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Authors
Meyers, S.
Schipper, Lee

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S. Meyers and L. Schipper

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WORLD ENERGY USE IN THE 1970s AND 1980s: EXPLORING THE CHANGES*

Stephen Meyers and Lee Schipper

International Energy Studies Group
Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

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ABSTRACT

Drawing on research from a number of projects of the International Energy Studies Group, we present a summary analysis of trends in final energy use for the industrial, developing, and "transitional" countries for the 1970-1988 period. We discuss change in activity, structure, and energy intensities for manufacturing, passenger travel, freight transport, the residential sector, and the service sector, and illustrate how these forces have shaped energy use in different ways in different parts of the world.

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1. INTRODUCTION

As the 20th century draws to a close, both individual countries and the world community face challenging problems related to the supply and use of energy. These include local and regional environmental impacts, the prospect of global climate and sea level change associated with the greenhouse effect, and threats to international relations in connection with oil supply or nuclear proliferation. For developing countries, the financial costs of providing energy to meet basic needs and fuel economic development pose an additional burden.

To assess the magnitude of future problems and the potential effectiveness of response strategies, it is important to understand how and why energy use has changed in the past. This requires study of the activities for which energy is used, and of how people and technology interact to provide the energy services that are desired. Over the past decade, the authors and their colleagues at Lawrence Berkeley Laboratory have analyzed trends in energy use by sector for most of the world's major energy-consuming countries. In this article, we summarize our findings for the 1970-1988 period, and draw on work by others as well. (We present data after 1988 in some cases.) Because of the nature of the available data and the focus of our own research, we are able to look in greater depth and speak with more certainty for the industrial (OECD) countries than for the developing and "transitional" countries.[1]

1.1. Energy Trends Since 1970: A Global Overview[2]

An overview of trends in energy use over the past two decades is helpful to place the sectoral analyses in context. World primary energy use has risen by over one-third since 1970.[3] Although demand was steady in the 1974-1975 and 1980-1983 periods as a result of response to higher energy prices and slowing of economic activity, growth continued after each period of stagnation as real oil prices declined and economic growth resumed. Between 1983 and 1989, the course of world energy use was steadily upward, averaging 2.8% per year. There was little increase in 1990, but this was due to slowing of the OECD economies and the radical changes that were taking place in the formerly-planned economies.

Most of the growth in world energy use since 1970 has been in the developing countries (Figure 1). Their share of the world total grew from 20% in 1970 to 31% in 1990. (Not counting biomass fuels, the share for the developing countries would be about 27%.) The share of the OECD countries fell from 60% to 48%, while that of the transitional countries rose slightly from 20% to 21%. Growth in energy use between 1970 and 1990 averaged 4.5% in the developing countries, 2.4% in the transitional countries, but only 1.3% in the OECD countries. Although energy use in the developing countries has grown much faster than in the rest of the world, per capita consumption remains far lower (Figure 2).

The reasons for these changes are explored in this article. A few points are worth mentioning now, however. First, population growth was greater in the developing countries than in the other groups, and economic growth was also somewhat higher. Further, in many developing countries commercial energy

[1] The OECD countries include the US, Japan, Western Europe, Australia, and New Zealand. The "transitional" countries include the former USSR and the former communist countries of Eastern Europe (including East Germany). The developing countries include all other countries, including those that have reached relatively high levels of per capita GDP.

[2] The data in this section are primarily based on British Petroleum Co. (2). The data on biomass energy use are mainly from the International Energy Agency (3,4), which relies on UN/FAO statistics. Estimates of biomass energy use in the developing countries are very uncertain. The authors have made some modifications based on Reference 5 which result in much higher use than the IEA indicates. Hall (6) estimates that total use is some 50% greater than these revised values.

[3] We primarily present energy use in Joules. 1 exajoule (EJ, 10^{18} Joules) = 0.948 quads = 23.9 million tons of oil equivalent (TOE). 1 gigajoule (GJ, 10^{6} Joules) = 0.948 million Btu. 1 megajoule (MJ, 10^{6} Joules) = 948 kBtu.

has grown faster than GDP due to increase in the role of manufacturing and building of basic infrastructure, to cite two key factors. In the OECD countries, on the other hand, structural change in economic activity and maturation of physical infrastructure has contributed to decline in the energy/GDP ratio. This "structural" decline was complemented by response to higher energy prices, as well as ongoing technological innovation. In many developing countries, energy users have been insulated from rising energy prices due to subsidies or, in the case of oil-producing countries, low domestic prices. In addition, information, skills, and capital to improve energy efficiency have been far more scarce than in the OECD countries.

Before presenting the sectoral analyses, we describe the conceptual framework that we use to study energy consumption, and discuss several issues that are important to understanding change in energy use.

2. UNDERSTANDING TRENDS IN ENERGY USE: A CONCEPTUAL FRAMEWORK

Understanding trends in energy use requires study of the activities for which energy is used, and of how people and technology interact to provide the energy services that are desired. The most aggregate description of the relationship between energy use and activity is the ratio of energy use to GDP. While appealing because it presents a societal overview in a single statistic, this approach has shortcomings which render it—in our view—an indicator best avoided. Trends in the energy/GDP ratio do not shed light on the two basic phenomena that shape energy use: 1) change in the levels of different activities; and 2) change in the amount of energy used to accomplish them (their "energy intensity"). To understand these changes, one must look at specific sectors of activities. In our work, we examine five sectors: manufacturing, passenger travel, freight transportation, residential, and services (often called the "commercial" sector).[4] Final energy is the main focus of our attention. Combining final use of electricity and fossil fuels is always problematic because electricity is often used very efficiently at the point of use, yet that use usually entails considerable loss of energy in electricity production and delivery (approximately twice as much if electricity is produced from fossil fuels).

Within each sector, we use a method of classification with which we can organize data on both energy use and activity. In manufacturing and services, the framework used for national accounts provides a means for valuing various activities in a common monetary unit (value added, which expresses the net economic output of various economic sectors). In manufacturing, data on energy use by subsector are often available, but such data are much less common for the service sector. In passenger travel and freight transport, the most workable approach is to classify by the modes of transport: automobiles, rail, bus, and air for passenger travel; truck, rail, and ship for freight transport. For each mode, statistics that indicate the total amount of activity in a given period (the product of the number of passengers or tonnes of freight and the distance they are moved) are often available. With careful use of energy data and judicious application of certain assumptions, one can often estimate the energy used in each mode.

Structural change within the above sectors refers to shifts in the shares of total sectoral activity accounted for by the different subsectors or transport modes. It may increase or decrease energy use, depending on the energy intensity of the activities whose role is rising or falling. In manufacturing, for example, a few industries are much more energy-intensive than all others. Thus, a structural shift away from these industries decreases energy use relative to aggregate manufacturing activity. In freight transport and travel, a shift toward relatively energy-intensive modes such as trucks and automobiles

[4] We have not analyzed energy use in agriculture, mining, and construction, as energy-use data for these sectors are often uncertain. These sectors account for only about 10% of total final energy use in the industrial countries and somewhat more in the developing countries.

increases energy use.

Structural change is shaped by factors specific to each sector. Basic trends in the economy obviously play a leading role in manufacturing and services. Household income and the cost and convenience of different modes are important in passenger travel. In freight transport, the modal structure is shaped by the type of goods that are moved. Mining and agricultural products, which are heavy relative to their value, are often transported via rail or ship, but the flexibility and speed of trucks tends to favor them as intermediate and final goods become more important in an economy.

Energy intensity expresses the amount of energy used per unit of activity. The aggregate energy intensity of each sector is determined by its subsectoral energy intensities and structure. *Technical energy efficiencies*, by which we mean the energy use of equipment or processes under some uniform operating conditions, are major determinants of energy intensities. Energy efficiency refers to the amount of service delivered per unit of energy. Thus, when efficiency increases, energy intensity declines. Energy efficiency depends on the characteristics of various components and how they interact. Technical energy efficiency is very difficult to estimate for an entire national stock of equipment or buildings, but it can sometimes be estimated for new equipment (such as cars or appliances).

Other factors that shape energy intensities vary among sectors. In manufacturing, changes in the product mix affect the energy intensity of particular industries. For example, the energy intensity of the paper & pulp industry is affected by shifts in production between energy-intensive pulp and finished paper goods. Change in the scale of factories or equipment may impact energy intensities. Energy intensities depend on how equipment is operated and maintained and how well its capacity is utilized. In manufacturing, factories operating at a low fraction of capacity are usually more energy-intensive than when operated at full capacity. Similarly in transport, falling load factors (decline in the ratio of passengers to available seats) raise energy intensity even if the characteristics of the vehicle stock are constant. Energy intensities are also affected by the type of energy that is used. For example, a change from oil-fired to electric heating equipment reduces the final energy intensity because the conversion of electricity to heat at the building is inherently more efficient than the conversion of oil to heat.

We approach the residential sector in a somewhat different manner from the others. Measuring activity is difficult since there are many different energy-using activities that take place in homes but no single measure. Here we use population as an indicator of residential activity. We define structural change with respect to household size, per capita ownership of energy-using equipment, and for space heating, dwelling area per person. Thus, it partly describes change in the types of activities that take place in homes. Energy intensities are expressed in terms of energy use per person, per device, or per unit of area for each major end use.

Together, change in activity, structure, and energy intensities shape trends in energy use in each sector. One can measure the impact of any one of the three factors by holding the other two constant. For the OECD countries, we employ a method that is rooted in the use of fixed-weight or Laspeyres indices, as described in the Appendix. Figure 3 illustrates the role of the different factors in the US manufacturing sector. Final energy use declined by 13% between 1973 and 1988 even though aggregate activity (value added) grew by around 50%. If sectoral structure and energy intensities had remained constant, energy use would have increased by that amount. In fact, the structure of the sector changed in a way that dampened growth in energy use slightly. Decline in energy intensities had an even more powerful downward effect. The combined result of these three forces was the 13% decrease in energy use.

2.1. Change in Energy Intensities: A Closer Look

In general, there are three basic ways in which change in energy intensities may occur: 1) modification of existing equipment or facilities (retrofit); 2) change in operation and maintenance; and 3) stock turnover, the addition of new and retirement of old equipment or facilities. In the long run, turnover of the stock and incorporation of new technology has the largest overall impact. In countries that are growing rapidly, or where a large part of the existing stock is obsolete, stock turnover can have a strong impact even in the medium term. In addition to the above factors, change in the operating environment and in inputs also affects energy intensity. For example, growing traffic congestion has increased the energy intensity of road transport modes. The quality of electric power supply affects the energy efficiency of electrical equipment—both in terms of actual operation and choice of equipment; this is an especially important factor in many developing countries.

Retrofit mainly affects buildings and factories. Improvement in the thermal properties of buildings or replacement of equipment may result from general-purpose renovation as well as from modifications made explicitly to conserve energy. Similarly, changes to industrial facilities designed to improve productivity generally may affect energy intensity.

Changes in operation and maintenance may be short-term in nature, but some changes endure over time or are only partly reversed. Procedures that improve productivity are likely to endure in competitive sectors like manufacturing, air travel, and freight transport. This is less the case in homes and personal travel, where many behavioral changes that occurred in response to increased energy prices have partially or entirely reversed over time. In all sectors, electronic control systems have facilitated more energy-efficient operation of equipment and buildings.

The impact of stock turnover on energy intensities may be positive or negative depending on the characteristics of existing and new equipment and facilities. The energy efficiency of many types of equipment and processes has improved over time—irrespective of energy prices—due to technological innovation, which may increase energy efficiency without that being a primary purpose of the change. In some cases, however, change in characteristics has pushed upward on energy intensity even as technological innovation improved technical energy efficiency. For automobiles, for example, increase in size and performance has partially counteracted the impact of improved technical energy efficiency in the OECD countries.

The rates of stock growth and turnover are key factors. In the OECD economies, the growth of the overall stock has been slower than in the 1960s. In many developing countries, there was rapid addition of new equipment and facilities in the 1970s and 1980s, but retirement of the old is usually slower than in the OECD countries. In general, where there are clear incentives to improve productivity, faster economic growth results in more rapid technological innovation as well as more rapid incorporation of technological advances. Faster growth implies expansion of production, which involves addition of new equipment or facilities. If firms successfully take advantage of opportunities during periods of higher economic growth, more resources are available for research and development (R&D) to develop better technologies. For households, however, increase in disposable income allows the acquisition of new energy-using goods or replacement of old equipment with models that offer more service, and also allows purchase of more living area per person and attainment of a more comfortable indoor environment. All of these increase energy use.

2.2. Sources of Data

In the rest of this article, we use the framework of activity, structure, and energy intensity to explain past trends in energy use. Our analysis is based on work done over the past decade by the authors and their colleagues in the International Energy Studies (IES) Group. We rely on data gathered from various sources in each country rather than international publications, as experience has shown that the latter are often not reliable or sufficiently detailed or documented. Our sources include official statistics and surveys, private data and surveys, and reports from local institutions or academic groups. Official data include figures published by government ministeries, transport and housing authorities, and the central bureaux of statistics. Private data include surveys of household equipment commissioned on a regular basis by energy suppliers, as well as energy consumption data from suppliers.

Our analysis of the industrial countries draws from a number of past and ongoing studies that have assembled detailed time-series data bases on energy use and related factors by sector for eight countries ("OECD-8"): the US, Japan, West Germany, France, Italy, the UK, Norway, and Sweden. Together, these eight countries account for around 75% of total OECD energy use. An important focus of our effort is data on the characteristics and structure of each sector. These include the types of homes, heating systems, and electric appliances; the types of motor vehicles and their usage; the levels of passenger travel and freight activity; and levels of output in the major sectors of manufacturing. To these "structural" data we join energy use by fuel for the main subsectors or end uses. In disaggregating energy use, assumptions are required to separate household energy consumption into end uses, or to separate the use of road, rail, and marine fuels into the various travel and freight modes. We typically use a "bottom-up" approach which entails combining data on energy-using stocks with estimates of average energy use for various purposes (either our own or those of in-country experts). The data sources for the OECD countries are described in Reference 1.

The analysis of energy use in the former USSR draws on a recent study by Schipper and Cooper (7). Data are mostly from sources within the former Soviet Union: published data from various ministeries; energy studies in the open literature; and a wealth of unpublished data provided by the Energy Research Institute (Moscow), the Siberian Energy Institute (Irkutsk), and the All-Union Institute for Technical Problems of the Fuel-Energy Complex (VNIIKTEP), an arm of the Soviet State Economic Planning Agency (GOSPLAN). Additionally, we used information from a series of studies led by M. Sagers of the US Bureau of the Census. The methods used to disaggregate energy use are described in the report cited above.

For the developing countries, a key source is a time-series data base on sectoral energy use and related factors for 13 countries that has been organized by the IES Group. The countries (China, India, Indonesia, Malaysia, Pakistan, the Philippines, South Korea, Taiwan, Thailand, Argentina, Brazil, Mexico, and Venezuela) together account for about 70% of total energy use (and a somewhat higher share of total commercial energy use) in the developing countries. Although these data are not as detailed as those for the OECD countries, they present trends in a comparable format. Past analysis using these data is given in Sathaye et al (8). We also use results from studies conducted by institutions in various countries, as referenced.

Unless noted otherwise, the data presented in the text, tables, and figures are drawn from the above sources.

3. MANUFACTURING

Manufacturing accounts for more of the world's final energy use than any other sector. Although its role has declined significantly in the OECD countries to about 27% of final energy, its share has increased in the developing countries to around 40% and has remained at around 35% in the transitional countries.

Manufacturing energy use has fluctuated since 1970 in the OECD countries, but was lower in 1988 than in 1973. In the developing countries, on the other hand, growth has been relatively steady. In the transitional countries, there was also moderate growth up until 1988 but it has declined since then with the collapse of the old economic order.

An important feature of manufacturing energy use is that a few industries are much more energy-intensive—in terms of energy use per unit of value-added—than the rest, and thus account for a large share of total energy use. The main energy-intensive industries are iron & steel; non-ferrous metals; paper & pulp; chemicals; and building materials. For the OECD countries that we studied, the average energy intensity of these industries in 1988 ranged from 31 MJ/1980$ of value-added for chemicals to 97 MJ for iron & steel. The average energy intensity of all other manufacturing was only 6 MJ/1980$. The energy-intensive sectors accounted for only around 20% of manufacturing value-added, but claimed 70% of energy use. Because of the great difference in energy intensity between these industries and all others, changes in their role have a major impact on aggregate manufacturing energy intensity.

3.1. Industrial Countries

For seven major OECD countries, manufacturing value added (MVA) rose at an average rate of 2.3% per year between 1973 and 1988.[5] Despite the growth in activity, energy use fell by 1.2% per year, although not smoothly over time. OECD-7 aggregate manufacturing energy intensity fell a remarkable 40%. The decline was greater in the US and Japan (43% and 45%) than in Europe (34%).[6] Structural change away from the energy-intensive industries accounted for about one-fourth of the decrease in aggregate intensity for the OECD-7. Particularly important was the decline in the share of iron & steel (the most energy-intensive sector) from 5.6% to 3.3% of total MVA. The one energy-intensive sector whose share grew (slightly) was chemicals, but the growth was in relatively less energy-intensive finished chemical products rather than in basic industrial chemicals such as ammonia and chlorine. Structural change played a more important role in the US and Japan than in Europe, which largely explains why the decline in aggregate intensity was less in Europe.

Decline in energy intensities at the industry level was the major force pushing aggregate intensity downward. For the OECD-7, the "structure-adjusted" manufacturing energy intensity, which describes how energy intensity would have evolved had the structure of the manufacturing sector remained in its 1973 configuration, declined by 32%. The drop in the three regions was rather similar: 32% in the US, 34% in Japan, and 30% in Europe. Within Europe, large decline in "structure-adjusted" energy intensity in the UK and France was partly balanced by a smaller decline in West Germany.

For the OECD-7 average, the largest intensity reduction was in chemicals (37%). The decline in other energy-intensive sectors was 27% in paper & pulp and in iron & steel; 26% in non-ferrous metals; and 32% in building materials. Interestingly, the decline of energy intensity in non-energy-intensive

[5] Value-added data were gathered from national sources in real 1980 currency and converted to 1980 U.S. dollars using the purchasing power parities published by the OECD. Italy is not included in the manufacturing analysis due to data uncertainties. We have not included chemical industry feedstocks in energy use. See Howarth & Schipper (9) for further discussion of OECD manufacturing.

[6] The US accounted for 54% of total OECD-7 manufacturing energy use in 1988, Japan for 20%, and Europe for 26%. "Europe" refers to the aggregate of West Germany, France, the UK, Sweden, and Norway.

industries (37%) was comparable to that in the energy-intensive sectors. This development reflects the trend toward higher value per unit of physical output as light manufacturing has shifted toward more "high-tech" products.

The trends have been very different for fuel intensity and electricity intensity. Structure-adjusted fuel intensity declined considerably in all countries, especially in the US, where the level in 1985 was 45% below the 1971 level (Figure 4). Electricity intensity declined after 1975 in the US and Japan (but much less than fuel intensity), was fairly steady in West Germany and France (with some increase since 1984 in the latter), and rose in the UK.[7] Switching from fuels to electricity in certain processes (especially in steel production) played a small role in shaping the above trends. Since there has been growing use of electrical processes in many industries (which would push electricity intensity up), the fact that electricity intensities have declined or remained stable strongly suggests that there has been improvement in the efficiency of specific processes.

Change in the product mix *within* industries (shift toward products that require less energy to produce per unit of value-added) contributed to decline in energy intensities. (As this occurred to a considerable extent in the chemical industry, it may explain why the intensity decline in chemicals was larger than in other energy-intensive industries.) Data on energy use per tonne of various products suggest, however, that most of the decline was due to improved efficiency in the manufacture of particular products. The key factor in this was the introduction of new production processes, which was a continuation of a long-term trend more than a response to higher energy prices. Improvements in operations and maintenance, retrofits to save energy, and retirement of older facilities also played a role.

3.2. Developing Countries

Manufacturing output and energy use grew significantly in the developing countries in the 1970-88 period. Both output and energy use in the developing countries as a group is dominated by China, India, and Brazil. China alone accounts for nearly half of total LDC manufacturing energy use. Not including China, growth in LDC manufacturing value-added averaged 3.9% per year in the 1980s, well below the average of 7.4% registered in the 1970s.[8] Growth in output has varied considerably among regions, being much higher in Asia and the Middle East than in Latin America and sub-Saharan Africa (especially in the 1980s).

The structure of manufacturing in the developing countries as a group has become somewhat more energy-intensive since 1975. Again excluding China, the share of the five energy-intensive industries in total value-added increased from 18% to 20%. Iron and steel and non-ferrous metals especially grew faster than the average, in part due to rising exports to the OECD countries. Structural change has varied among countries, however. Many oil-rich countries have used their resources to build energy-intensive industries (especially petrochemicals), and some countries have used their hydro resources to expand basic metals industries (e.g., Brazil and Venezuela). Other countries, especially in Southeast Asia, have developed less energy-intensive industries producing textiles, machinery and other metal products, and various consumer products. In China, the historically large share of heavy industries in total output has declined somewhat as industries devoted to export and consumer products have grown.

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[7] Since there was growth in industrial electricity cogeneration in the study period, and the energy used in cogeneration is counted as fuel use, the true increase in electricity intensity was somewhat higher than is the case if one counts only purchased electricity (as we have done).

[8] Data on value-added are from the United Nations (UN) Industrial Development Organization (10). The data are expressed in real prices, converted to US dollars using 1980 exchange rates. China is not included in the UNIDO statistics due to lack of comparable data. If it were included, the average growth would be higher.

Time-series data on manufacturing energy intensity are hard to obtain for most developing countries, there are indications that intensities declined in some countries, especially where substantial investment in new facilities has occurred. In China, aggregate industrial energy intensity (including mining and energy industries) declined by a remarkable 45% between 1980 and 1988. Between 1980 and 1985, when aggregate intensity declined by 27%, intensity reductions in various industries accounted for around three-fourths of the total decrease (11). Energy intensity declined more in non-energy-intensive industries (30%) than in energy-intensive ones (18%). This was likely due in part to the faster growth (and addition of new factories) of non-energy-intensive industries, and perhaps to change in their product mix as well.

In Asia's newly-industrialized countries (NICs), there is clear evidence that the rapid growth in manufacturing contributed to decline in energy intensity. In Taiwan, aggregate energy intensity on average declined by 5.1%/year between 1978 and 1987. The share of energy-intensive industries in output remained at about 35%, so the change in aggregate intensity was caused mainly by reduced intensities at the industry level (12). In South Korea between 1975 and 1987, aggregate energy intensity fell by 2.6%/year. While there was some decrease in the share of energy-intensive industries, reduced intensities at the industry level played the dominant role (13).

The situation has been different in Brazil, where aggregate energy intensity increased at an average rate of 0.9% per year between 1973 and 1988 (14). The growth rate of sectoral output was much slower than in Taiwan and Korea, so there was less introduction of new factories and equipment. In addition, the availability of cheap hydroelectricity favored the development of steel and aluminum industries in Brazil. Although this contributed to an increase in aggregate energy intensity, there was decline in energy intensity in the iron & steel, paper & pulp, non-ferrous metals, and cement industries.

3.3. Transitional Countries

Manufacturing accounted for around 35% of final energy use in the mid-1980s in the former USSR, and for a somewhat higher share in Eastern Europe. While the 1970s and 1980s were marked by considerable change in the manufacturing sector elsewhere, manufacturing in the formerly-planned economies, relatively isolated from competition and administered by government policy, saw growth in production but relatively little technological change. The sector continued to be dominated by the heavy industries that were established in the 1950s and 1960s.

Historical data on Soviet manufacturing energy use and production are uncertain. Industrial energy use (which includes mining, construction, and agriculture) grew at an average of about 2.5% per year between 1970 and 1985. This was less than the estimated growth in industrial output (around 3.5%), but some of that growth came from oil and gas production, which means that manufacturing output grew more slowly. Assessing the structural evolution of manufacturing is likewise difficult due to lack of disaggregated data, but trends in per capita production suggest that there has been some decline in the role of the steel and cement industries since the mid-1970s (Figure 5). Although per capita steel production levelled off in the 1980s, production per unit of GDP was still much higher than in the OECD countries, as was also the case in Eastern Europe (15). As for energy intensities, the available data show no reduction in energy use per tonne between 1975 and 1985 for the Soviet steel and cement industries, and an increase for the pulp and paper industries. Given the maintenance of low energy prices and lack of incentive for technological innovation, this is hardly surprising.

4. PASSENGER TRAVEL

Passenger travel accounts for a much higher share of final energy use in the industrial countries (22%) than in the developing and transitional countries (around 5%), where per capita automobile ownership and air travel are much lower. Energy for travel (primarily in the form of petroleum products) has risen in each country group. Structural change, by which we mean shifts in the role of different modes in total travel, has contributed to the increase, since the modes that have become more important, automobile and air, are more energy-intensive than the others. Automobiles account for nearly 90% of domestic travel energy use in the OECD countries. Their share is much smaller in the developing and transitional countries, but it has grown in both groups.[9]

4.1. Industrial Countries

Total domestic travel in passenger-km (p-km) grew by about 40% between 1973 and 1988 in the US, Europe, and Japan, but energy use for travel rose much less in the US.[10] Aggregate travel energy use per p-km increased slightly in Europe, rose substantially in Japan, but declined by 18% in the US. Because the US accounts for 70% of total OECD-8 travel energy use, the decline there caused OECD-8 travel energy intensity to decrease by 13%. Change in the modal structure of travel played a small role in increasing aggregate intensity in the US and Europe, but had a major effect in Japan, where the role of the automobile rose considerably in the 1980s. (In the US, it already accounted for 90% of travel in 1970.) Adjusted for structural change, travel energy intensity rose slightly in Europe and Japan, but declined by 15% in the US.

Automobile energy use per km fell by 30% in the US, but there was little change in Europe and Japan (Figure 6).[11] The decline in the US was the result of a dramatic decrease (50% between 1973 and 1982) in the fuel intensity of new automobiles (Figure 7). As these cars have come to play a larger role in the automobile fleet, average intensity has steadily declined. In Europe and Japan, there has been only minor decline in the average fuel intensity of new cars, as increase in size and power has offset gains from technical efficiency improvements. This phenomenon has caused the decline in new car fuel intensity to level off since 1982 in the US as well. In all of the countries, rising traffic congestion has dampened improvement in fleet fuel economy.

A large drop in the energy intensity of air travel contributed to the decrease in aggregate travel energy intensity. Domestic air travel intensity fell by 50% in the US between 1970 and 1988, and declined considerably in Europe and Japan as well. The main cause was introduction of new aircraft that were much more fuel-efficient than those they replaced (17). Retrofitting old planes with new engines and increased load factors also played a role.

4.2. Developing Countries

The magnitude of growth in travel is uncertain, since the reported statistics often do not include reliable estimates of private travel by cars, motorcycles, and mopeds. Even so, data for several countries show considerable increase in per capita travel in the past two decades (13,14,18): 7% per year in South Korea and Brazil (through 1985 for the latter), and 11% per year in China. The levels of per capita travel

[9] The data in this section include motorized modes only. Walking and bicycles account for a significant amount of travel in the developing countries.

[10] See Schipper et al. (16) for further analysis of energy use in passenger travel in the OECD countries.

[11] The decline in the US would have been somewhat larger but not for growth in the use of light trucks as passenger vehicles. Automobile energy use per p-km declined less in the US and rose slightly in Japan and Europe due to a drop in the average load factor of car travel.

(3-4,000 p-km in South Korea and Brazil and only 600 p-km in China) are well below the European average (11,000 p-km).

Buses (and in a few countries, rail) still account for a large majority of motorized travel in most developing countries. In South Korea, for example, the data show a decline in the shares of buses and rail, but they still accounted for 60% and 24% of total p-km in 1987, respectively, while cars (including taxis) accounted for only 14%. In China, rail still dominates travel, but its share declined from 70% to 53% between 1970 and 1988, while the share of road modes (mostly buses) increased from 23% to 41%. Use of automobiles has grown considerably, especially in Latin America and the Middle East, where historically higher income and urbanization levels have led to much greater per capita car ownership than in Asia and Africa. In much of Asia, where cities are more crowded, there has been growing use of mopeds and motorcycles. Lastly, domestic air travel has increased considerably in large countries in the past decade.

Change in the energy intensity of travel modes in developing countries is difficult to assess. Bus and rail systems have probably not seen very much efficiency improvement in most countries. For automobiles, it is likely that the energy efficiency of new cars has increased in keeping with international trends in vehicle technology, but there are signs of a shift to larger, more powerful cars in some countries. In Brazil, the transition from gasoline to ethanol-fueled cars reduced average fuel intensity, since the latter are inherently more fuel-efficient, and there has also been some improvement in the fuel economy of new gasoline and ethanol-fueled cars (14). As in the industrial countries, it seems likely that the worsening of urban traffic conditions has dampened improvement in the actual fuel economy of automobiles and buses.

4.3. Transitional Countries

Passenger travel has accounted for a very small share of final energy use (about 5%) in the formerly-planned economies due in part to the low levels of automobile ownership. Despite restrictions on travel, growth in reported p-km in the Soviet Union averaged 4-5%/year between 1973 and 1987. Although rail and bus dominate travel (with 31% and 28% of total p-km in 1987), automobile and air travel have increased their shares (to 21% and 12%). This development has contributed to an increase in aggregate travel energy intensity. The intensity of automobile travel itself has declined as more small cars entered the fleet. (Large official cars accounted for a considerable share of the Soviet fleet in the early 1970s.) The energy intensity of Soviet air travel has also declined slightly since the early 1970s due mainly to an increase in aircraft size. Since the demand for travel has exceeded the supply of flights, load factors remained constant at nearly 100%.

4.4. International Air Travel

International air travel increased nearly six-fold between 1970 and 1990, and the share of international travel in total air travel rose from 30% to 44% (19). The largest absolute growth has been in trans-Atlantic travel, but the relative increase has been much larger for trans-Pacific and Europe-Asia travel. International travel within Asia has also grown significantly. The energy intensity of international air travel is less than that of domestic air travel, since air carriers tend to use their largest, most efficient equipment on international routes, and load factors are high.

5. FREIGHT TRANSPORT

Freight transport accounts for only half as much energy use as passenger travel (about 10%) in the industrial countries, but it is much more important than travel in the developing and transitional countries, accounting for around 9% and 13% of final energy, respectively. The data for each country group do not include international shipping, but do include international land transport. The data do not include activity and energy use accounted for by pipeline shipments of oil and gas except in the former USSR, for which data were available.

Energy use for freight transport is strongly affected by the modal structure, which is in turn shaped by the types of goods that are moved. Mining and agricultural products, which have low value per tonne, are often transported via rail or ship, both of which have much lower energy intensity than trucks. As economies develop, intermediate and final goods take on a greater share of freight transport. Since trucks offer greater flexibility for such shipments, they tend to assume an increasing role in freight transport over time.

5.1. Industrial Countries

Energy use for freight transport in the OECD-8 increased at an average rate of 2.3% per year between 1973 and 1988, somewhat faster than the annual increase in tonne-km of 1.9%. The increase in aggregate energy intensity was higher in Europe and Japan than in the US, as structural change toward greater use of trucks played a larger role, especially in Japan.

Trucks account for 85% of total energy use for freight transport in the OECD-8. The energy intensity of freight trucking (energy per tonne-km) increased by about 13% in the US between 1973 and 1988, declined by 16% in Japan, and increased slightly in Europe (Figure 8). In the US, average fuel use per km was the same in 1988 as in 1973 for both medium and heavy (tractor-trailer) trucks. Improvement in technical efficiency was apparently offset by an 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 of an increase in empty backhauls, resulting in reduced tonnage per distance traveled (20). In addition, it is likely that the weight carried per volume of truck capacity declined (due in part to increased packaging for many goods).

The role of rail in OECD freight transport has declined since 1973. Rail energy intensity (final energy) declined by 34% in the US, by 26% in Europe-6, and by 58% in Japan, where rail activity fell considerably. Electrification accounts for part of the decline in Japan and Europe. Other factors were the use of stronger locomotives and the trend to cutting unprofitable lines, which presumably supported smaller trains with less than full loads.

5.2. Developing Countries

Freight transport activity and energy use have grown substantially in the developing countries. The ratio of reported freight activity (tonne-km) to GDP has declined slightly since 1980 in China as a result of the "lightening" of economic output (18), changed little in South Korea since 1970 (13), and risen significantly in Brazil (14), which may reflect greater transport of mining and logging products from the Amazon region. Structural change in freight transport has also varied across countries, but it appears that the role of trucks has grown in most cases. China and India, which together account for a large share of total LDC freight transport, still rely heavily on rail (and ships in China), but the role of trucks has risen in both countries. In South Korea, the share of trucks increased from only 11% in 1970 to 48% in 1987, while rail declined considerably in share. In Brazil, on the other hand, the data show a decline in the share of trucks from 62% in 1973 to 54% in 1985, and an increase in the share of ships.

Lack of data makes it difficult to assess how the energy intensity of particular freight transport modes has changed in developing countries. For trucks, however, two factors have undoubtedly contributed to a decline in energy intensity. One is a shift from gasoline to diesel-fueled trucks. Related to this is an increase in the share of heavy trucks, which use less energy per tonne-km than medium or light trucks (if their capacity is utilized). In Brazil, the share of diesel-fueled trucks increased from about 50% of the fleet in 1973 to over 85% by 1985, while the fraction of heavy and semi-heavy trucks rose from 15% to 28%. In India, the transition from gasoline to diesel-fueled trucks is nearly complete, while in China most trucks still use gasoline. In both countries, technological improvement affecting the fuel efficiency of gasoline and diesel trucks has been minimal. Similarly, the energy intensity of rail transport has declined in India due to increasing use of diesel and electric locomotives in place of steam locomotives using coal, but the efficiency of diesel and electric locomotives has not improved very much. In China, steam trains are still predominant, but greater use of diesel locomotives has decreased rail energy intensity.

5.3. Transitional Countries

Energy use and activity for freight transport grew considerably in 1970-1988 in the transitional countries, in part because of the increase in oil and gas shipments (primarily by pipeline) in the former USSR. Pipeline shipment of oil and gas (a substantial amount of which was destined for export) accounted for one-third of total Soviet tonne-km in 1987 and most of the growth in the total since the mid-1970s. Excluding pipelines, rail accounted for about 80% of Soviet tonne-km in 1988. Unlike in other parts of the world, there was little increase in the role of trucks, which reflects the continued dominance of heavy products in the economy, the lack of development of the distribution system, and the relative unimportance of consumer goods.

Because of the dominance of rail and large shipments of bulk materials, the aggregate energy intensity of Soviet freight transport is lower than Western European levels. Rail energy intensity has decreased, first through replacement of coal traction by oil, then through electrification. The fuel intensity of trucks has also fallen somewhat, mainly because of an increase in the share of diesel trucks.

5.4. International Maritime Freight Transport[12]

As international trade has expanded, so too has maritime shipping of goods. The total tonnage of goods shipped worldwide increased only slightly between 1973 and 1985, however. (Data on tonne-km are not available.) Shipment of dry cargo rose by 38%, but this was balanced by decline in shipment of crude oil and petroleum products, which accounted for nearly half of total goods shipped in 1973, but only 42% in 1985.

While the tonnage of goods shipped remained about the same, worldwide energy use by marine bunkers declined considerably from 5.2 EJ in 1973 to 3.9 EJ in 1987. (The latter figure was comparable to the combined energy use for all freight transport within Western Europe and Japan.) Several factors could explain the decline. One is the decline in the role of oil, which is a heavy good to transport. The energy efficiency of the world fleet of ships probably increased as new vessels replaced older ones. It may also be that average distances were shorter in 1987 than in the early 1970s.

[12] The data in this section are from United Nations statistical publications.

6. THE RESIDENTIAL SECTOR

Energy use in the home accounts for around 20% of final energy use in the industrial and transitional countries, but for about 35% in the developing countries. The high share in the developing countries is due to the heavy reliance on biomass, which is utilized with very low efficiency. In the OECD countries, residential energy use was about the same in 1988 as in 1973 despite a 10% growth in population (and a much larger increase in the number of households). In the developing countries, by contrast, it has grown considerably due to population increase and rising appliance ownership. Home energy use in the transitional countries grew somewhat faster than population over the past two decades.

The end-use structure of residential energy consumption is quite different in the three country groups. Space heating accounts for around 75% of total final energy use in the transitional countries due to both the cold climate and the relatively low electricity demand from home appliances. It is also the major end-use in the OECD countries (about 60%), but its role has declined since 1973. In the developing countries as a group, cooking is the dominant end use, and space heating is relatively minor.

6.1. Industrial Countries[13]

Trends in residential energy use have differed among the OECD countries. Final energy use per capita declined by 15% in the US between 1973 and 1988, but rose by 10% in Europe and by 46% in Japan. Increase in the market share of electricity for space heating, water heating, and cooking pushed down final energy use in all cases.[14] Decline in household size (from 3.1 to 2.7 persons in the US and Europe, and from 3.8 to 3.3 in Japan) worked in the opposite direction, since per capita energy use rises considerably as household size decreases.

Three structural factors increased residential energy use. One was growth in home area per capita, which meant more space to be heated or cooled. Another was increase in the levels of heating equipment (toward either central heating or use of more or larger heaters). Yet another was growth in appliance ownership. In the latter two cases, the effect was much larger in Europe and Japan than in the US, where these changes had begun already in the 1960s. This difference is a major reason why energy use per capita rose in Europe and Japan but fell in the US.

Between 1973 and 1982, the energy intensity of space heating (useful energy per square meter, adjusted for climate change) declined by 37% in the US; by 24% in Scandinavia; by 11% in the combination of France, West Germany, Italy, and the UK; and remained about the same in Japan (Figure 9). Had it not been for the changes in heating equipment mentioned above (which amount to more heating service) the decline would have been much greater in Europe and Japan. Judging the role of the various factors that contributed to intensity decline is difficult. Retrofits that improved building thermal integrity were important in the US and Europe, as was the penetration of more efficient heating equipment. Introduction of new homes that were more energy-efficient than the average also played a role, particularly in the US, where more new housing was added than was the case in Europe. Reduction in average indoor temperature was also a factor, especially in the US (22).

In contrast to space heating, water heating energy intensity (useful energy per capita) rose by nearly 30% in Europe 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 US, however,

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[13] For further discussion and analysis, see Ketoff & Schipper (21).

[14] To account for this effect, we employ the concept of "useful" energy, which is equal to final energy use minus estimated conversion losses at the home. Useful energy consumption per capita declined by 11% in the US but rose by 12% in Europe and by 59% in Japan.

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 intensity (energy use per device). These improvements were especially large in the US 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 (23). A weighted-average energy intensity of seven major appliances fell by 13% in the US and by 2% in West Germany, but rose by around 40% in Japan, where increase in size was especially strong.[15]

6.2. Developing Countries

Trends in residential energy use in the developing countries are hard to gauge with precision due to difficulties in disaggregating residential and commercial sector consumption of fuels and uncertainty about trends in biomass use. Combined residential/commercial kerosene and LPG consumption per capita, most of which is for residential use, was fairly level in Latin America (with growth in Brazil since the mid-1980s), rose considerably in South Asia, but declined in some other Asian countries. For biomass, Brazilian data show a significant decline in per capita household consumption since 1970, while data for several Asian countries show relatively little change. Residential electricity use has grown rapidly in nearly all countries, with the average annual rate exceeding 8% in many countries (24). Per capita electricity use increased enormously between 1970 and 1988 in Asia, but rose much less in Latin America, in part because levels of electrification and appliance ownership were much higher in 1970 than in Asia (Figure 10).

Change and growth in equipment ownership has been a significant force in the developing countries. As urbanization and incomes have increased, there has been a transition in the fuels used for cooking away from biomass to kerosene to LPG and, in some cases, electricity. The transition away from biomass has occurred to a much greater extent in urban than in rural areas, both because incomes are higher and because fuel availability is better. Surveys in several countries show a gradual decrease in use of biomass as city size increases (5). The transition to LPG was already well-advanced in Latin American cities in the early 1970s. In Asia, movement from biomass to kerosene, and especially from kerosene to LPG, occurred rapidly in the 1980s (25). In sub-Saharan Africa, there has been less change in fuels, and even movement back to biomass.

The other key structural change has been growth in the penetration of lighting and electric appliances. Rural electrification has advanced considerably since 1970, and lighting is the first end use that households acquire. As incomes have risen, rapid growth in ownership has occurred for TV sets and refrigerators (Table 1). There has also been growth in ownership of clothes washers in some countries. Air conditioners are as yet uncommon, except in Taiwan and the upper-income Middle East countries, but their ownership is growing.

The transition away from biomass has probably decreased overall cooking energy intensity (final energy), since kerosene and LPG stoves are usually much more efficient than biomass cooking. For electric appliances, there is evidence that efficiency has improved for new models of a given size and type. (New models in most developing countries are still well behind the state-of-the-art in the industrial countries, however.) In Brazil, test data show that the average energy use of new one-door refrigerators of 250-300 liter size declined from 490 kWh per year in 1986 to 435 kWh in 1989 (26). (The improvement occurred in part as a response to the government's refrigerator testing program.) In South Korea between

[15] The seven appliances are refrigerator, freezer, refrigerator-freezer, clothes washer, dryer, dishwasher, and air conditioner (in the US and Japan). The weighting is based on 1980 appliance penetration in each country.

1980 and 1987, manufacturers report a decline from 672 to 240 kWh per year for 200-liter refrigerators, and from 82 to 60 W for 14-inch TV sets (27). Even with improvement in efficiency, the average energy use of new appliances has likely increased in many cases due to growing penetration of larger and more feature-laden appliances. Growth has occurred in the market share of two-door refrigerators (with separate freezer) and color (and larger) TV sets.

6.3. Transitional Countries

Residential energy use per capita in the former USSR grew at an average rate of about 1% per year between 1970 and 1985. Most of the growth was in district heat, which serves the majority of urban homes. There was also growth in electricity use, but it remains relatively low on a per capita basis. Change in equipment played a modest role in the USSR, where there was some transition from reliance on stoves for heating to district heat. There was also growth in the ownership of refrigerators and TV sets.

Although lack of data make it difficult to evaluate historic trends in energy intensities, it appears that there was a slight decline in heating intensity in the USSR due to gradual improvement in equipment and building practices. A similar trend is apparent in Poland between 1980 and 1985 (28).

7. THE SERVICE SECTOR

The service sector accounts for 11% of final energy use in the industrial countries, but only around 5% in the developing countries and 6% in the transitional countries. (The share of primary energy use accounted for by the service sector is somewhat higher than its share of final energy in the industrial countries since the sector is relatively more electricity-intensive than the others.) Most service-sector energy use takes place in buildings, but the sector also includes non-building uses such as street lighting, water works, and sewage treatment. As in the residential sector, the end-use structure of energy consumption is quite different in the three country groups. Space heating is dominant in the transitional countries. It is also an important end use in the industrial countries, but space cooling, lighting, and other electric uses have come to play major roles. In the developing countries, the end-use structure is rather uncertain. Other than heating, which is insignificant outside of China and a few other countries, it is likely that no single end use is dominant.

7.1. Industrial Countries

Between 1973 and 1988, services energy use rose at an average annual rate of 0.8% in the US and Europe, but by 3.9% in Japan. In each case, the rise in energy use was much less than the increase in services value added. Energy use per value added declined by 28% in the US and Europe, and by 15% in Japan. The figures on energy use mask very different trends for electricity and fossil fuels, however. While fuel intensity declined by 36-43%, electricity intensity increased by 15% in the US, 36% in Japan, and 28% in Europe (Figure 11). The share of electricity in OECD-8 services final energy consumption rose from 25% in 1973 to 40% in 1988.

Structural change in sectoral composition plays a much smaller role in the service sector than in manufacturing, since the various subsectors (offices, education, health, retail, etc.) do not differ greatly in their energy intensity. In Japan, the only country for which a lengthy data series on energy use and area by subsector is available, structural change in the sector's composition pushed slightly upward on aggregate energy intensity between 1973 and 1988. In the US, it appears that there was little change in the relative importance of different subsectors.

The decline in aggregate fuel intensity resulted mainly from addition of new buildings with lower heating requirements per square meter, retrofit improvements to heating equipment and building envelopes of older buildings, and improved energy management, including changes in indoor temperature. Increasing popularity of electricity for heating also played a role in some countries. This also pushed upward on electricity intensity, as did growth in the penetration of computers and other office equipment. While improvements took place in the efficiency of lighting, and various equipment and building envelope measures reduced cooling requirements per square meter of floor area, these changes were not large enough to overcome the forces that pushed electricity intensity upward.

7.2. Developing Countries

Trends in services fuel consumption in the developing countries are rather uncertain. Electricity use has increased rapidly, especially in Asia, where growth averaged 10% per year between 1980 and 1988. This growth has been mainly due to rapid construction of new buildings, many of them more modern and energy-intensive than older buildings. In the warm, humid climates characteristic of many developing countries, air-conditioning is a major consumer of electricity, especially in the high-rise offices and modern hotels that have gone up in many countries. Service-sector electricity use has risen particularly fast in Southeast Asia and in the Asian NICs.

7.3. Transitional Countries

Services energy use in the former USSR increased at around 4% per year between 1970 and 1985, which was somewhat faster than the estimated growth in floor area. The increase in energy intensity, which took place primarily in the 1970s, reflects some improvement in indoor comfort levels. There is some indication that heating intensity declined slightly in the 1980s. (Part of the reason is the greater size of new buildings, which have lower heat losses per square meter of floor area.) Electricity intensity rose by about 30% between 1970 and 1985, but it is very low by Western standards.

8. CHANGES IN THE OECD COUNTRIES: A CLOSER LOOK

8.1. Decomposing the Changes in Energy Use

In the previous sections, we described the changes in activity, structure, and energy intensities in each sector. The overall impact of these changes on total energy use depends on the strength of each force in each sector and on the relative importance of the sector in total energy use. In order to measure these impacts quantitatively, we performed an analysis of the three largest industrial economies — the US, Japan, and West Germany — examining changes in over 20 subsectors or end uses. To assess the relative impact of the changes on total (primary) energy use, we allocated losses in electricity supply to each end use or subsector according to its share of total electricity consumption. Results are shown in Table 2. For a description of the method used to derive the values, see the Appendix.

Increase in sectoral *activity* placed strong upward pressure on manufacturing energy use in the US and Japan, but less so in West Germany. Growth in activity played a major role in passenger travel and in the service sector in all three countries. Activity in freight transport had a somewhat weaker impact. The smallest impact of activity (using our definitions) was in the residential sector. Weighting the activity impacts according to the share of each subsector in total energy use in 1973, we find that the cumulative impact of growth in activity levels was to increase energy use by 39% in the US, 54% in Japan, and 21% in West Germany.[16] In each case, the energy-weighted average of activity change was less than the

[16] Manufacturing accounts for a much higher percentage of total energy use in Japan than in the other countries, so changes in that sector play a large role in the weighted average.

growth in GDP.

Structural change contributed to reductions in energy use only in manufacturing. Increase in the share of passenger travel in automobiles and airplanes raised energy use slightly in the US and West Germany, but by 21% in Japan. Growth in the role of trucks in freight transport increased energy use more in Japan and West Germany than in the US. Structural change had the greatest impact in the residential sector. Increases in home floor area, heating equipment, and appliance ownership raised energy use by about 40% in the US and by about 60% in the other countries. In the service sector, data from the US and Japan indicate that there was little net impact. Overall, the weighted effect of structural change within the five sectors was to raise primary energy use by 7% in the US, 1% in Japan, and 15% in West Germany.

Change in *energy intensities* had a significant impact in reducing energy use in most sectors. In manufacturing, it reduced energy use by 27-29% in the US and Japan and by 14% in West Germany. In passenger travel, intensity change reduced energy use in the US but increased it in the other countries. In freight transportation, it reduced energy use by 13% in Japan and by 20% in West Germany, but had little effect in the US. In the residential sector, it reduced energy use by around 25% in the US and West Germany, but increased use by 21% in Japan. As a weighted average, changing energy intensities reduced primary energy use by 21% in the US, 16% in Japan, and 15% in West Germany. The change in particular subsectoral energy intensities varied among the countries, as shown in Table 3.

8.2. How Much Did Technical Energy Efficiencies Improve?

While improvements in technical energy efficiency have clearly played an important role in shaping energy intensities, it is difficult to disentangle them from other factors. For example, some of the decline in home heating energy intensity was due to lower indoor temperatures, which could be considered a reduction in the level of service. For automobiles and home appliances, there was an increase in the average level of service (size, features, power) which countered the effect of improved technical energy efficiency.

Estimating change in the average technical energy efficiency of a given subsector or end use is difficult in most cases. One exception is jet aircraft, for which the US fleet-average energy efficiency (seat-miles per gallon) nearly doubled between 1970 and 1989. In some cases, energy efficiency trends can be known for new equipment. The existence of a testing program for new appliances in the US has allowed tracking of the trends in "energy factors" that express the sales-weighted energy efficiency of various devices, adjusting for changes in size where appropriate. There has been considerable improvement in energy efficiency, especially for refrigerators and freezers (Figure 12). EPA test data for new cars in the US show much improvement in the fuel economy of cars in each size class (29). Since there has been an increase in the level of service (in terms of acceleration performance and other features) within each size class, even the data on fuel economy by class understate the actual efficiency improvement.

8.3. The Impact of Energy Price Changes

The increases in the real energy prices faced by users in the 1973-1982 period varied across countries and sectors.[17] The largest increases occurred for petroleum products used in industry and heating oil used in the buildings sectors. In most countries, fuel prices rose much less in transportation than in other

[17] We assembled data series for energy prices in each country using the International Energy Agency's quarterly publication, *Energy Prices and Taxes* for 1980 onward. For the years before 1980, we used an unpublished compilation of prices carried out by the U.S. Department of Energy. These data map almost perfectly into the IEA series, which begin in 1978. We converted prices were converted to real local (1980) currency and then converted to U.S. dollars using 1980 purchasing power parities, as given by the OECD.

sectors, mainly because transport fuels (especially gasoline outside the US) are heavily taxed and the rise in crude oil prices thus had a smaller proportional effect on the retail price. In industry and buildings, prices for natural gas and coal rose less than those for petroleum products.

For the most part, energy prices affected the levels of sectoral activity only indirectly through macroeconomic impacts, which were of a short-run nature. Price changes had little effect on sectoral structure except in the short run, as for example, when people temporarily switched away from automobiles to other modes when gasoline prices rose sharply.[18]

Change in energy prices clearly had an impact on energy intensities, but the role of prices independent from conservation policies and programs (see next section) and "autonomous" technological change is difficult to judge. In manufacturing, for example, aggregate energy intensity—holding sectoral structure fixed—fell at nearly the same rate between 1960 and 1973 as between 1973 and 1985 in the US, despite there being almost no change in real energy prices in the earlier period and a major increase in prices in the latter period (Figure 13). A similar trend is evident in Japan and West Germany. One might be tempted to conclude that the rise in prices had almost no effect, and that technological change "autonomous" of energy prices was the cause of intensity decline. However, value added grew substantially faster in the earlier period than in the latter. Since investment in new facilities is a principal source of intensity reduction, one would expect there to be more intensity decline in the earlier period. Thus, the increase in energy prices apparently had some effect in the 1973-1985 period, but probably less than that of autonomous technological change.

In the residential sector, there was a more evident response to the price rises, especially where there was much room for behavioral change, as in the US. The increase in heating oil prices was considerable and caused both switching away from oil for space heating and a decline in intensity among households that continued to use oil (part of which was not due to behavior or efficiency improvement but to greater use of secondary heating fuels such as wood and electricity). There was only modest increase in residential electricity prices in most countries over the 1973-1988 period.

Transport fuels saw relatively less price increase, as mentioned above. This was especially the case in Europe and Japan, so it is perhaps not surprising that automobile energy intensity did not decline there. In the US, where the intensity fell considerably, the impact of prices is hard to judge, since mandatory fuel economy standards were an important factor. Historically, low gasoline prices in the US had encouraged automobiles with higher fuel intensity than in Europe and Japan, so it was easier for intensity to decline in the US.

Prices of petroleum products fell sharply in industry and households in 1986, and fell somewhat less in transportation. In the case of households, little rebound in energy intensity is evident for oil-heated homes (Figure 14). This result is not unexpected, since households would not remove the insulation, windows, and more efficient furnaces that had previously been installed. One might expect some increase in indoor temperatures, but there are signs that these had already been rising in the mid-1980s.

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[18] Over the long run, lower gasoline prices in the US (due mainly to lower taxation) have contributed to greater reliance on the automobile as a travel mode, relative to Europe. But other factors have also played a role, including higher incomes, lower automobile prices, and geographic features, especially the low density of metropolitan areas. Energy prices also have a long-run effect on the structure of the manufacturing sector, as countries with relatively low prices tend to have more energy-intensive industries.

8.4. The Role of Energy Conservation Policies

Government energy conservation policies played a role in causing decline in energy intensities in some sectors. The main target of government programs has been the residential sector (30). Dissemination of information and exhortation to conserve energy has been extensive, but its impact seems to have been small and/or short-lived. Energy labelling for new appliances was instituted in US and Canada, but here too the evidence suggests that the impact on consumer behavior was relatively small (31). Efficiency standards probably had the strongest impact on energy intensities. Building codes for new houses in Western Europe and some US states raised efficiency levels above what the industry would have done on its own. In the US, two states (California and New York) and eventually the Federal government adopted appliance standards that accelerated efficiency improvement. In Japan and West Germany, voluntary agreements between government and domestic manufacturers led to higher efficiency in major household appliances. Grants for retrofit of existing homes were popular in Western Europe, and the US had tax credits for conservation investments, but the degree to which these incentives increased energy-saving activities over what would have occurred otherwise is uncertain.

In transportation, the US was the only country that established mandatory fuel efficiency standards for new cars and light trucks. Beginning in 1978, the sales-weighted average fuel economy of each manufacturer's new cars had to meet a standard that gradually became tighter. There has been considerable debate about the influence of the standards as opposed to gasoline price increases. An analysis that used detailed manufacturer data indicates that the standards were a significant factor in improving fuel efficiency for many manufacturers and were at least twice as important an influence as gasoline prices (32). In most other industrial countries with automobile industries, voluntary targets for fuel economy improvement were established during the 1970s. The impact of these targets, all of which had expired by 1985 or 1986, varied among countries (33).

In addition to government programs, many electric utilities in the US and, to a much lesser extent, in Western Europe have implemented programs to encourage electricity conservation by their customers. Until recent years, however, the scale of these programs was fairly modest, so their impact was not large at a national level in the 1973-1988 period.

8.5. Recent Trends in OECD Energy Intensities: Signs of Plateau

After 1982, the energy intensity of many end uses in the industrial countries ceased its previous declining trend or even increased. It is not surprising that this should occur, since real prices of fuels declined, and many energy conservation programs were discontinued or weakened. Much of the easy-to-cut "energy waste" was trimmed between 1973 and the early 1980s, and many inexpensive technical improvements were made.

The plateau in energy intensities is more apparent in "consumer" than in "producer" sectors. In the latter, competitive pressures and continuous technological innovation contributed to ongoing reduction in energy intensities. The decline in fuel prices has lessened interest in making investments for energy conservation, but addition of new capital stock has tended to reduce average energy intensities. Even so, there are some signs of a plateau. The structure-adjusted manufacturing energy intensity in the US and Japan was unchanged in the 1985-1988 period. For air travel, there was less decline in energy intensity in the 1984-1988 period than previously. In freight transport, truck energy intensity shows a plateau in the US and Western Europe since 1982, and has declined more slowly than before in Japan. In the service sector, the historical decline in fuel intensity has slowed since 1982 in the US and Western Europe, and there has been no change in Japan. Service-sector electricity intensities show roughly the same trends after 1982 as before, but this result is difficult to interpret, since there has been increase in equipment and improvement in end-use efficiency at the same time.

Consumer-dominated sectors (residential, automobiles) show a clear plateau in energy intensities. Home heating energy intensity has declined only slightly in the US and Western Europe since 1982, and has increased in Japan. Retrofit of older homes has slowed, and households have increased indoor temperatures somewhat. In the US, there has also been a plateau with respect to the thermal integrity of new houses; the average ceiling insulation installed by builders nearly doubled between 1973 and 1982, but remained about the same thereafter. For electric appliances, estimates of stock-average energy intensities show a plateau in recent years in many cases. In Western Europe and Japan, the plateau (or even rise in intensity) is mainly due to increase in size and features. In the US, the technical energy efficiency of new appliances has continued to decline in the 1980s for refrigerators, freezers, and room air conditioners, largely due to imposition of State efficiency standards and anticipation of Federal standards.

The energy intensity of automobiles followed the same trend after 1982 as before in Europe and Japan—essentially no change. In the US, the intensity has continued to decline as newer vehicles replace older ones. For new automobiles, however, there has been a plateau in average fuel economy in the US and Sweden, and less decline than previously in Italy and France (refer back to Figure 7). In West Germany and Japan, new car fuel intensity increased as consumers moved to larger and more powerful vehicles. As cars purchased after 1982 account for an increasing share of the fleet, the plateau for new cars will have an important effect on fleet fuel intensity.

9. SUMMARY AND CONCLUSION

World energy use has risen by over one-third since 1970, and grew steadily between 1983 and 1989. The forces of activity, structural change, and energy intensity have shaped energy use in different ways in the industrial, developing, and transitional countries. In the industrial countries, whose share of world energy use declined from 60% to 48% between 1970 and 1990, activity pushed moderately upward on energy demand. Structural change pushed upward on demand in passenger travel (more reliance on cars and air), freight transport (greater use of trucks), and households (more living area and appliances per person), but pushed downward in manufacturing (shift toward less energy-intensive industries). Energy intensities declined significantly in most areas. In manufacturing, there was considerable decline in energy intensity in all countries, largely due to ongoing technological innovation. For automobiles, changes toward greater size and power partially offset improvement in technical energy efficiency in Europe and Japan; intensity fell greatly in the US, but remained above the other OECD countries. Increase in size and features also balanced efficiency improvement for home appliances. In home heating, there was significant reduction in intensity in the US, but growth in use of central heating offset improved efficiency somewhat in Europe. On average, decline in energy intensities caused a reduction in OECD primary energy use of around 20% between 1973 and 1988. Since 1982, however, there has been a marked leveling off in most energy intensities, especially in households and automobiles outside the US.

In the developing countries, growth in energy use averaged nearly 5% per year between 1970 and 1990, and their share of world energy use rose from 20% to 31%. Increase in activity levels pushed strongly upward on energy use, although the pace of growth has varied among regions. Structural change also contributed to increase in energy use. In manufacturing, there has been some shift toward energy-intensive industries, especially in countries with abundant energy resources. In passenger travel, the role of automobiles has grown, and the share of trucks in freight transport has risen. In the residential sector, growth in the penetration of electric lighting and appliances contributed to rising electricity use. Change in energy intensities is difficult to judge. In manufacturing, the largest energy-using sector, there has been decline in some countries resulting mainly from adoption of more modern processes. There are signs of some improvement in other areas as well, but in general the degree of change appears to be much less than in the OECD countries.

In the transitional countries, energy use grew at a moderate pace in 1970-1988, but has declined since as the economies struggle to reform on a new basis. Activity increased in all sectors in these countries, but there was less change than in other parts of the world in sectoral structure and energy intensities. In manufacturing, the largest energy-use sector, there are signs of a modest decline in energy intensity in some Soviet industries. In this and other sectors, however, the improvement in energy efficiency was small compared to that which occurred in the West.

The analysis of past trends summarized here holds many lessons for understanding how energy use may evolve in various parts of the world, and how governments might influence that evolution. Among sectors and countries, activity, structure, and energy intensities have pushed energy use in different directions, and have been influenced by different factors. Considering these forces separately can help to illuminate more aggregate trends, and also provides a framework for evaluating the role of different forces and policies. Energy intensities have declined in many areas due to technological innovation and explicit response to higher energy prices, but increase in the levels of service have also counteracted improvements in technical energy efficiencies. In "producer" energy use sectors, competition and the resulting drive to increase productivity has proven to be an important force in improving the efficiency of energy use. In "consumer" sectors, where energy costs are often not a major (or lasting) consideration, efficiency gains have been more connected to government policies and subsidies.

Many of the basic forces that shaped energy use in the 1970s and 1980s will also be at work in the 1990s, but the context in each country group and the larger global environment will be different. The 1970-1988 period was one of large increase in energy prices in much of the world. Most observers expect little growth in prices in the 1990s, except of course in the transitional countries, where the price subsidies of the past are being lifted rather quickly. On the other hand, environmental problems, including the threat of global warming, are emerging as factors that seem likely to shape energy policy, especially in the industrial countries. In addition, rising international economic integration and the growing adoption of market-oriented economic polices throughout the world should facilitate adoption of more energy-efficient technologies. At the same time, increasing levels of activity and structural changes will push energy use upward, especially outside the OECD countries.

Appendix: Method for Measuring Activity, Structure, and Intensity Impacts

If we take E_{it} as the energy use of sector i in year t, A_{it} as its activity level, and S_{it} and I_{it} as vectors of structural and intensity parameters, we may write sectoral energy use symbolically as:

$$E_{it} = E_i(A_{it}, S_{it}, I_{it}).$$

It is clear from this identity that the impacts on E of changes in activity, structure, and intensity cannot uniquely be disaggregated in a linear fashion. We may, however, address the following question: If only activity, only structure, or only intensity had changed over time while the other two factors remained fixed, how would energy use have changed over time? The approach we use to quantitatively describe the relative impacts of the three factors on aggregate sectoral energy use is rooted in the use of fixed-weight or Laspeyres indices (34). The relative change in energy use driven by changes in activity between periods 0 and t, given constant structure and intensity, is:

$$\%\Delta E_{Ai} = \frac{E_i(A_{it}, S_{i0}, I_{i0}) - E_i(A_{i0}, S_{i0}, I_{i0})}{E_i(A_{i0}, S_{i0}, I_{i0})}.$$

The corresponding structure and intensity indicators are:

$$\%\Delta E_{Si} = \frac{E_i(A_{i0}, S_{it}, I_{i0}) - E_i(A_{i0}, S_{i0}, I_{i0})}{E_i(A_{i0}, S_{i0}, I_{i0})}$$

and:

$$\%\Delta E_{Ii} = \frac{E_i(A_{i0}, S_{i0}, I_{it}) - E_i(A_{i0}, S_{i0}, I_{i0})}{E_i(A_{i0}, S_{i0}, I_{i0})}.$$

To derive indicators of the impacts of changes in sectoral activity levels, structure, and energy intensities on aggregate energy use, we construct weighted sums of the sector-specific indicators so defined. The aggregate change in energy use induced by changes in sectoral activity levels, given constant structure and intensity, for example, is:

$$\sum_i [E_i(A_{it}, S_{i0}, I_{i0}) - E_i(A_{i0}, S_{i0}, I_{i0})].$$

Dividing this expression by aggregate base-year energy use, the relative change in energy use due to changing activity levels is:

$$\%\Delta E_A = \sum_i w_i \%\Delta E_{Ai}$$

where the weight w_i is sector i's share of base-year energy use. The same formula may be used to construct aggregate structural and intensity indicators.

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Table 1. Growth in saturation of selected electric appliances (percent of households)

	Year	TV set	Refrigerator	Clothes washer
China	1978	1	<1	<1
	1987	46	5	23
Thailand	1976	11	5	<1
	1986	56	21	4
Brazil	1975	39	36	7
	1988	66	63	22
S. Korea	1976	38	7	2
	1985	99	85	39

Source: Reference 27.

Table 2. Impacts of changing activity, structure, and energy intensities on sectoral primary energy use, 1973-1988

Indicator/sector	Definition/description of factors	United States (%)	Japan (%)	West Germany (%)
PRIMARY ENERGY USE				
Manufacturing		-6	0	-7
Passenger travel		11	76	56
Freight transport		40	33	17
Residential		14	89	18
Services		36	82	25
Total		12	27	12
ACTIVITY				
Manufacturing	manufacturing value-added	52	64	18
Passenger travel	passenger-km	36	40	33
Freight transport	tonne-km	34	18	24
Residential	population	16	13	-1
Services	service sector value-added	54	71	58
Weighted average[a]		39	54	21
GDP		45	83	34
STRUCTURE				
Manufacturing	subsector value-added shares	-12	-15	-8
Passenger travel	modal mix	3	21	5
Freight transport	modal mix	3	30	15
Residential	heated area and appliance ownership per capita, occupants per dwelling	39	57	63
Services	subsectoral mix	n/a	n/a	n/a
Weighted average[a]		7	1	15
ENERGY INTENSITIES				
Manufacturing	subsectoral energy intensities	-27	-29	-14
Passenger travel	modal energy intensities	-19	5	12
Freight transport	modal energy intensities	1	-13	-20
Residential	useful space heat energy per heated area, electricity per appliance, useful energy per capita for cooking and hot water	-25	21	-23
Services	energy per unit of value-added	-11	3	-21
Weighted average[a]		-21	-16	-15
Energy/GDP ratio		-26	-34	-23

[a] Weighted by sectoral shares of 1973 energy use.

Table 3. Change in key subsectoral energy intensities in the US, Japan, and West Germany, 1973-1988 (percent)[a]

	Intensity measure	US	Japan	W. Germany
Manufacturing				
Chemicals	MJ/VA	-37	-55	-25
Building materials	MJ/VA	-39	-27	-30
Iron & steel	MJ/VA	-17	-33	-17
Nonferrous metals	MJ/VA	-15	-50	-20
Paper & pulp	MJ/VA	-28	-33	-20
Other sectors	MJ/VA	-43	-31	-26
Travel				
Automobiles	MJ/p-km	-17	+8	+13
	MJ/km	-29	-2	-3
Air	MJ/p-km	-43	-26	-38
Freight				
Trucks	MJ/t-km	+13	-16	-12
Residential				
Home heating,[b]	MJ/m^2	-43	+8	-12
Adjusted	MJ/m^2	-45	-35	-38
Appliances[c]	kWh	-13	+40	-2
Services				
Fuels	MJ/VA	-43	-35	-45
Electricity	MJ/VA	+15	+33	+15

[a] Values refer to final energy, except as noted.
[b] Useful energy, climate-corrected. The adjustment removes the effect of growth in central heating in Germany and more heaters in Japan.
[c] Values reflect change in average unit consumption of 7 major appliances, weighted by 1980 saturation; the end year is 1987.

World Primary Energy Use, 1970-1990

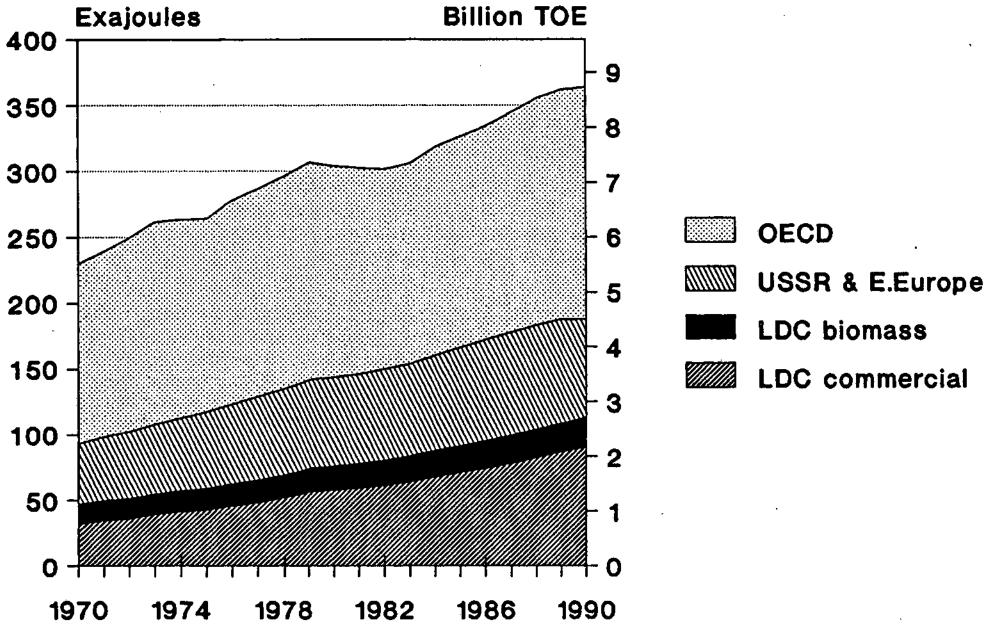


Figure 1

Primary Energy Use per Capita, 1970-1990

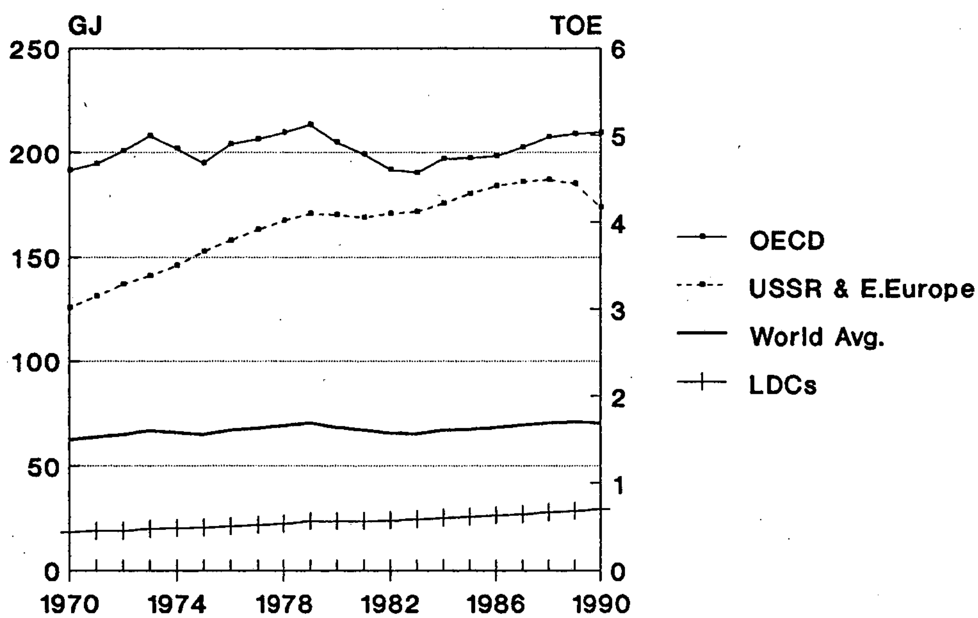


Figure 2

US Manufacturing 1970-1988
Activity, Structure, Intensity Effects

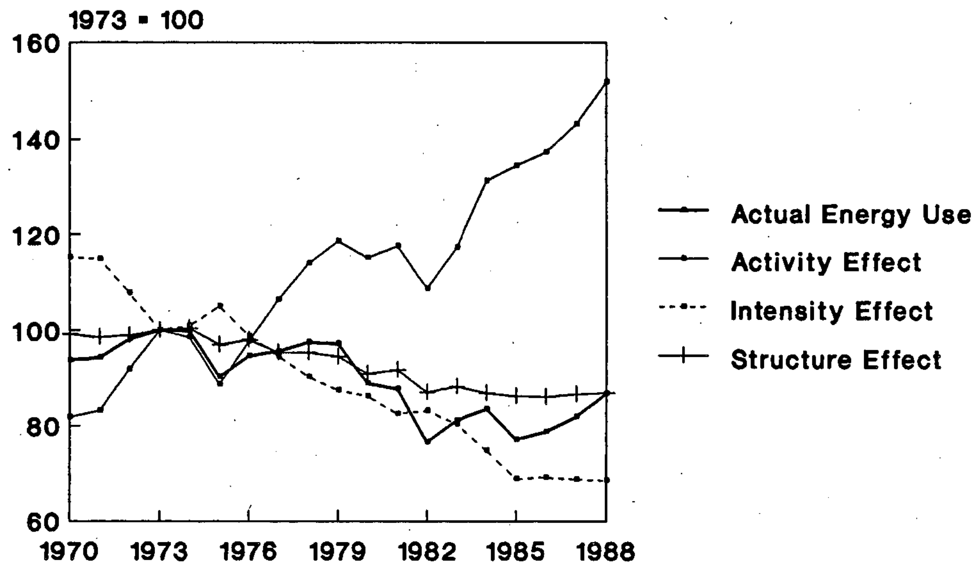


Figure 3

Manufacturing Energy Intensity, OECD: 1971-1988

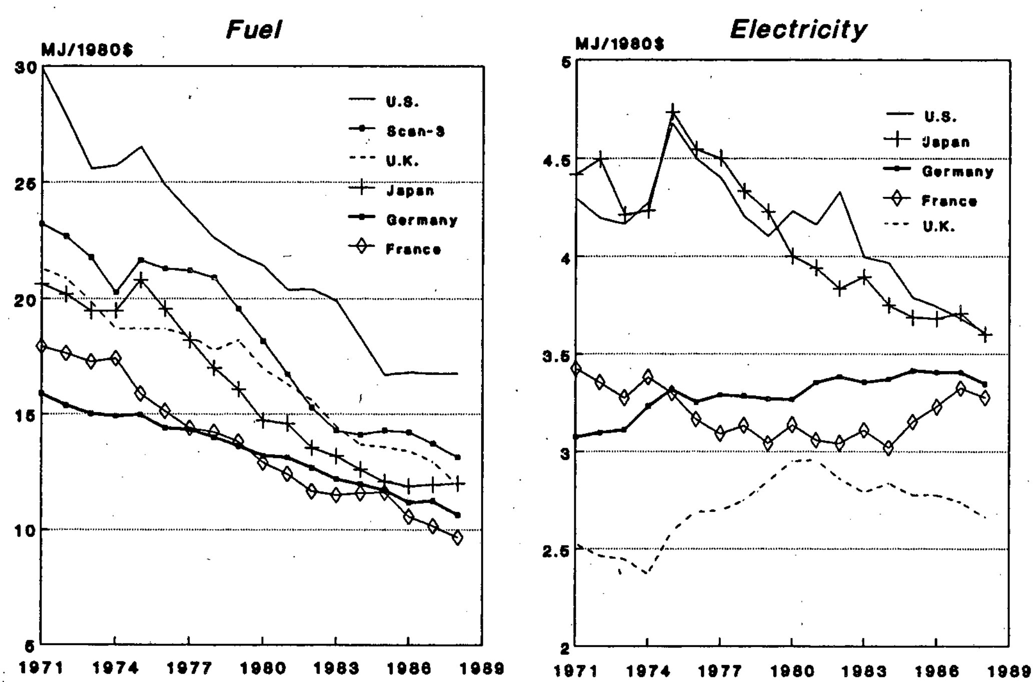


Figure 4

Production of Energy-Intensive Materials
USSR: 1960-1987

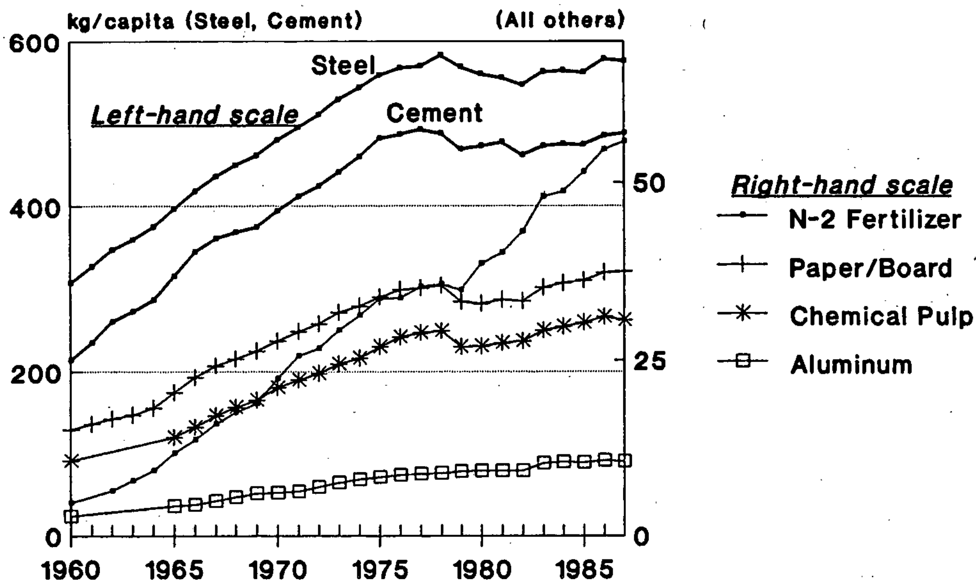


Figure 5

Automobile Energy Intensity
OECD: 1970-1988 (Fleet Average)

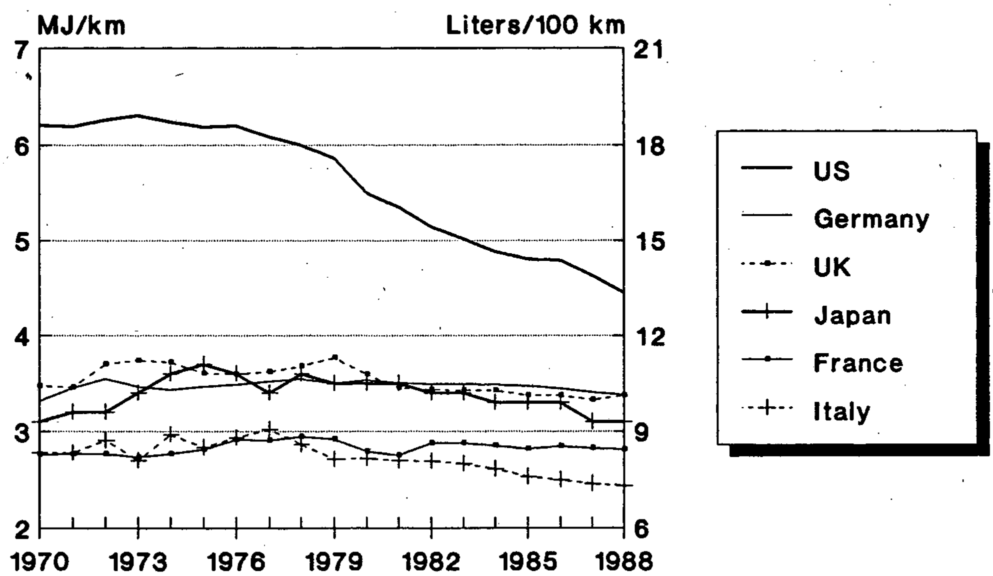
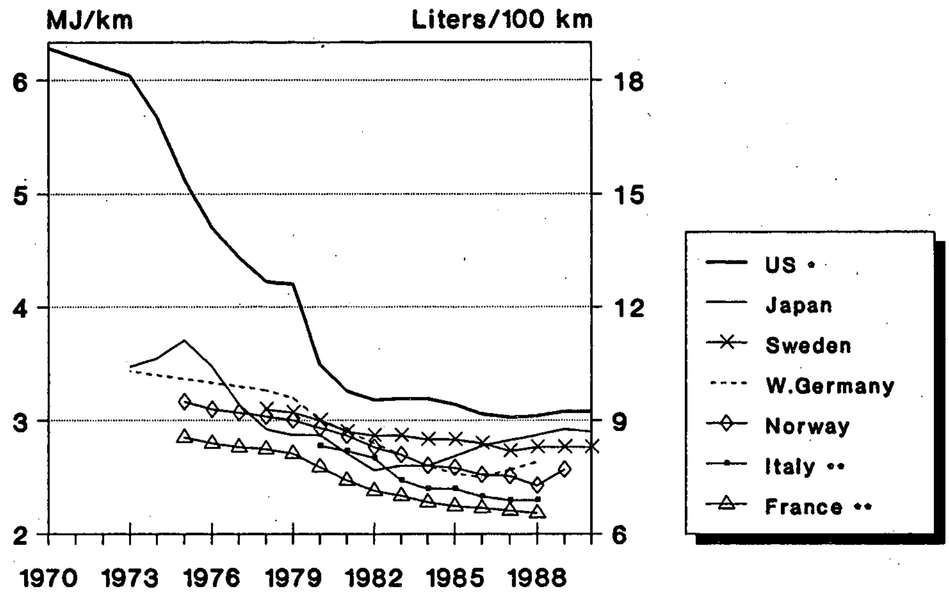


Figure 6

Automobile Energy Intensity, New Cars
OECD: 1970-1990



* Includes light trucks. ** Includes diesel cars.

Figure 7

Truck Freight Energy Intensity
OECD Countries 1970-1988

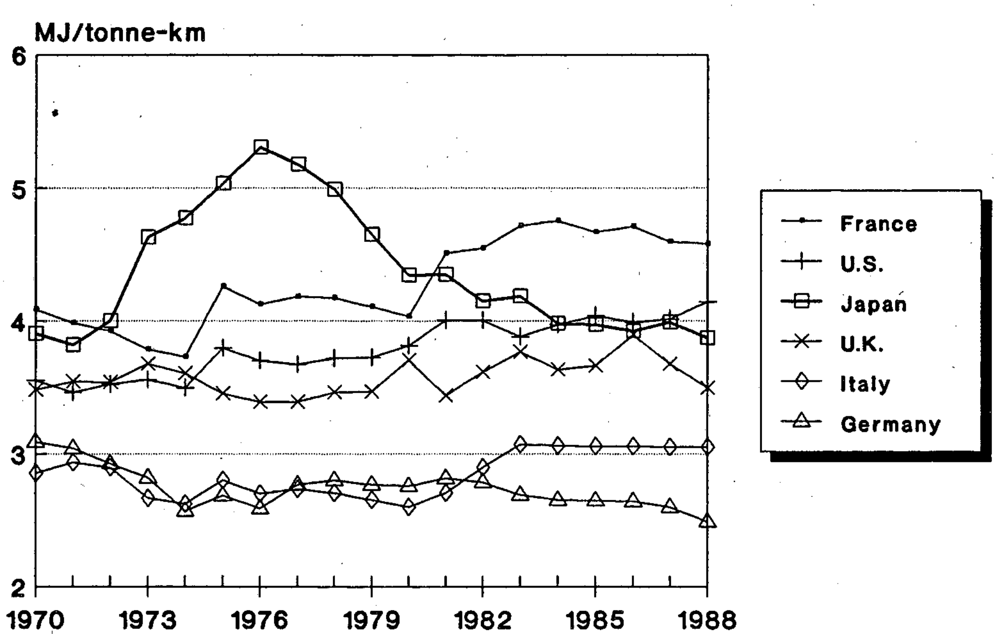


Figure 8

Space Heating Energy Intensities
OECD: 1973-1988

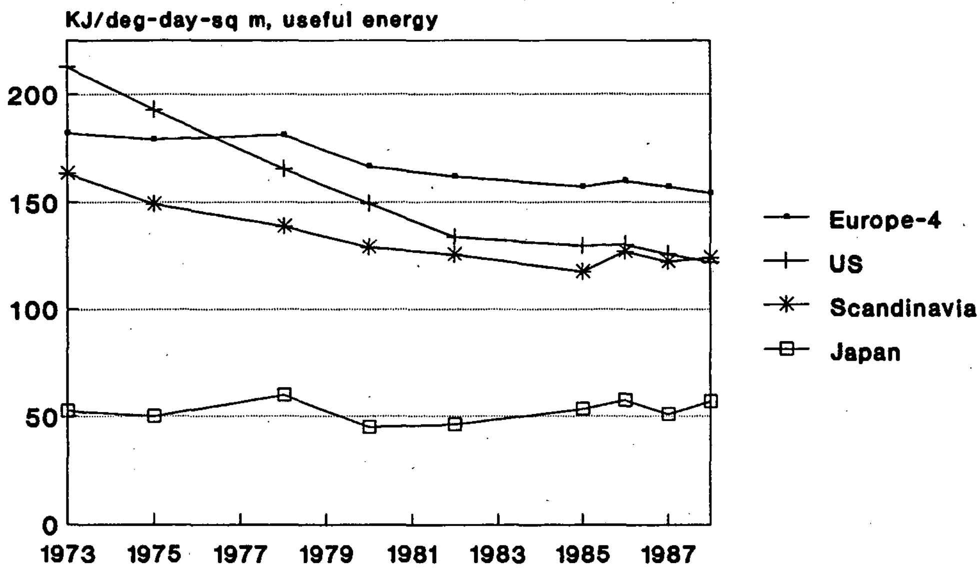


Figure 9

Residential Electricity Use per Capita
Developing Countries: 1970 & 1988

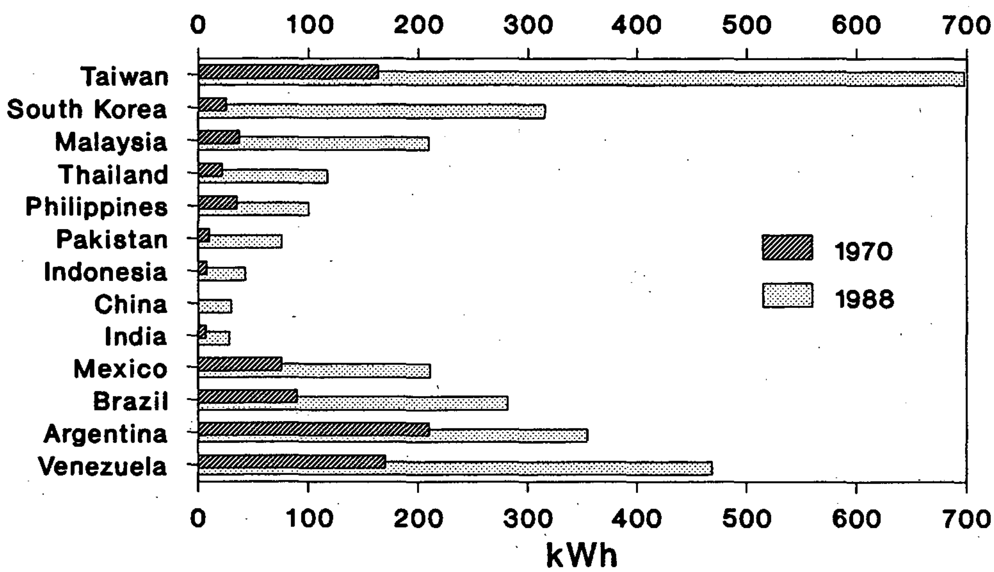


Figure 10

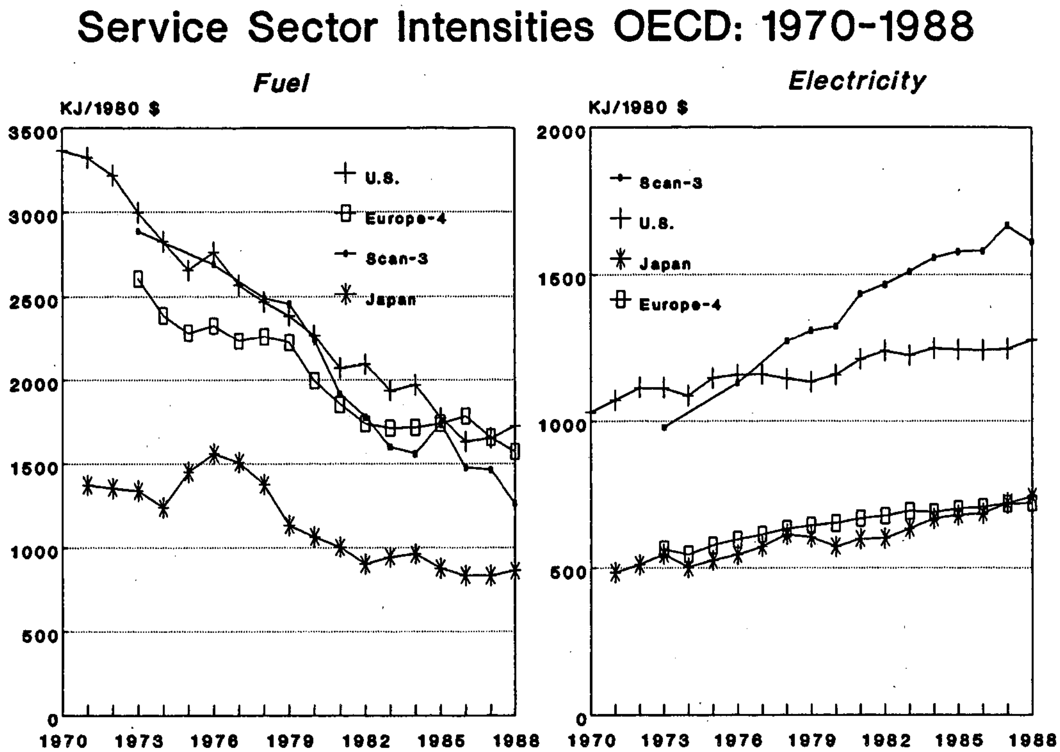
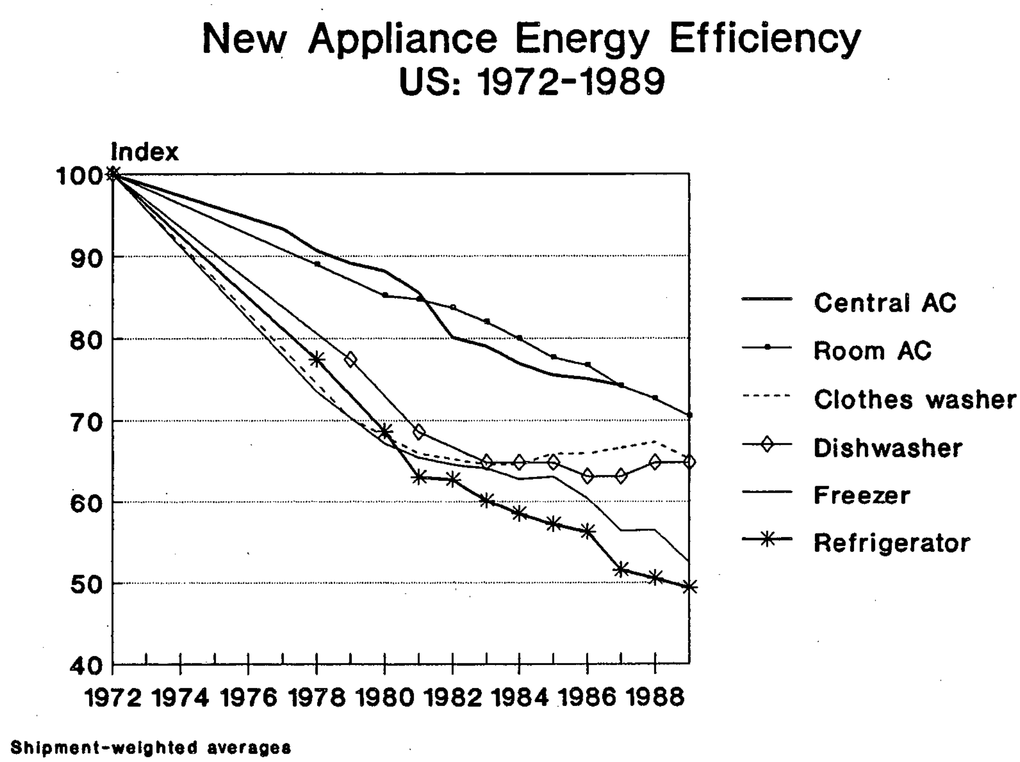


Figure 11



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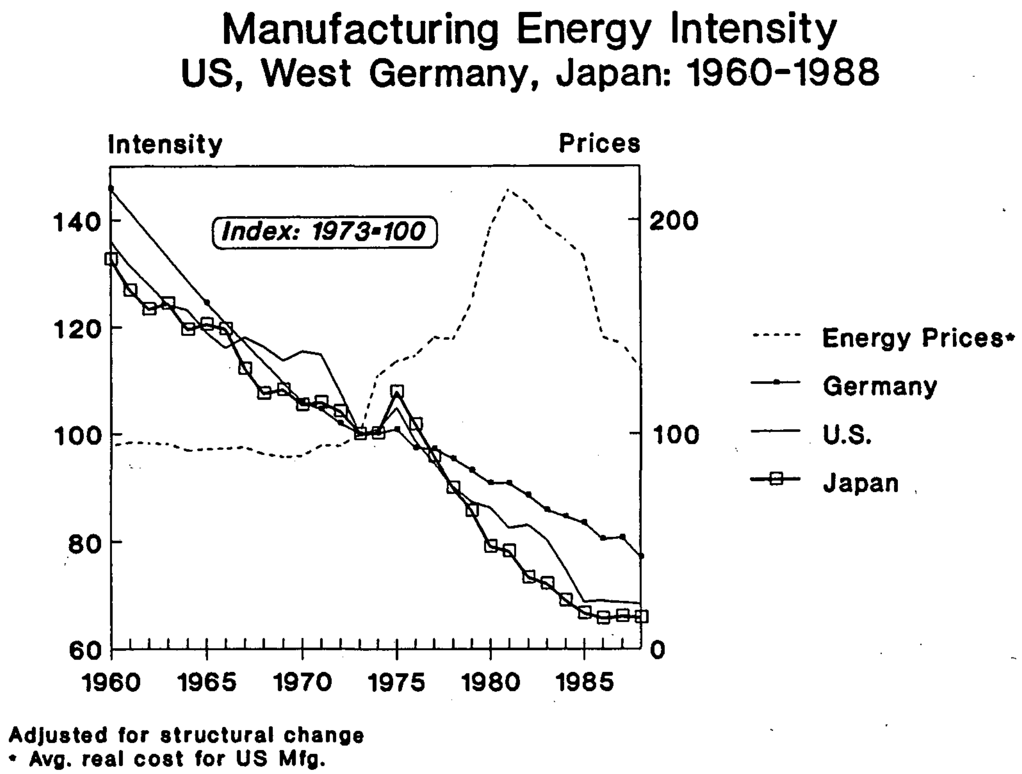

Figure 13

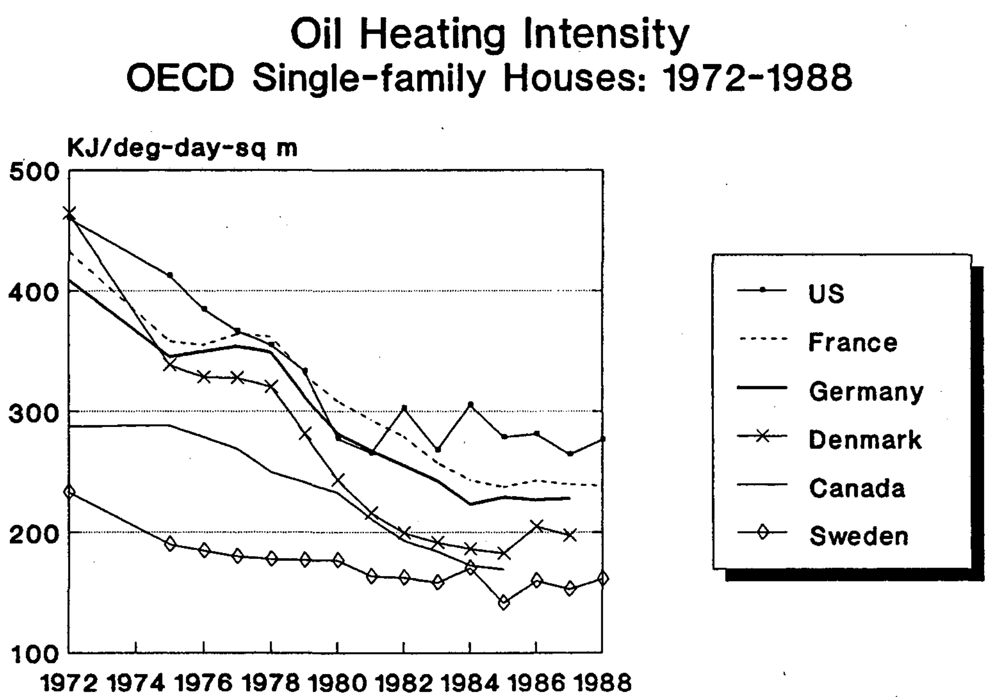

Figure 14