People in the Greenhouse Environment: International Comparison of Indicators of CO_2 Emissions from Homes and Travel

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In this paper we show how both energy use and CO_2 emissions from household activities and travel have evolved since 1973. We show how changes in the structure of activity (appliances owned, space heated, distance traveled by mode) have led to increased energy use and CO_2 emissions even as falling energy intensities and fuel switching have saved energy (or restrained growth) and reduced emissions. We then compare the trends in emissions from households (flat) with those from personal transportation (rising except in the United States, at least until recently). We explore some of the underlying reasons for these different trends, and point out that it is the size of homes in the United States and distances American travel that make the two largest contributions to the difference in per capita emission in the United States and the other countries. We show how the energy required to move a kilogram of average new car one kilometer is falling in most countries, with little variation between the countries, suggesting that ''efficiencies'' are improving and differ little among countries, but car weight differs significantly, suggesting that technology is far from the only element determining fuel use and therefore CO_2 emissions. We close by outline important research aimed at establishing at the invidual household level the links between lifestyles, expenditures, time use, transportation, and household energy use.

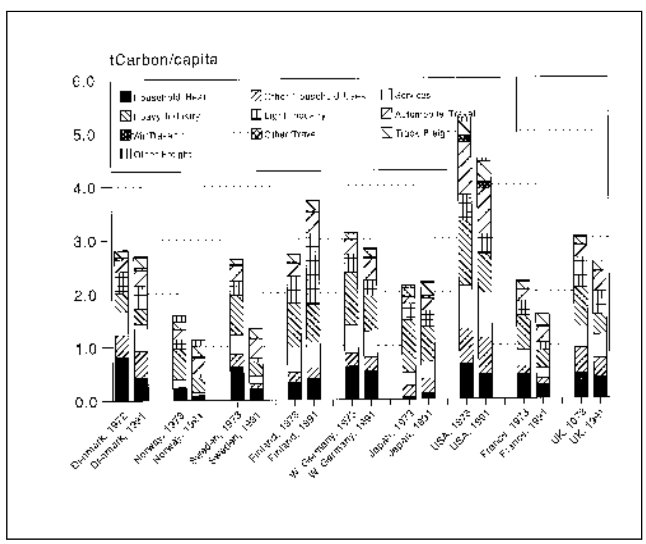
INTRODUCTION

In spite of growing concern to many over the greenhouse effect, there has been surprisingly little effort to link emissions to human activities, particularly those associated with energy use. This paper will make this link by discussing some of the underlying forces driving increased emissions of greenhouse gases in developed countries, focusing on carbon dioxide. In doing so, we shall also introduce some novel *indicators* to describe these forces.[1] These indicators, originally developed in work at the Lawrence Berkeley Laboratory (LBL), now form the basis of a pilot project led by the International Energy Agency, Paris, with inputs from LBL, the French Energy Agency *ADEME,* and the University of Utrecht.

Figure 1 gives the energy/CO_2 connection a more human meaning. We show the emissions per capita in International Energy Agency (IEA) member countries in 1973 and 1991 from energy-using activities, allocating the emissions arising in the production of both electricity and district heating to the end uses of those energy forms in proportion to final use (Schipper, Haas, and Sheinbaum 1996; Schipper, Scholl and Price, 1996; Schipper et al. 1996a, b; Scholl, Schipper, and Kiang 1996; Torvanger 1991). The figure suggests that it is possible to connect emissions to the activities where they arise. Note that for many countries, per capita emissions from these sectors actually fell between the years portrayed; were we to normalize by GDP in each year shown, we would find the decline in the resulting ratio dramatic in every country. Indeed, absolute emissions for a majority of the countries shown were close to or lower than their 1973 levels in 1991, but have begun to rise since then.

This paper explains the components of energy demand that drove the changes in carbon emissions implicit in Figure 1. Then we argue that the critical sectors for emissions changes have been those related to consumers, namely households and personal travel. We will then contrast those two sectors

Figure 1. *Carbon Emissions by End-Use in IEA Countries: 1973 and 1991*



to suggest that while emissions from the household sector have remained roughly constant, those from travel continue to increase. We suggest that while household energy uses, and therefore likely emissions as well, may be showing signs of saturation, those from travel do not show such saturation. Above all, we will highlight important *indicators* of factors that drive energy use and carbon emissions as well.

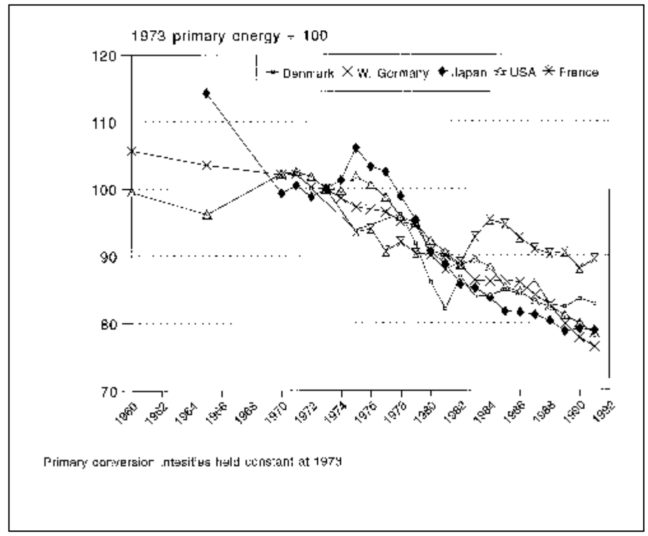
COMPONENTS OF ENERGY DEMAND: LESSONS FROM THE PAST 20 YEARS

Using a bottom-up decomposition of each economy studied into nearly three dozen transport modes, household energy uses, and branches of industrial production we examined the underlying elements of the structure and intensities of energy use in industrialized countries (Schipper et al., 1996a; 1996b; see also Schipper, Howarth, and Carlesarle 1992; Schipper, Howarth, Andersson and Price 1993; Howarth, Andersson and Schipper 1993; Schipper and Price 1994). We used Laspeyres indices to measure how components of energy use changed (Howarth, Schipper, and Andersson 1993; Greening, Davis, and Schipper 1996). We decompose energy use (or emissions) into a sum, over each end-use sector, of the products of subsectoral activity or output, energy use per unit of activity or output, and carbon emissions per unit of energy consumed. We then follow one of the components of energy use over time, holding the others constant, to see how that component affects each energy use.

We found that, all else equal, structural changes in the mix of goods produced in manufacturing had a profound impact on energy use, reducing consumption in that sector by as much as 12 percent between 1973 and 1991 in the United States, Japan, and West Germany, but by very little in the other countries shown in Figure 1 (Howarth, Schipper, Duerr and Stroem, 1991; Schipper, Meyers et al. 1992; Howarth, Schipper, and Andersson 1993; Schipper et al., 1994; Schipper et al., 1996a. At the same time, we found that *structural* changes in the ways consumers use energy (more comfort at home, more personal mobility, and indirect use in the services sector) raised energy use in all these respective sectors. Changes in energy intensities reduced energy needs in the countries shown in Figure 1 by as much as 25 percent (Denmark, Germany, and the United States), all else equal. Significant declines in intensities in manufacturing, households (except Japan), modest declines in services, and a big drop in travel intensity in the United States were the main factors.

To show the economy-wide impacts of lower energy intensities, consider Figure 2, developed in Howarth, Schipper, and Andersson 1993. This indicator holds the structure and activity of each sector constant at 1973 levels but allows all

Figure 2. *Primary Energy Use in IEA Countries: Impact of Changing End-Use Intensities*



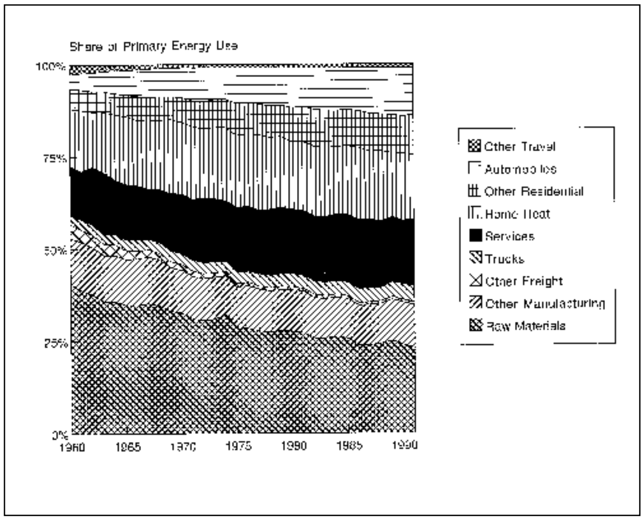
energy intensities to follow their actual evolution through 1991. We see a considerable decline in intensities in most countries, with the rate of decline slowing in the late 1980s. This new indicator is not influenced by changes in the structure of energy use, which, we noted, can also affect energy use significantly. This indicator gives a more realistic picture of how energy intensities changed than does the ratio of energy use to GDP.

As a result of these changes in both structure and energy intensities, energy demand is shifting from producers (manufacturing) and towards consumers (household comfort, mobility, personal services like shopping, entertainment, and leisure.) This effect is barely discernible for the United States because energy savings there were so great for household purposes and private cars, but very noticeable in W. Germany (Figure 3) or other IEA countries. This change also means that energy uses are spreading from the largest users (factories) to the smallest users (households, and the users of individual vehicles).

CHANGES IN THE ORIGIN OF CARBON EMISSIONS

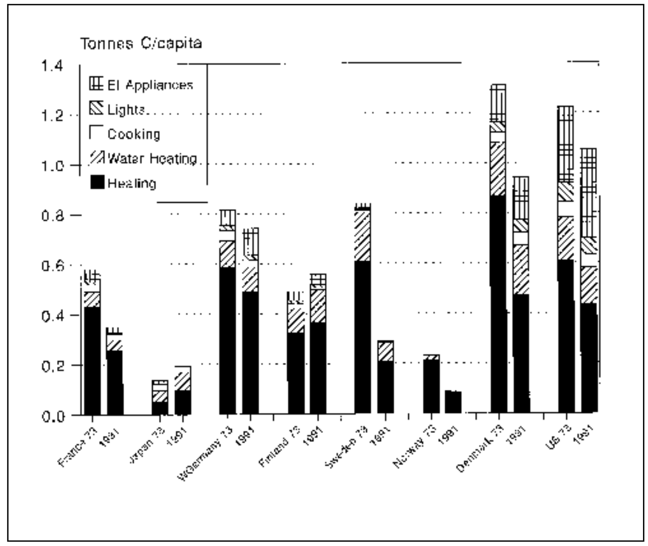
Carbon emissions depend on all of the previously analyzed factors as well as the fuel mix for each energy use. Using this same decomposition technique, we found that aggregate sectoral activity itself—total population, total travel volume, total freight volume, total manufacturing output, and total service sector output—raised emissions 20-80 percent, all else equal, with the most important growth arising from manufacturing and travel. Structural shifts of activity within each sector generally increased emissions by very little to

Figure 3. Evolution of Energy Use in the FRG 1960-1992: From Production to Pleasure



Primary conversion intesities held contrast at 1973

Figure 4. Carbon Emissions from Households



as much as 40 percent. Lower energy intensities reduced emissions in most countries, and the overall primary fuel mix became less carbon-intensive. Taking into account changes in activity, freight, travel (except in the United States), and households and services (in four of the countries) studied saw increased per capita emissions, while manufacturing saw declines everywhere. The shift ''from production to pleasure'' is thus manifest in emissions. In contrast to a decline from manufacturing, emissions from households and services increased slightly, those from freight and travel (except in the United States) increased strongly.

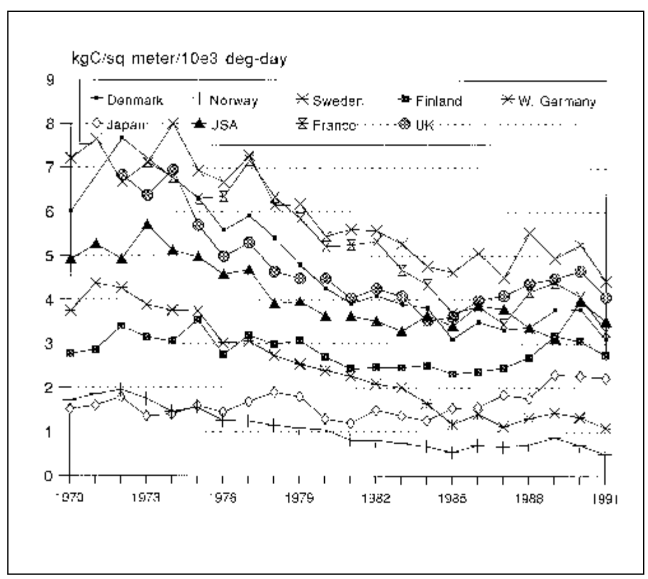
INDICATORS OF CARBON EMISSIONS FROM CONSUMER ACTIVITIES

Residential Sector

Figure 4, based on Sheinbaum and Schipper 1993 and Schipper, Haas, and Sheinbaum 1996, shows emissions per capita for major end-uses in 1973 and 1992. The evolution is characterized by similar trends across all countries. Activity—population—grew very slowly, but structure (floor area and appliance ownership per capita) grew rapidly in Japan and Europe and modestly (from already high levels in the United States) in the United States. These changes alone raised energy use and emissions by 50-80 percent. Overall, the residential primary energy mix became less carbon-intensive, both because end-users moved away from coal or oil and towards gas, and because some utilities moved away from fossil fuels for electricity or district heat. The net effect of these changes was that emissions in the residential sector grew very little or fell in absolute terms except in Japan and Finland. Figure 4 shows that residential carbon emissions per capita declined in most countries, led principally by the fall for space heating.

Intensities of electric appliances fell slowly as less energy-intensive models replaced older, ones. Space heating carbon emissions increased because of the near doubling in the number of homes with central heating in W. Europe and increased area as well, but decreased sharply because space heating carbon intensity (Figure 5) fell. Thus the role of space heating in the overall picture declined as that of electric appliances increased. The overall effect of all of these

Figure 5. Residential Space Heating Carbon Intensities in IEA Countries



changes was to reduce carbon emissions per capita in the household sector, particularly in the countries where significant amounts of low-carbon electricity were used (France, Sweden, and Norway) or where energy intensities fell strongly (Denmark, Germany, United States). Elsewhere, increased house size and equipment ownership swamped the other effects, leading to greater emissions.

Travel Sector

Figure 6 shows per capita emissions for travel by mode in 1973 and 1992 for Japan, the United States, and eight European countries aggregated (Scholl, Schipper, and Kiang 1996). Because the differences among European countries, and changes in Europe over time were relatively uniform, we have aggregated these countries to simplify part of this description.

Aggregate energy intensity of travel, dominated by the automobile, did not fall significantly except in the United States, and the predominant fuel remained oil products. Therefore, aggregate carbon intensity (Figure 7), the ratio of emissions to aggregate activity in passenger-km, *increased* over time except in the United States (and marginally in Denmark and Italy, relative to 1973).[2] Since total travel increased and the mix of modes shifted towards cars and air, per capita energy use and emissions increased, except in the United States.

Overall Considerations of Carbon Emissions

We now explain how various components affect the differences in carbon emissions shown in Figure 1:

- Differences in GDP per capita explain some of the differences in per capita energy use and per capita carbon emissions over a wide range of incomes, but are less important among the countries considered here.

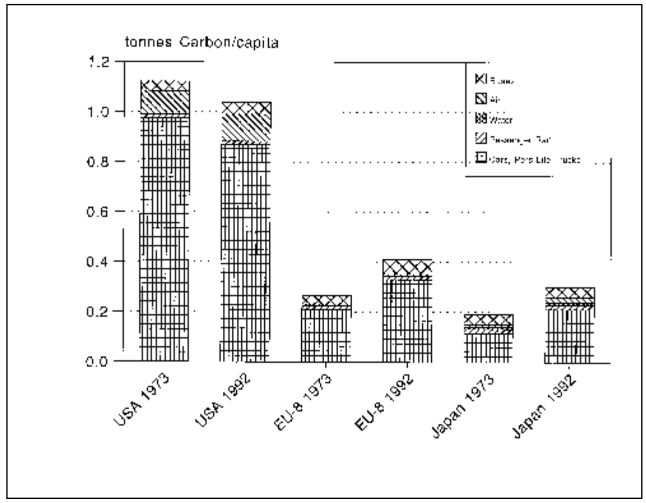
- Differences in the *structure* of economies—the mix of goods produced, distances people and goods travel (and by which modes), housing and equipment ownership and characteristics, etc., are the most important reason why there are differences among countries in carbon emissions from energy use, relative to GDP.

- Differences in fuel mix are about equally as important as differences in economic structure in accounting for differences in carbon emissions per unit of GDP.

- Differences in energy intensities rank after these factors in contributing to differences in per capita carbon emissions.

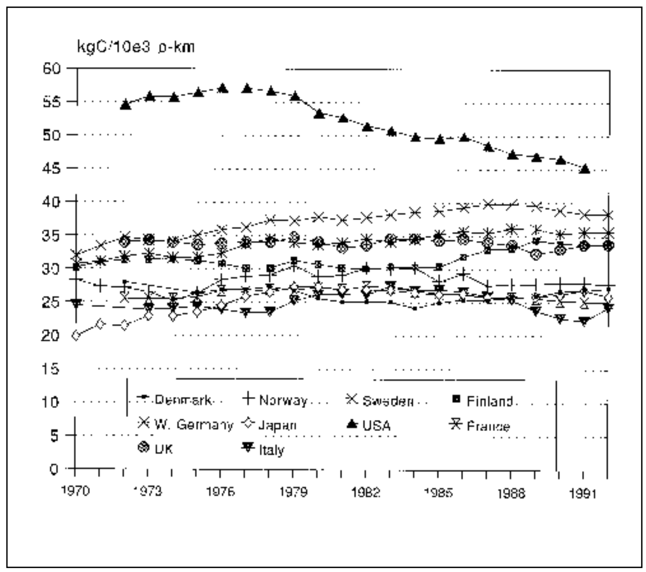
- Differences in the severity of the climate also contribute to differences in carbon emissions because climate is a strong determinant of energy use for space heating and, to a lesser degree, space cooling.

Figure 6. *Carbon Emissions from Travel*



EU-8: D (west), Kk, F, I, N, S, SF, UK

Figure 7. *Carbon Intensity of Aggregate Travel in IEA Countries*



Since 1973, structural differences that lay behind differences in emissions among countries have become smaller. In particular, four key elements of living standards and lifestyles—car ownership, total travel, central heating, living space, and appliance ownership—have increased rapidly towards U.S. levels, as shown (except for electric appliance ownership) in Figures 8 through 11. These changes alone increased household energy uses and energy use for travel, in Europe, as well as emissions, by more than 50 percent from each respective sector, all else equal. While increases in the num-

Figure 8. House Area/Capita in OECD Countries

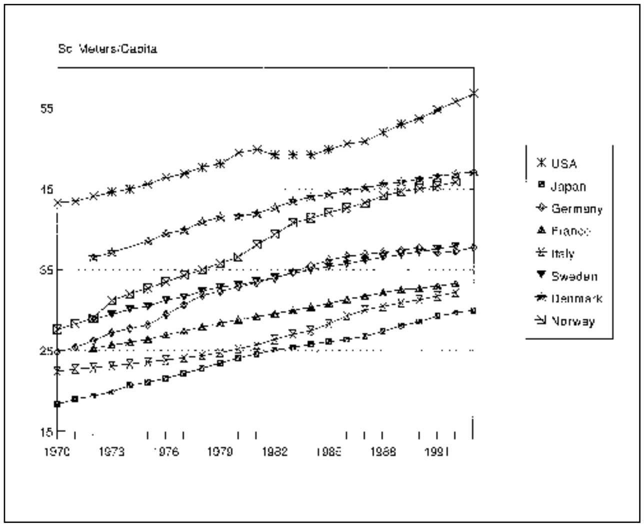
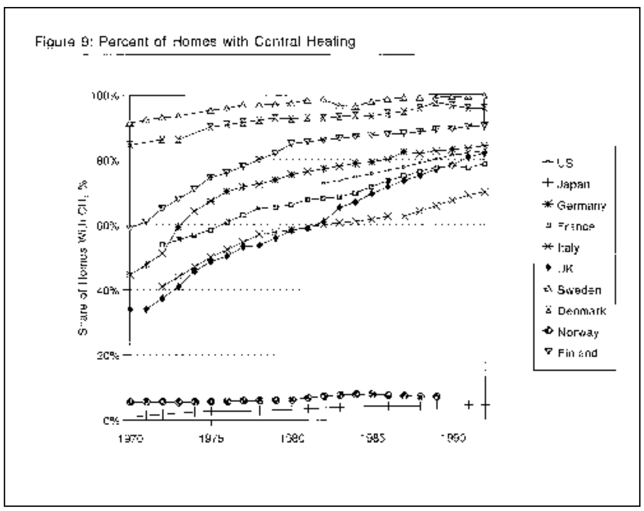
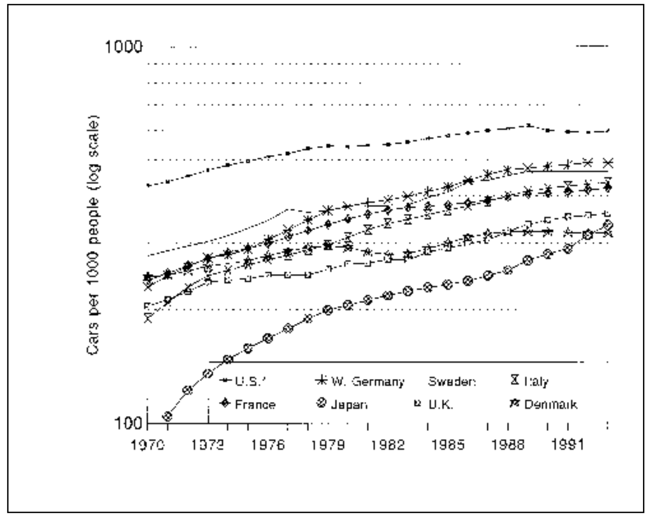


Figure 9. Percent of Homes with Central Heating



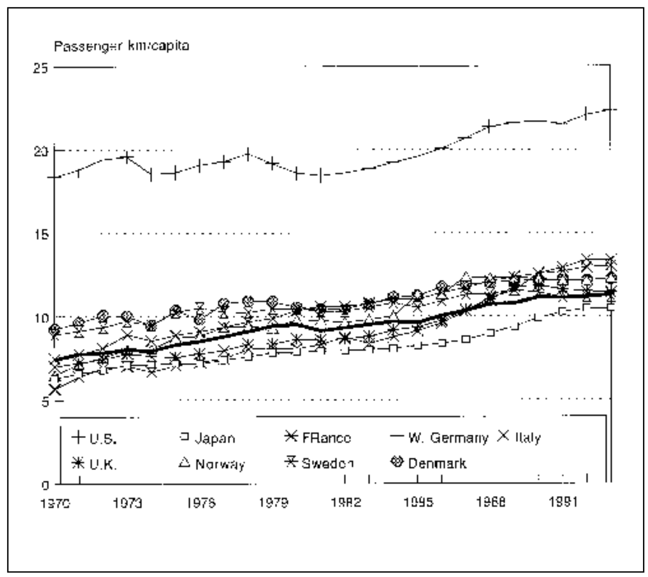
*Excludes electric heating in Norway; Add 60% points to include

Figure 10. Automobile Ownership in IEA Countries



*U.S., Denmark, U.K. includes personal light trucks.

Figure 11. Domestic Travel in IEA Countries: All Modes



ber and size of refrigeration equipment have been modest, dishwashers and clothes dryers made a prominent entrance in Europe. Thus there has been some convergence of per capita emissions driven by the rapid catch up of European consumers towards U.S. amenity levels, although a considerable gap remains. Only Japan remains ‘‘behind’’, with the smallest homes, lowest indoor temperatures, and fewest of the major appliances, as well as the mildest winter.

These considerations provide a surprising explanation for the high emissions in the United States relative to the other countries shown in Figure 1: the two most important elements distinguishing U.S. energy use from those of the other countries are the large sizes of American homes (20 to 75 percent more area per capita than in the other countries) and the distances Americans travel. In particular, Americans travel 60-100 percent farther per capita by car than Europeans. Surprisingly, however, an average car trip in either region is between 12.5 km and 15 km (Schipper, Gorham, and Figueroa 1996). Thus it is the frequency of car travel, not ‘‘distances’’ per se, that boost Americans’ travel. These structural differences are clearly important *indicators* of carbon emissions, because they explain key differences among countries, as well as changes over time.

Figures 5 and 7 revealed two ‘‘carbon intensities’’, ratios of emissions to activity in analogy with energy intensities. U.S. carbon intensities are about 25 percent above the average of the other countries for manufacturing, about 35 percent higher for automobiles and household appliances, and energy use in the service sector, but below average for household space heating and well below average for freight. The interesting position of space heating obtains both because the United States has slightly below average energy intensities for space heating (normalized to home size and climate) and because the United States has a low reliance on oil and almost no use of coal. Overall, the United States primary fuel mix is the least carbon intensive of those countries not relying heavily on biomass, hydro, and/or nuclear power (Finland, Sweden, Norway, or France). Thus we can say that the structural differences are the most important component of the gap between U.S. emissions and those of Europe or Japan. As a component of carbon intensity, energy intensity is the next most important source of difference, while fuel mix and utility fuels have a roughly neutral role.

ENERGY, EMISSIONS, AND LIFESTYLES

By illustrating which factors account most for variation in carbon emissions among industrialized countries, these comparisons suggest which factors might lie behind potential for future restraint in carbon. Certainly GDP is not. If anything, developed countries foresee increases in that term and developing countries count on much more. Economic structure will probably not be considered explicitly either but could evolve in ways important to future carbon emissions. One aspect of structure, the local climate and resulting needs for heating and cooling, is not likely to change except from climate change itself. Fuel mix and efficiency are two ‘‘free parameters’’ that authorities are considering in their climate plans. What about lifestyles?

Lifestyles and Energy

By ‘‘lifestyles,’’ we mean the bundle of activities in which individuals engage (Schipper et al., 1989). Central to the approach in that work are the variety of indicators that describe lifestyle: personal consumption expenditures, ownership of and access to energy-using consumer goods, time use, and distance traveled. Lifestyle ‘‘attributes’’ include the socio-demographic characteristics, like age distribution or employment status, of individuals and families. Some of these may be driven by policies, such as those that permit tax deductions for interest on home ownership loans or light taxation of cars provided by employers to employees for personal use. Lifestyle ‘‘choices’’ are activities that the population as a whole, socio-demographic subgroups or individuals, make, like choices on how much time to spend outside of the home. These characteristics are not independent, since families with small children may have to spend more time at home that those with no children, and tax policies encourage home purchase. Some of the trends that increased energy use, such as increased numbers of women working (and driving to work) or smaller household size (which raised per capita area) can hardly be ‘‘faulted’’ for raising CO_2 emissions, but other trends, such as the purchase of larger homes or the slow moving of households away from cities, must be considered conscious decisions, at least in part.

Our underlying paradigm is that as incomes rise, lifestyle choices become so diverse that we cannot predict what direction the changing lifestyles will take energy use in the future. But income-driven lifestyle changes during the past decades have raised energy use for pleasure, i.e., for comfort and mobility, as illustrated by Figure 3, and, as we have shown, this effect is still important for travel-related energy and emissions. It is clear then that ‘‘lifestyles’’, as measured by the ownership and use of household equipment, travel, and visits to the service sector, continues to lead to increases in carbon emissions, even if those increases are less than proportional to increases in incomes.

Without actually advocating what is a ‘‘correct’’ lifestyle, or even knowing how a given lifestyle is linked to a given level of energy use, it is important to understand the underlying components of these trends in energy use linked to lifestyles. As argued in Schipper et al., (1989), energy demand does not change much in the short term unless energy prices or incomes change and cause changes in energy services demanded (i.e., water heated to a given temperature, kilometers traveled). In the medium and longer term however, the systems converting energy to services are modified, renovated, or replaced, which permits enormous changes in energy requirements per unit of service, i.e., increased energy efficiency. This is the component of change, lower energy intensities, that reduced energy use and emissions in our previous formulation. Lower indoor temperatures and curtailed travel contributed in the short term to energy savings, but these effects have largely worn off. And the improvements in energy efficiency that continue to reduce many energy intensities are now much slower than during the period of higher oil prices. But during the whole period of high oil prices, new home size continued to increase and consumers acquired more appliances and cars. Car size and performance increased in Europe and Japan (in the United States after 1982) and consumers continued shifting modes towards cars and air travel. Higher incomes drove this evolution. Thus while many energy *uses* became less energy-intensive, *lifestyles* themselves became more energy intensive, continuing a long-term trend well established before the 1973 oil crisis and subsequent declines in energy intensities. Lest one suggest there is a rebound effect here, the largest energy savings and emissions reductions occurred in households, with the largest declines in energy intensities, while no savings occurred in travel, with no energy savings except in the United States. While it is fair to say that the net effect of all the changes was lower emissions *than otherwise*, the decline in per capita emissions from the combined household and travel sectors appears to be coming to an end.

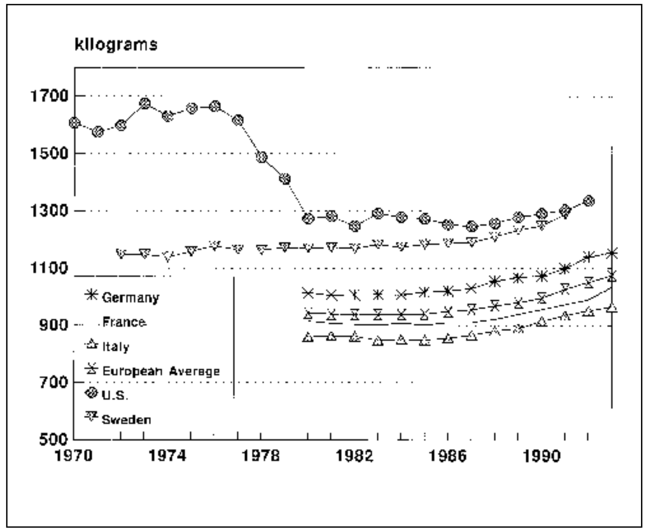
In the longer term, however, both technologies and people change. Much attention has been given to the *potential* for technological change among household and transportation energy uses that could save energy and other resources (Schipper, Meyers et al. 1992; Schipper 1993), but Figure 2 suggests that the potential is only being harvested *slowly*. That means that at present the ‘‘structural’’ changes in these sectors drive energy use, as people’s lifestyles change. Schipper et al., (1989) demonstrated, much of this change can be measured by following expenditures of money and time. As Gershuny and Jones (1987) demonstrated, most of us have more leisure time, and are spending increasing amounts of that leisure away from home, which is consistent with what the surveys of individual travel show (Schipper, Gorham, and Figueroa 1996). Greater income did not lead to proportional increases in *household* energy use, because the goods bought were not necessarily high-energy-using goods like heating or cooling systems. As saturation of the ownership of equipment approaches, however, and every household owns a given device, and every person with a driver’s licence has at least one car, the characteristics of these devices and their overall utilization become increasingly important in determining energy use, unless new energy-intensive appliances appear. Unless energy prices are extremely high, many of these choices will be made with little regard for energy prices. Household energy uses appear saturated. In travel, however, no such trend is apparent in the 1990s. In addition to increased car ownership, car characteristics and use have increasing importance to emissions, as we will show.

An Example: Recent Trends in Automobile Characteristics and Use

Figure 12 shows an important indicator of automobile characteristics that affect emissions, new car weight, in the United States and a variety of European countries (Schipper 1995). While the weight of a U.S. car fell significantly, growth reappeared after the early 1980s, while the weight of new cars in Europe appears to have increased continuously. If we added the rising share of light trucks to the U.S. figures, the rebound would be more dramatic, although still leave Americans in considerably lighter new cars in 1993 than they were in 1973. Needless to say, the size of engines or horsepower in Europe increased continuously, while the same parameters followed the same drop and then slow rebound in the United States.

The indicator of car weight 16 parallels that of central heating (Figure 9) representing quality of services delivered by energy, in this case car size and it turns out power. To be sure, the ratio of fuel consumption to weight in new cars in virtually every IEA country has fallen continuously in all the countries shown, and in fact differs very little between the countries. That is, in a technological sense cars are almost equally ‘‘efficient’’ in all countries, and this efficiency is improving. But aggregate test fuel consumption still differs significantly between countries because of differences in average weight, power, and other features. Because cars are heavier now than in 1980, actual fuel consumption per kilometer has fallen very little, except in the United States. This contrasts with the clear decline in space heating intensity in most countries, in spite of the improvements in central heating.

Figure 12. *Average New Car Weight in Europe, U.S.*



Source: US DOT, Stat. Sweden, European Assn. of Car Manufacturers Excludes light trucks

Figure 11, total travel, is dominated by car travel (80-85 percent in Europe, 85 percent in the United States, but only 55 percent in Japan). Actual car use per person, km/capita/year, which reflects both the distances cars are driven and the number of cars per person, behaves almost identically to total travel. In the countries with the fewest cars (Finland, Britain, or Denmark), yearly usage/car is very high, offsetting low ownership, accounting for the small range of total travel within Europe in Figure 11. Australia lies slightly above the European countries, Japan far below.[3]

Are large cars ‘‘bad’’? Is high car use ‘‘wrong’’. That cannot be judged here. Certainly neither outcome is a surprise in the country with fuel prices lying at 1/3 to 1/4 of the other countries in this study. (At the same time, many Europeans were shocked at the American ‘‘outrage’’ over the ‘‘high’’ fuel prices of May 1996). The same is true for those European countries where companies provide cars for employee use, which are larger and driven more than ''private'' cars, such as Sweden, Holland, or Great Britain (Fergesson 1990; Schipper et al., 1993; Schipper 1995). Whatever the exact coupling between fuel prices and new car characteristics or use, the result of Americans' ''lifestyle'' choices is three to four times the carbon emissions from personal vehicles, mostly because of greater per capita driving, but also because cars in the United States use 25-33 percent more fuel/km than those in Europe.

The parallels between homes and travel notwithstanding, our analysis found that while household equipment ownership and the extent of the housing stock itself appeared to be saturating, we see no such saturation for travel. And while new homes or appliances are significantly less energy-intensive than those they replace or supplant (Schipper, Meyers, et al, 1992), the same cannot be said of automobiles, only of aircraft. Finally, the overall performance of the household sector led to significant restraint from CO_2 emissions in a majority of countries studied. Only in the United States were emissions from the travel sector lower in 1991 than in 1973, after which they started to rise. Manufacturing emissions are well below what they were in 1973 and energy intensities are still falling, in contrast to those for freight. Consequently the ''difficult'' sectors for emissions restraint, as measured by trends, are travel and freight. Of these, travel represents roughly twice the emissions as freight. Hence the concern over travel.

What will drive emissions from households in the future? Larger homes and smaller households have led to increased per capita area to heat and cool; this trend may saturate as will likely the ownership of major energy-using equipment. Thus we expect only very slow growth in the structural factors that in the past pushed up household energy use.

The travel sector is different. Although gradual aging of the population may leave more of us at home more often, moving around less, roughly 30-40 percent of all Europeans of driving age (18 and over) still do not drive. These are mostly older people; among those in the 20-35 age group, car use is almost universal. Therefore, we expect car use to increase in Europe. Moreover, increases in driving in both the United States and Europe are mainly to visit the service sector or for free time and holidays. Liberalization of shopping hours in Europe may encourage more evening and weekend car use than is the case today. And the characteristics of new cars in Europe and the United States continue to evolve in ways that are more fuel intensive, offsetting much or all of the effort to use technology to reduce fuel use. The high level of fuel prices in Europe will probably keep a permanent wedge in per capita fuel use between the United States and Europe. But in contrast to the situation in the household sector, all of the indicators of energy use and CO_2 emissions from travel now point upwards (Schipper 1995).

CONCLUSIONS

In this brief review of industrialized countries, we showed that greater activity and, in some sectors, shifts towards more energy-intensive activities raised energy uses in all the countries, albeit not as fast as the rate of growth of GDP. Lower energy intensities reduced this growth significantly. In manufacturing, in the household sectors of some countries, and for travel in the United States, per capita energy use in 1991 was lower than in 1973 despite great increases in output or activities. Overall, energy use for manufacturing declined in share, while that for services, travel, households, and freight increased. We labeled this shift ''from production to pleasure''. Carbon emissions followed the same evolution, but fell more dramatically because of shifts in fuels away from coal or even oil to gas and biomass, as well as carbon-free sources of electricity generation. Relative to GDP, carbon emissions from the main energy-using sectors were 30-60 percent of their 1973 levels by the early 1990s.

In spite of concerns over carbon emissions professed by most governments, however, the downward trend seems to be over, led by emissions from freight, households and travel. Of these three sectors, households has been the largest source, but its growth is slow; freight is the smallest, and emissions are now growing with GDP. Travel is much larger, however, and its emissions are also growing close to the rate of GDP growth. While more efficient energy use and fuel switching cut per capita household sector emissions markedly, no decline occurred in freight and emissions for travel only fell in the United States, a drop that is now reversing. Thus travel emerges as the primary leader of growth in carbon emissions.

We showed that lifestyle changes, driven predominantly by higher incomes permitting larger houses and more appliances, as well as increased automobility, have consistently led to higher carbon emissions. While the trends raising emissions in households may be heading for saturation, no such saturation is apparent from the travel sector. Since the energy intensity of travel is barely falling, the coupling between lifestyles and emissions in the travel sector may lead to difficulties for governments intent on restraining or even cutting emissions. While we cannot advocate any one pattern of living as ''correct'', it is clear that all have to understand not only how efficient energy is converted to energy services, but how the levels of services are growing.

The comparison of the residential and travel sectors suggests an important research agenda. The literature is replete with careful studies of household equipment, household habits, energy savings resulting from changes in both of this, and of course detailed studies of how energy is used in households, as evidenced by many of the papers in previous

ACEEE conference. Key to facilitating the energy savings in households were studies of individual behavior, of how people respond to marketing of efficiency strategies, etc.

By contrast, the transportation literature, while covering many aspects of travel behavior of interest to town planners, automobile manufacturers, and economists, shows little careful research at the same level on the link between transportation energy use and how people actually drive, how their driving habits and lifestyles are intertwined with the kinds of cars they own, or how and why they choose car travel over other modes. Perhaps most important, there is a raging debate (reviewed in Schipper 1995) over the influence of where people live and their local surroundings, i.e., land use, population density, available of alternative modes—on how much they travel and how much energy they use for travel. In fact, Schipper et al. 1989 found very few studies that studied how energy for home and for all travel co-varied. Thus there is an enormous research agenda ahead, if policies are to achieve the same savings of energy use for travel that have been achieved in households.

Finally, there is little understanding of the relationship between household energy uses, energy uses for cars and other modes of transportation, and actual lifestyle patterns. Are residents of Paris and Stockholm who live in apartments and take transit to work ''energy efficient'' if they disappear to their ''summer'' cottages each weekend from March until November? Do ''low energy housing developments'' in outlying greenfield areas, planned communities with good access to transit, or rebuilt communities within large cities really lead families to reduce their total energy use, per unit of income? Or are there trade-offs between household energy use, energy consumed for every-day commuting, and energy used for transportation away from every-day life? These questions can only be answered with careful study of surveys of household energy use, expenditures, time use, and travel, the very instruments we used in the aggregate in this study to point to trends. It is this research that will define the possibilities for indicators that can be used to enlighten policies to restrain CO_2 emissions.

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ENDNOTES

1. In the remainder of this work, we refer to carbon emissions or CO_2 as metric tonnes of carbon. Conversions of oil, natural gas, and coal were made to carbon using standard coefficients from the Intergovernmental Panel on Climate Change, as published by the IEA **in Greenhouse Gas Inventory Workbook** (Paris: IEA, 1993, Vol. 2.) No emissions were assigned to wood, hydro, or nuclear power.
2. In this analysis the unit of activity, passenger-km, is calculated for automobiles as vehicle-km times load factor, or people/car.
3. Multiplying the values of driving/capita by the load factor, 1.5 to 1.7 people/car, gives the travel from cars, which is included in Figure 14. Only a small part of the U.S./Europe gap in either Figure 14 or Figure 17 is filled by much higher use of bus and rail in Europe.

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