country. The greatest declines occurred in the U.S., W. Germany, the U.K., Denmark, and Italy, where emissions fell around 30% because of the drop in final energy intensities. The slowdown in the intensity decline after 1990 was a major reason for the slow-down in the CO_2 intensity declines in most countries.

Changes in the final fuel mixes for energy uses has only weakly affected emissions, and usually upward. Continued increases in the use of high-carbon electricity in a few countries and transport fuels in all are the main reason. This trend seems to have flattened after 1990, but most countries still showed increasing emissions from this component. Exceptions to the trend are France, Finland, Norway, and Sweden, where the rising share of low carbon electricity means a less carbon-intensive final fuel mix.

The utility mix effect led to lower emissions in all countries because of the falling carbon coefficients for electricity and district heat. As in other sectors, however, this factor, which reduced emissions in 12 of 13 countries before 1990, was still effective only in 9 of 13 after 1990. The choice of 1990 as a base year affects this result, since some countries (notably Denmark and Italy) experienced increased carbon intensity as they moved towards more coal in their utility fuel mix in the 1970s and early 1980s. Note that this trend has continued downward slowly in all countries except Australia and Sweden. In Sweden the jump in the 1990s in utility carbon intensity appears to have been a short-term response to problems with hydro and nuclear. With coal waiting to yield to gas or other sources in W. Germany, the U.K., Denmark, and to a lesser extent in the U.S., this component should continue to lead to reduced emissions.

Figure 4 summarizes two important components of emissions before and after 1990. We show changes in both carbon intensities and energy services for all countries for the two periods. Clearly carbon saving has slowed. While carbon-raising activities appear to have slowed, too, much of this effect is due to slower GDP growth. Indeed, the ratio of carbon to GDP (from the sectors studied) continued to fall in all but one country, but almost universally at a slower rate after 1990 than before[10]. Thus we can now "explain" the slower drop in the value of CO_2 per capita or CO_2 per GDP in each country after 1990: both energy or carbon intensity fell less rapidly, while economic structure itself either proceeded less rapidly away from carbon-intensive activities or in a few countries even became slightly more carbon intensive. Lower economic growth offered some respite from absolute emissions growth, but only the U.K. showed a strong decoupling of emissions from economic growth and structure. Can others follow?

Conclusions and Implications

This review has shown that between 1970 and the mid 1990s, CO_2 emissions from the major energy-using sectors in 13 IEA countries have declined or not increased as rapidly as overall economic output. Falling energy intensities, shifts away from coal and oil, and in some countries a marked reduction in the role of energy-intensive manufacturing all contributed to this restraint. In all countries, however, greater consumer household comforts, personal mobility, and increased reliance on trucks all led to oppose this general trend. Relative to GDP growth, the evolution of sectoral activity and sectoral structure since the early 1970s has undermined the restraint of CO_2 emissions in all but one country. Recent trends, combining renewed economic growth with a slowdown in the decline in energy intensities and growth in the size and power of personal vehicles, slowed or reversed the decline in emissions relative to GDP.

A key issue raised above is that of differentiation of present emissions based on long term differences among countries. Consider the following factors driving emissions, some of which are relatively independent of GDP:

- Heating degree-days vary from 900 in Australia and 1800 in Japan to over 4500 in Canada and Finland.
- Automobile use per capita varies from a high of 13,500 km/year in the U.S. to a low of 3900 km in Japan; trucking tonne-km vary by a factor of two; and the ratio of freight hauled/GDP varies by more than a factor of two, clearly a function of geography as well as other considerations.
- Home size varies from over 155 sq meters/home (or nearly 60 sq meters/capita in the U.S.) to less than 90 sq meters/home, and closer to 30 sq meters/home in Japan.
- Road fuel prices vary by a factor of three, home heating fuel prices by a factor of two, electricity prices in any sector by as much as a factor of three across countries, all compared using purchasing power parity.

[10] Note how for Australia, Finland, and the Netherlands, this "energy services" term grew at almost the same rate as GDP up until 1990.

Some of these factors are "natural", such as climate or geography, while others, such as those affecting the size of the built environment for example, depend on tax, housing, and urban policies. Will any of these driving factors relax their apparent grip on patterns of energy use and therefore carbon emissions? We cannot say, but we estimate that these kinds of differences and the policies underlying them contribute to more than half of the differences in the ratio of carbon emissions to GDP, with primary fuel mix, final fuel mix, and energy intensities contributing the rest. Ironically, energy intensities have converged in some sectors as technologies are international. This is an important consideration since most equipment for transport and buildings is produced by multinational firms. With one important exception, then, efficiency can 'travel' if it pays. The exception is buildings, which are erected under strong influence of local traditions, building codes, and domestic materials.

We also contrasted the energy- and carbon-saving record of households with that of travel. With building codes and, in some countries, appliance efficiency standards already in place, key policies in the buildings sector must focus on lowering energy uses in existing homes and buildings, which is now moving very slowly. And while vehicle stocks turn over more rapidly than do homes, there are no simple retrofits available at all, and the new/on-road gap is small for cars. Recent pledges by European manufacturers may lead to 20-25% lower fuel intensities in new cars after the turn of the century, which is encouraging. But that only leads to the same change in the entire stock by 2020, unless consumers also change their buying habits, particularly in the U.S.

How many driving factors will be challenged in each country's attempt to pursue its Kyoto targets? Will Americans accept higher energy prices? Will company car privileges in Europe finally end, along with the American tax deduction for interest on money borrowed to buy a house? Will diesel fuel prices rise to those of gasoline in Europe? Will effective energy efficiency policies be strengthened? These are questions we cannot answer at this writing, yet they all appear to be key to understanding the future path of emissions.

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