Title

Energy Intensities in OECD Countries, 1970-1989: A Sectoral Analysis

Authors

Schipper, Lee
Meyers, S.
Howarth, R.

Publication Date

1992-11-01

LBL-33108
UC-000

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

Energy Intensities in OECD Countries, 1970–1989: A Sectoral Analysis

L. Schipper, S. Meyers, and R. Howarth

November 1992

ENERGY & ENVIRONMENT DIVISION

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

DISCLAIMER

LBL-33108
UC-000

Energy Intensities in OECD Countries, 1970-1989:
A Sectoral Analysis

Lee Schipper, Stephen Meyers, and Richard Howarth
Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

November 1992

ABSTRACT

We discuss the evolution of energy intensities in key sectors or subsectors between the early 1970s and the late 1980s in nine OECD countries. The sectors covered are manufacturing, automobile and air travel, freight trucking, residential space heating, and the service sector. Intensity changes varied among the sectors and countries, but common trends are visible in many cases. In most cases, the intensity decline slowed or ceased in the mid-1980s. We discuss the causes for the changes observed in each area, showing how energy-price changes were but one of many factors that played a role. Weighting the changes in intensities by 1973 energy use patterns, we find that the aggregate energy intensity index fell by 14-19% between 1973 and 1988 in the U.S., Japan, and West Germany.

The work was supported by the Stockholm Environment Institute and the U.S. Environmental Protection Agency through the U.S. Department of Energy Contract No. DE-AC03-76SF00098.

1. INTRODUCTION

Concerns over environmental problems associated with energy production and use have led to growing interest in the extent to which future energy use might by restrained by improvements in energy efficiency. There exists a wide range of opinions as to the future impact of changes in energy efficiency, and what role policies could play in accelerating improvement. Measuring and understanding the improvements seen in the past two decades offers insights into the future prospects.

Since 1973, the ratio of energy use to Gross Domestic Product (GDP) in OECD countries fell considerably. Changes in the mix of goods and services produced and consumed and other structural changes played a role in the decline, but the more important cause was improved energy efficiencies, manifest as declines in the quantities of energy used to manufacture a given amount of goods, move people and goods around a given distance, or provide comfortable buildings and other services that consumers and businesses want. However, changes in these quantities, referred to as *energy intensities*, were not uniform over time and varied among sectors, subsectors, and countries.

In this paper, we discuss the evolution of energy intensities in key sectors or subsectors between the early 1970s and the late 1980s in nine OECD countries: the United States (U.S.), Japan, West Germany, France, the United Kingdom (U.K.), Italy, Sweden, Norway, and Denmark. These nine countries account for around 75% of total OECD energy use. In addition, we describe the impact of intensity changes on overall energy use for the U.S., Japan, and West Germany.

Collection and organization of the data in a comparable format among countries has been a multi-year effort.[1] The detailed data required are generally only available from national sources. Published data on energy use from international sources do not break the use of fuels into end uses or modes of transportation. Data reported on manufacturing are not reliably split into the industrial sectors we required. Data for the residential and commercial/service sectors are rarely correctly distinguished from each other, even if labelled so. Further, data on the use of biomass fuels in households and industry are only available from national sources. To match energy use with output or activity to form intensity indicators, we gathered information on economic output, travel and freight activity, and the ownership of energy-consuming household equipment.

We describe energy intensities in five sectors: manufacturing, passenger travel, freight transport, residential, and services. As shown in Table 1, the importance of each sector in total energy use varies among the U.S., Japan, and the "Europe-7". Manufacturing accounted for 52% of primary energy use in Japan in 1988, but for 35% in Europe-7 and only 27% in the U.S. In contrast, the residential sector accounted for 26% of primary energy use in the U.S., 30% in Europe-7, but only 13% in Japan. These differences reflect the Japanese climate, the importance of manufacturing exports in the economy, lifestyle, and other factors. Passenger travel is most significant in the U.S. due to the high ownership and use of automobiles.

Energy intensities can be evaluated in many ways. The indicators presented here, which are somewhat different in character in each sector, reflect the availability of comparable data among countries and the feasibility of making reasonable estimates of how much energy is used for each measured activity or output. Energy is counted in terms of its thermal equivalent at the point of utilization (final energy), unless primary energy is indicated. Reported biomass use is included. In some cases, we present data through 1989 (or 1990 in a few cases); for others, the last year is 1988.

---

[1] For further discussion of data sources, see Schipper and Meyers, et al. (1992) or the references cited in each section.

Table 1. Energy Use by Sector and Selected Subsectors, 1988[a]

	U.S.		Japan		Europe-7	
	PJ	%	PJ	%	PJ	%
FINAL ENERGY	50723	100	10202	100	24424	100
Manufacturing	13035	26	4729	46	7653	31
Passenger travel	14309	28	1590	16	4514	19
Automobiles	12558	25	1354	13	4102	17
Other	1751	3	236	3	412	2
Freight transport	5575	11	1210	12	2142	9
Trucks	473	9	953	9	1959	8
Other	841	2	257	3	183	1
Residential sector	11174	22	1562	15	6895	28
Space heating	6385	13	566	5	5232	21
Other	4789	9	996	10	1663	7
Service sector	6630	13	1111	11	3220	13
PRIMARY ENERGY[b]	71018	100	14682	100	35729	100
Manufacturing	18837	27	7619	52	12471	35
Passenger travel	14309	20	1590	11	4514	13
Automobiles	12558	17	1354	9	4102	12
Other	1751	3	236	2	412	1
Freight transport	5575	8	1210	8	2142	6
Trucks	4733	6	953	6	1959	5.5
Other	841	2	257	2	183	0.5
Residential sector	18888	26	1917	13	10778	30
Space heating	7250	10	695	5	6273	17
Other	11638	16	1222	8	4505	13
Service sector	13409	19	2346	16	5824	16

[a] The totals given for final and primary energy do not include energy use in mining, agriculture, construction, petrochemical feedstocks, and non-energy use of petroleum products.

[b] Primary energy use attributable to each sector has been estimated by multiplying final use of electricity and district heat by factors of 3.24 and 1.15 to approximate the losses that occur in the conversion and distribution of these energy carriers.

2. MANUFACTURING

We analyzed manufacturing energy use for five energy-intensive industries and placed all other manufacturing activities in a residual "other" category. The five industries are paper and pulp (ISIC 341); chemicals (ISIC 351-352); stone, clay & glass (ISIC 36); iron and steel (ISIC 371); and nonferrous metals (ISIC 372). We have not included the petroleum refining industry due to lack of or inconsistency in data. Energy used in petroleum refining is usually not included in manufacturing in national energy balances. The level of aggregation chosen ensures that the data are fairly comparable among countries.[2]

We calculated the energy intensities over time in each subsector in terms of energy use per U.S. dollar of value added. Value-added data were gathered from national sources, converted to real 1980 local currency and then converted to 1980 U.S. dollars using the purchasing power parities published by the OECD.[3]

Below we present *aggregate* sectoral energy intensity for each country, holding the mix of output constant at 1973 values. The resulting "structure-constant" value represents how energy intensity would have evolved if the shares of each subsector in total value added had remained constant at 1973 levels. Note that the adjustment does *not* make the countries exactly comparable with one another, since they each have a somewhat different industrial structure. In order to better understand the trends, we present separate data for *fuel intensity* and *electricity intensity*.

2.1. Fuel Intensity

Structure-constant fuel intensity declined considerably in all countries (Figure 1a). The average rate of decline was between 3.1% and 3.6% per year for all of the countries except West Germany (2.3%).[4] A surprising feature of Figure 1a is the lack of a visible response to the rise in fuel prices that occurred in 1974-75 and again in 1979-81. Indeed, intensity increased in some countries in 1975 when industrial production declined. As we discuss below, this suggests that factors other than energy prices have played the dominant role in shaping industrial fuel intensity.

Fuel intensity declined within each of the six industry subsectors. For the eight-country average,[5] the reductions in fuel intensity in 1973-88 were 39% in chemicals, 30% in paper and pulp; 37% in stone, clay and glass; 31% in ferrous metals; 33% in nonferrous metals; and 46% in other industries. The large drop in the non-energy-intensive industries indicates that change in production technologies and shifts toward higher value-added products played an important role.

---

[2] The energy data include biomass use as reported in national statistics. For most countries, on-site electricity generation is counted as electricity consumption, while the fuel used for generation is excluded from fuel use (to avoid double-counting). Data on heat from cogeneration that has substituted for fuel use are unfortunately not available. We subtracted chemical industry feedstocks from energy use statistics, since these are properly viewed as material rather than energy inputs.

[3] Italy is not included in the manufacturing analysis due to data uncertainties. See Howarth & Schipper (1991) for further discussion of trends and data sources.

[4] The U.S. data include fuel used for on-site electricity generation. Since on-site as a percentage of total electricity generation fell from 1971 to 1981, if we could remove the fuel used the U.S. intensity decline would not be as great, and the 1985-88 plateau would change, since there was a large increase in on-site electricity generation (some of which was sold to utilities) in that period. In addition, the 1985 and 1988 values for the U.S. are not entirely comparable, as the survey frame on which the data are based was enlarged in 1988. This change means that the 1988 value may be too high relative to the earlier values.

[5] Within the eight-country aggregate (Italy is not included), the U.S. accounted for 54% of total manufacturing energy use in 1988, while Japan and "Europe-6" accounted for 20% and 26%, respectively.

2.2. Electricity Intensity

In contrast to fuel intensity, trends in electricity intensity were varied (Figure 1b). It fell in the U.S. and Japan, rose slightly in West Germany, fluctuated down and then up in France, and rose considerably but then declined somewhat in the U.K. (Norway and Sweden are not shown because they are much higher than the other countries, with intensity in 1988 of 20 and 10 MJ/$, respectively. This reflects the large role of electricity-intensive industries in these countries.) It is not clear why the trend was so different in the U.S. and Japan relative to Europe. The fact that industrial electricity prices remained rather stable in most European nations while sharp increases occurred in Japan and the U.S. may have played a role, but technological change specific to each country was likely the dominant factor. There is a common view that the particular productivity-enhancing properties of electricity-driven technologies has encouraged their adoption and pushed up electricity intensity. But in case studies of particular industries, Kahane (1989) has shown that the connections between technological change and electricity intensity are not so simple and have varied among industries. The difference in trends shown here confirms this view and suggests that generalizations about the future path of electricity intensity must be made with care.

How much of the decline in fuel intensity and increase in electricity intensity was due to substitution of electricity in applications that previously relied on fuels? The question is difficult to answer without a careful analysis of technology trends in each country. Electricity-driven technologies have displaced fuel-fired ones in some cases (e.g., electric arc furnaces in steelmaking or electric boilers in paper mills), but these process changes are often accompanied by overall rationalization which can indirectly reduce unit consumption and offset the direct increase from the new electricity-using equipment.

2.3. Causes of Intensity Change

We have not analyzed the role of structural change *within* the six subsectors, but in many cases there was a shift toward less energy-intensive products. In the steel industry, for example, the product mix in several countries shifted toward more refined, specialty products which require less energy use per unit of value (or weight) than do simpler products. In the chemicals industry, there has been a shift away from industrial chemicals, which are more energy-intensive to produce, toward specialized chemical products. A similar evolution has taken place in other industries. Another trend that pushed energy intensity down was the incorporation of more value in products.

While these structural changes played a role, studies of trends for specific products indicate that most of the decline in overall intensities (at least in the energy-intensive industries) was due to reduction in the energy consumption per ton of output. The IEA (1991) reports that energy use per metric ton of crude steel, averaged over all IEA countries, declined by 22% between 1980 and 1988. Increase in use of electric arc furnace and continuous casting technology contributed strongly to the decline. Energy use per metric ton of wood pulp fell by 12% in the 1980-86 period; energy use per ton of paper declined slightly more due to increased use of waste rather than virgin pulp. In the cement industry, where energy accounts for about half of total production costs, energy use per metric ton of clinker fell by 28% in the U.S. between 1980 and 1988, by 14% in Japan, but by only 6% in Europe. The degree of change mainly reflects the penetration of the dry process and improvements in this process.

Introduction of new production processes has played a leading role in reducing specific energy intensities. Changes in the inputs to production were also significant in some industries. Increase in use of scrap or recycled material rather than virgin ore contributed to decline in energy intensity in the steel, aluminum, and paper industries. Other factors include improvements in operations and maintenance, retrofits with low-cost equipment, marginal changes in existing process equipment, and use of "add-on" energy conservation technologies. Decisions in these latter areas are motivated mainly by the desire to reduce energy costs, and are often a response to recent price changes (though incremental improvements are likely to be made over time once energy management programs have been institutionalized).

Significant changes in process equipment and introduction of new production processes primarily result from the desire to improve productivity generally; reduction in energy costs is only one among several desired results. One can see evidence of the impact of technological change by examining long-term trends in manufacturing energy intensities. We assembled data going back to 1960 or earlier for the U.S., West Germany, and Japan, and found that structure-constant manufacturing energy intensity fell at about the same average rate between 1960 and 1973 as between 1973 and 1988, despite there being almost no change in energy prices in the earlier period and major increase in prices in the latter. One might be tempted to conclude that the rise in prices had no effect at all, and that so-called autonomous technological change alone was the cause of intensity decline. However, value added grew substantially faster in the earlier period (5.4% in the U.S. and 4.9% in West Germany) than the latter (2.6% and 1.0% respectively). Since a principal source of intensity reduction is investment in new facilities that incorporate new technologies, one would expect there to be more intensity decline from this source in the earlier period. Other causes of intensity decline in the 1958-73 period include increase in the average scale of operations in some industries and improvement in efficiency related to switching from coal to oil and natural gas. Thus, the increase in energy prices obviously had an effect in the 1973-88 period, but it appears to have been smaller than the autonomous effect of technological change.

While it seems reasonable to expect decline in energy intensity over a period of years to be greater when growth in output is high (since expansion of capacity implies addition of new production lines), the relationship between output growth and energy intensity over the 1973-88 period for the countries studied shows a mixed picture. The correlation is strong for the chemicals and paper and pulp industries, but less so in other industries. In the steel industry, for example, intensity declined by 30-40% in six of the eight countries even though there was little growth or even decline in output. Furthermore, aggregate fuel intensity declined substantially in Western Europe, even though growth in value added was relatively modest compared to the U.S. and Japan. This indicates that even where there is not significant expansion of overall capacity, producers in a competitive environment attempt to enhance quality and improve productivity by closing less-efficient plants and upgrading existing facilities through installation of better methods and technologies.

3. TRANSPORTATION[6]

We disaggregated transportation energy use into passenger travel and freight transport. We split the use of road fuels into that for automobiles (including personal light trucks and vans), motorcycles, buses, and trucks, using information from each country's energy and transportation authorities, academic experts, and fuel industries. The method involved a balancing of "bottom-up" procedures based on surveys with total consumption of each fuel. We organized data on passenger- or tonne-kilometers (km) by mode and vehicle-km travelled for particular vehicle types taken from each country's transportation authorities, taking care to make information from different countries compatible.

3.1. Automobile Travel

Automobile travel accounted for 88% of total energy use for *domestic* travel in 1988 in the U.S., 85% in Japan, and 90% in "Europe-7".[7] Average automobile fuel use per km fell significantly in the U.S.

---

[6] See Schipper, Steiner, and Meyers (1992) or Schipper, et al. (1992) for further discussion of trends and data sources.

[7] The share is high in Europe because we have counted fuel used for *domestic* air travel only.

between 1973 and 1989, but declined only slightly in Europe and Japan (Figure 2). The large U.S. decline occurred because its automobile intensity was around twice that of Europe and Japan in 1973, and it dropped significantly as the fuel economy of new cars improved and these penetrated the stock. The U.S. was still well above Europe and Japan in 1989, although the difference is partly due to the popularity of light trucks in the U.S. The drop in the fuel intensity of U.S. cars (to 12 liters/100 km, or 20 mpg) was balanced somewhat by an increase in the use of light trucks as passenger vehicles. (The estimated share of personal light trucks in total automobile vehicle-km increased from 9% to 18%.) The fuel intensity of light trucks fell also (to 18 liters/100 km, or 13 mpg), but remained well above that of cars.

In the U.S., the sales-weighted average fuel intensity of *new* automobiles (including all light trucks) declined by nearly 50% between 1973 and 1982, so turnover of the stock strongly depressed fleet-average fuel intensity. A shift to smaller cars contributed only slightly to the decline in new car fuel intensity after 1975. Average interior volume hardly changed between 1978 and 1988. Since 1980, compacts have gained share at the expense of sub-compacts, but mid-size cars have also lost share. Most of the change came from a decrease in fuel intensity within each size class. The average power of new cars fell by 25% between 1975 and 1980, contributing to a decline in intensity, but has increased since 1982, pushing intensity upward (Heavenrich and Murrell, 1990).

In Europe and Japan, the fuel intensity of new cars improved much less than in the U.S., in part because it was already much lower in 1973, and in part because growth in vehicle size and power offset technical efficiency gains. Test data show some decline in new car fuel intensity since 1975 in several countries, but intensity has increased since 1982 in Japan and since 1985 in West Germany as average vehicle size and power have risen. In West Germany, for example, the fraction of all automobiles that had engine displacement of 1500 cm^3 and above increased from 40% in 1973 to 60% in 1987, and the average horsepower rose from 59 to 77. By 1990, more than 80% of all cars sold in West Germany could reach 150 km/hr or greater, and 30% of them could surpass 180 km/hr. The average size of engines in the U.K. and France also rose. The continued decline in new-car fuel intensity in France and Italy is partly due to growing penetration of diesel-fueled cars, which have lower intensity than comparable gasoline-fueled cars.

Fuel economy improvements have come from three main sources: propulsion-system engineering, other elements of vehicle design, and performance trade-offs. Engineering improvements are exemplified by the remarkable 36% increase in power per unit of engine size between 1978 and 1987 in the U.S. (Ross, 1989). The ratio of vehicle weight to interior volume was reduced by 16% in this period, and reductions in air drag and rolling resistance (through introduction of radial tires) have also contributed to fuel economy improvement. Acceleration performance decreased in the 1980-82 period, which contributed to a decline in fuel intensity, but it has progressively risen since. Similar changes in the *technical efficiency* of new vehicles occurred in Europe and Japan.

Worsening traffic congestion has pushed upward on fleet fuel intensity in most OECD countries. In the early 1980s, the U.S. Environmental Protection Agency determined that vehicles in use achieved 15% lower fuel economy than the nominal vehicle rating based on the driving cycle test (Westbrook and Patterson, 1989). Some observers believe that the discrepancy has grown to as much as 25% as a result of rising traffic congestion, the increasing share of urban driving, higher speeds on open highways, and higher levels of acceleration in actual use than in the test.

Automobile energy use per *passenger-km* declined less than did energy use per vehicle-km. This reflects a decline in the number of passengers per trip (mainly due to a decrease in family size and increased numbers of cars per household). In the U.S., the average load declined from 2.2 persons per car in 1970 to 1.7 in 1983 and 1.5 in 1990. A decline also occurred in Japan (2.2 to 1.8), West Germany (1.7 to 1.5), Sweden (2.0 to 1.5), and elsewhere in Europe.

Although we have not performed a formal analysis of the impact of fuel price changes on automobile energy intensity, some observations may be made. The net increase in real gasoline prices in the 1970s was fairly modest in most countries. Prices increased more in 1979-81, but declined thereafter. In Europe and Japan, the rise in prices and pressure from governments concerned about oil imports caused manufacturers to incorporate technical improvements that kept new car fuel intensity from rising, even as car buyers sought larger and more powerful cars. The largest declines in fleet intensity in Europe occurred in Italy and Denmark, where fuel prices in the late 1980s were well above their 1970s values. In the U.S., the impact of higher gasoline prices is difficult to judge, since the Federal fuel economy standards were an influential intervention in the market (Greene, 1990). The steady decline in real gasoline price since 1981 certainly contributed to lessened interest in fuel economy on the part of buyers. The real price of gasoline in 1988 in most countries was close to its 1970-73 level, and the cost of fuel per km was lower in 1988 than in 1970-73 for every country.

3.2. Air Travel

Energy use per passenger-km in *domestic* air travel declined by a remarkable 50% in the U.S. and 38% in Western Europe between 1970 and 1988.[8] The decline in fuel use per seat-km as new planes with significantly lower fuel intensity entered the fleets in large numbers was the major reason for this drop in energy intensity. An increase in load factor (passengers per available seats) also contributed (the average load factor in the U.S. rose from 54% of available seats in 1973 to 63% in 1988). The new planes were on average larger than those they replaced, and larger planes tend to use less energy per seat-km than smaller planes with comparable technology. (For U.S. aircraft, available seats per plane increased from 111 in 1970 to 148 in 1980 and 161 in 1987.) There was also considerable decline in fuel intensity in planes of a given size (Gately, 1988). Technological changes included more fuel efficient engines, improvement in aircraft structural efficiency (lighter airframes), and improved lift/drag performance. Airlines also retrofitted old planes with new engines (often for noise abatement reasons), and added seats. Lastly, airlines and airports instituted various operational improvements. As a result of all these factors, energy use per seat-mile of U.S. jet aircraft declined by one-third between 1973 and 1988.

3.3. Freight Trucking

Trucks account for around 80% of total energy use for domestic freight transport in the U.S. and Japan, and for over 90% in Western Europe. Fuel use per tonne-km for freight trucking was roughly steady in most of the nine countries over the study period (Figure 3). It increased somewhat in the U.S. through 1982. In Japan, intensity rose through 1976, but fell sharply in the 1977-80 period. In West Germany, there has been a slight downward trend since 1981, while France and the U.K. have been roughly steady since the mid-1970s.

Trends in truck fuel intensity have not received much study. In the U.S., the data show that average fuel use per *km* was the same in 1988 as in 1973 for both medium and heavy (tractor-trailer) trucks (Davis and Hu, 1991). Improvement in technical efficiency was apparently offset by increase in operating speeds on intercity highways and increasing traffic congestion in urban areas. The overall increase in energy per *tonne-km* was probably due to factors related to the operation of trucking fleets and the nature of freight carried. Despite deregulation of the trucking industry, there is evidence that there was an increase in empty backhauls, resulting in reduced tonnage per distance traveled (Mintz, 1991). In addition, it appears

---

[8] Data supplied by several European airlines confirmed that this trend was also seen in international travel. Indeed, the long-range aircraft used for intercontinental travel have significantly lower energy use per p-km than do the smaller planes flown on domestic routes.

that the weight carried per volume of truck capacity declined. One reason for this is increased packaging (which is light but takes up truck capacity). An additional reason apparent in Europe is the proliferation of lighter trucks for local transport.

4. RESIDENTIAL SECTOR

We took data on residential use of gas, electricity, and district heat from utility reports or national statistics. The split of oil and coal use between residential and commercial buildings is somewhat uncertain; in most cases, residential consumption is estimated from bottom-up calculations either by national authorities or by us (for discussion of methodology, see Schipper, Ketoff, and Kahane, 1985). Wood use, which is not trivial in some countries, is typically estimated from household surveys. Estimation of the end-use structure of consumption for each energy source relies on surveys of equipment ownership to determine the number of households using a fuel for each major end use, and various sources (fuel use surveys and engineering and regression estimates) to estimate average energy use for each case. The procedure requires balancing the bottom-up estimates with actual consumption. Since electricity is used for many purposes in homes, its disaggregation is more uncertain than that of fuels.

4.1. Space Heating

Space heating is the major residential end use in the U.S. and Europe in terms of final energy. Its role is smaller in terms of primary energy, however, since most heating does not rely on electricity. Change in the energy sources used has been a significant factor for space heating. In many cases, substitution of electricity for fossil fuels has depressed heating energy intensity expressed in terms of final energy. To eliminate the effect of change in energy sources, we apply the concept of "useful energy," which is equal to final energy use minus estimated conversion losses at the home.[9]

To express energy intensity, we divide annual space heating energy use by the number of heating-degree days and the total heated area.[10] The latter is estimated from surveys in most cases. As shown in Figure 4, intensity has declined in all of the countries except Japan and Norway since 1973. Most of the reduction in energy intensity took place in the 1970s and early 1980s. There was little decline after 1982. The decline was greater in the U.S. than in Europe (except for Denmark, which aggressively promoted retrofits to save energy). In Japan, there was some decline in 1980 as households responded to higher fuel prices, but a gradual rise thereafter.

A key reason why the decline in intensity was less in Germany, France, and the U.K. is that use of central heating rose from around 40-45% of homes in 1972 to 65-75% in 1988. This transition was not a major factor in the U.S. (or in Scandinavia), where the share of central heating was already high in 1972. A comparable change in Japan was the considerable increase in the number of room heaters per home and in the size of heaters.

The decline in space heating energy intensity was due to physical and behavioral changes in older homes, and introduction of new homes with improved thermal integrity and heating equipment. Estimates of the reduction in heating energy intensity in pre-1975 homes between 1973-75 and 1985 are shown in Table 2 for four countries. The reductions were largest for oil-heated homes, as would be

---

[9] We calculate "useful energy" as 66% of final energy use for oil and gas, 55% for coal and wood, and 100% for electricity and district heat. The resulting values are not precise estimates of useful energy in each country, since the actual conversion efficiencies differ somewhat among countries.

[10] We include estimated energy use by secondary space heaters (including fireplaces). Increased use of secondary heaters was an important factor in the U.S. and Scandinavia.

expected since oil prices rose more than did prices of gas and electricity.

Table 2. Reduction in Space Heating Energy Intensity in pre-1975 Homes Between 1973-75 and 1985 (%)

Heating Fuel	U.S.	France	Sweden	Denmark
Oil	40	28	25	40
Gas	25	16	-	-
Electricity	25	17	10	25

Source: Authors' estimates based on surveys from each country.

Reduction in average indoor temperature has been an important factor in most countries, according to surveys of reported practices. In the U.S., winter indoor temperatures declined considerably after 1973-74 and declined further after the oil price rise in 1979-80. The percentage of homes keeping the daytime temperature at 21 °C (70 °F) or above (when someone is at home) declined from 85% in the 1972-73 winter to 52% in 1974-75, and to 46% in 1981-82 (Meyers, 1987). Decline in nighttime temperature from 1972-73 to 1974-75 was even greater: from 51% of homes at 21 °C or above to 29%. After 1981, temperatures increased, reflecting stabilizing of energy prices and lessened concern over energy.[11] Surveys in Denmark and West Germany show a similar pattern of sharp declines in indoor temperature in 1973-75 and 1979-81 followed by gradual rebound. The relative magnitude of the decline was probably not as great as in the U.S., however, since the average temperature was higher in the U.S. in the early 1970s. In Japan as well, there were declines in 1973-74 and 1979-80, but they were reversed within a few years.

Improvement of the thermal integrity and heating equipment of pre-1975 homes has been considerable in Europe and North America. Homeowners increased insulation in ceilings and walls, added storm windows and doors, and reduced heat leaks. Heating equipment tune-up and replacement of old equipment also played an important role. In the U.S., new gas furnaces were about 15% more energy efficient in 1987 than in 1975 (U.S. DOE, 1988). In Japan and the U.S., considerable growth in use of heat pumps pushed downward on heating energy intensity.

It is difficult to separate the impact of retrofit and equipment replacement from that of change in heating practices. For the U.S., data from national surveys (U.S. EIA, 1983, 1989) show that heating intensities in older homes declined between 1981-82 and 1987 despite the rise in indoor temperature described above, which indicates that retrofit and equipment replacement had an important effect.

Introduction of new homes to the housing stock decreased average heating energy intensity, since dwellings built after 1974 have higher thermal integrity and more energy-efficient heating equipment than those built earlier. In France, for example, space heating energy consumption in 1985 in single-family houses was 16% lower in post-1974 oil-heated homes than in pre-1975 ones. The difference was 24% for

---

[11] The U.S. data illustrate the importance of home occupancy. Since the average daytime temperature is much lower when no one is at home than when someone is, it follows that increase in the fraction of hours that a home is unoccupied decreases average temperature. In Europe and Japan, where apartments comprise a larger fraction of the housing stock, the impact of reduced occupancy has been smaller, since an unoccupied apartment gets heated somewhat by its neighbors.

gas- and electric-heated homes. In the U.S. in 1984-85, heating intensity in gas-heated single-family houses was 22% less in post-1974 dwellings than in dwellings built in 1950-74 (U.S. EIA, 1987), and the latter had been considerably improved through retrofit and equipment replacement by 1984. If we could compare the consumption in the post-1975 homes to what would have been the case in pre-1975 homes had retrofit not occurred, the difference would be greater than noted above.

The impact of new housing on the stock average has been most significant in the U.S. because there has been more new construction than in Europe. Of all homes existing in 1988, about 25% were built after 1974 in the U.S. In Western Europe, only 15-18% of the 1988 stock was built after 1974.

Rise in energy prices (especially oil) brought on behavioral change and stimulated installation of retrofit measures. Public subsidies for retrofit measures (grants, tax credits) also had an effect, although the degree to which the incentives increased energy-saving activities over what would have been adopted otherwise is uncertain. In Denmark, Sweden, and West Germany, a large share of the initial grants went to retrofits of outside walls (essentially building rehabilitation) or exchange of useable single-frame windows for new double glazing. While each of these actions had benefits, the energy paybacks relative to the grants were small (Wilson, et al., 1989). For new homes, building codes in Western Europe and some U.S. states produced major improvements in construction practices. In the U.S., utility incentive programs also encouraged retrofit measures and higher energy efficiency in new construction (mainly for electric-heated homes).

4.2. Other End Uses

We estimated trends in energy intensities for water heating, cooking, and electric appliances, although these are more uncertain than space heating intensities. In contrast to space heating, water heating energy intensity (useful energy) rose by nearly 30% in Europe-7 and by 60% in Japan due to greater use of central heaters with storage and growth in ownership of clothes washers and dishwashers. There was little change in intensity in the U.S., however, where central heaters were already the norm in 1970.

For electric-specific appliances, improvements in the technical energy efficiency of new appliances pushed downward on energy intensity (defined as energy use per device). These improvements were especially large in the U.S. for refrigerators and freezers. As with automobiles, however, the effect of higher efficiency was partially offset by increase in the size and/or features of many appliances (Schipper and Hawk, 1991). Using estimates of average energy use per device, we constructed a weighted-average energy intensity index for seven major appliances.[12] The index fell by 13% in the U.S. and by 2% in West Germany between 1973 and 1988, but rose by around 40% in Japan, where increase in size was especially strong.

5. SERVICE SECTOR

Energy use in the service sector takes place in many types of public and private buildings. As with the residential sector, oil consumption is somewhat uncertain, while data on gas, electricity, and district heat come from utility reports. The end-use structure of fuel use is dominated by space heating. The breakdown of electricity use is more problematic. While estimates have been made for particular years in some countries, there are no reliable time series of energy use split into the major end uses, and we did

---

[12] The seven appliances are refrigerator, freezer, refrigerator-freezer, clothes washer, dryer, dishwasher, and air conditioner (in the U.S. and Japan). The weighting is based on 1980 appliance penetration in each country. Intensity is expressed in kWh per capita. For further discussion, see Schipper and Meyers, et al. (1992) or Ketoff and Schipper (1991).

not attempt to construct them. Total floor area would be the preferred measure of activity, but time-series data are not available for most countries. As an alternative, we used value added as reported for the economic activities that are generally defined as belonging to services (in ISIC categories 6-9).[13]

As in manufacturing, we express energy intensity in terms of aggregate final energy use per U.S. dollar of value added. Whereas for manufacturing it is important to adjust aggregate energy intensity for structural change among subsectors, for the service sector this is relatively unimportant, since the differences in energy intensity among subsectors (i.e., offices, retail, education, etc.) are fairly small.

As was the case for manufacturing, the trends in total service-sector energy intensity mask very different trends for electricity and fossil fuels. *Fuel intensity* declined greatly in almost all countries (Figure 5a). The decline for the nine-country aggregate was 42%. The main component of the decline in fuel intensity was a decrease in the energy intensity of fuel-based space heating. In France, Sweden, and Norway, a fall in the fraction of floor area heated with fuels (as opposed to electricity) was also a major factor. In Sweden and Norway, there was considerable switching from heating with oil alone to oil supplemented with some other fuel or electricity.

The decline in the intensity of fuel-based heating was due to addition of new buildings with lower heating requirements per square meter, retrofit improvements to heating equipment and building envelopes of older buildings, and improved building energy management. In the U.S., the fraction of floor area in warmer climates increased significantly, which contributed to decline in average heating energy intensity.

The effect of higher oil prices on fuel intensity in older buildings, as well as the change in new building practices brought on by higher prices and tightened building codes, can be seen in survey data from Sweden. Oil use per square meter in oil-heated buildings declined between 1978 and 1988 in each building cohort. Oil intensity was lower in 1988 in buildings built after 1975 than in those built before, though the difference was not so large. In part this was due to the conversion of many older, rather inefficient buildings to district heat, which brought down the average oil intensity of pre-1976 buildings.

In contrast to fuel intensity, *electricity intensity* increased in all countries (Figure 5b). The increase was modest in the U.S., West Germany, Italy, and the U.K., considerable in Japan and France, and very high in Sweden and Norway. Many factors contributed to rising electricity intensity: growth in use of electricity for space heating (especially important in France and Scandinavia), increase in hours of operation in some subsectors, and growth in the saturation of electrical office equipment. In the U.S., there was an increase in air-conditioning requirements due to the growth in the fraction of buildings in warmer climates. Given the factors pushing intensity upward, the fact that the increase in the U.S. was relatively low suggests that there was considerable decline in electricity intensity at the end-use level.

Installation of conservation features in older buildings affected fuel and electricity intensity, especially for heating, ventilation, and air-conditioning (HVAC) equipment and lighting. In the U.S., the national surveys of commercial buildings (e.g., U.S. EIA, 1988) suggest that there was more activity in the 1980s than before 1980, which could reflect the increase in utility programs and the activities of energy service companies. Two of the most popular features installed in the 1980-86 period were computerized energy management control systems and high-efficiency ballasts for lighting.

---

[13] Service subsectors are defined in a uniform manner among countries in national account statistics. The categories that are found in floor area estimates differ somewhat among countries, however, making it difficult to draw comparisons. The ratio of value added to estimated floor area varies among countries. See Schipper, Meyers, and Ketoff (1986) for further discussion of service-sector trends and data issues.

6. THE AGGREGATE IMPACT OF CHANGE IN ENERGY INTENSITIES

As we have shown, intensity changes varied markedly among different sectors. To assess trends in aggregate energy intensity, we used an index number approach.[14] Following the sectoral analyses presented above, we calculated an *energy intensity index* for over 20 categories in the industrial, residential, transportation, and service sectors.[15] If A_{it} is the level of the ith activity in year t and I_{it} the corresponding energy intensity, total energy use is given by $E_t = \sum_{i=1}^{n} A_{it} I_{it}$. According to this framework, we define the Laspeyres (fixed-weight) *intensity index*

$$LI_t = (\sum_{i=1}^{n} A_{i0} I_{it})/E_0$$

as the level of energy use in year t relative to the base year ($t=0$) that would have prevailed if activity levels had remained fixed at their base year values while energy intensities followed their actual paths. To calculate aggregate energy intensity, each separate intensity is weighted according to its share of 1973 energy use in each country.

The results of this calculation show that between 1973 and 1988, the aggregate *final* energy intensity fell by 23% in the U.S., 22% in West Germany, and 20% in Japan (these changes correspond to annual rates of 1.7%, 1.7% and 1.5%). In terms of primary energy, for which we weight the use of district heat and electricity by factors of 1.15 and 3.24 to account for the losses that occur in the generation and distribution of these energy carriers,[16] the reduction was 19% (1.4%/yr) for the U.S., 15% (1.1%/yr) for Germany, and 14% (1.0%/yr) for Japan. Because the share of electricity in total final energy use increased in each case, the declines in primary energy use were lower than for final energy.

In the U.S., the decline of energy intensity was relatively smooth over time (Figure 6). In Germany, there was little decline in the 1970s, but considerable decline in the 1980-83 period. In Japan, the energy intensity increased sharply between 1973 and 1975, presumably due to inefficiencies related to low capacity utilization in a recessionary period. (Manufacturing receives much more weight in Japan than in the U.S. and Germany.) There was a plateau of energy intensity in both Germany (mid-1980s) and Japan (1985-88) and a slower pace of decline in the U.S. due in part to easing of energy prices (Schipper and Ketoff, 1989).

It is useful to consider the relationship between our energy intensity indices and the energy/GDP ratio. In each case, the reduction in the energy/GDP ratio is greater than the change in the intensity index (Table 3). This disparity is particularly apparent for Japan, where delivered and primary energy intensity fell by 20% and 14% while the corresponding energy/GDP ratios fell by 34% and 28%. These differences are due to the fact that many energy-intensive activities grew more slowly than GDP. Japanese industry reduced its emphasis on the production of energy-intensive raw materials, and a large fraction of national income was invested in capital goods as opposed to final demand goods such as larger homes and automobiles. We conclude that reliance on aggregate indicators such as the energy/GDP ratio is best avoided where more detailed analysis can be carried out.

---

[14] A more detailed discussion is set forth by Howarth, Schipper, and Andersson (1992).

[15] Here the industrial sector includes the activities of mining, construction, and agriculture. Although these activities typically account for only about 5% of energy use and the quality and availability of data precludes their detailed analysis, their inclusion permits us to examine trends in the total end-use of energy.

[16] These values are approximate OECD averages.

Table 3. Changes in Energy Intensity Indices and Energy/GDP Ratios, 1973-1988

	Delivered Energy		Primary Energy	
	Intensity	E/GDP	Intensity	E/GDP
United States	-23%	-29%	-19%	-23%
West Germany	-22%	-24%	-15%	-17%
Japan	-20%	-34%	-14%	-28%

7. CONCLUSION

Between 1973 and 1989, fuel intensities fell considerably in manufacturing, air travel, residential space heating, and in the service sector. There was also a strong decrease in automobile fuel intensity in the U.S., but not in Europe and Japan. Higher energy prices, autonomous trends in technology (especially in manufacturing and air travel), and in some cases energy efficiency programs and policies caused the declines in intensities. Electricity intensity behaved rather differently, increasing in some cases (the service sector and manufacturing in some countries) or remaining relatively unchanged. An index of aggregate (primary) energy intensity based on the intensity changes in each subsector shows a decline of 14-19% between 1973 and 1988 in the three largest OECD countries. This was less than the decline in the ratios of energy use to GDP.

The rate of decline in energy intensities eased in the mid-1980s, in large part because energy prices fell. However, since most new energy-using systems are less energy intensive than those in the stock, replacement or expansion of activity virtually assures a reduction in average energy intensities for many years, albeit at slower rates than in the 1973-88 period (Schipper and Meyers, 1993). The gap between new and stock-average intensities is partially due to policies such as thermal performance requirements for new buildings and energy efficiency standards for new household appliances, or incentives for purchase of energy-efficient equipment. However, the rate of *decline* in the energy intensity of new systems has slowed, which in turn slows the rate of decline in average energy intensities. While there are many very energy-efficient technologies on the market, their market share is relatively small. While ample evidence suggests that the potential for further cost-effective reductions in energy intensities may be as great in the 1990s as it was in the 1970s, the actual realization is well short of the potential. Accelerating the pace of intensity decline to the levels experienced in the 1973-88 period will require higher energy prices, stronger energy-efficiency policies, and a general economic environment conducive to modernization and investment.

ACKNOWLEDGEMENTS

We acknowlege the support of the Stockholm Environment Institute, as well as the U.S. Environmental Protection Agency and Dept. of Energy for patient funding of the many years of data gathering and analysis. Additionally, many individuals worked on organizing the data described in this paper: Richard Howarth and Peter Duerr (manufacturing); Peter Duerr, Ruth Steiner, Kari Dolan, and Lee Schipper (transportation); Lee Schipper, Andrea Ketoff, Claudia Scheinbaum, Steve Meyers (residential); Anne Sprunt (services). Charles Campbell produced the graphics. We are also indebted to colleagues around the world who have kindly provided information and assistance.

REFERENCES

Davis, S. and P. Hu (1991). *Transportation Energy Data Book: Edition 11,* Oak Ridge, TN: Oak Ridge National Laboratory.

Gately, D. 1988. "Taking off: The U.S. demand for air travel and jet fuel," *Energy Journal,* Vol. 9,4:63-88.

Greene, D.L. (1990). "CAFE OR PRICE?: An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89," *The Energy Journal* (11)3: 37-57.

Heavenrich, R. and J. Murrell (1990). "Light-Duty Automotive Technology and Fuel Economy Trends Through 1990." Ann Arbor, MI: U.S. Environmental Protection Agency.

Howarth, R.B., L. Schipper, and B. Andersson (1992). "The Structure and Intensity of Energy Use: Trends in Five OECD Nations," *The Energy Journal* (in press).

Howarth, R.B. and L. Schipper (1991). "Manufacturing Energy Use in Eight OECD Countries: Trends Through 1988." *The Energy Journal* 12(4): 15-40.

International Energy Agency (1991). *Energy Efficiency and the Environment.* Paris: OECD.

Kahane, A. (1989). "Technological Change and Industrial Electricity Use: Towards Better Generalizations." In Johansson, T. B., et al., *Electricity: Efficient End Use and New Generation Technologies, and Their Planning Implications.* Lund, Sweden: Lund University Press.

Ketoff, A. and L. Schipper (1991). "Looking Beyond the Aggregate Figures: What Really Happened to Household Energy Conservation." In E. Vine and D. Crawley (eds.) *State of the Art of Energy Efficiency: Future Directions.* Washington, DC: American Council for an Energy-Efficient Economy.

Meyers, S. (1987). "Energy Consumption and Structure of the US Residential Sector: Changes Between 1970 and 1985," *Annual Review of Energy,* 12: 81-97.

Mintz, M.A.M. (1991). "Trends in Demand for Freight Transportation," Presented at the Conference on Transportation and Global Climate Change: Long-Run Options, August 25-28, 1991, Asilomar, CA.

Ross, M. (1989). "Energy and Transportation in the United States," *Annual Review of Energy,* 14: 131-171.

Schipper, L. and S. Meyers (1993). "Using Scenarios to Explore Future Energy Demand in Industrialized Countries." *Energy Policy,* Vol. 21 (in press).

Schipper, L. and S. Meyers, with R. Howarth and R. Steiner (1992). *Energy Efficiency and Human Activity: Past Trends, Future Prospects.* Cambridge, UK: Cambridge University Press.

Schipper, L., R. Steiner, M.J. Figueroa, and K. Dolan (1992). "Fuel Prices, Automobile Fuel Economy, and Fuel Use for Land Travel: Findings from an International Comparison." Berkeley, CA: Lawrence Berkeley Laboratory.

Schipper, L., R. Steiner and S. Meyers (1992). "Trends in Transportation Energy Use, 1970-1988: An International Perspective." Berkeley, CA: Lawrence Berkeley Laboratory.

Schipper, L. and D. Hawk (1991). "More Efficient Household Electricity Use: An International Perspective," *Energy Policy,* Vol. 19:244-265.

Schipper, L. and A. Ketoff (1989). "Energy Efficiency: The Perils of a Plateau." *Energy Policy,* Vol. 17 (December).

Schipper, L., S. Meyers and A. Ketoff (1986). "Energy Use in the Service Sector: An International Perspective." *Energy Policy,* Vol. 14 (June).

Schipper, L., A. Ketoff and A. Kahane (1985). "Explaining Residential Energy Use With International Bottom-up Comparisons." *Annual Review of Energy* 10: 341-405.

U.S. Department of Energy (1988). "Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets." Washington, DC.

U.S. Energy Information Administration (1983). "Residential Energy Consumption Survey: Consumption and Expenditures, April 1981 through March 1982, Part 1: National Data." Washington, DC: U.S. Department of Energy.

——. (1987). "Residential Energy Consumption Survey: Consumption and Expenditures April 1984 through March 1985, Part 1: National Data." Washington, DC: U.S. Department of Energy.

——. (1988). "Characteristics of Commercial Buildings 1986." Washington, DC: U.S. Department of Energy.

——. (1989). "Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 1987, Part 1: National Data." Washington, DC: U.S. Department of Energy.

Westbrook, F. and P. Patterson (1989). "Changing Driving Patterns and Their Effect on Fuel Economy." Presented at the 1989 SAE Government/Industry Meeting, Washington, DC.

Wilson, D., L. Schipper, S. Tyler and S. Bartlett (1989). "Policies and Programs for Promoting Energy Conservation in the Residential Sector: Lessons from Five OECD Countries." Berkeley, CA: Lawrence Berkeley Laboratory.

Manufacturing Fuel Intensities
Constant 1973 Output Structure

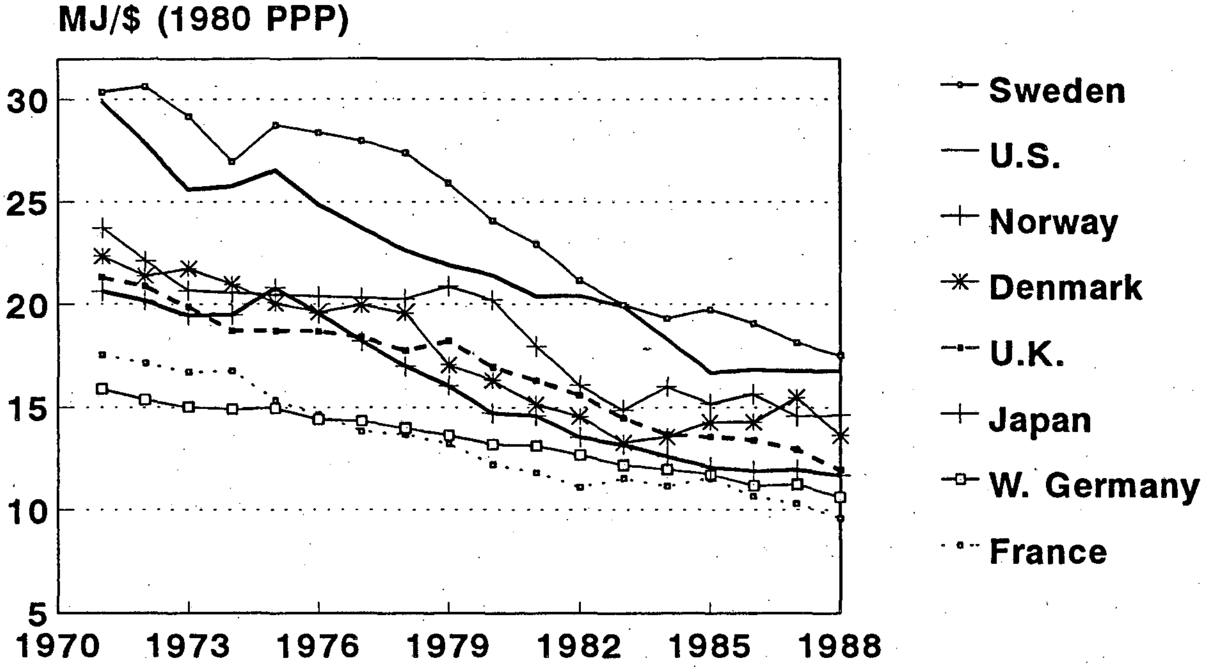


Figure 1-A

Manufacturing Electricity Intensities
Constant 1973 Output Structure

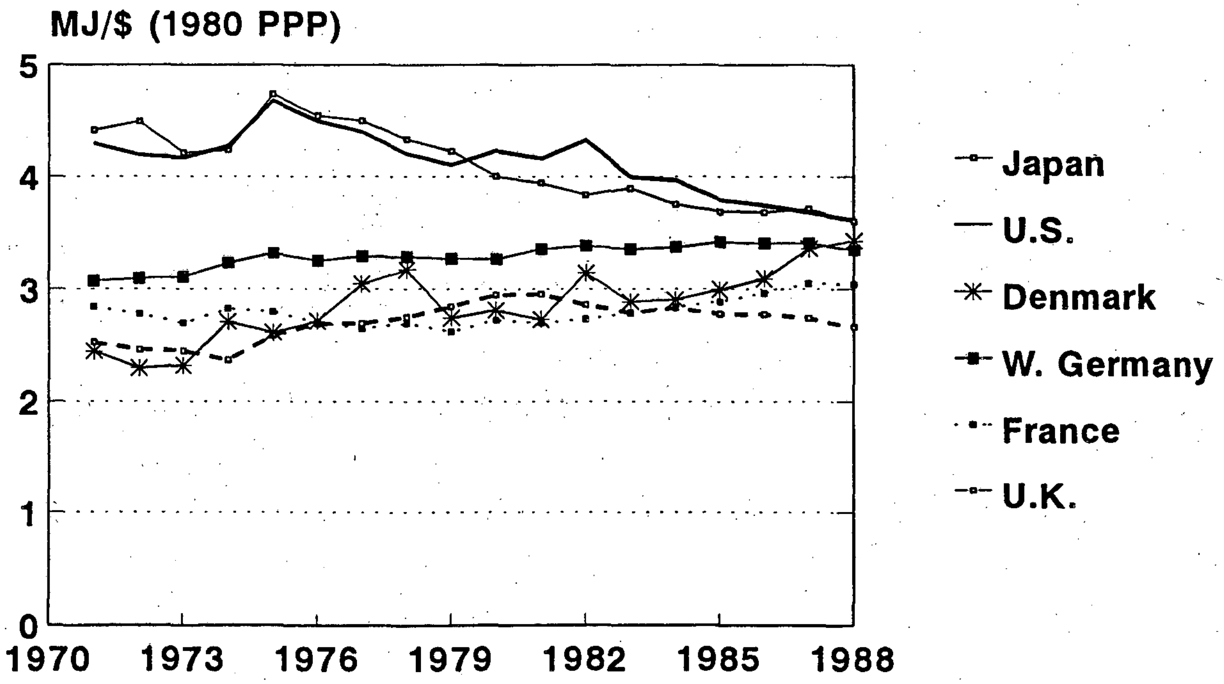
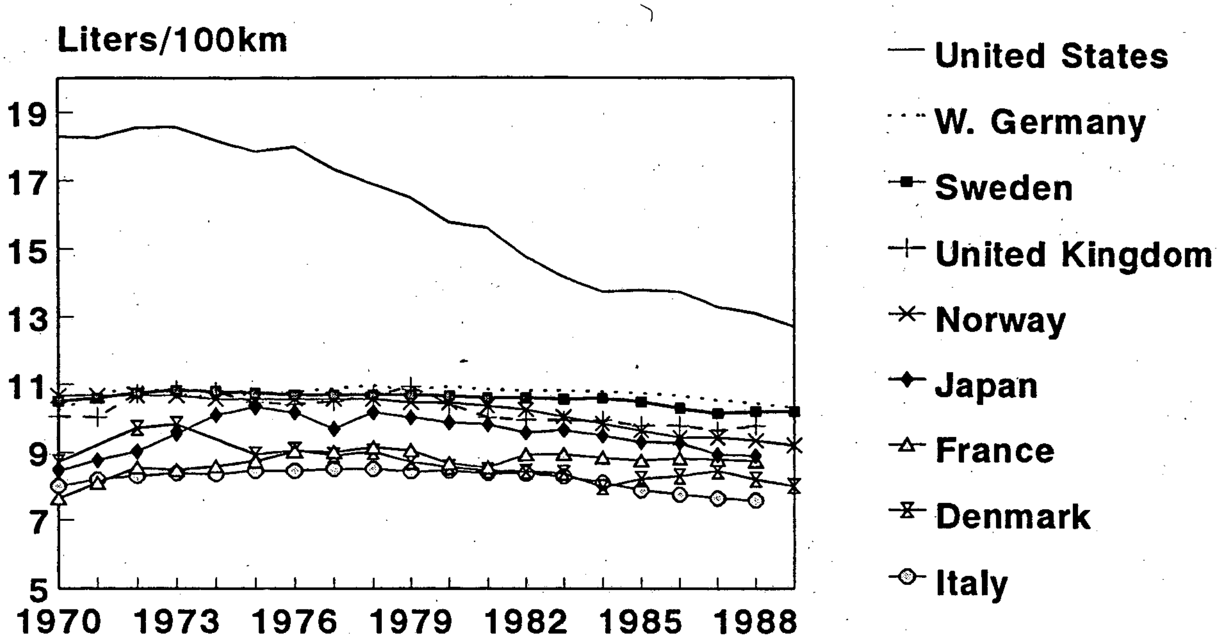


Figure 1-B

Automobile Fuel Intensities
On Road Fleet Averages



Includes diesels and light trucks.
10 ltrs/100km = 23.6 mpg

Figure 2

Truck Freight Energy Intensities

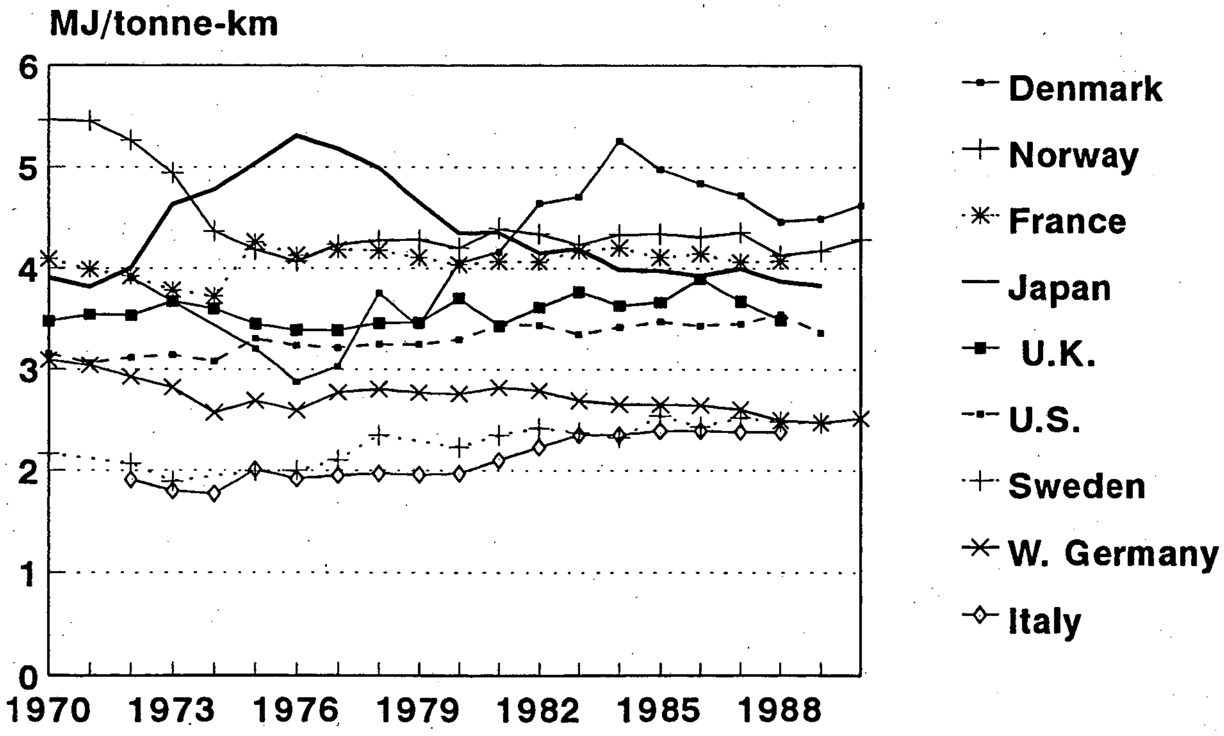


Figure 3

Space Heating Intensities

Useful Energy

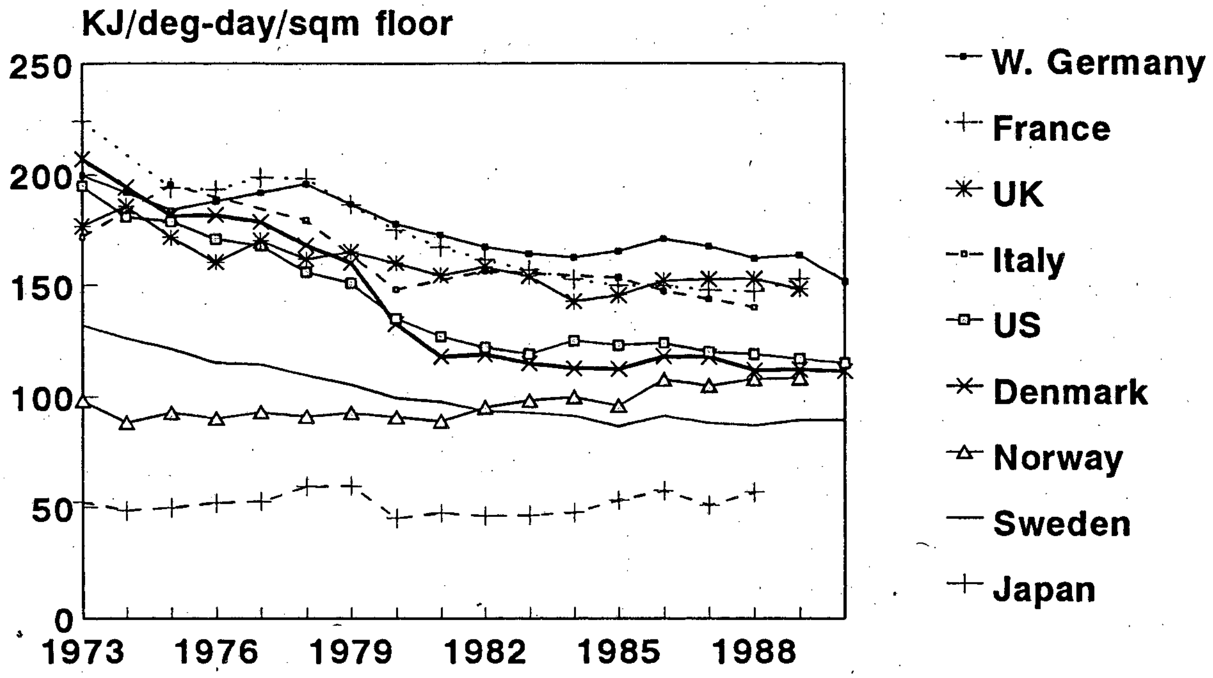


Figure 4

Service Sector Fuel Intensities

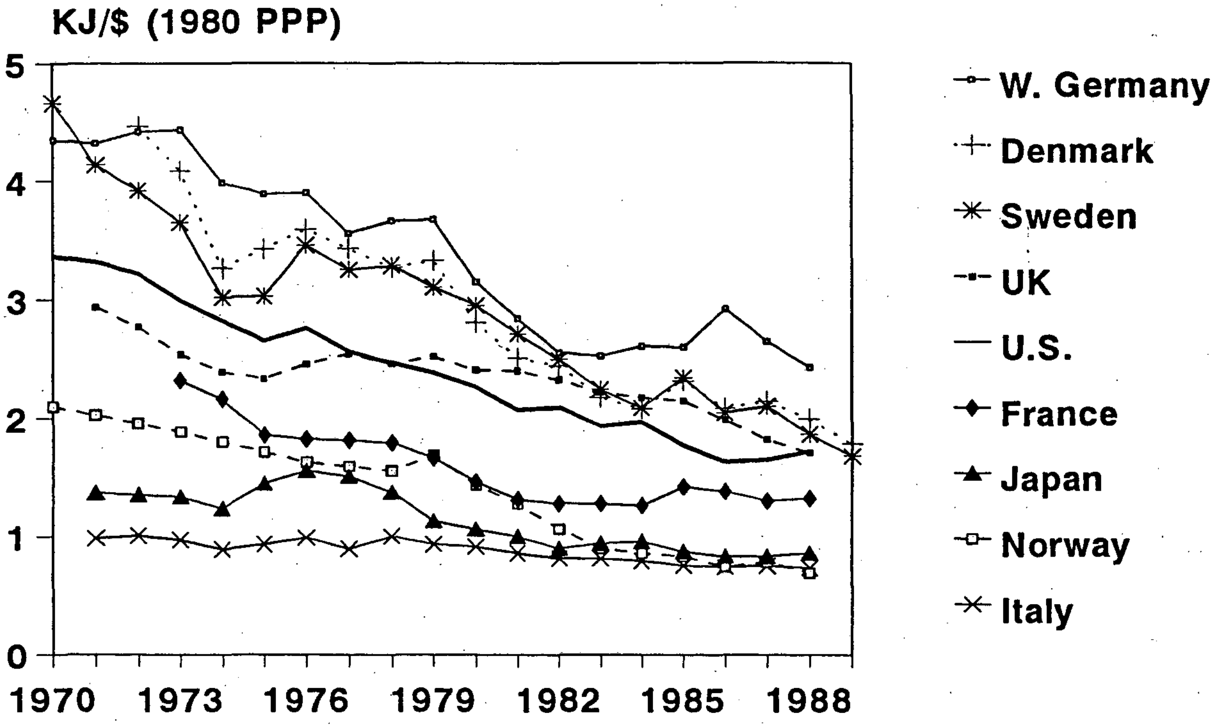


Figure 5-A

Service Sector Electricity Intensities

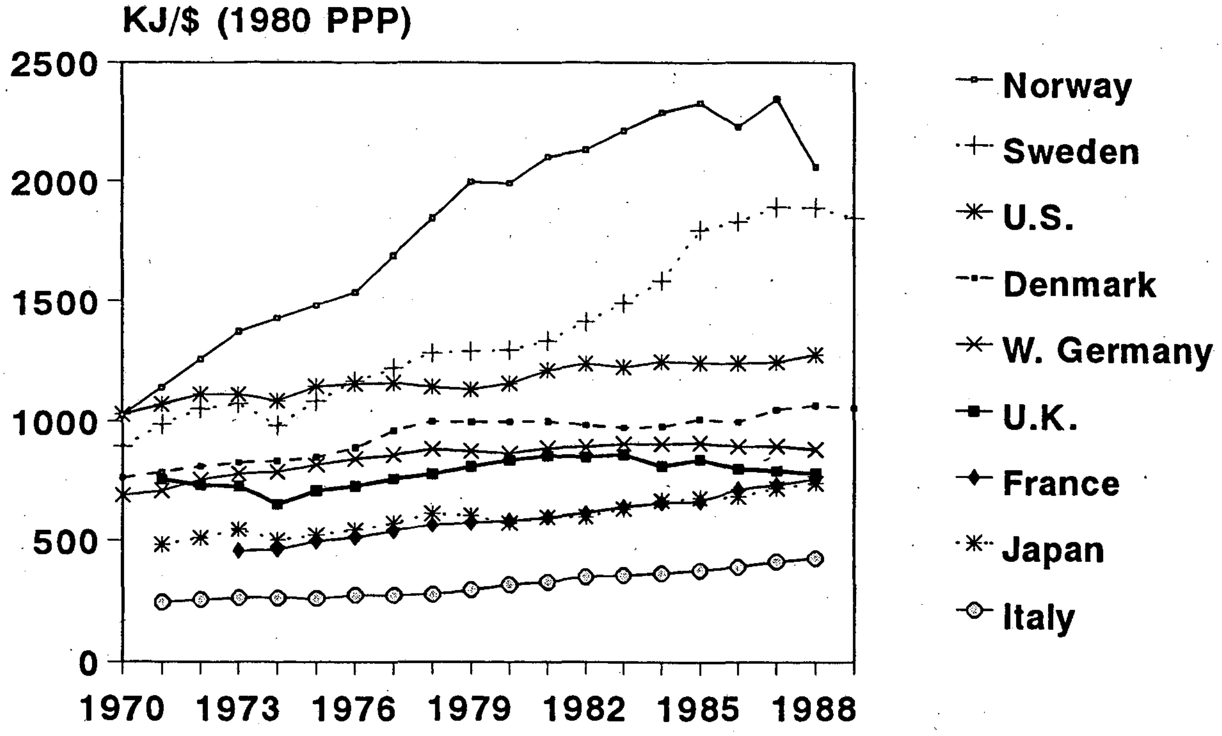


Figure 5-B

Weighted Energy Intensities
All Sectors, Constant 1973 Structure and Activity

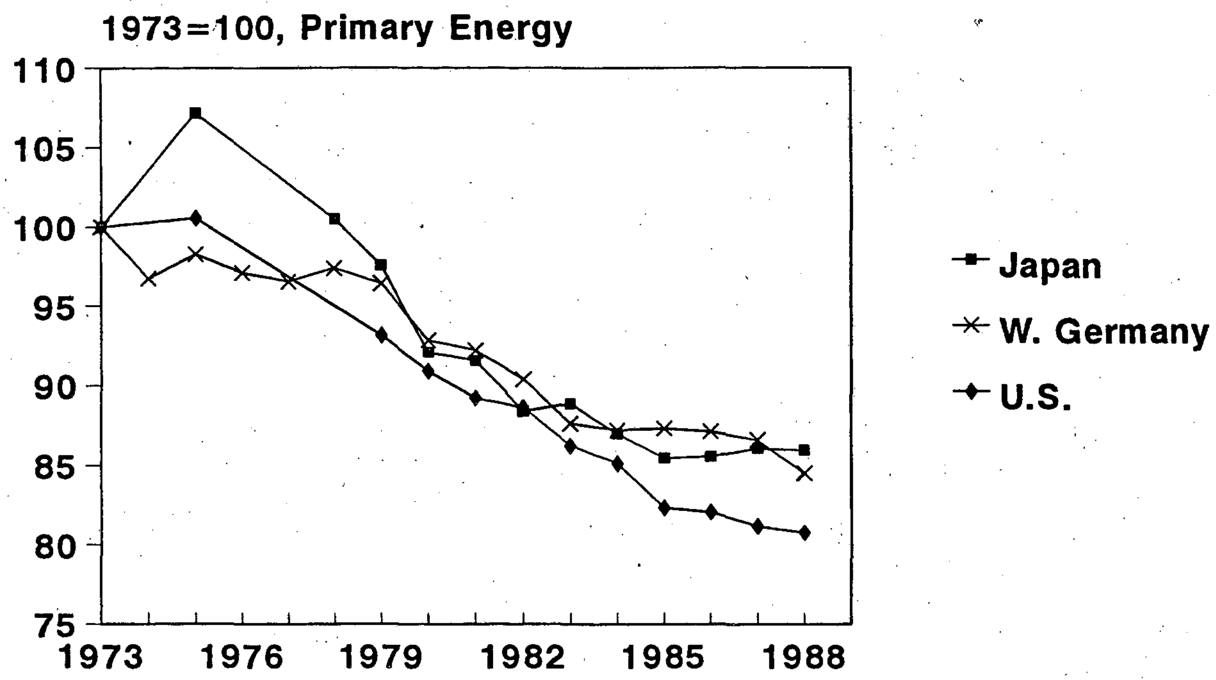


Figure 6

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720