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Energy Use in Denmark: An International Perspective

Lee Schipper, Richard Howarth, and Bo Andersson
with Lynn Price

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International Energy Studies Group
Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, California, U.S.A. 94720

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ABSTRACT

This report analyzes the evolution of energy use in Denmark since the early 1970s in order to shed light on the future path of energy use in Denmark, with particular emphasis on the role of energy efficiency. In a recent policy document, *Energi 2000*, the Danish Ministry of Energy set forth an ambitious plan of action to achieve an environmentally sustainable energy future (*Energiministeriet* 1990). *Energi 2000* calls for the reduction of energy-related carbon dioxide emissions to at most 80% of their 1988 levels by 2005, with even larger reductions in emissions of oxides of sulfur and nitrogen. Most of these reductions will take place within the energy sector, but about one-third is expected in homes, buildings, manufacturing and other industry. The heart of the plan for these final-demand sectors lies in the adoption of higher energy taxes and accompanying policy measures to achieve enhanced energy efficiency and restraint in energy-using activities. *Regeringens transporthandlingsplan for miljö og udvikling* (*Trafikministeriet* 1990a) examined the transportation sector separately. The transportation plan calls for a less ambitious drop in CO_2 emissions, closer to 5% compared with 1988. In both plans improved energy efficiency plays a central role.

How much did efficiency in Denmark improve in the past? We found that improvements in end-use energy efficiency reduced primary energy requirements in Denmark by 22% between 1972 and 1988. This change accounts for two-thirds of the decline in the ratio of energy use to gross domestic product that occurred during this time; the rest of the decline was caused by changes in the mix of goods and services produced and consumed by Danes. Additionally, increased efficiency in the energy conversion sector itself contributed important energy savings in Denmark. We also found that the share of oil in final energy use fell from 78% to 55%, with large declines in all sectors except transportation. Including all primary energy losses, the share of oil fell from 93% in 1972 to 48% in 1988 as oil was almost eliminated from the power sector.

Focusing on developments in six individual sectors of the Danish economy (residential, manufacturing, other industry, service, travel, and freight), we found that the residential, manufacturing, and service sectors have led the improvements in efficiency since 1972. For example, by 1988 residential space heating intensity had fallen by almost 50%, household appliances required 10% less electricity, manufacturing used 14% less final energy, and the primary energy intensity of the service sector fell by over 20%. By contrast, travel showed few significant efficiency improvements and the efficiency of freight transportation worsened. In fact, 62% more energy was required to move freight in 1988 than in 1972.

Our international comparisons showed that the structure of energy use in Denmark is less energy-intensive than that of most high-income OECD countries, with the exception of Japan. Total energy savings achieved between 1972 and 1988 in Denmark ranked among the highest we measured in any major OECD country; that is, if energy intensities had not fallen, Denmark would have required 31% more energy in 1988 than was actually used. This is more than would have been required for the U.S. (29%), West Germany (22%), Japan (17%), and Norway (3%).

Overall, we concluded that most of the energy savings achieved in Denmark were brought about through improvements in technology. Short-term changes in consumer behavior were significant in reducing energy needs for space heating and, through shifts from car to bus and rail travel, in transportation as well. These changes have reversed somewhat since the early 1980s, but do not threaten the overwhelming part of total energy saved through technology improvements. We also found that an important stimulus for improved efficiency was higher energy prices, led in no small part by significant taxes imposed on small consumers of heating oil, electricity, and motor fuels. Energy-efficiency programs accelerated energy savings in homes and commercial buildings. Programs currently in place promise to boost efficiency in all sectors where electricity is used. Future programs could push efficiency of all energy uses even farther, if supported by high prices.

The rate of improvement of energy efficiency in Denmark has slowed down significantly since 1984, consistent with trends we observed in other major countries. While many of the energy-efficiency goals stated or implied in Denmark's *Energi 2000* are achievable over a very long period, present trends to not point towards achievement of these goals by 2010 or even 2020. Strong measures will have to be developed by both public and private authorities if energy efficiency is to make a key contribution to reducing environmental problems associated with energy use in Denmark.

Acknowledgments

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ENERGY USE IN DENMARK: OVERVIEW AND SECTORAL ANALYSIS

1. INTRODUCTION

Nearly twenty years ago, Danish policy makers and the public at large were confronted by unwelcome and unanticipated increases in energy prices. While world oil markets previously had been marked by relative stability, the Arab oil embargo of 1973 sent fossil fuel prices to record highs. In 1979, oil prices jumped once again, spurred by the Iranian Revolution and ensuing Iran-Iraq War. The impacts of these events on the Danish economy should not be underestimated. In each case, the rise in oil prices was followed by a deep and prolonged recession as producers and consumers adapted to new conditions and the government made compensating adjustments in economic policy.

Denmark was particularly vulnerable to the oil price shocks of the 1970s because the nation depended almost entirely on imported energy and because oil supplied a full 93% of gross energy use.[1] Not surprisingly, the energy shocks triggered significant changes in national policy and individual behavior that substantially reduced the nation's dependence on oil imports. In electricity generation, Denmark substituted coal imported from ostensibly secure regions of the world for oil and developed indigenous resources of oil and renewable energy. Today Denmark is for the most part energy self-sufficient. The changes that occurred were not limited to energy supply. Changes in the structure and efficiency of energy demand led gross energy use to decrease by 4% between 1972 and 1988 despite a 44% increase in Gross National Product. This record of achievement, coupled with recent developments in oil markets, has largely alleviated concerns about the security of energy supplies. In the mid-1980s, oil prices collapsed due to curtailed world demand and increased production in non-OPEC nations. While prices rose briefly during the Persian Gulf Crisis of 1990, even this major event had only fleeting impacts on the supply of oil.

In the 1990s, the "energy problem" has been redefined in light of concerns over the relationship between energy use and environmental degradation. Fossil fuels are a major source of urban air pollution and contribute to the acid deposition that threatens terrestrial and aquatic ecosystems in Northern Europe and Scandinavia. Nuclear power imposes risks related to reactor safety and the storage of high-level radioactive waste. Perhaps most importantly, carboniferous fuels such as coal, oil, and natural gas are a driving force behind the greenhouse effect, which threatens to bring about highly uncertain but potentially devastating changes in the earth's climate. The energy successes of the 1970s and 1980s had both positive and negative impacts on the environment. Certainly enhanced energy efficiency reduced the environmental burdens associated with energy use. Increased reliance on coal and coal-based electricity, however, has exacerbated the environmental impacts of Danish energy use and poses a special challenge to future policy: How can the nation enhance its energy security while reducing energy-related environmental insults to acceptable levels?

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[1] Gross energy use is the sum of domestic energy production and net imports before conversion to finished energy products. The energy data discussed in this section were provided by *Energistyrelsen*. The data on economic activity are from *Danmarks Statistik*.

In a recent policy document, the Danish Ministry of Energy (*Energiministeriet* 1990) set forth an ambitious plan of action to achieve an environmentally sustainable energy future. The plan calls for the reduction of energy-related carbon dioxide emissions to 80% of their 1988 level, with even larger reductions in emissions of oxides of sulfur and nitrogen. A portion of these reductions would be achieved through expanded reliance on renewable energy sources such as biofuels and windpower, along with the substitution of natural gas for more polluting coal and oil. The plan precludes the development of domestic nuclear power. The heart of the plan, however, lies in the adoption of higher energy taxes and accompanying policy measures to achieve enhanced energy efficiency and restraint in energy-using activities. Under the plan, energy use would fall by 15% by 2005.

The goals of the national energy plan are certainly achievable both in principle and in practice. Nevertheless, both the specific policies required to realize these objectives and their impacts on Danish society are difficult to foresee. While energy use showed no net growth in the 1970s and 1980s, such restraint was won at the cost of higher energy prices and foregone economic opportunities.

This report reviews the long-term evolution of Danish energy use, focusing on developments in six sectors of the economy: residential, manufacturing, other industry, service, travel and freight. Where possible, we start our investigation in the 1950s or 1960s, although lack of data constrains our ability to construct a detailed history of the nation's energy use prior to the 1970s. We examine trends in both the activities that drive energy use and their corresponding energy intensities, seeking to understand not only the technical efficiency of energy utilization but also the human context in which energy is used.

This report also examines Danish energy use in a broader perspective, drawing detailed comparisons to developments in other nations. First we compare energy use in Denmark to that in other OECD countries (Sweden, Norway, Italy, France, the U.K., West Germany, Japan and the U.S.) on a sectoral basis. Then we assess Denmark's standing amoung four of these countries (Norway, West Germany, Japan and the U.S.) in terms of sectoral activity levels, the structure of energy use, and energy intensities.

1.1. Aggregate Energy-Use Trends

The development of Danish energy use between 1950 and the present is characterized by two fundamental trends: strong energy growth in the 1950s and 1960s and comparative restraint in the 1970s and 1980s. Between 1950 and 1972, gross energy use grew explosively from about 282 PJ to 821 PJ (Figure 1-1). While energy use in 1950 was dominated by the use of coal, coal use shrank considerably during this period as energy users switched to oil because of its relative cleanness and convenience at the point of end use. As noted above, oil was the major energy input to the Danish economy in the early 1970s, a problematic fact given the upheaval in oil markets during that decade. During the 1950s and 1960s, the ratio of gross energy use to gross domestic product (GDP) grew at an average rate of 1.0 %/yr (Figure 1-2). This change was driven largely by lifestyle changes—larger homes, higher appliance ownership, and increased personal mobility—during a period when there was little emphasis on using energy efficiently.

The events of the 1970s led to a break from the energy growth trends of the 1950s and 1960s. Although oil is still an important gross energy input, its share in 1988 was only 46% as compared to 93% in 1972. Coal and to a lesser extent natural gas and renewable energy were substituted for oil. Simultaneously, the nation developed its domestic petroleum resources in the North Sea. Even more striking, however, is the fact that energy use has shown no net growth since the early 1970s, decreasing significantly during the recessions that followed the 1973 and 1979 oil price shocks and increasing during periods of strong economic growth. Some of the reasons for this relative stability are intuitively obvious. Over the short run, higher energy prices forced Danes to "tighten their belts," or make short-term sacrifices during a period of economic disruption and uncertainty. Over the longer term, the efficiency of energy use improved substantially, allowing higher living standards without accompanying increases in energy use.

1.2. The Energy Sector

The effects of the post-energy-shock transition are clearly evident in the energy sector, where gross energy inputs are converted into finished energy products such as refined petroleum, district heat, and electricity. The production of district heat and electricity accounted for about 90% of Danish coal use during the 1970s and 1980s. The increase in coal use during the period was thus due mainly to the substitution of coal for oil in heat and power generation, not the response of final energy users to altered market conditions.

The share of gross energy use lost in energy production and distribution remained relatively constant at around 25% during the 1970s and 1980s (Figure 1-3). This fact does not, however, imply that there were no improvements in the conversion and delivery of energy carriers. The share of electricity in *final energy use* (energy at the point of end use evaluated in thermal units) rose from 9% to 18% between 1972 and 1988, while the share for district heat rose from 10% to 14% (Figure 1-4). Since conversion and distribution losses are associated mainly with these energy carriers, the total loss share would have increased substantially in the absence of efficiency improvements. Further light is shed on this subject by a look at some of the details. In 1972, Danish central heat and power stations produced 11 units of district heat and 32 units of electricity for every 100 units of fuel input for a total conversion efficiency of 43%. By 1981, overall efficiency was raised to 48%, with district heat production at 16% of thermal input and electricity at 32%. By 1988, the district heating component rose to 19%, while electricity edged up to 34%. Overall efficiency was thus 53%, a relative improvement of 24% over the 1972 figure. A small improvement also occurred in pure district heat plants, where conversion efficiencies were raised from 81% to 84% between 1972 and 1988. Electrical transmission and distribution losses remained relatively constant at 7%, while the distribution losses for district heat systems fell from 25% to 21%.

While the developments in the Danish energy sector are interesting given the special role district heat and central heat and power systems play in the nation, they are not the primary focus of this report. We are interested in characterizing the forces that shape final energy use—the technological and behavioral factors that determine the demands that are satisfied by energy-sector activities. Trends in final energy use for the most part followed gross energy-use trends. Final energy use fell substantially following the 1973 and 1979 energy shocks, but rose modestly during periods of economic expansion. In 1988, Denmark used 572 PJ of final energy, 7% less than in 1972.

Primary energy use is a helpful measure of energy use when we are concerned with total system requirements. This is certainly true when measuring the environmental impact of energy use, the impact of fossil fuel use. Trends in final energy use weighted by the calorific values of energy carriers present a somewhat misleading picture of the demands placed on the energy system. Given the relatively strong growth of district heat and electricity use, it is important to count the losses incurred when primary fuels are converted to these final forms. Primary energy use, another measure of energy utilization, counts these losses. A simplified measure of primary energy use adds to district heating a loss of approximately 15% for preparation, and to electricity a loss of 240%. Other losses (petroleum refining, gas transmission) tend to be much smaller as a share of the final consumption of other fuels, and are usually ignored in analyses similar to ours (although they appear in their own right in the energy sector.)

Our estimates of primary energy losses represent approximate OECD averages and not actual Danish figures. It is important to see whether our approximation leads to any important distortions in our results, particularly as we assume a *constant* ratio of primary to secondary conversion losses for both electricity and district heat.

The actual figure for losses in producing electricity in Denmark is lower than ours, according to the ENS convention, because of the importance of combined heat and power. In 1990, 2.8 units of primary energy were required to provide 1 unit of final electricity consumption, considerably less than the OECD average of 3.24 we used. The actual figure for losses incurred in providing district heat in Denmark, 1.25 units of primary energy to produce 1 unit of heat reaching a building, is higher than the figure of 1.15 we used. The "efficiency" of production of district heat, according to Danish figures, is 128% in 1990, i.e., 0.78 units of extra fuel were required to produce 1 unit of heat at the plant, an average of heat-only plants and CHP plants. What raises the primary requirements of district heating are the large distribution losses, 20% of production. In 1972, the overall intensity of production was 1.33, a result of high losses (25% of production) and a production efficiency of only 102%.

The overall unit losses for both electricity and district heating production in Denmark each fell significantly between 1972 and 1990. But offsetting these trends was the continually increasing importance of each energy carrier in the final energy mix in Denmark. This increase more than offset the impact of improvements in the generation of either district heating or electricity on primary energy losses. Consequently, the difference between primary and final energy utilization in Danish households (or indeed in other sectors) diverged between 1972 and 1990, as our figures show. Using the Danish conventions for calculating primary energy use, which count actual conversion losses for district heat, combined heat and power, and thermal power plants according to each year's actual performance, the resulting divergence is only slightly smaller from the result we obtain if we use our own convention. Since we use the results from our analysis for international comparisons repeatedly, we use them in the Danish sectoral analyses as well. We therefore also consider trends in *primary energy use*, where the final use of district heat is weighted by a factor of 1.15 and electricity by a factor of 3.24 to account in an approximate way for conversion and distribution losses. While these figures do not exactly match the true figures for Denmark, that represent OECD averages that facilitate comparisons with other nations. Between 1973 and 1988, this primary energy use grew by 5%.

Both delivered and primary energy use lagged substantially behind GDP growth over the period so that the final energy/GDP ratio fell by 39% while the primary energy/GDP ratio fell by 28%. Electricity use per unit of GDP, on the other hand, grew by 27% between 1972 and 1988.

1.3. Methodology

Trends in aggregate energy use and economic activity are often used as indicators to gauge improvements in the efficiency of energy utilization over time or to anticipate future developments. While broad-based measures are indispensable because they convey facts in simple and hence digestible terms, they often hide information that is crucial in understanding the nature of energy use. Energy, after all, is not used in the abstract to produce abstract units of GDP. Instead, it is used to carry out numerous specific activities such as maintaining comfortable indoor temperatures; providing mobility in automobiles and other vehicles; and producing chemicals, steel, and other raw materials.

Previous research has shown that the structure of energy use—its disposition among different activities—changes substantially over time in response to demographic trends and changes in lifestyles and technologies (Schipper et al. 1989; Schipper, Howarth, and Geller 1990; Schipper and Meyers 1992). To see that this is true, it is useful to break final energy use down into six end-use sectors: residential, manufacturing, other industry, service, travel, and freight. As Figure 1-5 shows, the residential and manufacturing sectors are the most important end-use sectors in Denmark, accounting respectively for 38% and 23% of final energy use in 1972. The share in the residential sector fell to 32% by 1988, while the manufacturing share remained relatively constant over time. Little change was observed in the shares of the service sector and other industry category, which in 1988 accounted for 12% and 8% of final energy use. The energy share for the travel sector grew from 12% to 15% between 1972 and 1988, while the share for freight rose from 6% to 9%.

For each end-use sector, it is possible to define an indicator of *aggregate sectoral activity* that represents in broad terms the factors that drive energy use. In travel, for example, aggregate activity is defined as personal mobility measured in passenger-km. Within particular end-use sectors, it is possible to obtain more detailed information regarding the disposition of energy use between *specific activities*. In the residential sector, it is interesting to consider developments in space heating, water heating, cooking, lighting, and appliance energy use. In manufacturing one may divide energy use among different subsectors that produce fundamentally different kinds of products. To each specific activity corresponds a measure of *energy intensity*, or energy use per unit of specific activity.

According to this formulation, changes in the level of energy use in a given sector may be attributed to three factors: growth in aggregate activity; structural change (changes in the ratio of specific activities to aggregate activity); and changes in energy intensities. In formal terms, let A_{it} represent the aggregate activity level in sector i in year t, S_{ijt} ($j = 1,2,...,n$) be the level of specific activity j per unit of aggregate activity, and I_{ijt} be the energy intensity of specific activity j. Then the energy use of sector i is:

$$E_{it} = A_{it} \sum_{j=1}^{n} S_{ijt} I_{ijt} \ .$$

While this formula is simply an accounting identity, it provides the basis for constructing meaningful indicators of the determinants of energy use in a given end-use sector.

To measure the relative change in energy use that would have occurred over time if sectoral structure and energy intensities had remained fixed at base year ($t = 0$) values while aggregate activity had followed its actual development, we calculate the *activity effect* as:

$$\%\Delta E_{Ai} = (A_{it} \sum_{j=1}^{n} S_{ij0} I_{ij0} - E_{i0}) / E_{i0} .$$

Similarly, the hypothetical change in energy use given constant aggregate activity and energy intensities but varying sectoral structure (the *structure effect*) is:

$$\%\Delta E_{Si} = (A_{i0} \sum_{j=1}^{n} S_{ijt} I_{ij0} - E_{i0}) / E_{i0}$$

and the proportional change in energy use given constant activity and structure but varying energy intensities (the *intensity effect*) is:

$$\%\Delta E_{Ii} = (A_{i0} \sum_{j=1}^{n} S_{ij0} I_{ijt} - E_{i0}) / E_{i0} .$$

The specific numbers attached to each effect depend on the definitional framework used in the analysis, determined by the analyst based on theoretical considerations, data availability, and professional judgement; the specific definitions we use in each sector are summarized in Table 1-1 and discussed in the main body of the paper. This approach gives us a means of understanding the complex realities that lie behind energy-use trends. In particular, the methodology shows the importance of considering not only the efficiency but also the structure of energy use. To understand energy use one must focus therefore not only on the technical characteristics of energy-using equipment but also on the level of energy-using activities and the human context in which energy use occurs.

Combining the changes in activity level and structure, we obtain a measure of energy services. This measures the overall output derived from energy use in any sector, much like GDP measures changes in economic activity. Using changes in energy services weighted by energy use in each sector in a base year, we can estimate how much changes in energy services alone affected overall energy use. This result can be compared to changes in energy use that would have occurred had only GDP changed; conversely, changes in the ratio of energy services to GDP affect the energy/GDP ratio independently from the effects of evolving energy intensities.

We define conservation as the difference between actual energy use and the amount of energy that would have been used in a given year if energy intensities in each sector were frozen at a base year level, but the activity and structure of each sector had evolved as they actually did. We measure this as:

$$\%E \ savings \ in \ sector = A_{it} \sum_{j=1}^{n} S_{ijt} (I_{ij0} - I_{ijt}) / E_{it} .$$

Table 1-1. Definition of Factors for Impacts of Changing Activity Levels, Sectoral Structure, and Structure-Adjusted Energy Intensity on Sectoral Energy Use.

Sector/indicator	Definition/description of factors
RESIDENTIAL	
Activity	Population
Intensity	Space heat energy per unit of home floor area, electricity per appliance, energy per capita for cooking and hot water adjusted for home occupancy, lighting energy use per unit of floor area
Structure	Household floor area per capita, persons per household, appliance ownership per capita
MANUFACTURING	
Activity	Manufacturing value added
Intensity	Industry-group energy use/value added
Structure	Industry-group value added shares
OTHER INDUSTRY	
Activity	Value added in agriculture, forestry, fishing, mining, and construction
Intensity	Energy use/value added
Structure	Not applicable
SERVICES	
Activity	Service sector value added
Intensity	Energy use/value added
Structure	Not applicable
PASSENGER TRANSPORT	
Activity	Passenger-km/year
Intensity	Modal energy use/passenger-km
Structure	Modal mix
FREIGHT TRANSPORT	
Activity	Tonne-km/year
Intensity	Modal energy use/tonne-km
Structure	Modal mix

Denmark Gross Energy Use

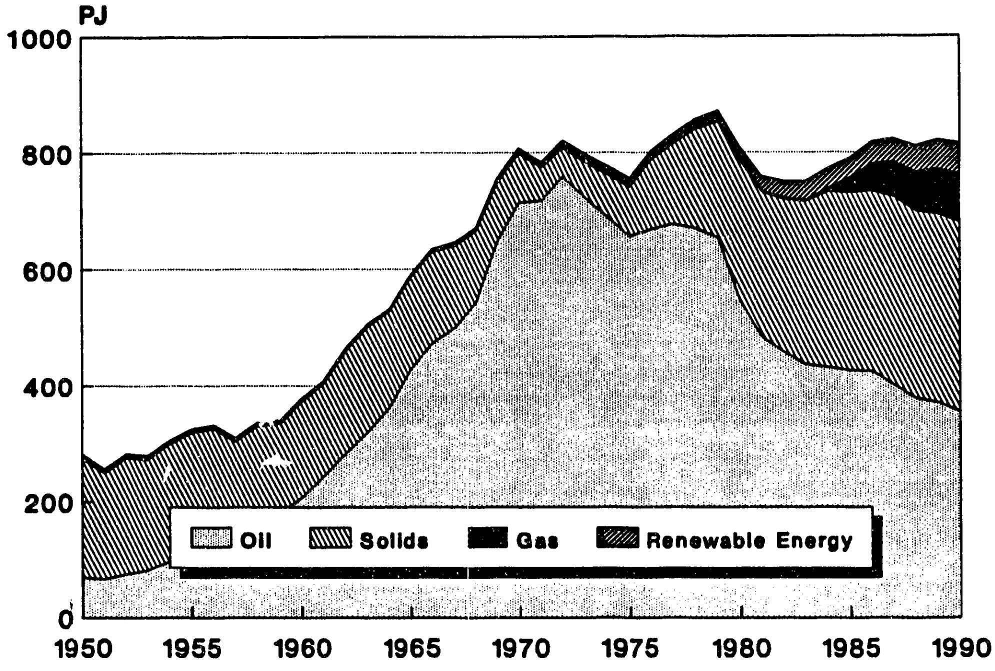


Figure 1-1

Denmark GDP and Gross Energy/GDP

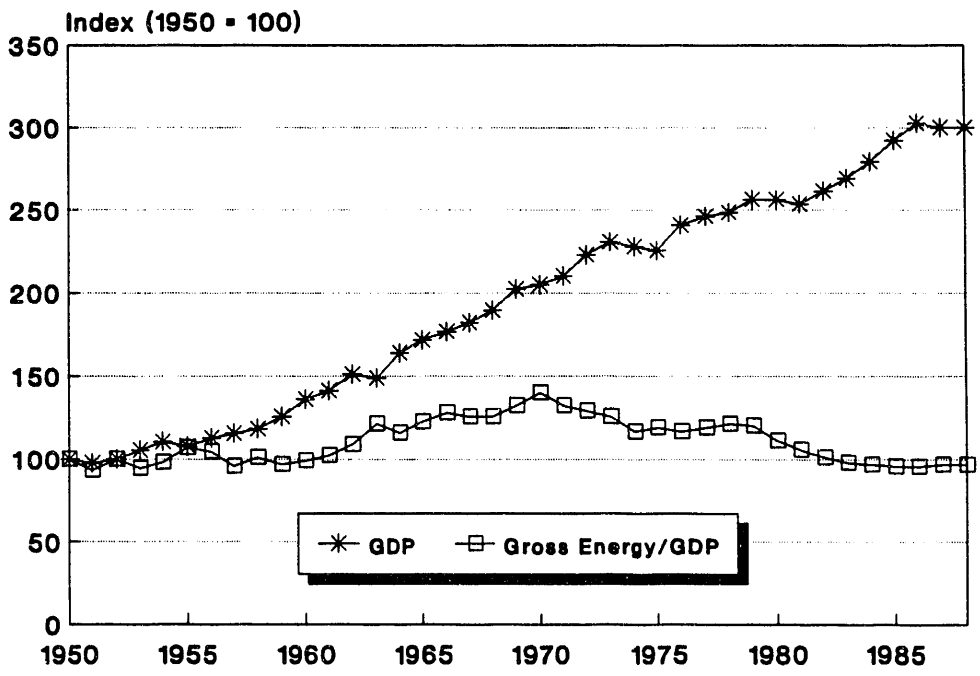


Figure 1-2

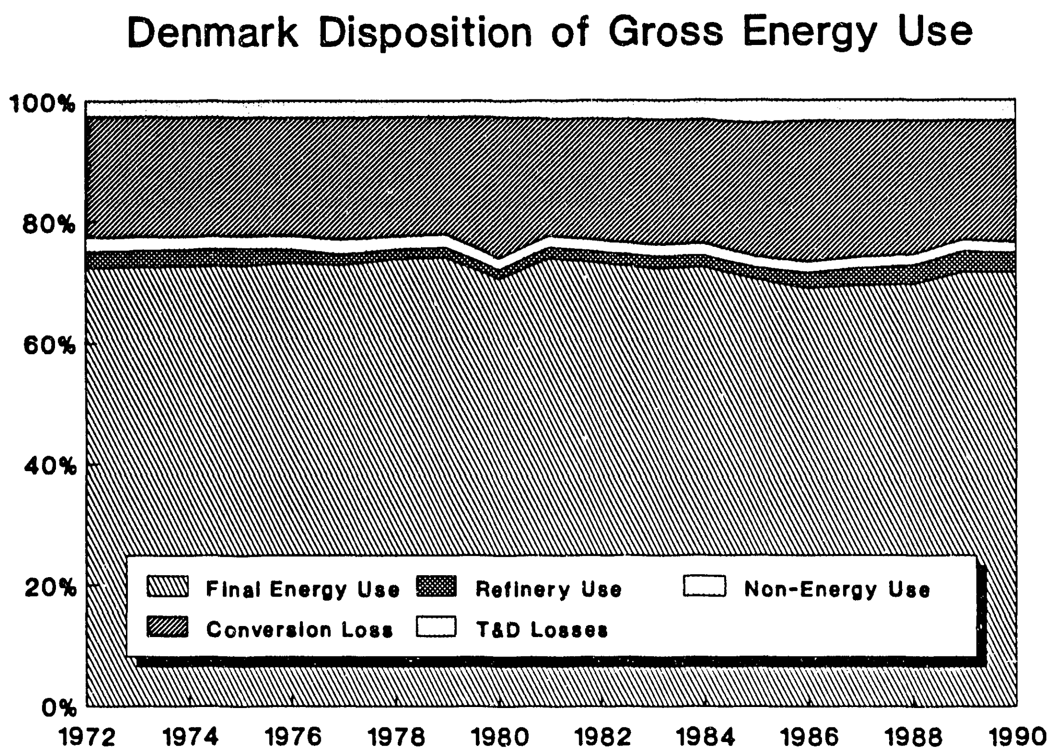


Figure 1-3

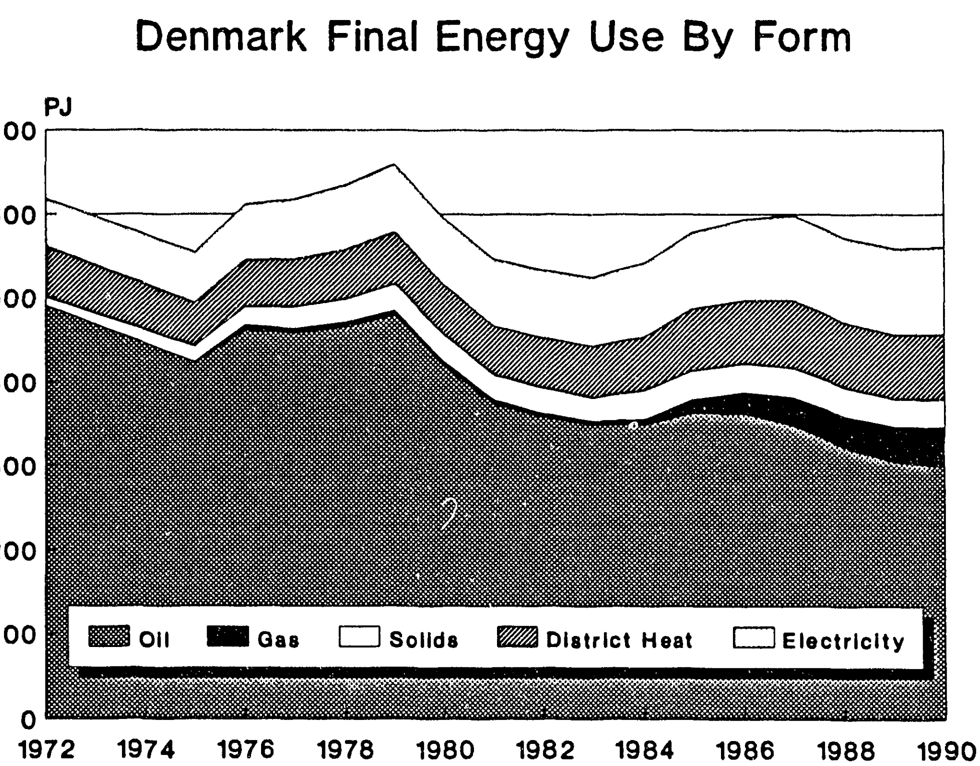
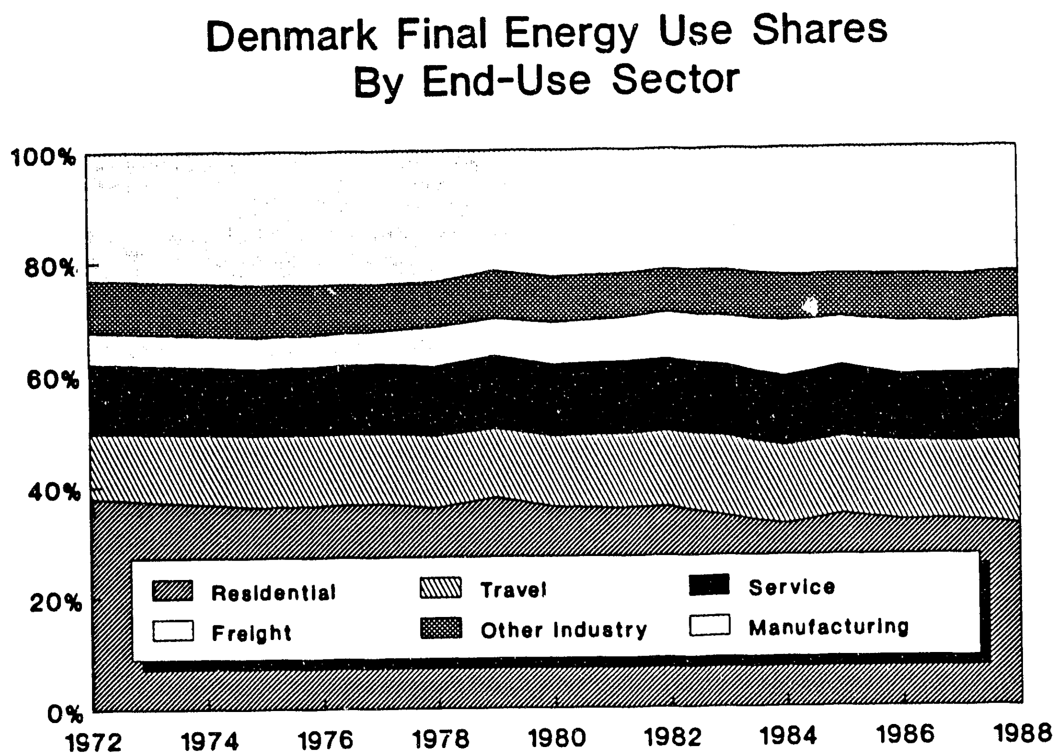


Figure 1-4



Denmark Final Energy Use Shares
By End-Use Sector
100%
80%
60%
40%
20%
0%
1972
1974
1976
1978
1980
1982
1984
1986
1988
Residential
Travel
Service
Freight
Other Industry
Manufacturing

Figure 1-5

2. THE RESIDENTIAL SECTOR

The residential sector, which accounted for 38% of Danish final energy use and 35% of final oil consumption in 1972, was the object of furious public and private efforts to save energy in the 1970s and 1980s. By 1979, residential energy use had grown slightly relative to that in other sectors, but by 1990, the share had fallen to around 32% for both final energy and oil. Total energy use in the sector lay below its 1972 level. Did efforts to save energy in this sector succeed and thereby bring down household energy use? This section will discuss the answer to this question.

The evolution of energy use in Danish households has taken many dramatic turns. A rapid rise in total energy use in the 1960s and early 1970s, driven by improved living standards, was interrupted temporarily by the first oil shock and permanently by the second. A large drop in energy use occurred in the 1980s, a result of very deep cuts in energy use for space heating and significant reductions in energy use for water heating and household appliances as well. The fuel mix, which was dominated by oil in 1972, shifted away from oil by the mid-1980s. The shares of final energy supplied by district heat, electricity, and natural gas increased significantly, although oil still heats more than 36% of all homes and provides nearly one-third of final energy use.

While the physical standards of Danish homes and the material comfort of Danish people continued to rise into the 1990s, the period of rapid growth in the main amenities that drive energy use is probably over, so energy demand should grow very slowly if at all. Significant reductions in energy use could be achieved if existing energy-efficiency opportunities were exploited.

In this discussion, we have analyzed energy use for space heating, water heating, cooking, lighting, and major electric appliances.[1] The major driver of activity in this sector is *population*, and the broadest measure of energy intensity is energy use per capita. The *structure* of residential energy use is related to physical measures of the standard of living: house area and the number of appliances per person. Additionally, family size is related to the structure of energy use, because smaller families tend to have higher per capita energy use than larger ones: energy services are shared over more occupants in large families.

We discuss energy intensities (or unit consumption, when referring to a particular end-use or appliance) on a per household or dwelling, per square meter, or per appliance basis. We have made many assumptions based on our ongoing analyses of the patterns of energy use in Danish households that began in 1981 (see Schipper 1983). For derivation of figures used in this section, see Appendix A.

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[1] *Sommerhuse*, or vacation homes, are excluded from our definition of the residential sector. The fuel consumed in vacation homes is unavoidably counted in the residential sector, but makes up a very small share. The electricity consumed in summer homes is excluded from our calculations, and appears in the residual consumption we have not accounted for. For farmhouses (*landbrugsejendom* and *stuehuse*), only the portion of electricity used to support residential activities is considered based on the assumption that consumption of electricity for household purposes, in kWh/household, in farmhouses is identical to that in *parcelhuse*, or detached single-family dwellings. Energy use for heating and household purposes in farmhouses is counted in the residential sector.

2.1. Sectoral Activity and Structure

In 1972, Danes had some of the highest housing comfort levels in Europe. The penetration of central heating lay above 80%, the share of detached or semi-detached homes in the housing stock was above 50%, and the average dwelling had a gross area of nearly 100 m^2. Given the average family size of 2.64, the typical Dane living in a home or apartment had close to 37 m^2 of total space at his or her disposal. Almost every home had a television and a refrigerator or combined refrigerator-freezer, and nearly half had freezers and washing machines.

The Danish material standard continued to improve after 1972, even as oil prices skyrocketed. Ownership of clothes dryers and dishwashers rose rapidly. Freezer and washer ownership had also increased substantially. By the time of the second oil shock in 1979, average home area passed 106 m^2, or 43 m^2 per capita. But the second oil shock sent Denmark's economy into a tailspin, slowing home construction and appliance acquisition during the first part of the 1980s. Still, the average Dane had 31% more living space and far more (and larger) household appliances in 1990 than in 1972. Almost 96% of all homes had either central heating or fixed electric heating panels in almost every room. These changes increased comfort and convenience levels in Danish homes, but also increased energy use, as we will see below.

Figure 2-1 portrays data that illustrate long-term trends in indoor housing comfort. Using figures from *Danmarks Statistik*, as well as our own estimates for energy consumption and central heating penetration in the 1950s, we have estimated the growth in population, the housing stock, home floor area, and total "comfort," all indexed to 1950 values.[2] By this standard, heated area has risen by over a factor of 2.4 since 1950. The growth in these parameters appears to have neared saturation in the mid 1970s, coinciding with the first energy shock. By this time, 90% of all homes had central heat or full electric heating. Thus the rise in housing standards in Denmark has been a long and slow process, although the entry of first oil, and more recently natural gas, into the heating market has been rapid. While we do not present a forecast of these trends, it is clear that future changes are likely to be slow, a fact reflected in *Energi 2000* (*Energiministeriet* 1990).

2.2. Fuel Choice and Fuel Shares

Supporting the rise in household comfort was an important shift in fuels. Whereas coal supplied most household heat in the 1950s and early 1960s, oil rapidly replaced coal in the 1960s and served as the most important heating fuel by 1972. District heating based principally on oil was a distant second. Many families still used coal or kerosene in heating stoves, while some had city gas, particularly in apartments in larger cities. By the time the second oil shock occurred, the shares of oil and solids had fallen only slightly; these fuels were replaced by district heat and, particularly in new homes, electricity. But after the second oil shock, and particularly after 1985, natural gas and district heating together reduced

[2] "Comfort" is measured as the index $A^*(1 + \%CH)/2$, where A is the per capita area of homes and $\%CH$ is the share of homes with central heat or fixed electric radiators. This formulation reflects algebraically the fact that occupants in a home with central heating typically use about twice as much energy to provide warm indoor environments than those in a home with independent room stoves. The index reaches the total area heated per capita when all homes have central heat.

the share of homes using oil from slightly over 50% to around 36%, a far greater percentage drop than had occurred between 1972 and 1985. Finally, solids, which consisted principally of renewables (wood, straw, etc.) increased their share of homes heated after 1979, then fell back somewhat, settling at around 3%. Solids also provided secondary heating in many homes where oil was the principal heating source.

Electricity's share grew only slowly, providing 8% of all homes with principal heating in 1990. Electricity use was boosted by increased ownership of electric water heaters and cooking stoves, as well as continued increases in appliance ownership. The Danish household fuel mix was cleaner at the point of end-use (i.e., less coal and oil, more electricity, gas, and district heat) in 1990 than in 1972, although substantial increases in the use of coal for electricity generation meant that, directly and indirectly, household energy use still emit considerable amounts of pollution. Much of the pollution now occurs at power plants, where it can be removed, rather than in residential areas or city centers. This development also improved comfort standards by reducing some of the pollution associated with using energy in the home.

2.3. Energy Use and Energy Intensity

What is striking about the historical trends in energy use in Danish homes is that they tend to first outpace the activity changes implied in Figure 2-1 (Cf. Table 1-1 in the introduction), then turn in opposite directions. The reasons for this evolution lie both in changes in efficiency and changes in behavior. Before 1965—a poorly documented period—it appears that household energy use rose rapidly to feed both the rise in indoor comfort and convenience *(Danmarks Statistik 1967). This development took place as real energy prices fell and incomes increased.*

Figure 2-2 shows the total use of fuels for households from 1965 to 1990.[3] By contrast with the previous period, final energy use in the residential sector remained relatively constant in the 1970s and decreased in the 1980s. The high value, 248 PJ, was reached in 1972, while the low of 181 PJ occurred in 1983, as Figure 2-2 shows. The 1990 level was 186 PJ. Primary energy use, measured according to the convention discussed in the introduction, increased during most of the period, starting at 264 PJ in 1970, rising to 289 PJ in 1978, falling sharply to 265 PJ in 1982, then growing slowly to 271 PJ in 1990.[4]

The aggregate intensity of residential energy use in Denmark, measured in per capita or per household terms, declined considerably in the 1970s and again in the early 1980s. To be able to see this, we have to aggregate fuels, district heating, and electricity. We define *useful energy* as the energy reaching the interior of the home after on-site combustion losses are subtracted. We count 66% of the energy in liquid and gaseous fuels, 55% of the energy in solids, and 100% of the electricity and district heat delivered to the home as useful energy.[5] Intensity, measured in useful energy per dwelling, increased

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[3] Unless otherwise noted, all data are corrected to normal climate (see Appendix A). Actual energy use in 1970 was higher than that in 1972, but 1970 was nearly 10% colder than normal, while 1972 was almost 5% warmer than normal.

[4] Counting primary energy using the Danish convention, which has lower losses for electricity but higher losses for district heating, would reveal approximately the same pattern.

[5] This convention eliminates much of the distortion that arises when electricity and district heating, energy sources with almost no losses within homes or buildings, are aggregated with fossil fuels and biomass, whose use entails significant combustion losses. The figures we use model average combustion efficiency. In reality the combustion efficiency improved over the period we studied. *Energistyrelsen* uses somewhat lower figures for conversion efficiency in the early 1970s and higher figures for the end of the 1980s. By

through 1972, as Figure 2-3 shows. There was a sharp decline through 1975, a brief recovery until the second oil shock of 1979, then an even more marked fall until a plateau was reached in the mid 1980s. Overall, useful energy per dwelling fell by some 30%. Useful energy per capita fell less, by 25%, because the number of people per dwelling fell by 18%. This decline in household size reduced energy use for cooking and water heating, two uses particularly sensitive to the number of people in a home. Figure 2-4 presents per capita energy utilization for each end use.

In measuring changes in energy intensity in homes, we have to average the changes that occurred to several important end uses. The indicators presented in Figure 2-4 are *not* calculated to take into account important increases in comfort (cf. Figure 2-1) and other energy services. To rectify this problem, we develop new indicators. As noted above, we defined population as our activity variable, and then examined several parameters of the "structure" of residential energy use. Space heating intensity is defined as the ratio of useful energy consumed to area heated, with the area weighted by the index of central heating. By this measure, the intensity of space heating in Denmark fell by 48% between 1972 and 1990.

Indicators for intensity of cooking and water heating are much harder to define, because we have no direct indicators of the quantities (or temperature) of hot water consumed, or of the number of meals cooked. However, in another study (Schipper et al. 1989), we observed that energy consumption per household for these purposes tends to vary with the square-root of household size, other things being equal. With this in mind, we define an indicator of energy intensity of water heating, or of cooking, as the ratio of fuel and electricity consumed for each purpose, divided by the square root of household size. We compare the change in fuel and electricity per household for each purpose to the change in the square-root of household size over time. A change in energy use that is less than that we would expect from changes in household size alone is attributed to changes in the actual intensity of energy use for these purposes. By these measures, the intensity of water heating in Denmark fell 10% between 1972 and 1988, while that of cooking was almost unchanged or even increased slightly over the same period.

Measuring changes in the intensity of lighting and electric appliances is somewhat more straightforward. We expect that electricity use for lighting will vary with home size; larger homes have more lights. Therefore, we compare the ratio of electricity consumed for lighting to home area in any year with that in the base year to estimate changes in the intensity of lighting. To track the evolution of electric appliances, we calculate the consumption of electricity for the six major appliances that would have occurred had ownership levels been frozen at their 1972 values while intensities (taken from Møller and Nielsen 1991) changed. We take the result, expressed as a ratio, to represent all electricity uses in the home not counted in heating, water heating, cooking, or lighting. By this measure, the intensity of electric appliances fell by almost 12% between 1972 and 1988, and is still declining.

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their figures, improved combustion efficiency raised the amount of useful energy provided for each unit of energy delivered to the combustion system. Our approximation thus overstates the decline in useful energy, i.e., what actually reached rooms and water faucets.

2.4. Decomposing the Changes in Energy Use

We can characterize the major forces behind the changes that occurred in household energy use using the system of calculations described in the introduction. Figure 2-5, for example, shows how final energy use changed between 1970 and 1990; Figure 2-6 shows the same results computed for primary energy using our convention. Figures 2-7 and 2-8 portray the evolution of electricity use for major appliances and for all electricity use.[6]

"Activity" shows how much energy use would have changed had only population grown. This effect was minor: the Danish population barely grew during the period 1972-1990. "Structure" illustrates the impact on energy use of increased home area per capita, more central heat, more appliances, and smaller household size. A strong increase in energy use, approximately 35%, occurred because of rising living standards. For electric appliances, the structural increase was greater than 50%, and for all electricity uses the structural effect was similar. "Intensity" isolates the impact of changes in the energy intensities of space and water heating, cooking, and individual electric appliances. As "Intensity" shows, however, there was a 46% drop in final energy use, and a 34% drop in primary energy, due to reduced energy intensities for all major end uses except cooking.

Comparison of Figures 2-5 and 2-6 shows that primary energy intensity fell less rapidly than that of delivered energy. This is because the intensity effect was less notable for electric appliances (Figure 2-7) or for electricity as a whole (Figure 2-8) than for all energy uses, where space heating dominates. Since electricity is weighted more heavily in primary than in final energy, the overall intensity effect appears smaller in the primary energy representation. Some of this divergence could arise because of the direct substitution of electricity for fuels is responsible for only a small part of this divergence.

This increase in the share of homes using electricity for certain purposes led directly to reductions of fuel use (predominantly oil) of perhaps 15 PJ. But the increase in electricity use, 10 PJ, was far smaller than the decline in overall household energy use from the intensity effect, which reached nearly 100 PJ. In other words, the decline in household energy intensities in Denmark was far greater than can be explained by factors related to fuel accounting. Thus the drop in household energy intensities in Denmark, however measured, reveals that Danes saved significant amounts of energy in their homes.

Figure 2-8 contains a hidden effect caused by the evolution of the share of homes using electricity for heating, cooking, and water heating. That is, electricity use for a given purpose is compared with all homes, not just those using electricity for that purpose. Since the shares of homes using electricity for these purposes increased, total electricity use for certain end uses increased, although the unit consumption for each purpose decreased. As noted above, this substitution raised electricity use by almost 10 PJ between 1972 and 1988. Consequently, the "intensity" line in Figure 2-8 does not fall as much as the

[6] The calculations used in Figure 2-8 differ from those applied to electricity in other sectors. In other sectors, it is difficult to count the number of users of electricity for any particular use, so we can only measure the overall electricity intensity of the other sectors. But in the residential sector, we know the number of homes using electricity for virtually every important purpose. We consider thus in Figure 2-8 the intensity of each electricity use as electricity used/number of users. Electricity intensity for heating is thus measured over homes with electric heat, and similarly for other uses. The "conservation effect" shows the results of this calculation, as distinct from the "intensity effect".

intensity of each electricity use fell.[7] The "Conservation" effect shows the impact of changes in electricity use intensities on electricity uses, given that a household has that individual electricity use. This effect was substantial, as can be seen from the divergence between "intensity" and " conservation" in Figure 2-8.

2.5. The Decline in Household Energy Intensities

The enormous reduction in heating intensity in Danish homes between 1972 and 1990 can be explained as the product of changes in behavior, higher equipment efficiencies, and improved building shells. The DEMO Project (Nørgård 1977) suggests that indoor temperatures in Denmark were well above 21°C in 1972, in part to keep poorly insulated homes warm. Following the 1979 oil price shocks through the mid-1980s, space-heating intensities fell considerably. The decline was far too rapid to have been caused by careful retrofit of building shells, windows and equipment. Hence, behavioral change may have accounted for as much as 50% of the decline during that time period. In recent years, indoor temperatures as well as other measures of conservation behavior have fluctuated. Recent *ScanTest* surveys (*ScanTest* various years) indicate that the vigilance of Danish householders has relaxed somewhat since the mid-1980s. Nonetheless, Danes still heat their homes to lower temperatures (probably 2-3 degrees C lower) than they did prior to 1973. All in all, we estimate that approximately 25% of the decline in heating intensities between 1972 and 1990 stemmed from behavioral changes.

Technological improvements accounted for most of the remaining decline. *Energistyrelsen* figures estimate that between 1972 and 1990 the conversion from delivered energy to useful heat rose from 55% to 70% for heating oil and from 40% to 50% for various solid fuels. District heating and electricity remained constant at 95% and 97% respectively. The fact that the intensity of oil heating declined more than the intensity of district or electric heat is a result of greater improvements in the oil-heating equipment.

Improvements in building shells—increased insulation, caulking and weatherstripping, new windows, etc.—also contributed to the reduction. Additionally, the acquisition and use of heating controls (thermostats, shunts, etc.) reduced unnecessary heating and allowed for better control of the heat produced. These controls also contributed to better performance of heating equipment by permitting better matching of load to output.

Overall, higher energy prices have played an important role in depressing household energy use in Denmark. As Figure 2-9 shows, major changes in household energy prices occurred over the observed time period. In 1989, heating oil prices lay at 335% of their 1972 value, whereas household electricity prices had reached only 44% of their 1972 level. The price of natural gas followed that of oil closely; as a result, save biomass or other sources of non-commercial solids, Danish households have no "cheap" energy alternatives. Still, the prices for district heat, gas, and oil rose markedly relative to that of electricity (shown in Figure 2-9), leading to some substitution towards electricity.

[7] Calculation of the intensity of electricity use in Figure 2-8 is consistent with the way electricity was treated for the manufacturing, industry, and service sectors. But in other calculations presented in our discussion of residential energy use, we compare the use of electricity for heating, water heating, and cooking with the number of homes using electricity for these purposes.

One of the initial goals of energy policies aimed at the residential sector was to reduce the importance of oil use in this sector, which is what occurred. Two important effects were responsible for the large decline in oil use we observed. Until 1982, declining use of oil in homes heated with oil reduced oil use; after 1982, substitution to other fuels became increasingly important and by 1985 drove almost all of the continued reduction in household oil use. This distinction is important: the unit consumption of oil in homes heated with oil appears to be level, but the number of homes heated with oil is still sinking in 1991, to the advantage of gas. Thus oil use in Danish homes should continue to decline in the 1990s.

Although electricity prices rose far less dramatically than oil prices, the share of new homes using electricity remained relatively low, because the Heat Plan placed restrictions on electric heating (see below) and consumers still perceived the price of electricity as unreasonably high. It was only when natural gas became more available that a large number of Danish households abandoned oil.

The policies promulgated by the Danish government also contributed to the significant decline in household energy use. The Danish government has undertaken one of the most ambitious household energy-efficiency programs ever attempted by an OECD country (Wilson et al. 1989). Billions of dollars have been poured into grants and subsidies to encourage home owners and occupants to reduce their use of energy.

Trying to determine the relative impacts of prices and policies on energy use—and to disaggregate the effects of each—proves elusive. However, a quick survey of Denmark's policies provides some insight into the effect of government intervention on household energy consumption. Take, for example, the subsidies for retrofits that were available in the late 1970s and early 1980s. While these may have reached their targets, they could have accounted for only a part of the overall drop in heating intensity observed between 1978 and 1981 (Schipper 1983). And the *Varmesynsordningen* (Heat Consultant Plan)—which required sellers of homes to offer energy audits of their properties to buyers (the *Varmetattest*) and encouraged inexpensive inspections to all interested parties—had an impact in the mid 1980s, but the total number of homes affected was only a small part of the overall stock (Birch & Krogboe 1986). The levels of insulation required by the building codes (*Bygningsreglement*, or BR) of 1979 and 1982 certainly forced an even greater increase in insulation levels of new homes, which represented more than 10% of the stock by 1990 (*Byggestyrelsen* 1982). Additionally, the Heat Plan forced even more marked improvements in homes for which electricity was to be the heating source, since these homes had to be designed so that space heating losses would make up less than half of the total energy requirements for the homes, so-called *lavenergihus*. In short, many different policies coaxed energy use in homes downward. Yet a rough estimate of the impact of these various measures (see Schipper 1983) suggests that they do not account for all the savings: a significant amount either arose because building occupants heated differently, or because occupants or owners undertook retrofit measures for their own account. Moreover, virtually no policies were applied nationwide to non-heating household electricity use (efficiency standards, etc.) until the late 1980s. While it would be very difficult to account for the exact marginal effects of government programs, we believe that they "caused" less than half of the total energy savings in Danish homes. This does not, however, mean that programs were ineffective, only that other forces, predominately price changes, caused even more improvement in energy use than programs.

2.6. The Plateau of Household Energy Use: Implications

The summary figures document the significant savings of energy in Denmark between 1972 and 1990. The curves also show a clear stagnation in this effect after 1986, aside from a brief upturn in intensities for heating that occurred in 1986 and 1987, the years of the large decline in oil prices. Indeed, residential energy prices have been flat since the oil price crash. The rapid energy savings developments in Denmark have clearly ceased.

These developments are reflected in interviews with house occupants. The *ScanTest* interviews show a clear drop-off in the number of households adding key efficiency improvements to their homes. Some of this decline is caused by saturation of measures. The same interviews also show that through 1986 there was a steady increase in indoor temperatures, then a turn around, then stagnation. Some of energy saved by lowering temperatures in the early 1980s may have been "taken back" by careful retrofit measures taken in the mid 1980s. That is, people cut back on comfort until they were able to make investments to reduce the energy costs of that comfort. Danes have not lost interest in energy efficiency, but they have lost some of the zeal they showed in the early 1980s.

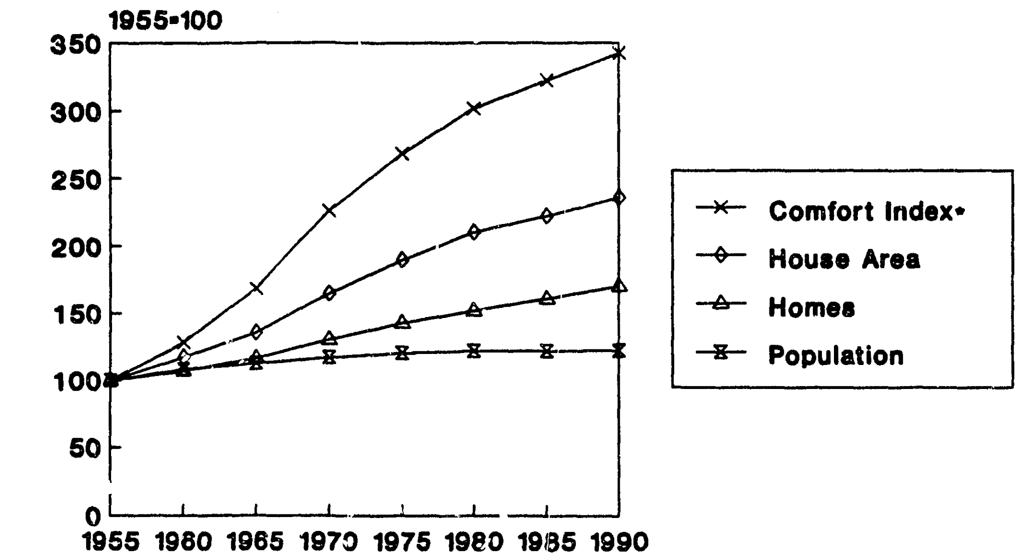
The plateau in energy intensity should not be surprising. Real oil and gas prices fluctuated only slightly after 1987, while household electricity prices, which had dipped sharply in 1984 and 1985, recovered somewhat, though not to their highest level in 1982. The stagnation or fall in energy prices explains much of the reason for the plateau in energy intensity in Danish households.

A key issue for Danish policy makers is whether the potential for improved efficiency, which is well documented,[8] can be harvested. Declining interest in the *Varmesynordningen* and even obtaining an energy certificate (*Energiattest*) (*EK-Sekretariet*, 1991), suggests that the retrofitting of existing homes will be very slow. And the minuscule rate of new construction, estimated by *Energistyrelsen* at around 20,000 homes per year (out of a total stock of more than 2.3 million units) suggests that replacement of older homes by new will be rather slow. Thus reducing heating needs in Danish homes, while attractive economically, will take a long time.

More positive steps may be those aimed at household electricity use. A variety of utilities have begun to offer low-energy compact fluorescent lamps (see Mills 1991a). Others are aggressively marketing information on efficient appliances, including the low-energy refrigerator of *Brødrene Gram*. And the leadership of Denmark in *NORDEFF* and *NORDNORM* appears to be leading to an efficiency standard for refrigerators and like equipment, which could accelerate the improvements that already have occurred.

[8] These were carried out by Fritzel et al. (1991), Møller (1987), *Energistyrelsen* (1990), and Nørgård (1989).

Energy in Denmark: Long Term Trends
Structural Factors in Housing



* For explanation see text
Home Area estimated 1955-1965

Figure 2-1

Household Energy Use In Denmark
By Fuel Type

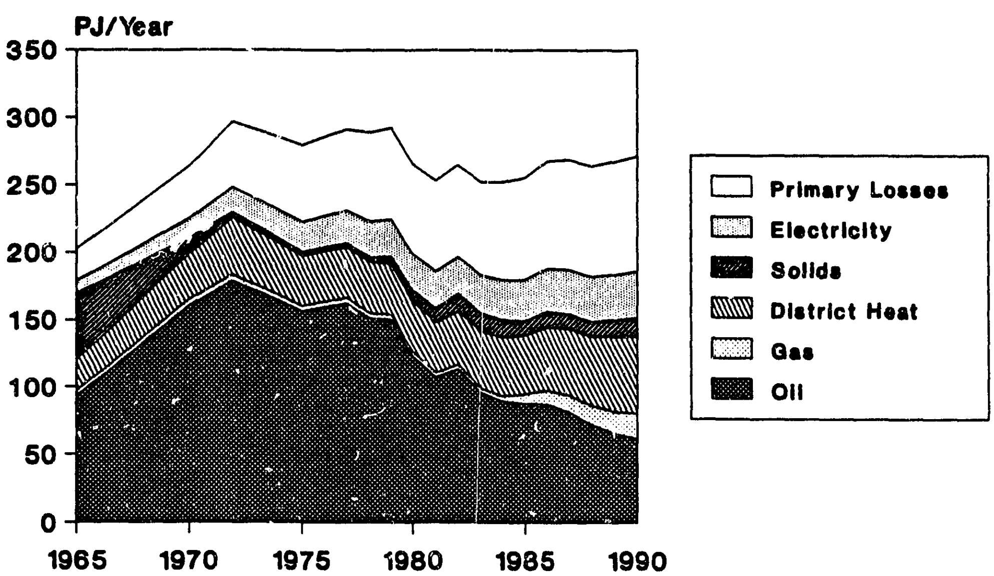


Figure 2-2

Household Useful Energy Use In Denmark

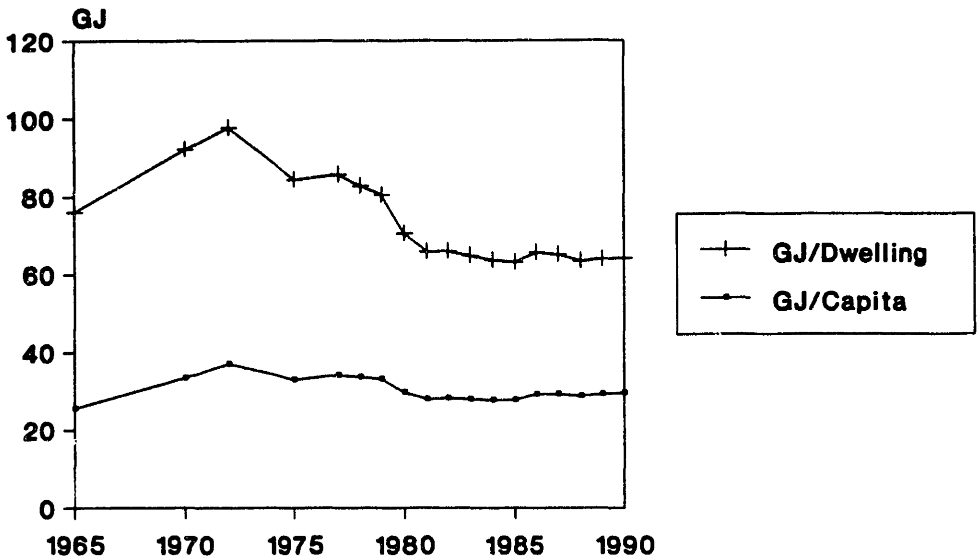


Figure 2-3

Household Useful Energy Per Capita

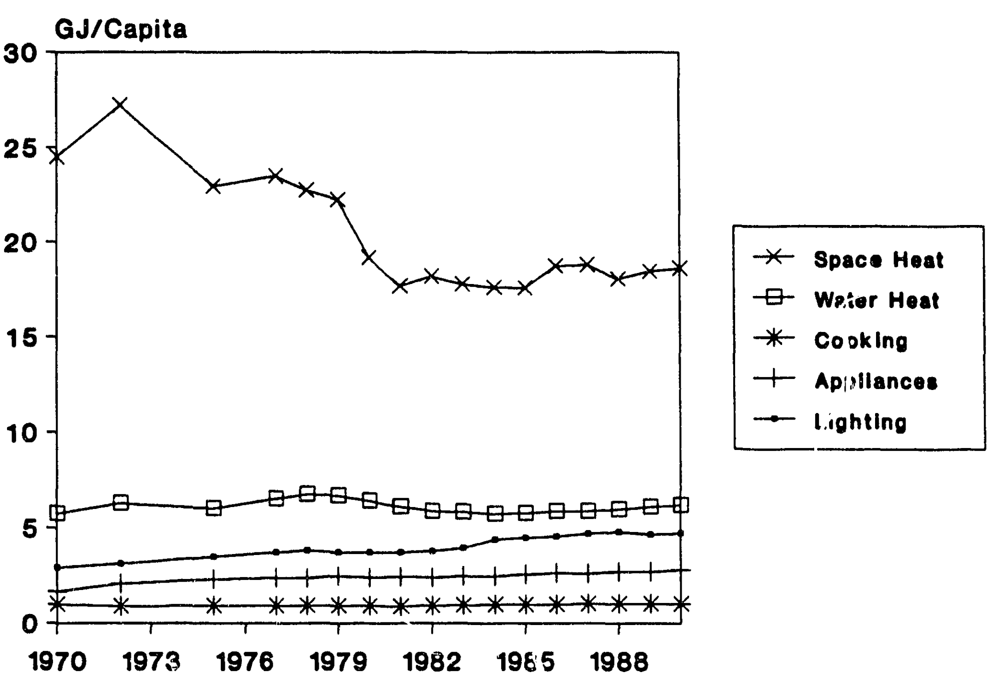


Figure 2-4

Household Energy Use in Denmark
Final Energy
Activity, Structure, Intensity Effects

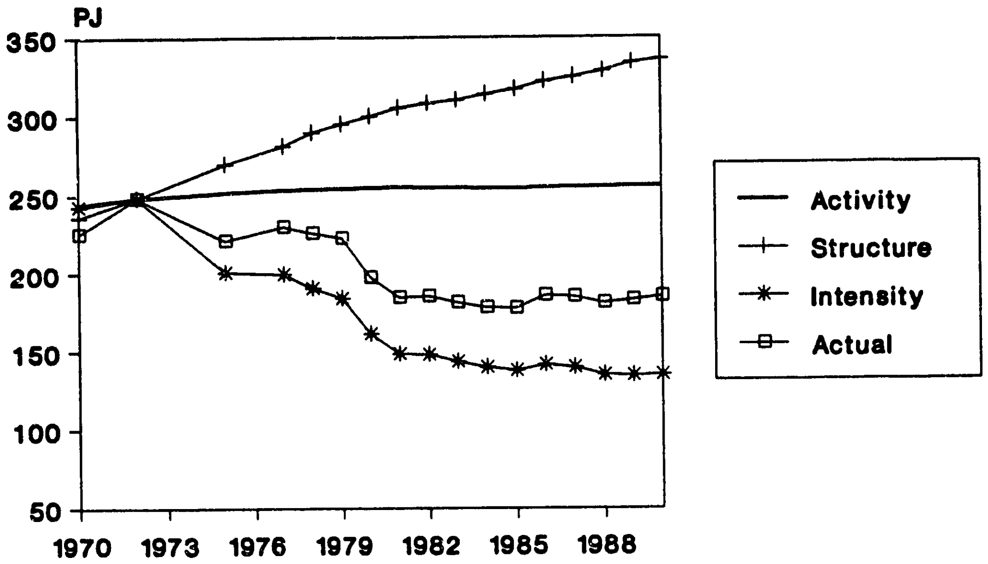


Figure 2-5

Household Energy Use in Denmark
Primary Energy
Activity, Structure, Intensity Effects

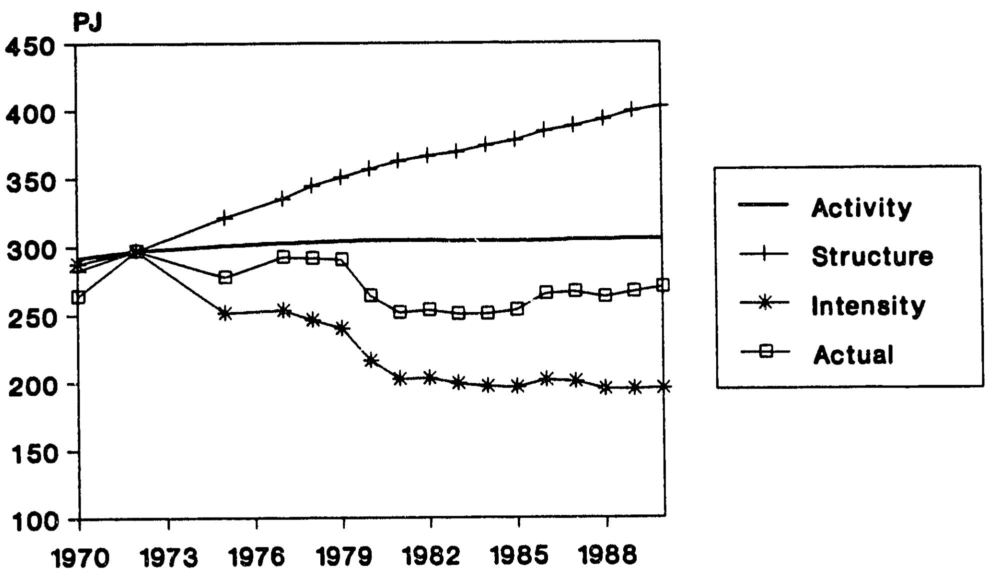


Figure 2-6

Household Energy Use in Denmark
Appliances
Activity, Structure, Intensity Effects

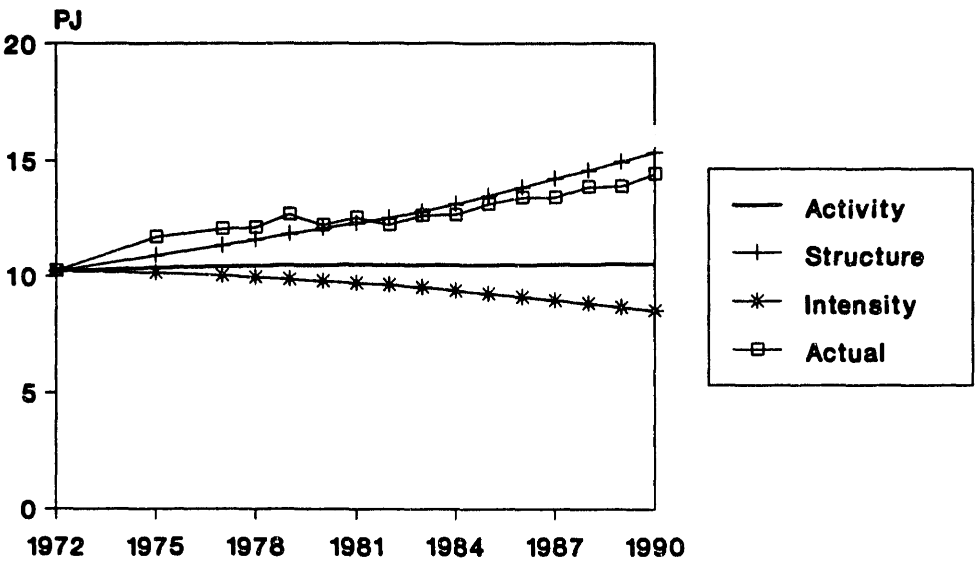


Figure 2-7

Household Electricity Use in Denmark
Activity, Structure, Intensity Effects

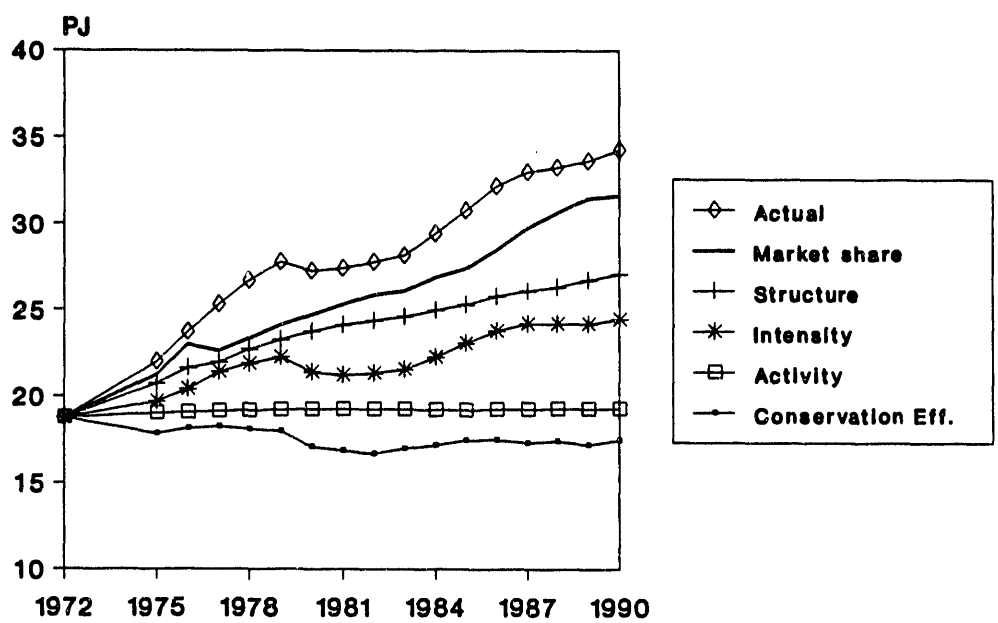


Figure 2-8

Household Energy Prices in Denmark
Real (1980) Prices

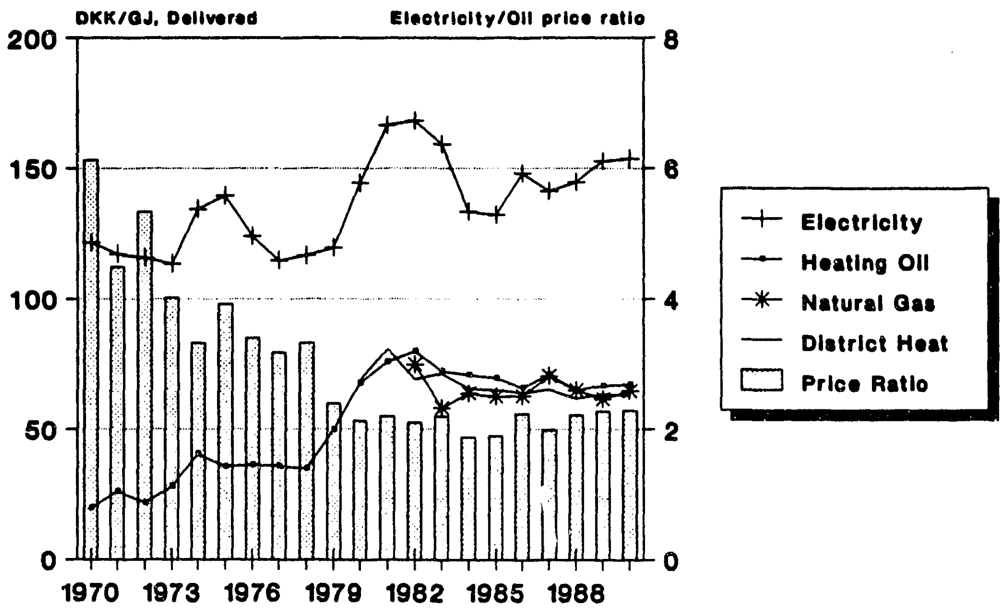


Figure 2-9

3. THE MANUFACTURING SECTOR

The manufacturing sector (ISIC[1] 3) is involved in the processing and assembly of raw materials into finished commodities. The sector is important in both energy and economic terms, accounting for 23% of final energy use and 18% of GDP.[2] While manufacturing output, measured by real value added, grew at 4.8 %/yr during the late 1960s and early 1970s, the growth rate fell substantially following the energy shocks in 1973 and 1979 (Figure 3-1). Over the entire 1973-1990 time period, output growth averaged only 1.5 %/yr, with no net growth in the mid- to late-1980s.

Aggregate sectoral energy use grew from 121 PJ in 1966 to 155 PJ in 1973 (Figure 3-2). The level of energy use was relatively stable between 1973 and 1978, declined by 24% between 1978 and its low in 1983, and rose somewhat in more recent years. The most pronounced changes occurred in oil, which fell by 58% between 1973 and 1988 while its share of final manufacturing energy use fell from 77% to 40%. Electricity use rose by nearly a factor of two between 1973 and 1988 while its share rose from 10% to 23%. Natural gas use reached 14% of final demand by 1988, even though gas was not available until the mid-1980s. The use of solid fuels fluctuated over the period, but increased in its share of total energy use from 11% in 1973 to 21% in 1988. Small amounts of district heat (about 2% of sectoral energy use) are used to heat manufacturing buildings. While the energy data from *Danmarks Statistik* on which this analysis is principally based extend only to 1988, supplementary data from *Energistyrelsen* indicate that final energy use showed no net change between 1988 and 1990. Because electricity use grew by 7%, primary energy grew by 2%.

Aggregate manufacturing energy intensity, or energy use per unit of value added, fell substantially over the period of analysis (Figure 3-1). This ratio declined by 1.3 %/yr between 1966 and 1973, by 3.7 %/yr between 1973 and 1979, and by 6.9 %/yr between 1979 and 1983. Aggregate intensity rose by a total of 16% between 1983 and 1987 but then fell by 9% between 1987 and 1988. The reductions that occurred were focused mainly on oil use. While oil use per unit of output fell by 66% between 1973 and 1988, aggregate intensity increased by 50% for electricity and by a smaller proportion for solids. Between 1988 and 1990, final energy intensity dropped by 3%, while electricity intensity rose by a similar figure.

3.1. The Structure of Energy Use

To make further progress in understanding manufacturing energy trends it is necessary to look at some of the details that lie behind this aggregate picture. The sector's energy use may be described by either the physical or economic context in which it occurs. While broad indicators of the energy used to provide process heat, power electric motors, or perform other physical tasks are useful in certain contexts—for example, evaluating the potential for the cogeneration of heat and power—the great diversity of the sector and the technologies it employs complicates both the definition and measurement of

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[1] International Standard Industrial Classification.

[2] Both the energy and national accounts data discussed in this section are drawn from *Danmarks Statistik*. While *Energistyrelsen* reports less energy use in manufacturing than *Danmarks Statistik* (104 vs. 124 PJ in 1988), the reasons for this difference are not entirely clear. We use the *Danmarks Statistik* data because they provide details on the breakdown of energy use by sector not available from *Energistyrelsen*.

generic energy services. While case studies of particular facilities can yield important insights into technological trends and opportunities to save energy, the statistics produced by government agencies typically disaggregate industrial energy use by economic classification and not by physical process. For these reasons, we focus on the sectoral breakdown of energy within manufacturing, not on its allocation by physical process.

Previous studies have found that energy intensity (energy use per unit of value added) varies greatly across manufacturing industries (Howarth and Schipper, 1991). While value added is dominated by the production and assembly of finished goods, energy use is typically concentrated in the processing of basic materials by thermal, mechanical, and electrochemical means. In most OECD nations, five basic materials industries—the paper and pulp (ISIC 341); chemicals (ISIC 351-2); stone, clay, and glass (ISIC 36); iron and steel (ISIC 371); and nonferrous metals (ISIC 372) sectors—account for 70% of final energy use. In Denmark, these industries account for 34% of manufacturing energy use but only 17% of manufacturing value added.

Since the industry groups enumerated above are 2.6 times as fuel intensive and 2.4 times as electricity intensive as the rest of the manufacturing sector, changes in their economic importance would have significant implications for sectoral energy use. Between 1973 and 1988, the value-added share rose from 2.1% to 2.5% for paper and pulp; from 5.4% to 8.9% for chemicals; and from 0.7% to 1.1% for iron and steel. The output share fell from 7.8% to 4.3% for the stone, clay, and glass sector and from 0.3% to 0.2% in for nonferrous metals. The share of output originating in other industry groups remained nearly constant at around 84%.

To gauge the impacts of such structural change on sectoral energy use, we calculated the development of energy use that would have occurred if total manufacturing output and the energy intensities of each industry group had remained constant at their 1972 levels while the output shares of each industry group had followed their historical paths.[3] The details of this calculation are explained in the introduction. On the whole, the results indicate that changes in the structure of the manufacturing sector had only modest impacts on energy use over the period of analysis (Figure 3-3). While structural change, given constant output and energy intensities, would have reduced energy use by 7% between 1973 and 1982, a slight shift back to energy-intensive industries occurred during the mid- to late-1980s. Structural change had little impact on oil and electricity use, while the use of solids would have declined by 26% between 1973 and 1988 given constant output and energy intensities. The decline for solids was due mainly to the decreased output share of the stone, clay, and glass industry, which accounted for 66% of manufacturing solids use in 1973.

3.2. Energy Intensity

More important were changes in the energy intensities of the various manufacturing industry groups. Between 1973 and 1988, energy intensities fell by 42% for paper and pulp; 75% for chemicals; 29% for stone, clay, and glass; 68% for iron and steel; 59% for nonferrous metals; and 12% for other

[3] The 1972 base year is chosen for compatibility with sectors where energy-use data are not available for 1973.

industries (Figure 3-4). The level of final energy use given constant (1972) manufacturing value added and output shares but actual energy intensities would have fallen by 30% between 1973 and 1988 (Figures 3-5 and 3-6). Oil intensity, adjusted for structural change, fell by 66% between 1973 and 1988. A substantial increase occurred for solids, while structure-adjusted electricity intensity rose by 50% (Figure 3-7). Although the detailed data on which these calculations depend extend only to 1988, little structural change occurred between 1988 and 1990. Thus the 3% 1988-1990 reduction in aggregate final energy intensity reported above—and the corresponding 3% increase in electricity use per unit of manufacturing value added—are indicative of changes in energy intensities at the industry-group level.

Consideration of long-term trends suggests that the energy shocks had a significant impact on developments in energy intensity. Manufacturing energy intensity, adjusted for structural change, fell by 1.6 %/yr between 1966 and 1973. The rate increased following the energy shocks to 3.1 %/yr between 1973 and 1979 and 5.4 %/yr between 1979 and 1983. Between 1983 and 1987, however, structure-adjusted intensity *increased* by 3.7 %/yr, although an apparent decrease of 8% occurred between 1987 and 1988. Whether the 1987-88 reduction was real or due to shortcomings in the data is not altogether apparent. The rate of change in structure-adjusted energy intensity between 1983 and 1988 was -1.0%/year.

3.3. Primary Energy Use Trends

The calculations presented above are based on final energy, ignoring the transformation and distribution losses occurring in the energy sector. To gauge the evolution of the total direct and indirect energy requirements of the manufacturing sector, we evaluated the impacts of changes in industrial structure and energy intensities on primary energy use as defined in the introduction. The results indicate that the trends for final and primary energy were similar in shape but different in magnitude (Figure 3-8). Because of the strong relative growth in electricity use, primary energy use showed no net decrease between 1973 and 1988, while final energy use declined by 20%. Energy intensity, adjusted for structural change, decreased by 15% for primary energy and 29% for final energy. The impacts of structural change were small for both energy aggregates.

3.4. Interpreting the Results

The analysis presented in this section raises a number of interesting questions. First, why did electricity intensity grow so rapidly in Danish industry? Industrial electricity prices peaked in 1974 and then fell by over 50% as of 1988.[4] All else equal, this decline had a stimulative influence on electricity utilization. An analysis of technological trends in Danish industry, however, shows that other factors were also at work (Andersen et al., 1991; see also Mikkelsen, 1987). In the 1960s, Danish manufacturing was dominated by small, labor-intensive establishments. The 1970s and 1980s saw the introduction of modern, larger-scale technologies more in line with European standards. In such facilities, human labor was replaced to a significant degree by the work of machines powered by electricity. Hence the increase in electricity intensity reported here does not necessarily indicate reduced technical efficiency.

[4] Industrial energy prices are discussed in further detail later in the paper.

A second question relates to the plateau in energy intensity that occurred during the mid to late 1980s. The reductions in oil prices that occurred during this period certainly softened manufacturers' direct concern for saving energy. As we noted above, however, substantial improvements in energy productivity were achieved in the 1960s and early 1970s, a period of low and stable energy prices. Over the long term, energy intensity is shaped not only by price-induced factor substitution but also by technological developments that reduce requirements for all inputs, energy included (Ingham et al. 1991). New technologies, however, are incorporated into the stock of capital equipment only when new factories are built or old ones are retooled. In the late 1960s and early 1970s, manufacturing output grew by more than 4 %/yr, providing rapid penetration for state-of-the-art technologies. In the mid- to late-1980s, on the other hand, manufacturing output was stagnant, and the rate of investment slowed to a crawl. As a result, the entry of new, more efficient technologies slowed as did the improvement in energy intensity.

The implications of these trends for future energy use are uncertain. While manufacturing output fell disproportionately during the recession of the late 1980s, over the long term the share of GDP originating in manufacturing has been relatively constant. Resumed economic growth therefore should imply renewed growth in manufacturing. While this growth in turn should lead to reduced energy intensity, the rate of improvement will depend on national policies regarding the pricing of fuels and electricity. Although Danish consumers pay stiff taxes on energy products, private firms may credit the energy taxes they pay against their value-added tax assessments. The result is that energy taxes are effectively zero except for private households, a fact that reduces the incentive in industry to save energy.

Denmark Manufacturing Output and Aggregate Energy Intensity

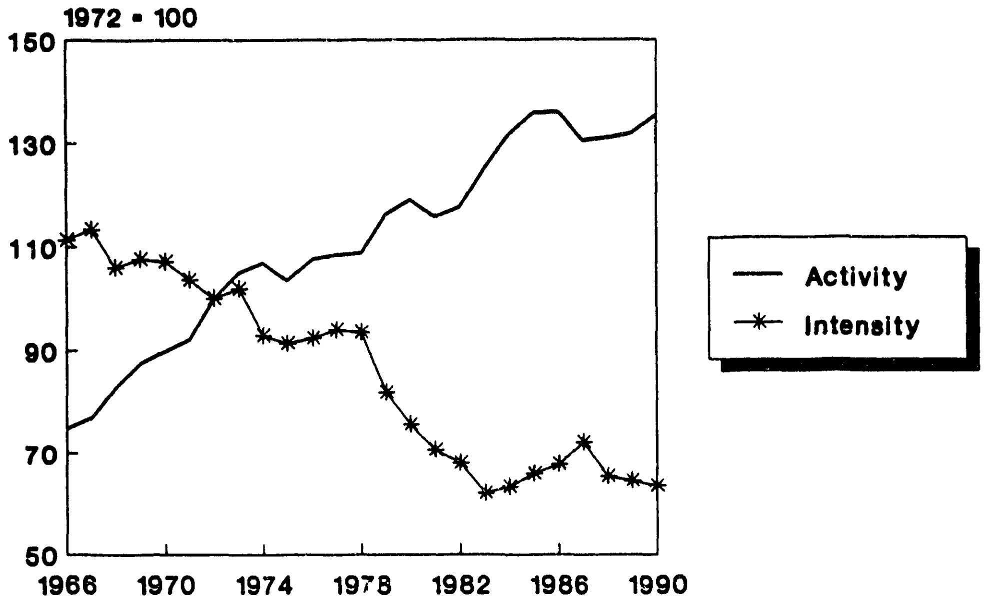

Figure 3-1

Denmark Manufacturing Energy Use

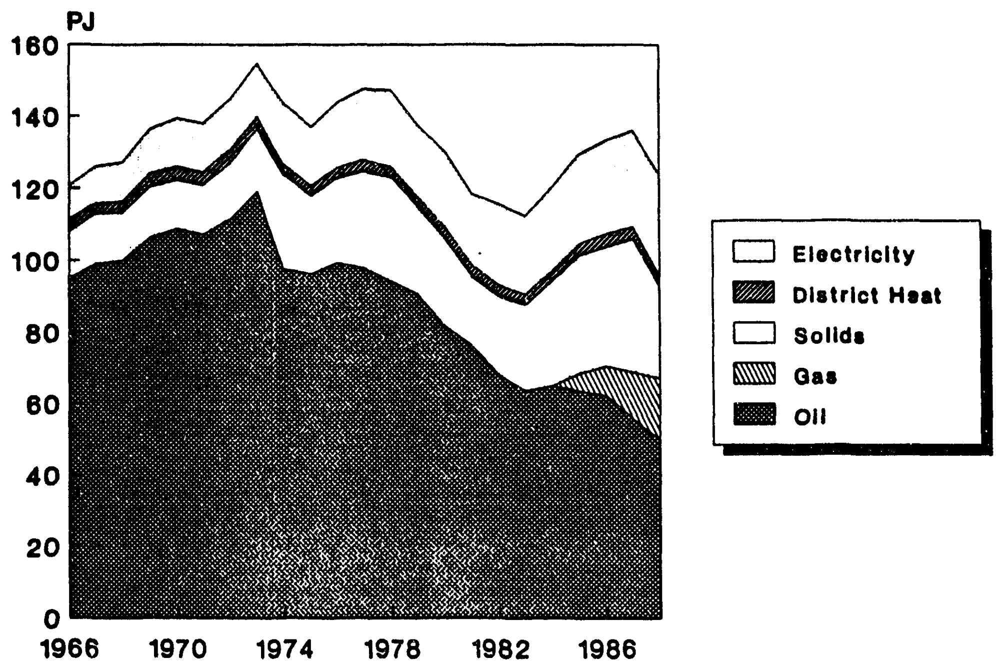

Figure 3-2

Denmark Manufacturing Energy Use
Varying Industry Structure
1972 Output and Intensities

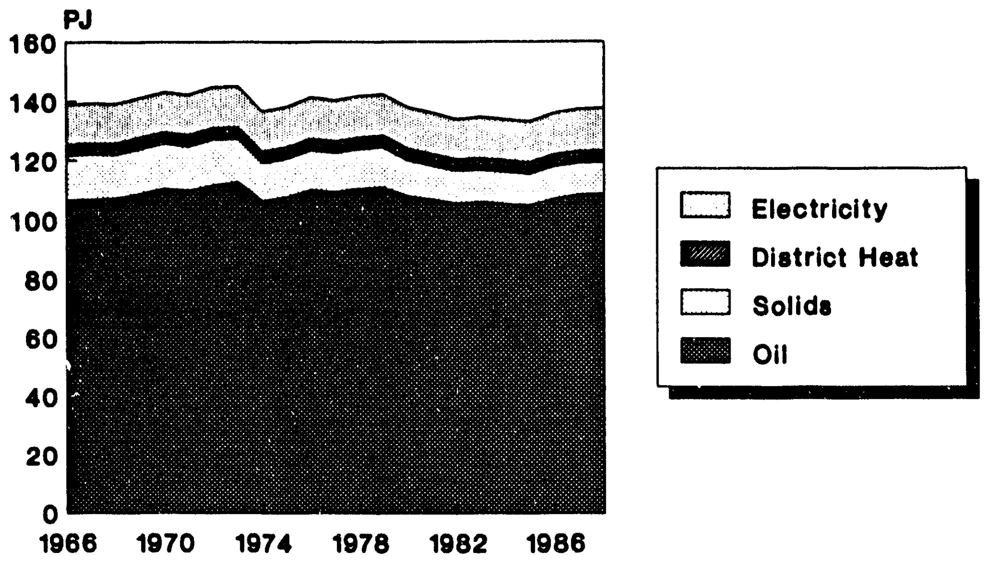

Figure 3-3

Denmark Energy Intensity
By Industry Group

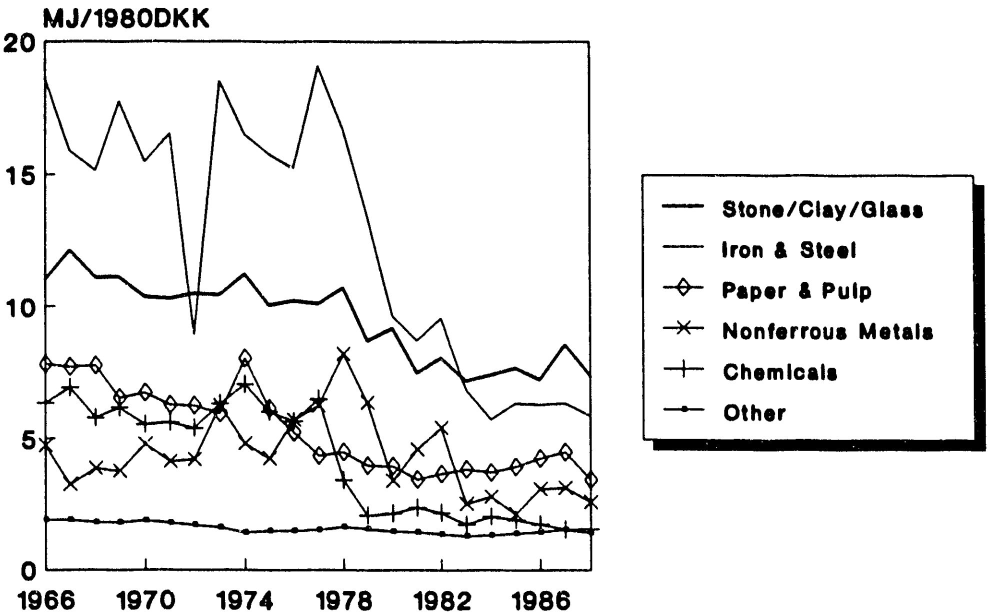

Figure 3-4

Denmark Manufacturing Energy Use
Varying Energy Intensities
1972 Output and Structure

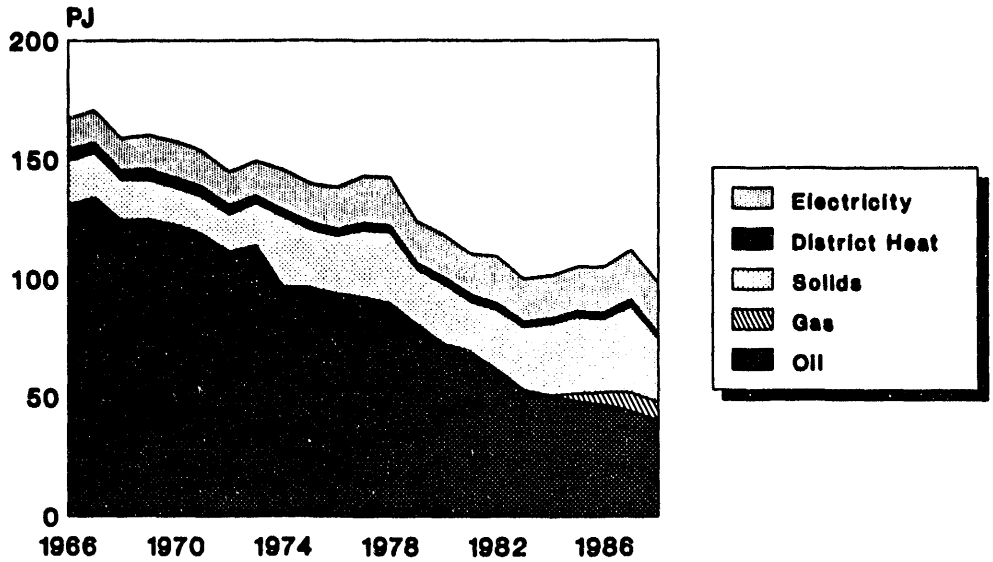

Figure 3-5

Denmark Manufacturing Final Energy Use
Activity, Structure, Intensity Effects

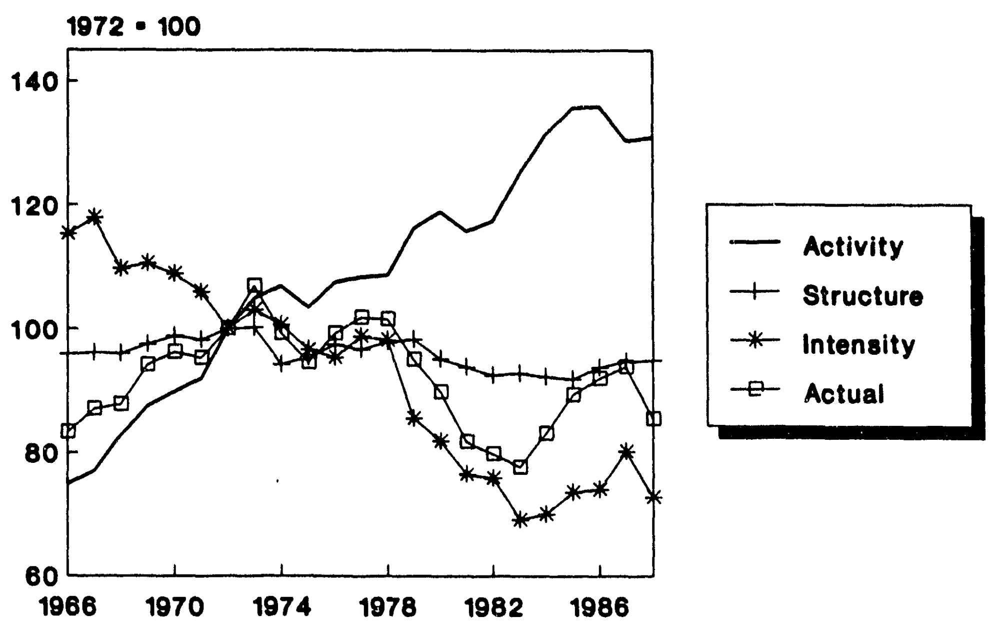

Figure 3-6

Denmark Manufacturing Electricity Use
Activity, Structure, Intensity Effects

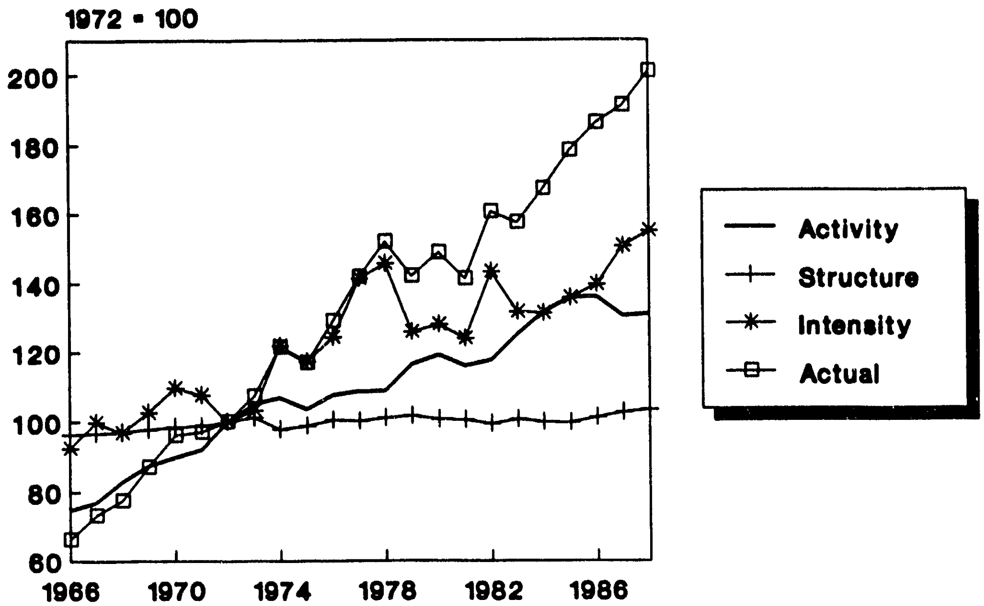

Figure 3-7

Denmark Manufacturing Primary Energy Use
Activity, Structure, Intensity Effects

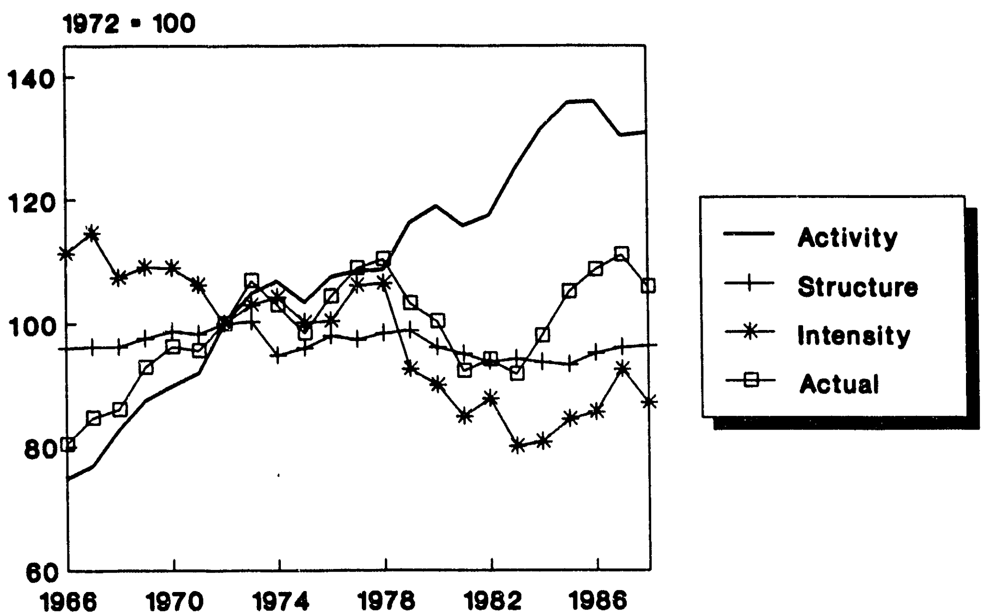

Figure 3-8

4. OTHER INDUSTRY

In addition to manufacturing, there are several industries that use significant quantities of energy: agriculture, mineral extraction, and construction. While we do not analyze these sectors in detail, we describe principal trends in each sector's production, energy use, and energy intensity. Together, these sectors accounted for 8% of Danish final energy use in 1988 (Figures 4-1 and 4-2).[1]

On the whole, energy use trends in these sectors taken as a group resemble those in manufacturing. Reduced energy intensities led to reduced energy use even while sectoral output grew substantially. But while manufacturing electricity intensity grew at a rapid rate, electricity intensity was relatively constant in non-manufacturing industries, where a large share of energy is used tractors, construction equipment, and other machinery not well suited to electrification.

4.1. Agriculture

The agricultural sector as defined in this report consists of ISIC sectors 11 through 13 and includes activities relating to forestry and fishing in addition to farming. The sector's final energy use increased from 42 PJ in 1966 to 48 PJ in 1973 (Figure 4-3). Energy use fell during most of the 1970s and early 1980s, reaching a low of 33 PJ in 1982. By 1988, the level had increased to 37 PJ. In 1973, oil accounted for 92% of sectoral energy use as compared with 8% for electricity and less than 1% for district heat. During the 1980s, interfuel substitution reduced the oil share to 70% in 1988 and increased the shares of other fuels to 4% for natural gas, 9% for solids, 5% for district heat, and 12% for electricity.

Agricultural value added showed little growth in the late 1960s and early 1970s, but grew by 63% between 1973 and 1984. In the mid-1980s, however, Danish agriculture stagnated with the national economy. While the energy intensity of the sector increased in the late 1960s, substantial reductions were realized in the 1970s and early 1980s. Between 1973 and 1984, energy intensity fell at an average rate of 7.5 %/yr. In more recent years, however, this trend was partially reversed, with an intensity increase of 13% between 1984 and 1988.

4.2. Mineral Extraction

The mineral extraction ("mining") sector consists of ISIC sector 2 excluding activities related to the extraction of crude oil and natural gas (ISIC 20099). In fact, the sector is dominated by a single facility engaged in salt extraction. Mining accounted for only 2.6 PJ of energy use in 1973 and 2.2 PJ in 1988 (Figure 4-4). The data, obtained from *Danmarks Statistik*, indicate an unexplained jump in energy use between 1973 and 1974. Sectoral value added rose by 22% between 1973 and 1988, while energy intensity fell by 31%. While oil was the dominant fuel in 1973, by 1988 final energy use was 30% oil, 62% solids, and 8% electricity.

[1] As in manufacturing, the economic and energy data discussed in this section are from *Danmarks Statistik*.

4.3. Construction

The energy use of the construction sector (ISIC 50) is somewhat difficult to ascertain. While *Energistyrelsen* reports final energy use for recent years, long-term data are available only from the *Danmarks Statistik* (DS) energy accounts, which count the use of tar and related materials as oil consumption. Based on a comparison of the two sources, we estimate that such non-energy uses account for 60% of the oil use reported by DS. To approximate long-term trends in construction energy use, we use the DS data but subtract out the estimated non-energy use of oil. The results indicate that final energy use fell from about 6.5 PJ in 1973 to 4.8 PJ in 1982, rising back to 6.6 PJ in 1988 (Figure 4-5). Oil is the major fuel used in the sector, accounting for an estimated 79% of energy use in 1988. The electricity share was 14%, while gas and solids accounted for 1% and 6% respectively. Sectoral output fell by 14% over the period, while energy intensity showed a net increase of 16%.

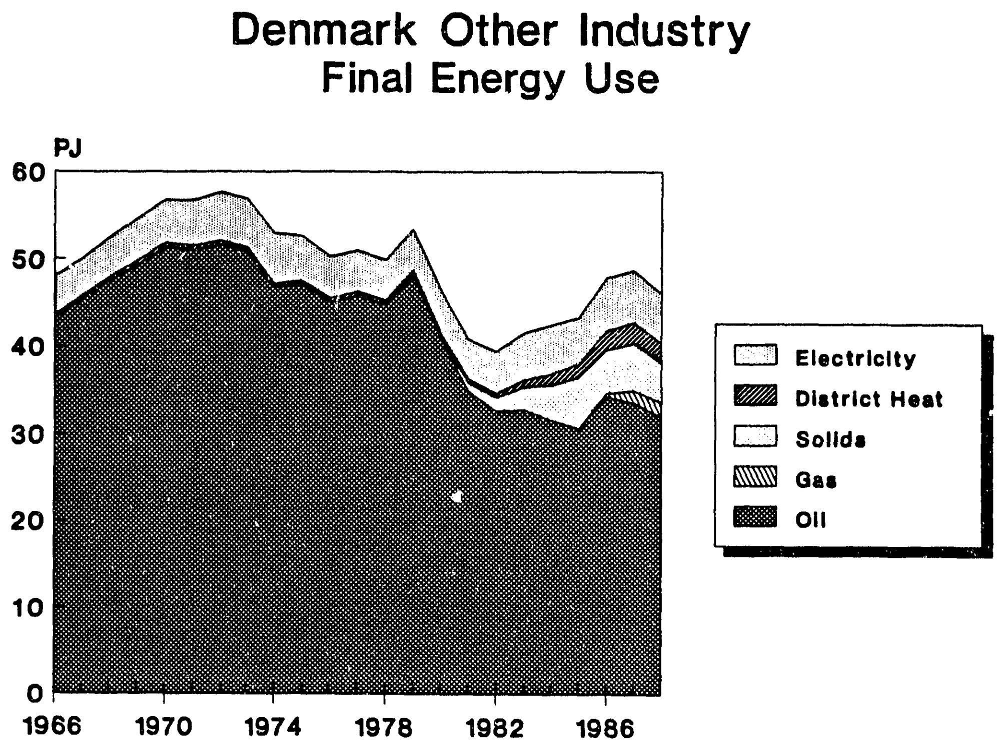

Figure 4-1

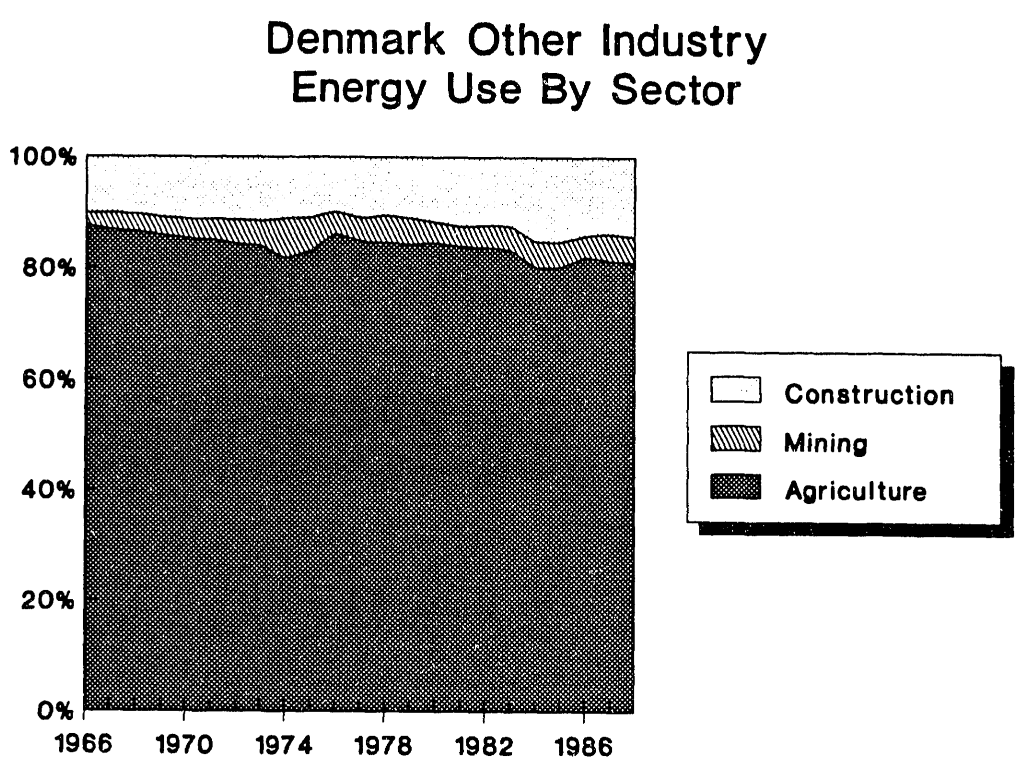

Figure 4-2

Agriculture, Forestry, and Fishing
Denmark

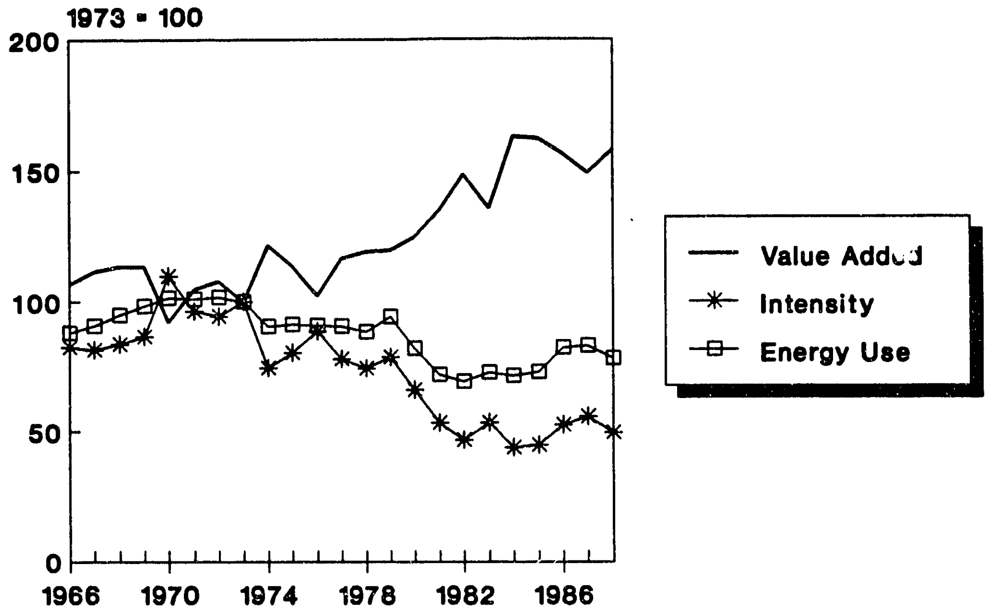

Figure 4-3

Denmark Mineral Extraction

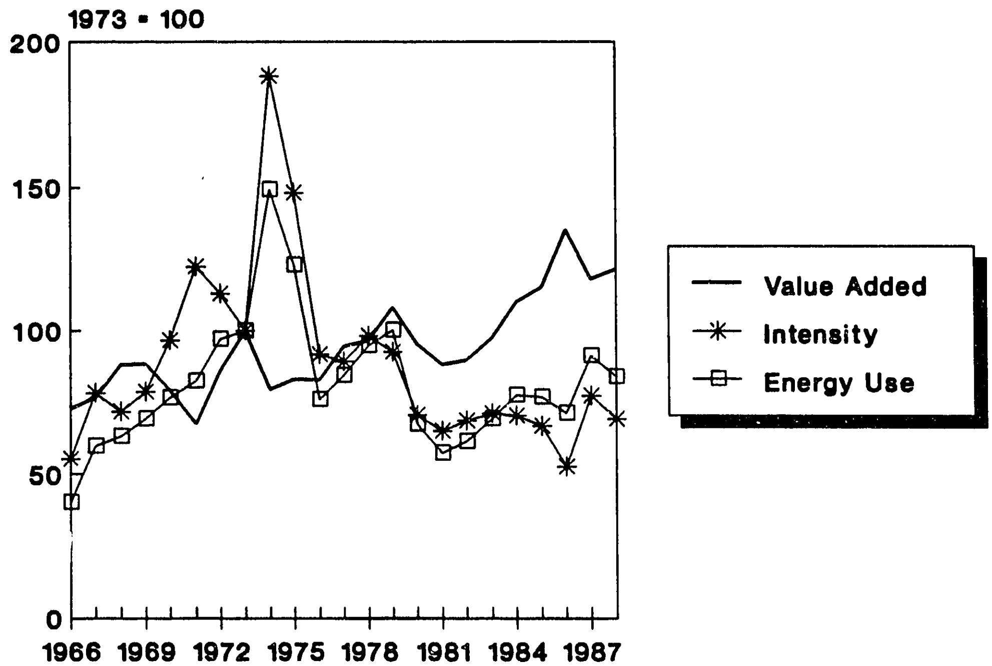

Figure 4-4

Denmark Construction

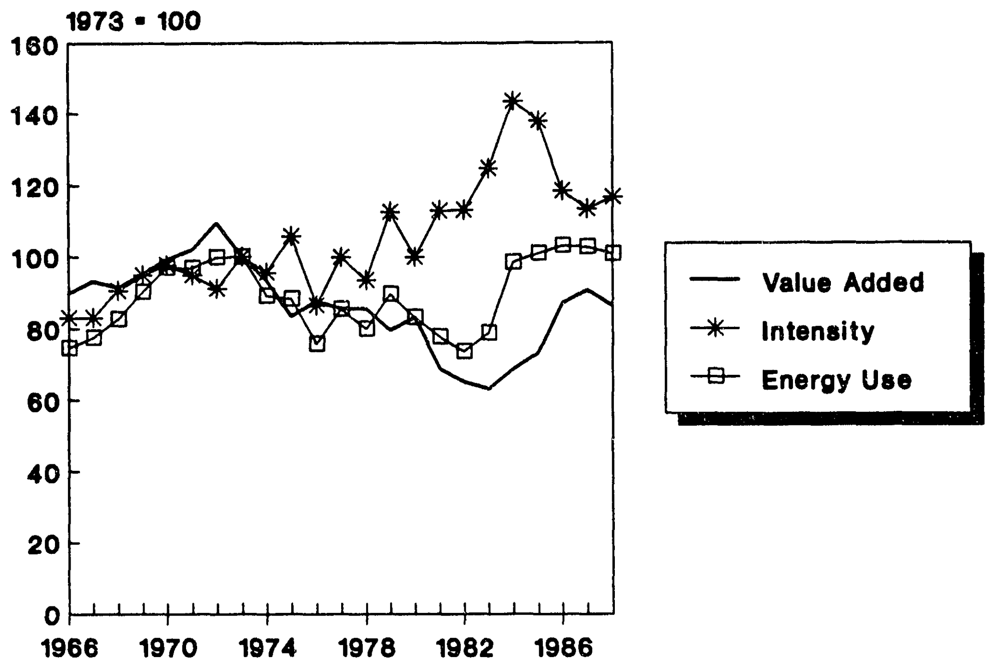

Figure 4-5

5. THE SERVICE SECTOR

The service sector (ISIC 6-9) shares characteristics with both the residential and industrial sectors in terms of its organization and energy-use patterns. As in the residential sector, service sector energy use is dominated by the provision of building services—space conditioning, hot water, lighting, and the operation of electrical equipment. As in industry, energy is used to support economic activity in an environment where managers have explicit incentives to reduce costs. This analogy should not be taken too far, however, since service sector energy use accounts for only a small share of an establishment's operating costs and decisions regarding energy use are decentralized amongst numerous individuals who have limited knowledge concerning energy options.

Data on service sector energy use are not available for years prior to 1972. In 1972, the sector used 78 PJ of energy, or 13% of total final energy use (Figure 5-1). Energy use fell in the aftermath of the energy shocks in 1973 and 1979, but the total level did not change substantially over time. In 1990, a year with only 83% of the normal number of heating degree days, final energy use stood at 69 PJ. These aggregate figures hide interesting details concerning the breakdown of energy use by type. In 1972, oil accounted for 56% of final energy use, compared with 24% for district heat, 25% for electricity, and 1% for city gas. The energy shocks led to substantial reductions in oil use, decreasing its share to under 20% in 1990. Meanwhile, the district heat share increased to 35% and natural gas came to provide as much as 10% of all energy.[1] Between 1973 and 1990 electricity grew from 13 to 26 PJ. As a result of the conversion and distribution losses associated with district heat and electricity, primary energy use grew by 16% over the period despite the reduction in final energy use.

Available data do not permit a breakdown of sectoral energy use either by economic sector or physical process. The small share of the building stock heated by electricity tells us, however, that most electricity is used for lighting, machines, motors, and other electric-specific purposes—a finding confirmed by Nielsen (1987) and Johansson and Pedersen (1988). These studies provide estimates of electricity utilization for particular end uses but lack the time-series data necessary to track historical developments.

As a result, it is impossible to look behind the aggregates to understand the structure of the sector. At an aggregate level, service sector activity may be measured either in terms of value added or floor area. All else equal, sectoral energy use tends to grow in proportion to floor area since many energy using activities—the provision of light and space heat, for example—are physically tied to building utilization. We rely on value added as our activity indicator because it captures the economic orientation of the sector. Sectoral output, measured in 1980 currency, grew by 38% between 1973 and 1988, from 47% to 53% of GDP (Figure 5-2). This growth was not constant over time, but was punctuated by periods of stagnation in 1973-1975, 1979-1981, and 1986-1988.

Final energy intensity, or energy per unit of service sector value added, fell by 43% between 1972 and 1988. This reduction was concentrated in the 1972-1983 period with no net 1983-1988 improvement.

[1] The share of service-sector floor area warmed by district heat increased from 41% to 53% between 1977 and 1989 (*Danmarks Statistik, BBR*), while the share heated by oil dropped from 56% to 35%. These changes were a major reason for the changes that occurred in the shares of energy use attributed to each energy carrier.

Thermal energy per unit of value added fell by 56%, while electricity intensity increased by 31%. Thus primary energy intensity, which accounts for the losses associated with the production and distribution of district heat and electricity, showed a net 23% reduction between 1973 and 1988 (Figure 5-3).

Denmark Service Sector
Final Energy Use

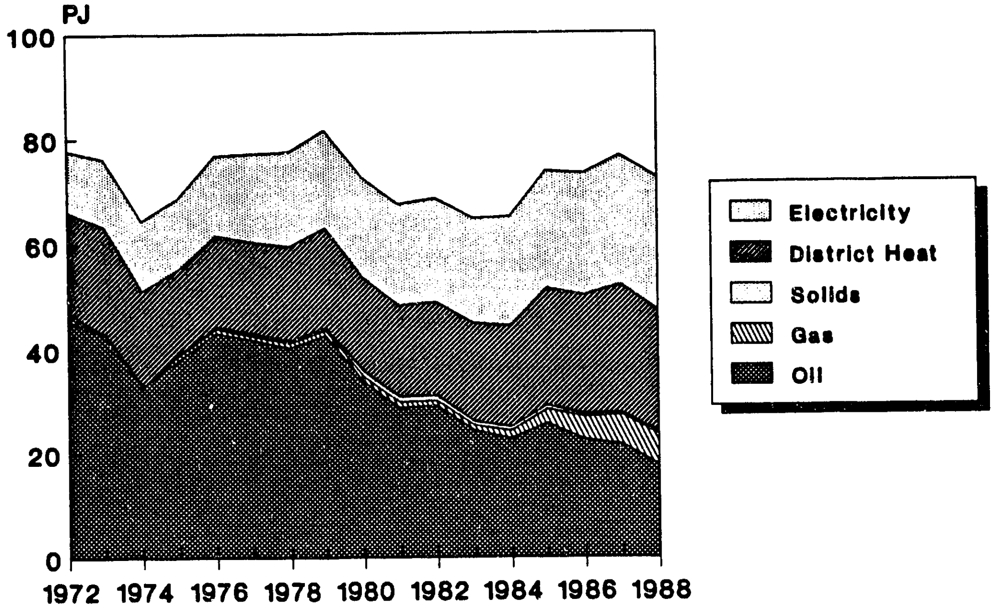

Figure 5-1

Denmark Service Sector Final Energy Use
Value Added and Energy Intensity

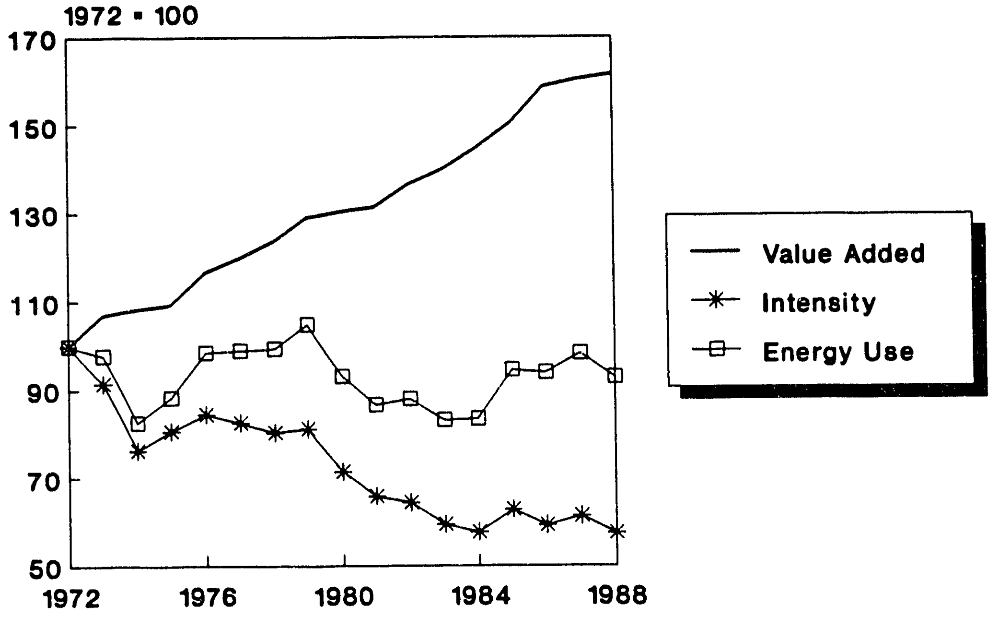

Figure 5-2

6. PASSENGER TRANSPORTATION[1]

This section examines energy use for passenger transport, or travel. Environmental concerns have focused increasingly on this sector, the growth of which has been important to the rise in air pollution. Having grown rapidly with increased mobility and automobile use in the 1960s, energy use for travel comprised 12% of final energy use in 1972. By 1979 this share was still at 12%, but it grew to 15% by 1988 as the level of travel grew and energy use in other sectors contracted. Most studies indicate that energy use in this sector will continue to grow. Hence a clear understanding of the underlying forces in this sector is important if policies to restrain growth in this sector are to be effective.

6.1. Activity and Structure

Total travel grew rapidly in Denmark, from around 12 billion passenger-km in 1950 to over 50 billion passenger-km in 1972. Fueling this increase was rising GDP, but travel grew more rapidly than GDP: The ratio of travel to GDP nearly doubled during that period. Thereafter travel grew more slowly, and the ratio of travel to GDP fell slowly to 85% of its 1970 value.

Figure 6-1 illustrates trends in per capita travel by mode. In 1950, Danes stayed at home—or on the farm—as they each moved only 2700 passenger-km by motorized means (and perhaps 500-1000 km/year walking and cycling). By 1972, mobility had increased by a factor of 3.5, to 10,040 passenger-km/capita. This rapid rise was slowed significantly by the two oil price shocks and the associated periods of recession. Mobility in 1978 was slightly higher (10 700 passenger-km/capita), but the following year began a significant decline in travel that hit bottom in 1982, driven down by high fuel prices and recession. Thereafter, Danes started to move again, as fuel prices fell and the economy picked up: By 1990, Danes were moving 12,500 passenger-km each year in domestic travel, and possibly as much as 1000 passenger-km in foreign travel as well (*Trafikministeriet* 1990a).[2]

Long-term changes in mobility in Denmark, as well as short-term fluctuations, have been driven by similar changes in the role of automobiles, as Figure 6-2 shows clearly. In 1950, Danes had very few private vehicles, about 40 per 1000 people. High taxes and other factors prevented large-scale imports of vehicles. By 1972, however, there were 256 cars (including taxis and light trucks) per 1000 Danes. Given the high traffic volume—each car was driven about 16,500 km—in total, cars delivered about 7500 passenger-km per capita, or 82% of all travel in 1972.

Automobile travel and ownership were struck hard by high fuel prices and recession. Per capita ownership fell in the early 1980s, and appears to have stagnated after 1988. New car sales fell (and bicycles grew in popularity!). Ministry of Transport figures show a decline in traffic through 1975, a brief recovery, then a sharp decline from 1979 to 1983 as both the number of cars and the utilization of each car fell. Since the number of people per car appears to have declined over the long run as well (see Appendix B), all these factors together led to a drop in per capita auto traffic from 1978 to 1983, and an

[1] In this report, "car" refers to automobiles and light trucks (*varebiler*) with under two tonnes capacity.

[2] Appendix B gives details concerning our derivations of these data. We use different assumptions than do Danish authorities about the use of automobiles, which leads to significantly different figures for total automobile travel. These assumptions have an important impact on our conclusions.

even deeper cut in per capita *travel* by car, from 8250 passenger-km in 1972 to only 7400 passenger-km in 1982. After this low point, however, auto traffic (vehicle-km) and auto travel (passenger-km) increased steadily. Automobile travel surpassed its 1978 peak in 1987 and has continued to rise since then as well.

The average weight of a Danish car increased by only 5% between 1972 and 1989, according to data on the numbers of cars in different weight classes. This slow change is due in part to the fact that Danish cars are taxed very heavily on the basis of value and to a lesser extent on weight as well. These taxes, which can increase the ultimate price of a car by nearly 200% over its base price, force Danes to buy small cars and keep them for long periods of time. Similarly, the high cost of obtaining a car means that those cars in the stock are used heavily. As we will see from the international comparison, travel in Denmark is characterized by an unusual role for automobile use.

While the automobile dominates travel, changes in travel by other modes were slow but important, as Figure 6-1 shows. Bus travel, which accounted for 30% of total travel in 1950, peaked in 1965, fell back, then grew in the 1970 and 1980s. Rising from 10% of travel in 1972, the share of buses increased slowly in the 1970s, jumped after the 1979 oil price increases and subsequent recession, and peaked at nearly 16% of travel in 1986, thenceforth declining by to only 15% in 1990 as automobile travel increased. Similarly, rail, which held 28% of the travel market in 1950, also peaked in 1965, fell back considerably in the early 1970s, then grew again in the 1980s, surging after the auto fuel prices increases and recession of the early 1980s. However, traffic stagnated in the mid 1980s, and the market share of rail fell steadily after peaking again in 1982s. Significantly, the combined share of bus and rail in total travel, 16% in 1972, increased steadily through 1982 to 24%, then fell back slowly, but still lay above its 1972 value in 1990. Total per capita travel in rail and bus has increased or remained constant during most of the 1980s; the rise and fall of the use of cars with both fuel prices and economic fortunes played the key role in swings in total travel, and thereby the shares of both rail and bus travel.

Two other modes of travel account for the remaining small share of total domestic travel. Ship travel, mostly by ferries, provides about 1% of total travel, but has been declining. Air travel by scheduled carrier accounts for about the same share, but its importance has been rising slowly. International air travel through Kastrup, the airport in Copenhagen, is far more important than domestic air travel. Accounting for more than 10 times the fuel consumption of domestic travel, it is likely that international air travel for Danes is 10 times the level of their domestic travel.[3] Although these modes of domestic travel are not important to total mobility in Denmark, they are important energy users because they are energy-intensive, as we will see below.

As can be surmised from the preceding discussion, the overall rise in travel since the mid 1980s has been driven principally by automobiles. One reason is the rise in consumer incomes. Another is the rise in the number of families with two wage earners, a situation that usually forces one member to use a car to get to work. But work trips are only part of the story. Equally important has been the increase in free-

[3] If half of all departing passengers from Kastrup were Danes and they travelled on average as far as the fuel loading would permit, then returned on planes fueled in other countries, then their total travel would be in proportion to the fuel used in Denmark for international travel.

time activities. The 1986 *Trafikundersøgelsen* (*Trafikministeriet* 1988) shows that while the pattern of driving in weekdays is strongly influenced by work trips, a high share of which are taken on public transport, weekend travel is dominated by family business and free time, and dominated by use of cars. Not surprisingly, by the late 1980s, cars were increasing their share of travel again.

It is possible to explain some of the shifts in modes by comparing the cost of fuel for cars with the cost of using buses or trains. In 1982, when the share of bus and rail had risen for three years, rail and bus travel costs had risen 72% and 30%, respectively, over their 1975 levels, while gasoline costs had risen by 160%. By 1988, the reverse had occurred: the price of gasoline had risen by only 39% compared to 1980, while the price of riding the bus increased by 125% and rail by 90% (*Danmarks Statistik* 1985, 1991). These relative price changes, combined with the recession of the early 1980s, certainly explain part of the shift towards mass transit in the early 1980s and the shift back to cars.

The decline in the number of people per car, or load factor, has slowed the trend towards rising car travel. Lund (1975) estimated there were between 2.00 and 2.05 people in a car on average in 1973 (the load factor). Our own analysis of cross-tabulations from the 1981 *Trafikundersøgelsen* (*Trafikministeriet* 1983), shows that the ratio of passenger-km travelled by drivers *and* passengers (including children under 16 years) to that travelled only by drivers lay around 1.84. A similar analysis applied to data from the 1986 Survey (*Trafikministeriet 1988*) suggests this factor fell to 1.74 by 1986.[4] One reason for the decline is the increased number of trips to work where the driver is alone. Others include the fall in household size (fewer family members) and the slow increase in the number of second cars in a household. The decline in load factor is significant, because it implies that traffic is increasing more rapidly than travel.

The 1987 analysis of how Danes use time (Andersen 1988) and the companion analysis of time studies going back to 1964 (Viby-Mogensen, 1990) indicate that total time spent in travel has risen from under 25 minutes per day in 1964 to as much as one hour in 1987. Time spent for leisure travel (and to or from services) lies above that for travel to or from work, indicating the importance of leisure travel. Consumption surveys (Brodersen, in Viby-Mogensen 1990) show a steady increase in the share of private expenditures (excluding housing) for transportation, rising from 7% in 1955 to 19% in 1976. While the share fell to 16% in the recession year of 1981, it returned to 19% in 1987. Not surprisingly, expenditures for public transportation fell through 1966 as more Danes took to private cars. These expenditures then began to increase in the late 1960s, presumably as more Danes flew. As a share of all transport expenditures, expenditures for public transport fell through 1971, then rose in the recession year of 1981, then fell back. Both measures of time use and measures of consumption expenditures mirror the rise in travel, the shift in shares, the drop in 1981, and the second rise in the late 1980s. By all measures, Danes are on the move again!

[4] The 1981 value that we derived from 1981 *Trafikundersøgelsen* (see Appendix B) agrees with the value suggested by a report from *Vejdirektoratet* (*Vejdirektoratet*, 1981). We estimated the contribution from children based on the study by *Vejdirektorat* as well. For 1986, we assumed a slightly smaller number of children per car, consistent with the decline in family size. For all years we have also averaged in light trucks, whose load factor is assumed to be 1.4.

6.2. Energy Use and Intensities

Total energy use for travel lay at 73 PJ in 1972 and rose to 78 PJ in 1978. After the second oil shock consumption fell rapidly, hitting a low of under 70 PJ in 1981, but then it has risen ever since (Figure 6-3). Oil dominates energy use for travel, although electricity accounts for a small share of delivered energy use (it provided 15% of the delivered energy for passenger rail travel) in 1988. Automobiles dominate travel, so their gasoline is the dominant fuel for travel, although the number of diesel cars rose markedly in the 1980s to nearly 5% of the vehicle stock. By contrast, the number of cars using clean-burning LPG has fallen to under 10,000, well under 1% of the vehicle stock.

Total energy use followed travel patterns closely. Figure 6-4 shows the modal intensities (i.e., energy per passenger-km) of the main travel modes. Only air travel showed a significant improvement, a drop of 38% in energy intensity, between 1972 and 1988. Automobile vehicle intensity fell (i.e., MJ/vehicle-km) by over 15% but modal intensity (MJ/passenger-km) in 1988 was only slightly lower than it was in 1972. The decline in the load factor offset most of the energy savings offered by smaller, more efficient automobiles. Intensity for rail was also lower in 1988 than in 1972, even if we count electricity in units of primary energy equivalent. In 1988, the aggregate travel energy intensity in Denmark lay 2% lower than it did in 1972. In other words, it took nearly as much energy to move a Dane a kilometer in 1988 by motorized means as it did in 1972.[5] Clearly there was little major saving of energy for motorized travel in Denmark.

The vehicle intensity of the Danish car fleet fell significantly between 1972 and 1988, by nearly 1% per year (Figure 6-4). Much of the decline occurred after 1980. The vehicle intensity of new cars decreased as well, by approximately 25%. (These new-car figures are derived from tests, which rarely match on-road figures, but the tests generally indicate what will happen to on-road fuel economy of new cars. See Viby-Petersen, 1991.) When the effect of the falling fuel intensity of these new cars is averaged into the stock, the stock shows clear improvement above and beyond any uncertainties in the data for both fuel consumed and distance driven. The international trend towards more efficient vehicle technology more than compensated for the increase in weight and power in Danish cars. Clearly high taxes, particular those pegged to the prices of cars, have limited the increases in power and weight.

6.3. Summary of Evolution of Energy Use

We can estimate the relative importance of the growth in travel activity (passenger-km), shifts in the structure of travel (i.e., the modal mix), and the energy intensities of individual modes in changing energy use for travel in Denmark (Figure 6-5). The rise in travel activity alone caused a 22% increase in energy use between 1972 and 1990, following a 400% rise between 1950 and 1972. Shifts in the mix of modes, which boosted travel-related energy use by some 33% between 1950 and 1972, led to a slight decline of 5% in travel energy use by 1988. Changes in the energy intensities of individual modes led to a decrease in travel-related energy use of 3% between 1972 and 1988, with most of the gain coming after 1985, the

[5] Given signs that traffic by motorcycles, bicycles, and walking may have increased substantially during the 1970s and 1980s, the reduction in energy use per passenger-km may be greater than what which is presented here. Walking and bicycles may account for as much as one third of all trips and 10% of total distance travelled (*Trafikministeriet* 1990a.)

year of the peak automobile modal intensity.[6] If automobile load factors had not declined, changing modal intensities would have *reduced* travel-related energy use by some 18%, and the aggregate energy intensity of Danish travel would have declined by nearly 15%. Although the use of trains and buses rose somewhat during the 1970s and 1980s, we can say that while travel-related technology permitted energy savings in Denmark, changes in travel behavior more than offset those savings. And the impact of modal shifts on energy use was roughly the same size as the impact of lower energy intensities of each mode! This result challenges energy and environmental planners in Denmark who foresee significant reductions in future energy use accompanying increases in travel (*COWIconsult* 1990a).

What explains the apparent behavior of the components of travel-related energy use in Denmark? Fuel prices in Denmark increased; the real price of motor gasoline was more than 30% higher in 1988 than in 1972, and autodiesel (including taxes) was about 20% higher. Thereafter real prices fell somewhat, in part to discourage Danes in *Sønderjylland* from buying fuel in Germany. The fall in fuel intensity of gasoline cars almost offset the increase in fuel prices, so that it cost only 5% more to pay for fuel for one kilometer in 1989 than it did in 1972.

Given the cost of travel in Denmark, it may seem surprising that load factors in cars dropped. The reasons, however, are clear, as we noted above: smaller families, particularly one person driver households and more two-worker families. Offsetting this trend somewhat has been increased driving for pleasure, when the entire family tends to be in the car. And it is clear that when real fuel prices were at their highest level in the early 1980s, Danes drove considerably less. Gradually, however, they appear to have adjusted to this level of prices, as their cars became less fuel-intensive, and their driving returned to its historical higher level.

The change in the energy intensities of other modes are relatively straightforward to understand. The energy intensities of rail and bus travel are much lower than that of car travel, so changes in fuel prices are less important to these modes. But the rise and fall of travel in these modes affects load factors. Since the energy use per vehicle is almost independent of its load, a rise in the number of passengers per vehicle reduces the energy use per passenger. Air travel is different. Fuel prices are a large part of the costs of running airlines. Hence, improvements in this sector were large, driven principally by worldwide improvements in the fleets of airliners (Schipper and Meyers et al. 1992). In fact, the ratio of passenger-km to vehicle-km in domestic flights in Denmark fell somewhat, which would have increased energy intensity, had the fleet of aircraft not improved as it did.

6.4. Implications

We found that little energy was saved for travel in Denmark between 1972 and 1988, despite improvements in vehicle efficiencies of cars and aircraft. We also noted that travel continues to increase in Denmark, although its evolution is marked by changes in fuel prices and costs of travelling by other modes, as well as by economic swings. Yet given the high level of taxation of both vehicles and travel, it is not clear what might be done to restrain either travel or energy use.

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[6] The data do not permit a meaningful evaluation of intensities in the period before 1972 or after 1988.

Certainly, there are technical means for lowering automobile energy use. As Viby-Petersen (1991) points out, there are already automobiles available on the world and Danish market whose use would lower average fuel use per km. Viby-Petersen and other Danish sources (such as the Ministries of Finance and Taxes) seem to propose changes in the taxation of new cars to favor acquisition of light-weight, safe, fuel efficient cars. Equally important are changes in the variable cost of driving to discourage some uses: City tolls, higher parking fees, pay-as-you-go insurance, and even higher fuel prices all have this effect. We noted that the relation between fuel prices and the cost of using the bus or the train had a notable influence on the choice between cars and alternative modes of travel. If mass transport is to play a key role in the future travel plans of Danes, however, considerable economic pressure (or other policy instruments) must be raised against auto travel and for other modes. Recent discussion of city tolls in Copenhagen, as well as the new parking costs, may have to be part of the package that reduces the incentive to use cars. Improving the efficiency of rail and bus transport appears to depend as much on technology (better, perhaps smaller vehicles) as on increasing the load factors on these vehicles.

Data provided by *HT*, the Greater Copenhagen Transport Authority (Vexoe 1992), illustrate well the trends in public transportation visible in the aggregate national data. The average number of passengers per bus in the *HT* region was only 17.6, down slightly from 19.3 in 1986. Significantly, total travel by bus fell in 1989 and 1990 from its level of almost 1.6 billion passenger-km in 1985-1988. These rough figures indicate falling travel by bus and declining load factors as well. Overall, the total number of trips in *HT* (bus, *S-tog* [commuter train], and a combination) dropped from over 300 million per year in the early 1980s to 238 million in 1989 and 1990. *HT* figures also indicate a slight increase in the modal intensity of their buses. While other buses, particularly for schools and tourism, may have higher load factors and continue to provide important services, the trend away from collective travel is ominous if restraining energy use for travel is important to an environmental strategy.

Per Capita Travel in Denmark
1950-1990

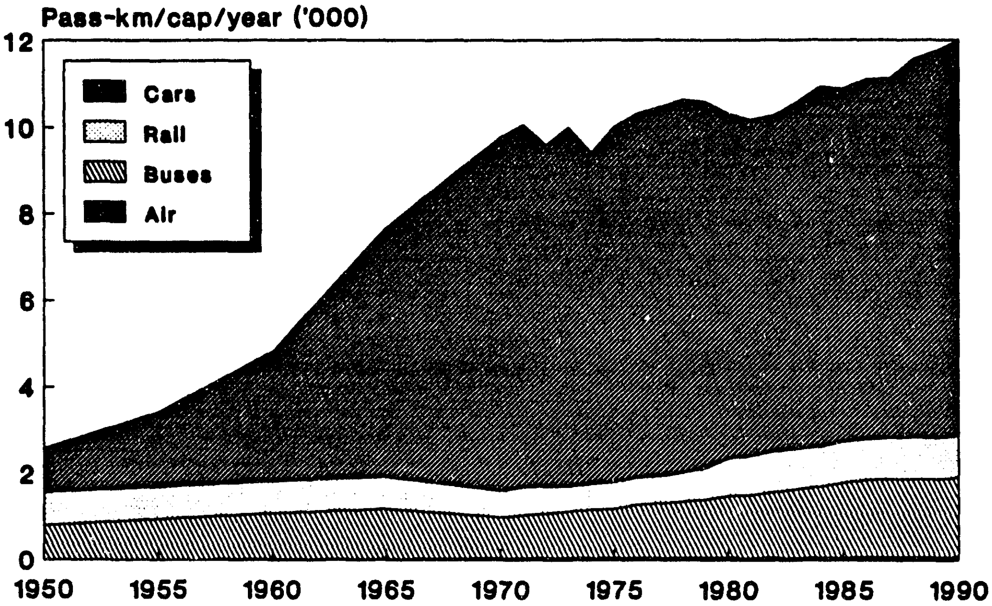


Figure 6-1

Danish Car Ownership and Total Travel

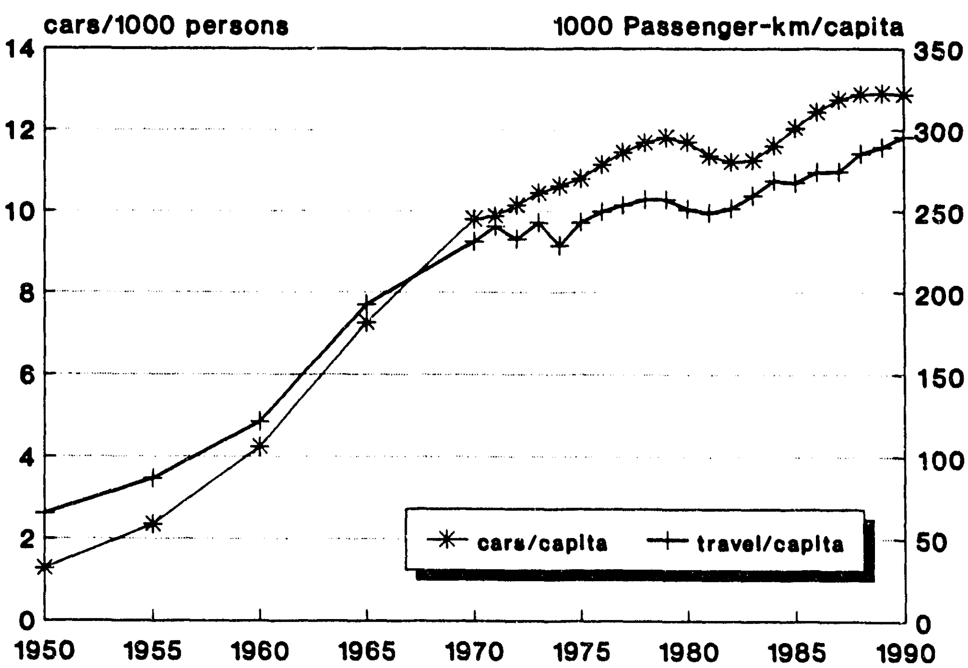


Figure 6-2

Denmark Transport Energy Use, by Mode

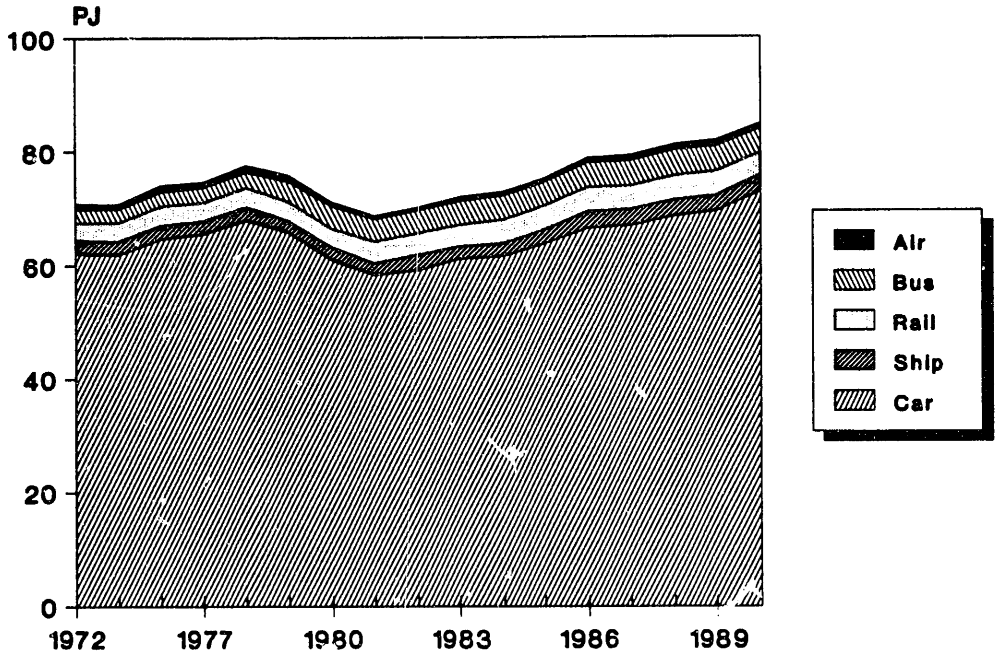


Figure 6-3

Danish Travel Energy Intensities

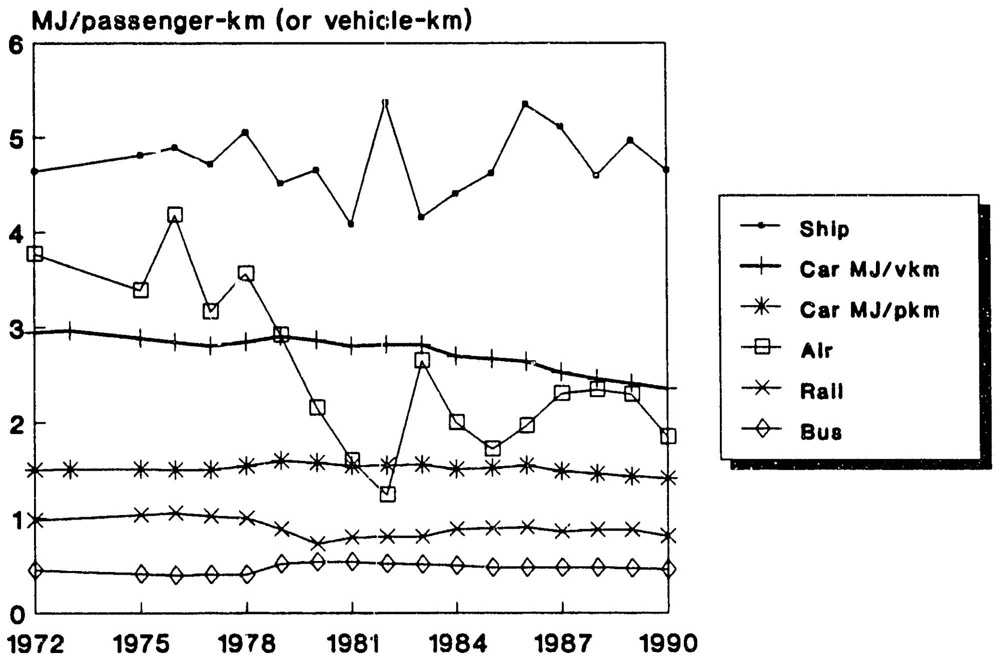


Figure 6-4

Danish Travel Energy Use
Activity, Structure, Intensity Effects

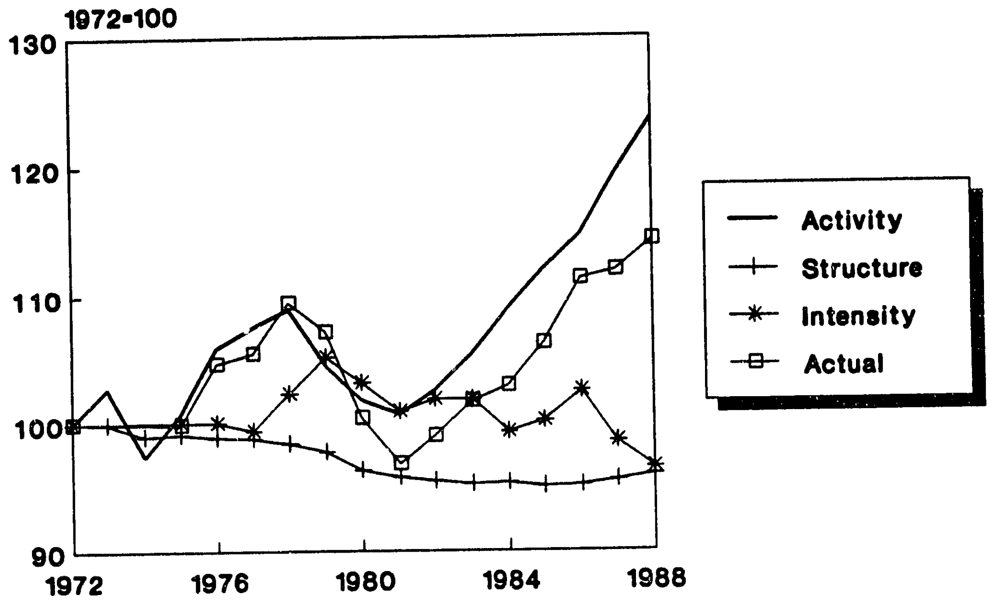


Figure 6-5

7. THE FREIGHT SECTOR[1]

Domestic freight in Denmark has closely tracked trends in the economy as a whole. Because freight volumes in the 1980s grew slightly more rapidly than did travel, energy use for freight, while still less than that for travel, has become progressively more important.[2] This is significant, because much of the discussion about energy use or emissions from the transportation sector in Denmark (and elsewhere) focuses on the automobile. As we shall see, the energy intensities of truck freight in Denmark performed poorly, particularly when compared with those for automobiles. This development is well illustrated by Figure 7-1, which shows trends in domestic travel and freight activity relative to GDP. And this discussion omits international freight, which may make up 5 times more volume in tonne-km that domestic freight. Thus the freight sector, which is often neglected in energy studies, represents an important and growing use of energy.

Figure 7-2 shows the development of domestic freight in Denmark by mode. The level of domestic freight grew rapidly after World War II, rising from only 4.5 billion tonne-km in 1950 to 10.5 billion tonne-km in 1972 (Knudsen 1975).[3] Thereafter the level swung with the fortunes of the economy, peaking in 1979, falling by almost 20% to a low level of 11.0 billion tonne-km in 1982, then recovering steadily to 15.7 billion tonne-km by 1990. (Excluding pipelines, which accounted for half of the growth between 1983 and 1990, the value in 1990 was 13.8 billion tonne-km.) The ratio of domestic freight to GDP increased from 0.26 x 10^3 tonne-km/1980DKK in 1950 to 0.33 x 10^3 tonne-km/1980DKK in 1972, then edged up to 0.36 during the 1976-1979 period. In the 1980s, this ratio fell to as low as 0.30 x 10^3 tonne-km/1980DKK in 1982, recovering only to 0.31 x 10^3 tonne-km/1980DKK by 1990. This behavior, first a rise in the GDP intensity of freight, then a slow decline, is found in many countries. Were we to include all overseas freight, it is likely that this ratio would show much slower growth, since Denmark was already an important trading country in 1950. In other words, the trends we are studying reflect principally the development of the domestic economy, particularly the enormous increase in the shipment of goods by truck over short distances.[4]

The modal shift in the composition of freight reflects this change, too. Whereas rail provided almost 50% of all goods movements in 1950, that share fell to only 18% in 1972. The same fate awaited shipping, whose role fell from 1950 through 1972, settling on about the same share as rail by then. At the same time, truck freight increased in volume more than six-fold, increasing its share to around 75% of freight in 1978. This share dropped to around 70% of shipments for the period after 1983. Domestic Danish freight became almost totally dominated by road traffic. International freight, by contrast, is led

[1] In this report, "truck" refers to both small and medium-sized trucks (*varebiler* above two tonnes) and all heavy trucks (*lastbiler*).

[2] If we exclude the contribution of pipeline activity to total freight volume, total travel grows more than total freight. However, energy intensity for aggregate freight in 1988 was higher than in 1972, so the share of freight-related energy in total energy for transportation increased.

[3] Truck freight through 1979 was adjusted (*Trafikministeriet* 1990a) to reflect a new method of accounting introduced in 1979, in accordance with a Ministry of Public Works internal memo of January 1984. Using this memo and figures from the Ministry of Traffic (*Trafikministeriet* 1990a), we obtained a consistent series 1970-1988.

[3] With pipelines, this ratio stabilized at 0.34.

[4] These figures include transit rail freight, which made up less than 3% of the total by 1990.

by shipping (*Trafikministeriet* 1990a).

Pipeline shipments of oil and gas, excluded from these figures, were first recorded in 1984 and actually reached over 10% of total freight including pipelines by 1990. This is important since natural gas substitutes for domestic or imported oil in boilers, and provides an important export as well. Some of the freight activity representing shipments of oil is recorded in our domestic freight, as is the energy used for this freight. Unfortunately, no figures for the energy requirements for utilization of pipelines are available, so we must exclude these from our energy analysis. This means that we have underestimated somewhat energy use for domestic freight in Denmark.

What is driving the shift to trucks? Two factors lay behind this shift. First, data from the Ministry of Transport[5] indicate that increasing numbers of goods are shipped over shorter distances, for which trucks are ideally suited. Second, the same data also indicate that trucks have been operating at progressively lower load factors, with more empty backhauls (Sørensen 1991). Third, less bulk and more bytes, i.e., high value-added articles, are being shipped in most domestic economies (Grübler and Nakićenović 1990). These smaller shipments also favor trucks. This high value puts an increased premium on time, which means that more trucks, particularly smaller trucks for rapid local collection and distribution of goods, are used. As a result, trucks carry more and more freight, in smaller vehicles, every year, a shift that is clear from the Ministry data.

Total energy use for freight is poorly known because of uncertainties over trucking, as we note in Appendix B. Nevertheless, Figure 7-3 gives a fair representation of the distribution of total energy use for freight by mode. The domination by trucks is clear. All of the energy is provided by oil products, electricity being assigned to electric passenger trains and transit.

The energy intensities of Danish freight modes vary in puzzling ways that reflect both real changes in freight conditions as well as wide uncertainties in data (Figure 7-4). The intensity of rail freight fell during the period 1972-1988. But during the early 1980s, when the volume of freight fell by 20%, intensity increased, as trains were underutilized. The intensity of domestic shipping, on the other hand, fell through 1981 but rose in the mid to late 1980s, although a net improvement occurred between 1972 and 1988.

The energy intensity of trucks increased substantially, beyond attribution to the uncertainties implicit in the data. Truck energy intensity was around 3.93 MJ/tonne-km in 1972, above average by international standards, and then climbed steadily to a peak of 5.3 MJ/tonne-km in 1984 before falling to around 4.5 by 1988. At first it is tempting to reject this finding, yet it is consistent with other data (Sørensen 1990; Sommer 1992) showing both a fall in the load factor of trucks as well as a decided shift towards smaller trucks. Quite simply, total vehicle-km for trucks increased considerably faster then the total tonne-km shipped, raising energy proportionately. As a result of all of these changes, the energy required to ship one tonne of freight in Denmark rose steadily after 1979.

[5] The data base was made available to this project by Sørensen (1991). The Ministry publishes many of these figures in *Transportstatistik*, a yearly handbook (*Trafikministeriet* 1990b).

Our analysis permits us to separate the components of changes in energy use for freight, excluding pipelines. Figure 7-5 summarizes the findings. Increased shipments alone increased energy use by 28% between 1972 and 1988 given constant sectoral structure and energy intensities. Note, too, that the overall volume of freight experienced wide swings, driven by cyclical changes in the economy as a whole.

Shifts among modes, principally towards trucks, boosted energy use for freight by 10% between 1972 and 1988. (By contrast, the increase from the same effect in the period between 1950 and 1972 was close to 20%.) Changes in modal energy intensities alone raised freight energy use in Denmark by almost 12% between 1972 and 1988. Almost all of this change was caused by the changes in the energy intensity of trucks that took place after 1978. All in all, 28% more energy was required to move freight in 1988 than in 1972. Hence in Denmark there was no energy saved in freight; the slight decrease in volume (excluding pipelines) was offset by an increased, though small, shift towards trucks. While these results are open to some question because of data problems, independent study of the structure of truck use confirms the shift to smaller trucks and decline in truck loadings as likely causes of the increase in energy intensity for this important mode. And it is clear that changes in all three components—activity, structure, and intensity—drove energy use upward.

The rising importance of fuel consumption for freight, particularly in trucks, challenges policies that aim to restrain both energy use and resultant emissions. While there are many proposals and designs for great improvements in the engines and emissions of all sizes of trucks (Schipper and Meyers et al. 1992), there is little encouraging evidence that such improvements are being realized. Certainly the energy efficiency of individual vehicles has improved over the past two decades. But changes in how freight vehicles have been used caused changes in energy use that more than offset the savings available. Unfortunately, this trend is found in many if not most industrialized countries (see Chapter 9). The continual shift of freight to smaller trucks and the shrinking of loads really represents a tradeoff of energy for time. The growth in fuel use for trucks is due in large part to rapid growth in the importance of smaller trucks (*varebiler*) of between two and six tonnes capacity, whose diesel and gasoline use cannot be distinguished from the fuel use of heavy trucks for the entire time period.

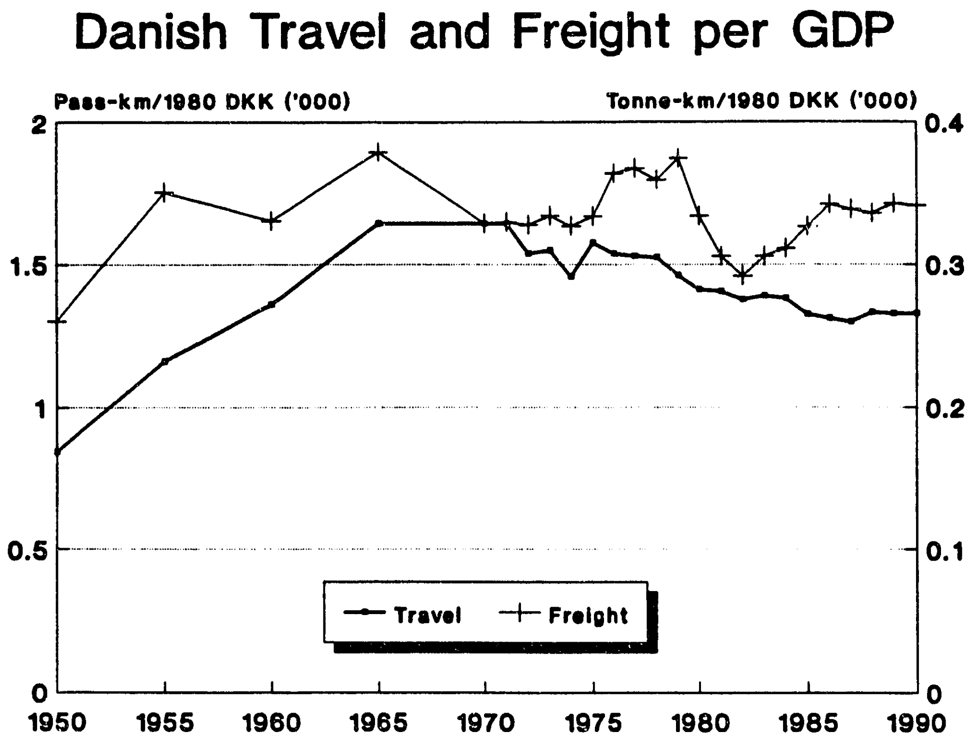


Figure 7-1

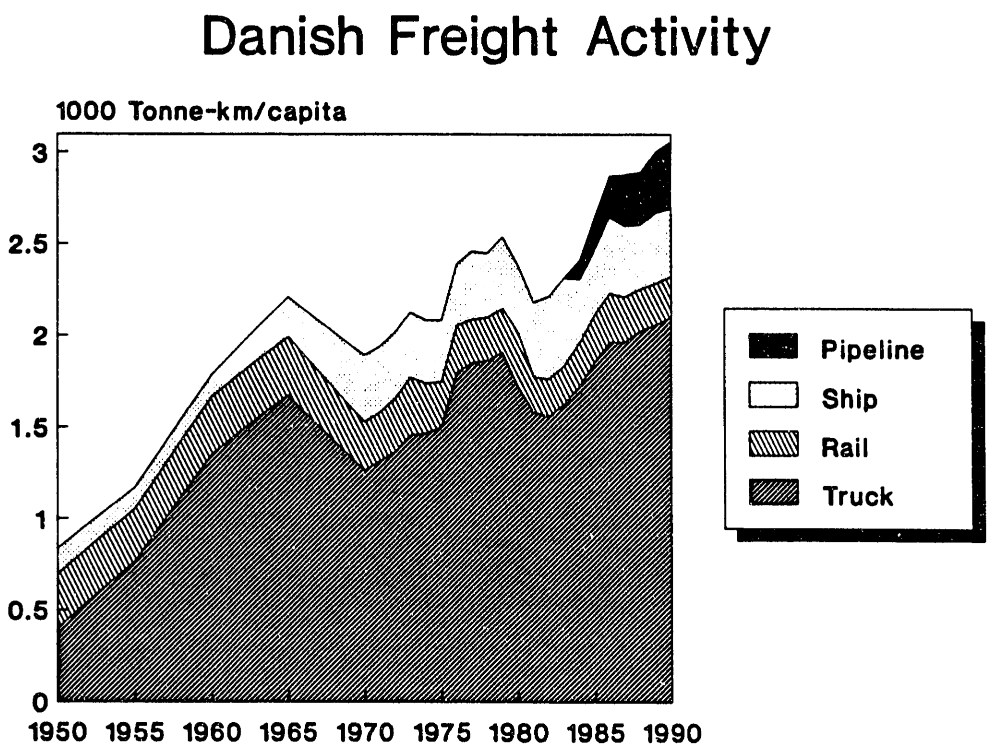


Figure 7-2

Energy Use for Freight in Denmark

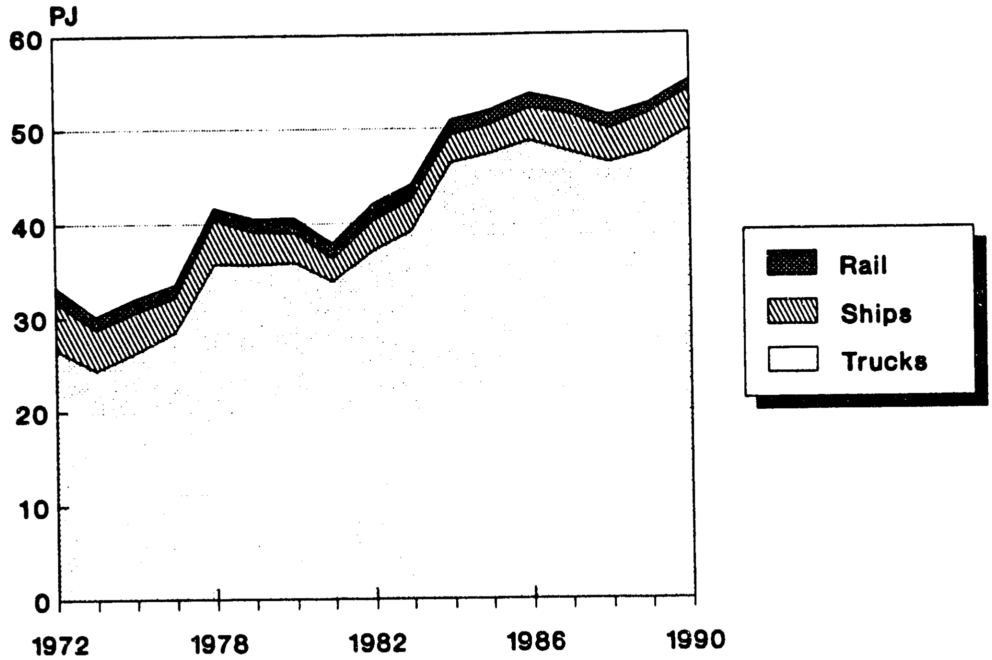


Figure 7-3

Danish Freight Energy Intensities

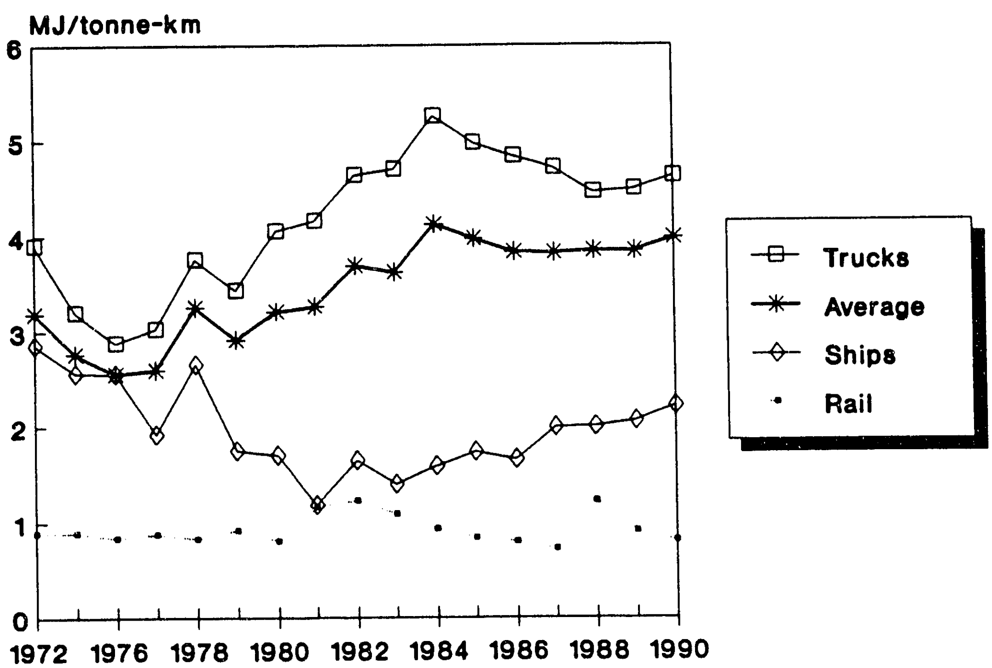


Figure 7-4

Energy Use for Freight in Denmark
Activity, Structure, Intensity Effects

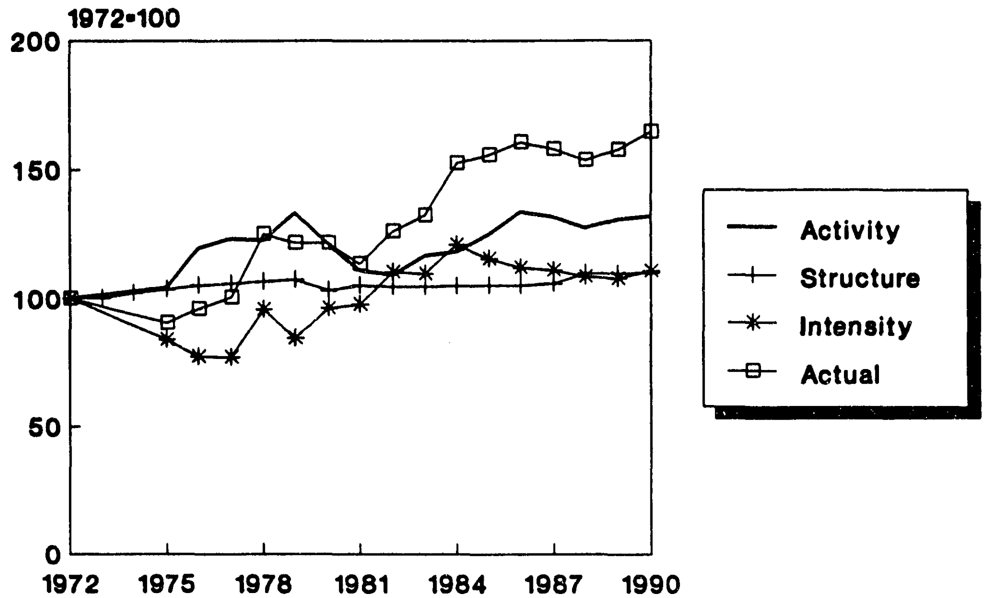


Figure 7-5

8. SUMMARY: INTEGRATING THE RESULTS

Policy-makers in every country have asked: what are the quantitative results of improved energy efficiency? This question cannot be answered by examining a country's overall energy/GDP ratio because the energy use/GDP ratio is clouded by effects not related to changes in individual energy intensities (Schipper and Meyers et al. 1992; Schipper 1991a; Schipper 1991b). Certainly, per capita energy use in Denmark was lower in the 1980s than in 1972 (Figure 8-1). However, for a complete understanding, we must quantify the impact of changes in individual energy intensities on sectoral energy use, as well as gauge the impact of structural change itself on sectoral energy use. To do this, we turn first to a review of the sectoral findings and then to more detailed calculations that separate most of the effects of changes in structure and activity from those that arise principally from improved energy utilization. The first calculation uses the sectoral findings that show how much changes in energy intensities alone reduced (or in some cases, increased) energy use. The second method estimates how much energy use would have been in 1988 had energy intensities *not* decreased (or increased). Since downward changes in energy intensities are related to "energy conservation", both of these calculations offer a useful measure that can be evaluated over different time periods or compared with results from other countries. Despite their imperfections, these calculations illustrate the impact of reduced energy intensities on total energy demand far better than the aggregate numbers.

8.1. Review of Sectoral Findings

Significant reductions in fuel intensity were achieved in the Danish residential, service, and manufacturing sectors between 1972 and 1988, while electricity intensity rose rapidly (Figures 8-2 to 8-4). Figure 8-5 shows that year-to-year behavior of these intensity indices. The rise in electricity intensity, of course, need not imply reduced efficiency in end-use technologies; instead, the growth may be due to fuel switching and the increased penetration of electrical equipment. The provision of energy services grew substantially in these sectors with the affluence afforded by economic growth. On balance, final energy use decreased by 6% to 26% in these sectors while electricity use grew by 77% to 112%. The changes in primary energy use ranged from a 10% decrease to a 24% increase.

The other industrial (combined agriculture, mining, and construction) sector differs from this pattern. Although final energy intensity fell by 21%, there was essentially no growth in sectoral output. Electricity is not an important energy carrier in this sector. As a result, final and primary energy use trends are closely similar.

The travel and freight transportation sectors also break the mold. In travel, structural change reduced energy use by about 4%, and energy intensities lowered energy use by a similar degree. Thus sectoral energy use was most strongly influenced by a 24% increase in travel activity. In freight, the level and structure of sectoral activity both changed in ways that increased energy use by nearly 40%, as did energy intensities, which alone caused a 12% increase in energy demand.

8.2. Detailed Intensity Calculations

The first of our detailed calculations shows what Danish energy use would have been if energy intensities had matched their 1988 levels but the level and structure of energy-using activities were in their 1972 configuration. This is done by summing the effects of changes in energy intensities, sector by sector, on total energy use. By comparing this hypothetical level of energy use against the actual 1972 level, the impacts of intensity changes between 1972 and 1988 become apparent. Figures 8-6 through 8-8 show the results of this calculation over time applied to final energy use, electricity alone, and primary energy use as well. This quantifies the overall impact of lower energy intensities on Danish energy use, with structure and activity measures in each sector remaining constant. Using this method, we start by noting that in 1972 primary energy demand in Denmark for the sectors we studied totaled 757 PJ. Recalculating this demand using the lower 1988 energy intensities for each sector yields a demand of 597 PJ. As shown in Table 8-1, this is a 21% reduction in primary energy. We also calculated that between 1972 and 1988, energy intensity reductions would have reduced final energy use in 1972 by 31% and increased electricity use by 33%.

The second calculation estimates how much energy would have been used in Denmark given 1988 activity and structure but 1972 energy intensities. By comparing the result with actual 1988 energy use, one obtains a gauge of the energy savings achieved by reductions in energy intensity over the period. This second calculation takes into account the fact that changes in the level and structure of energy-using activities on balance raised energy use between 1972 and 1988. Using this calculation, primary energy use in the 6 sectors would have reached 1022 PJ, about 30% higher than it actually was, in 1988. Equivalently, intensity reductions over the period reduced the level of primary energy use by 24% (Table 8-1). Note that for freight, there were no savings, i.e., with actual energy intensities, *more* energy was used in 1988 than would have been used at 1972 intensities. We also calculated that between 1972 and 1988, growth in energy-using activities would have increased final energy use by 32% and electricity use by 41% given constant 1972 energy intensities.

Neither of these calculations is perfect, however. These methods ignore the interactions among intensity, structure, and activity that took place in the real world. For example, had Danes not reduced their use of energy for space heating markedly, they would have had to reduce expenditures for other goods and services in order to pay for space heating. And if Danes had not bought automobiles in the 1975-1988 period that were less fuel-intensive than those they drove in 1972, the cars they drove in 1988 would have used more fuel per kilometer. It is likely they would have driven less than they actually did in 1988 with such cars, in order to reduce their expenditures for fuel. These effects should be borne in mind when interpreting our results.

8.3. Danish Energy/GDP Ratio

Between 1972 and 1988, the Danish energy/GDP ratio declined by 38% in terms of final energy and 28% in terms of primary energy. However, these decreases are significantly larger than the energy intensity declines we calculate above, indicating that the energy/GDP ratio should not be construed as a pure indicator of changes in energy efficiency. The reason for such differences is straightforward: real GDP grew by 44% over the period, significantly more than the growth in energy-using activities. Put another way, the ratio of energy use to GDP in Denmark fell 8% because growth in energy services was slower than growth in GDP. The energy/GDP ratio fell both because of reductions in energy intensities and because of relatively weak growth in energy-using activities.

8.4. Denmark's Energy Efficiency Plateau

The development of energy-using activities and energy intensities was not consistent over time. The growth in energy services, for example, slumped during the sharp recession that fell on the Danish economy after the 1979 oil price shock. More striking, however, is the development of energy intensity. While reduced energy intensities would have led energy use to decline by 3.1% per year in terms of final energy and 2.2% per year in terms of primary energy between 1972 and 1981 given fixed specific activity levels, little change has occurred in more recent years. This means, in effect, that although Danes managed impressive improvements in energy efficiency in the 1970s and early 1980s, this progress came to a standstill as energy prices eased in the mid-1980s (Figure 8-9).

The behavior of either of these measures of intensity over time shows that increases in energy saving, as we measure it here, were concentrated into two important periods following each oil shock. Using the second measure, for example, savings rose to 9% of actual use by 1975, then increased slowly to 14% of use by 1979. The following year savings shot up again to 23%, then increased until hitting a maximum of 32% of actual energy use in 1984. That is, the Danish economy would have used 32% more primary energy in six major sectors than it actually did in 1984 had not energy intensities fallen. After 1985, however, the rate of savings fell back, falling below 30% between 1985 and 1987, then returning to 31% in 1988.[1]

Overall, these detailed calculations show that the impact of lower energy intensities reached a maximum in the mid-1980s and then fell back somewhat. Energy efficiency in Denmark, to the broad extent it is related to energy intensities, seems to have hit a plateau.

[1] The figures for 1985-1987 are affected by the uncertainties in the manufacturing sector.

Table 8-1: Energy Savings in Denmark 1972-1988

Method One

Sector	Actual 1972 Energy Use (PJ)	Energy Use (PJ) 1972 Activity & Structure 1988 Energy Intensities	% Difference
Residential	297	196	-34%
Manufacturing	176	154	-13%
Other Industry	70	59	-16%
Services	106	81	-24%
Travel	75	71	-5%
Freight	33	36	+8%
Total Primary Energy	757	597	-21%

Method Two

Sector	Energy Use (PJ) 1988 Activity & Structure 1972 Energy Intensities	Actual 1988 Energy Use (PJ)	% Difference
Residential	418	264	-37%
Manufacturing	222	187	-16%
Other Industry	71	59	-17%
Services	170	132	-23%
Travel	90	84	-7%
Freight	51	56	+10%
Total Primary Energy	1022	782	-24%

Method One: Energy demand with the structure and activity levels of 1972 but energy intensities of 1988. The difference shows the impact of changes in energy intensities between 1972 and 1988, other factors held constant.

Method Two: Energy demand with the structure and activity levels of 1988 but the energy intensities of 1972. The difference shows how much energy was saved relative to the level that would have prevailed in the absence of intensity reductions.

Final Energy Use in Denmark
by End-Use Sector

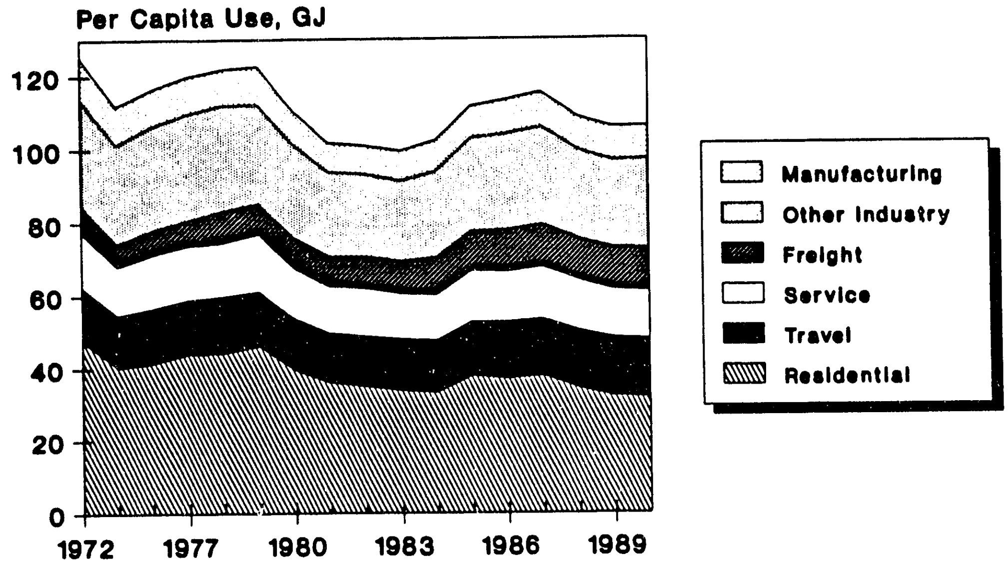


Figure 8-1

Final Energy Use in Denmark
Activity, Structure, Intensity Effects

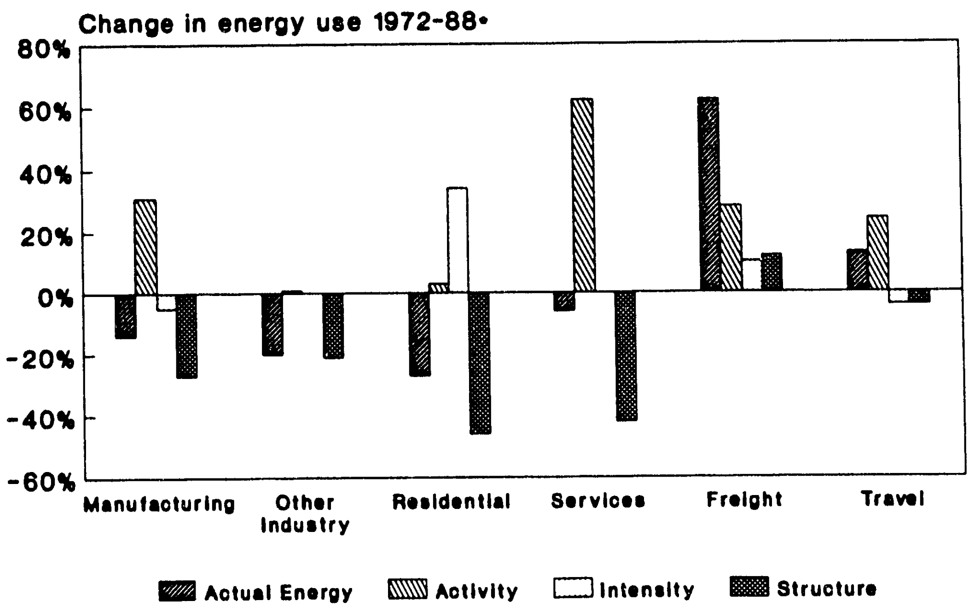
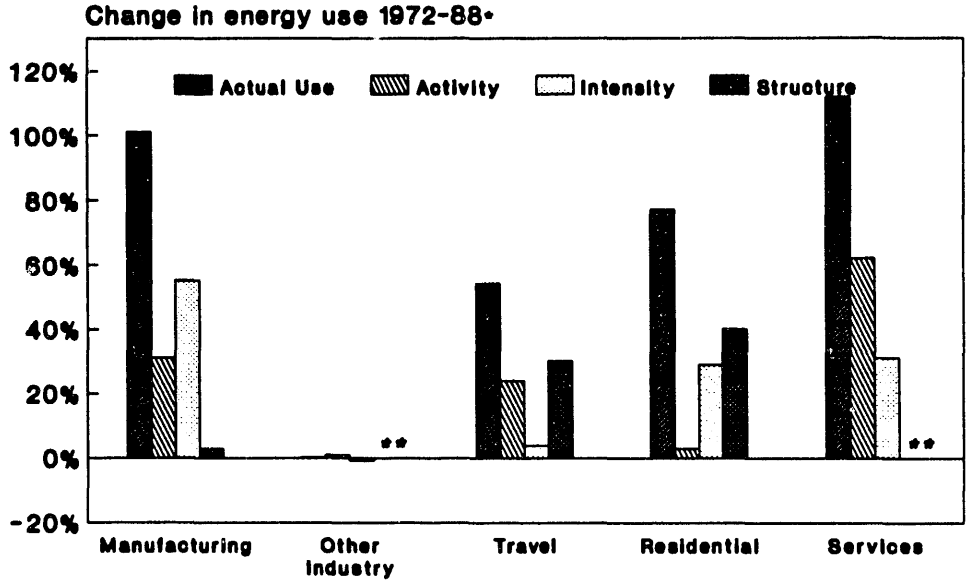


Figure 8-2

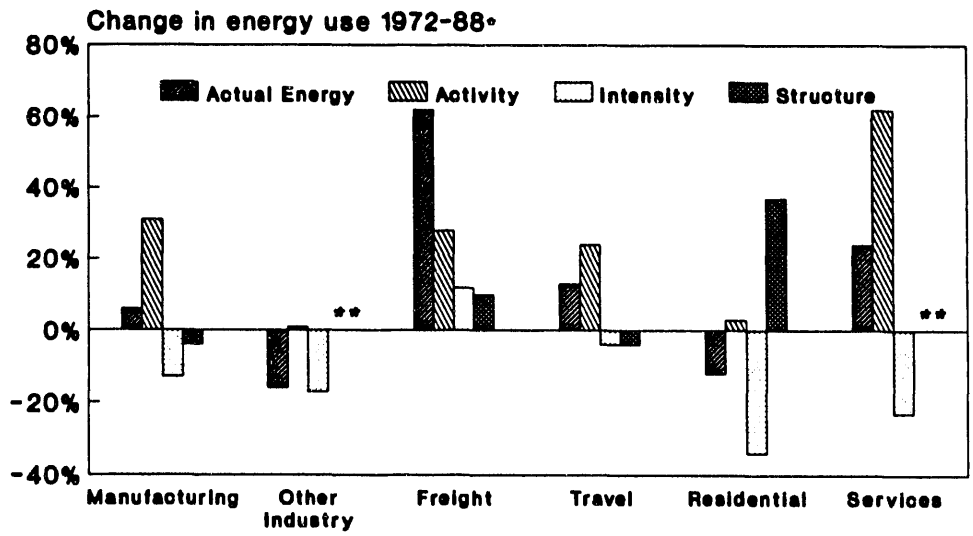
Electricity Use in Denmark
Activity, Structure, Intensity Effects



** Structure effects not calculated for other industry or services

Figure 8-3

Primary Energy Use In Denmark
Activity, Structure, Intensity Effects
Impact on Sectoral Energy Use



** Structure effects not calculated for other industry or services

Figure 8-4

Denmark Intensity Changes 1972-88
By End-Use Sector

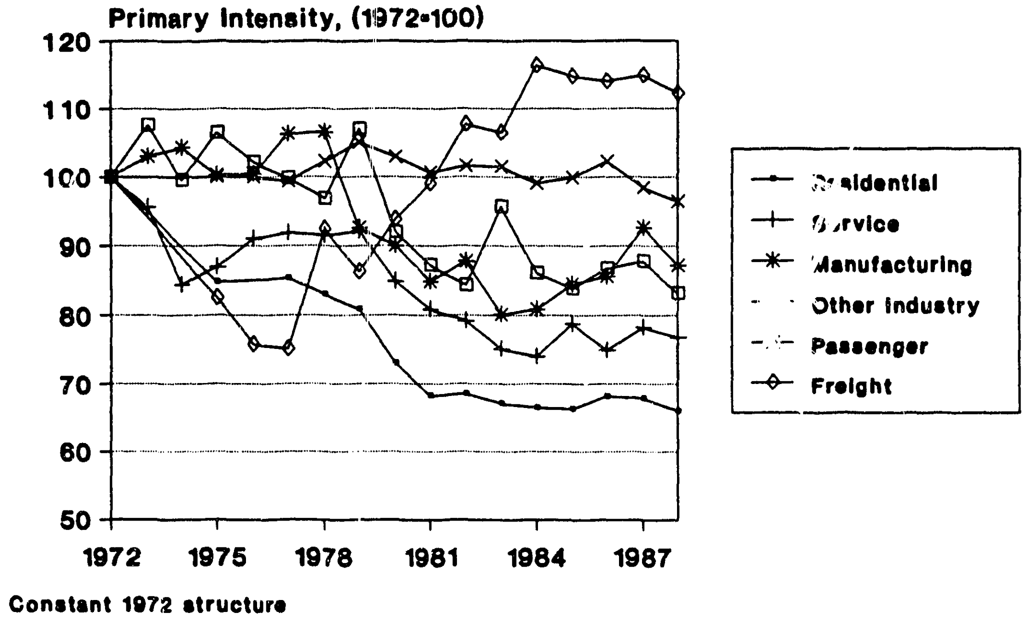


Figure 8-5

Energy Use in Denmark
Final Energy

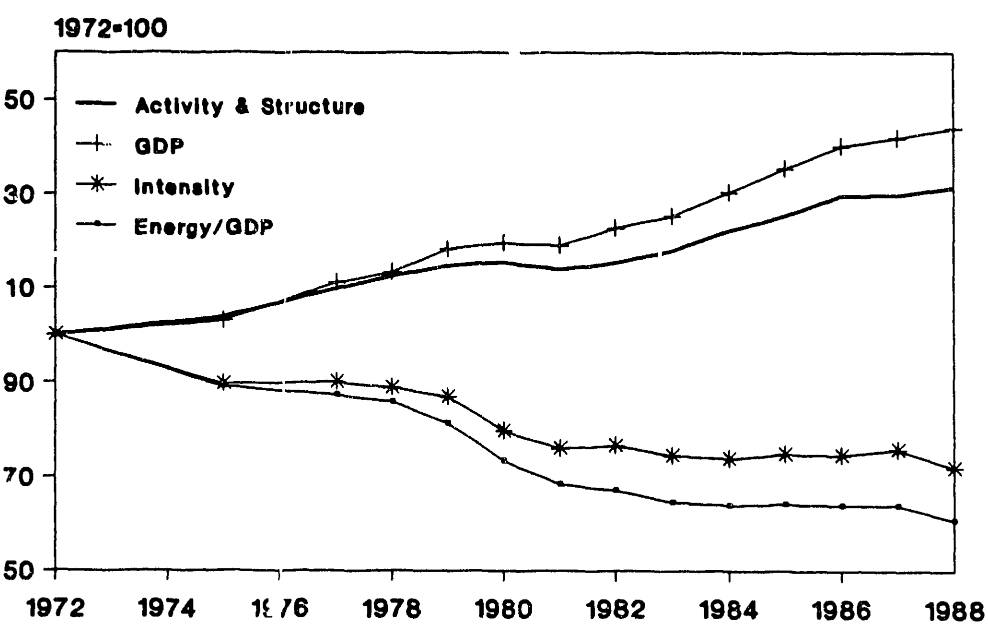


Figure 8-6

Energy Use In Denmark
Electricity

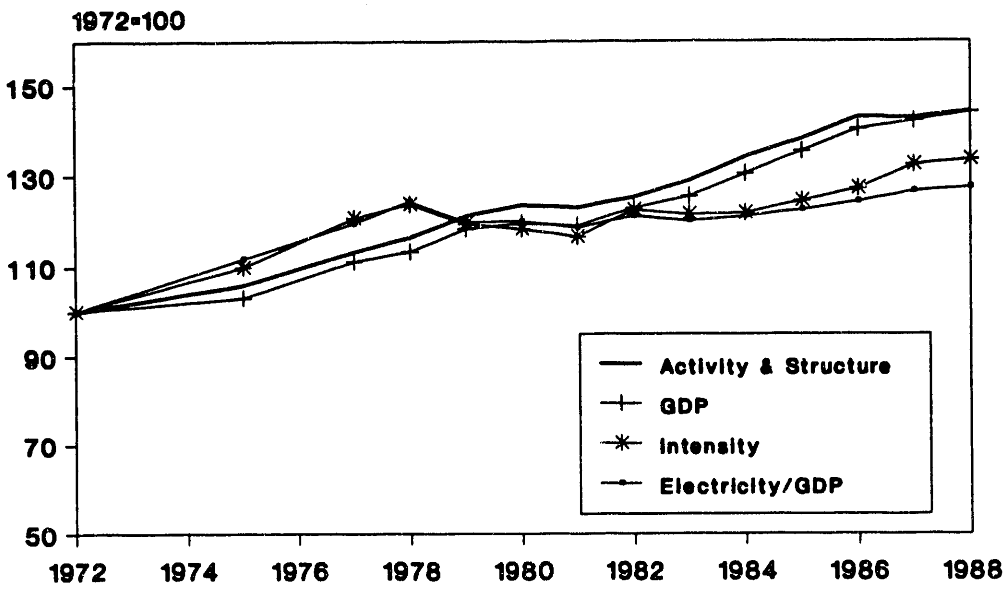


Figure 8-7

Denmark Primary Energy Use

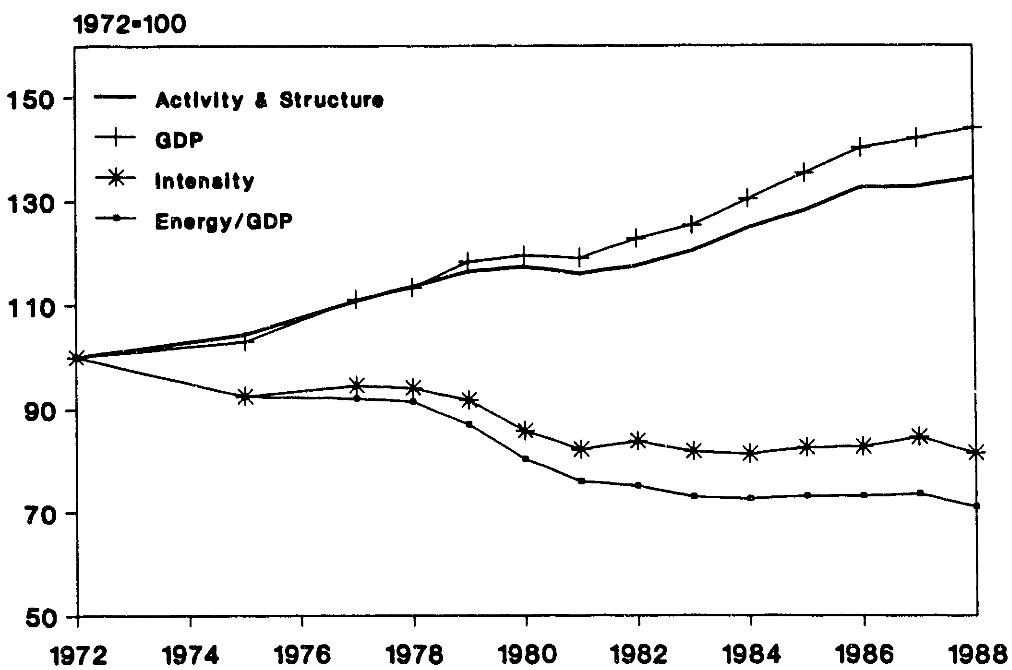
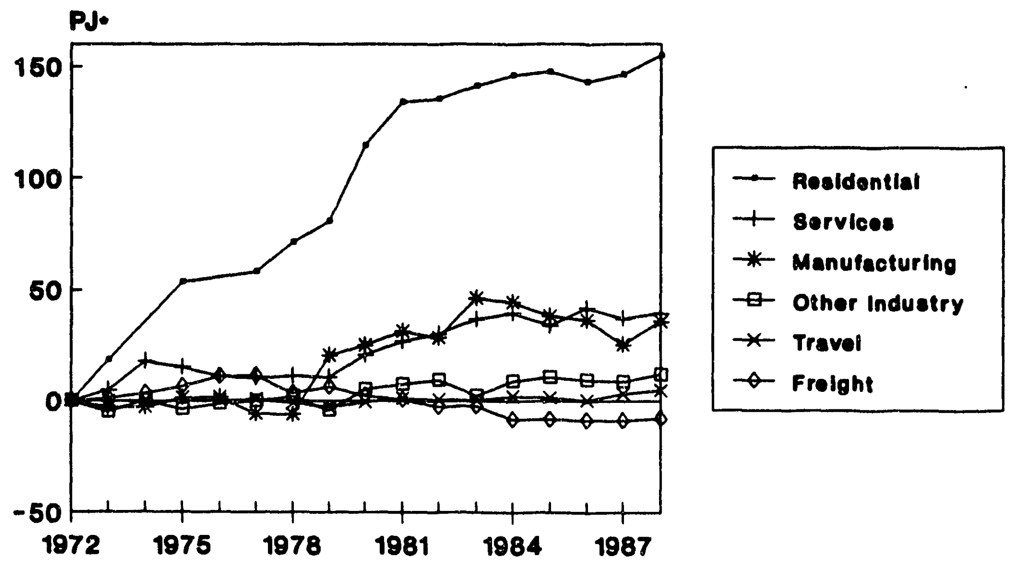


Figure 8-8

Denmark Primary Energy Saved By Sector
Constant 1972 Intensities
Actual Activity and Structure



* Annual savings, not accumulated

Figure 8-9

9. INTERNATIONAL COMPARISON

There are many important reasons for comparing the structure and efficiency of energy use in Denmark with that of other industrialized countries. One obvious reason is political. In the international community countries are positioning themselves for the United Nations Conference on Environment and Development (UNCED) and beyond. Points of competition among nations are both the present state of energy efficiency as well as future plans for improvements. Each nation needs to know where the others stand.

There is also a very practical reason for understanding differences between energy use in one's own nation and elsewhere. Certain energy use patterns in another country may resemble those that form the goals at home. Understanding how the other country arrived at a particular pattern may provide insights on how to steer one's own course. For example, careful study of the efficient state of housing in Sweden led to many ideas for promoting efficiency in the U.S. (Schipper, Meyers, and Kelly 1985). Such international study may turn up important technologies that save energy as well as key policies that promote energy saving.

The final reason for undertaking cross-country comparisons of energy use and efficiency is to identify boundary conditions in highly efficient countries. That is, the inter-country differences in some particular policy parameter are often great enough to permit policy analysts to isolate the effects of that parameter on a particular energy use. For example, Denmark has very high taxes on automobiles and authorities in other countries considering such policies could learn a great deal from studying the Danish experience. In the U.S. there is great interest among some policy analysts in understanding how energy use for travel could be reduced significantly. One method is through gasoline taxes. Unfortunately, there is virtually no modern experience in the U.S. with fuel prices as high as those in Europe. Only study of Europe can illuminate how individuals and society as a whole adjust to higher energy prices.

The following comparison of energy use in Denmark and other countries aims to satisfy all of these purposes. We will show how energy use patterns in Denmark differ from those in other industrialized countries. We will briefly compare the sectoral trends in the structure of energy use in Denmark and other countries. We will also compare key energy intensities in Denmark with those in other countries. We shall see that while Denmark was a relatively energy-intensive country in 1972, energy saving, as well as some structure change, has markedly reduced energy use in Denmark. Energy savings in Denmark are now among the highest in OECD countries.

9.1. The Residential Sector

Danes enjoyed some of Europe's largest and most well-outfitted homes in 1972. However, these homes were inefficiently heated. After two oil crises and much conservation activity, though, Danish space heating intensity fell to one of the lowest levels in Europe, while Danish-made appliances began to take honors world-wide for their efficiency. While families in other countries narrowed the gap somewhat, the comfort in Danish homes in 1990 was still among the very highest in Europe. This section explores how household energy use in Denmark compares with that in other countries.

In 1972, Danish households had a relatively high standard of comfort, as measured by house area per capita (Figure 9-1).[1] Penetration of central heating was over 90%. Compared to Sweden, Danish homes were actually larger, but the penetration of central heating was lower. However, Danish standard of living was more "advanced" than that of Norway or the Western European countries outside of Scandinavia: larger homes, more central heating, and more electric appliances. Per capita home area in these countries grew slightly faster than it did in Denmark, but, as the figure shows, the gap between Denmark and other countries in Western Europe was still significant in the late 1980s.

In 1972, Danish homes were well equipped with electric appliances by Western European standards, but had somewhat fewer (and smaller) appliances than did homes in Sweden (Tyler and Schipper 1990). Electric appliance holdings in Denmark expanded rapidly in the early 1970s, then slowed in the early 1980s, an apparent consequence of slow economic growth. By contrast, appliance ownership grew rapidly in Norway, France, and West Germany during the same period (Tyler and Schipper 1990), narrowing the gap with Denmark. By 1990 ownership levels of major appliances were similar throughout Western Europe and Scandinavia.

9.1.1. Fuel Mix

In 1972, Danish homes were critically dependent upon oil, as Figure 9-2 shows. Sixty-two percent of Danish homes used heating oil, LPG, or kerosene (*petroleum*) for space heating in that year. While Sweden had a higher share of *heating systems* reliant directly on oil in 1972, Denmark had a higher share of oil, kerosene, and LPG *use* in the residential fuel mix. As a result, total residential oil use per capita in Denmark was the highest in Western Europe.

The reduction in oil use in Danish homes that occurred after 1972 was drastic. The principal cause of the drop in total residential oil consumption in Denmark was an approximately 50% decline in specific consumption for this fuel. This decline appears to have been the greatest drop in the specific consumption of any heating fuel in any major OECD country. Figure 9-3 shows that over 50% of the homes were heated directly by oil in Denmark (as well as in West Germany) through the mid 1980s. In contrast, the share of homes heated directly by oil tumbled drastically in both Sweden and France starting in the late 1970s. Although massive substitution away from oil set in after 1985, the penetration of oil heating in Danish homes still remains (as in West Germany) the highest in Western Europe.[2] But with the unit consumption of oil so low, and the share of homes using oil now falling rapidly, total oil consumption in Danish homes is heading downward. As Figure 9-3 shows, the share of oil in household energy use in 1989 was close to that of most other European countries that were initially dependent upon oil for most residential energy (France, West Germany, and Sweden). By 1990, the backout of oil from Danish homes was one of the most thorough experienced.

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[1] The area for Denmark, *"samlade utnyttade areal"*, appears to include some commercial space and other spaces not always heated. Using this definition, Danish homes were over 107 m^2 in 1989. This may put Denmark's figures about 10% too high. That is, the figure for the average Danish dwelling that would be comparable with those from other countries is probably about 98 m^2, about 10% less. Using this figure would boost the heating intensity by 10%, as shown below.

[2] See Schipper and Ketoff, 1985.

In 1972, Denmark had the highest share of homes in the OECD heated with district heat. District heating was an important factor holding the dependence of Danish homes on direct oil heat from reaching even higher levels in the early 1970s. A consequence of the high penetration in 1972, however, was that changes in the share of homes heated with district heat after 1972 came slowly. Nevertheless, by 1990, fully 45% of all Danish homes were heated this way, a high level shared only with Finland and Sweden. Interestingly, the penetration of district heat into single-family dwellings in Denmark is the highest in Western Europe.

Electric heating has remained relatively unimportant in Denmark. While far over 33% of homes in Sweden, 30% in France, and 20% in the U.S. relied on electricity for their principal heating source in the late 1980s, the share for Denmark is less than 8%. Certainly the Danish Heat Planning Law is one reason for this.[3] But the high price of residential electricity in Denmark is another reason, as pointed out in Tyler and Schipper (1990). In Holland and West Germany, high electricity prices, relative to those of other fuels, have also discouraged the spread of electric heating.

9.1.2. Energy Use, Energy Intensities, and Efficiency

By international standards household energy use in Denmark was high in 1972. Figure 9-4 shows each major end use for Denmark and other OECD countries.[4] Denmark's residential consumption ranked second, after the United States. Given the large size of Danish homes, its position *vis-a-vis* other countries in Europe is not surprising.

By 1988, however, the picture had changed considerably. Per capita household energy use in Denmark fell to lower than the level in either Norway or Sweden, two countries that saw a very high penetration of electricity (and district heat in Sweden) that helped reduce oil use as well as delivered energy. Note, too, that energy use per capita in Norway and Sweden as well as in the EU-4 (Italy, France, Britain, and West Germany) and Japan as well, increased over this period, while it fell only in Denmark and the U.S. The increase in the penetration of central heating and appliances ownership in the EU-4 and of all energy-based amenities in Japan was more rapid than in Denmark, which explains some of the reason why the gap in energy consumption between Denmark and most other countries narrowed. More important, however, were the declines in key energy intensities in Denmark, as discussed in the chapter on Danish residential energy use.

For example, in 1972 Danish homes had one of the highest space heating intensities in the OECD, as Figure 9-5 shows. If we only compare single-family dwellings centrally heated with oil, then Denmark, West Germany, France, and the U.S. all lie very close (Schipper and Meyers, et al. 1992). Clearly

[3] California has a similar law restricting electric heating to cases where insulation is so well applied that one can show that small electric heaters yield the lowest lifecycle heating cost for the owner.

[4] In our international data base, Denmark has 3141 degree days (DD) to base 18C in a normal year. For comparison, West Germany has 3116DD, Sweden and Norway nearly 4000, the U.S. 2600DD, and the EU-4 (Italy, France, U.K., and Western Germany, weighted by population) 2700 DD. The Danish index is calculated as the *Energistyrelsen* index plus 450 degree days (see Appendix A). For this comparison, we have scaled energy use for space heating to 2700 Deg-Days Celsius, the average of the EU-4 and close to that of the U.S. This adjustment lowers the figures for Norway and Sweden by some 40%, lowers those of Denmark by about 10%, and increases those for Japan by 50%.

the high heating intensity for Denmark is explained in part by a high level of central heating, and, at least in 1972, high indoor temperatures. But by 1985, space heating intensity in Denmark had declined more than in any other OECD country, even when only homes with central heating are compared. Even after a slight rebound in space heating intensity (still subject to some data uncertainties) in the late 1980s, Denmark now has one of the lowest space heating intensities, lying close to those of Sweden and Norway at near 120 KJ/m^2/degree day. And while there are few direct measurements, we believe that the intensities of fuel or electricity used for water heating in Denmark also decreased more rapidly than those of other countries.

Household electricity use per capita in Denmark is markedly lower than electricity use in other countries in Scandinavia or in the U.S., but lies close to average for Western Europe and Japan (Figure 9-6). Denmark has a very high share of electric cooking, but a very low share of electric heating or water heating by European standards, which explains in part the distribution of electricity sales that are indicated in Figures 9-3 and 9-6. Growth in electricity use was moderate in Denmark compared to other countries with even higher prices such as West Germany, Italy, and Japan and far below the rates of growth apparent in Norway, Sweden, and France, where increases in electric space and water heating were especially strong. (The reverse in the U.K. was caused by the entry of natural gas, which dislodged electricity from significant positions in both space- and water-heating markets.) Given the structural increases driving electricity use in Denmark, it is clear from the international comparison that increased efficiency played a prominent role in restraining growth in household electricity demand.

The decline in the intensity of electric heating seen in Denmark also seems to have been experienced in France and the U.S., two countries with relatively important markets for electric heating, as well as in West Germany, with a small electric heating market based mostly on night-time storage heating. In Sweden and Norway, very little decline in the intensity of electric heating in existing homes was observed, but electricity prices were low in both countries for most of the period we observed. In Denmark, as well as in France and Sweden, earnest efforts were undertaken to reduce needs for space heating in homes using electricity, efforts that paid off. In the U.S., electric heat pumps captured a significant share of heating in new single-family dwellings, lowering the average electricity use for heating there significantly.

The evolution of electricity use for electric appliances in Denmark is unusual for Europe (Figure 9-7). Weighted by 1972 ownership levels, the decrease in average consumption of the six major appliances (refrigerator, combination refrigerator/freezer ["combi"], freezer, washer, dryer, dishwasher) in Denmark was nearly 25% by 1988, the largest improvement in stock-wide average consumption for these appliances of any country in our OECD sample. Improvements in the average consumption of *new* appliances were even greater. (The Gram refrigerator that appeared in Denmark in the late 1980s is recognized around the world as the leader in efficiency.)[5]

[5] Mills (1991b) questions whether there is any significant difference in the mix of appliances offered for sale in Denmark and Sweden. Danish washing machines use far less water than those in Sweden, according to Boysen and Mosbaek (1992). They also pointed out that a substantial share of new freezers in Denmark are "super insulated", while none of these have even been offered for sale in Sweden. And a very low electricity-using refrigerator developed by Electrolux for a Swedish government program will appear very soon on the Danish market as well, with no government prompting. This reinforces our suspicion that appli-

Two obvious factors help explain the path that residential energy use has taken in Denmark since 1972. One is its aggressive conservation policies, which we have reviewed in a comparative light elsewhere (Wilson et al. 1989). Most notable are the wide-reaching retrofit programs and the significant tightening of thermal requirements (walls) of new homes. Figure 9-8 shows changes in thermal requirements in OECD countries over time.[6] Note the 1972 code value in Denmark was high by present Scandinavian standards, but very low compared to the rest of Europe. On the other hand, practices in Denmark before 1960s appeared to have put little insulation into homes. Hence the codes in 1972 and 1979 represented a large improvement over the average for the entire stock before 1973, a similar situation to that in Europe outside of Scandinavia. Thus Denmark had to "catch up" to Sweden, using policies to accelerate changes that have taken much longer elsewhere in Western Europe.

The other important factor is Denmark's high residential energy prices. Using 1980 purchasing power parities to convert prices from 1980 real local currency into U.S Dollars (or DKK),[7] we compared residential oil and electricity prices in Figures 9-9 and 9-10. Because of very high taxes imposed on both heating oil and electricity in the late 1970s and thereafter, Danes faced the greatest increases in residential energy prices of anyone in Europe except Italy. While heating oil was taxed heavily in Sweden and France, electricity was relatively inexpensive in those countries. Conversely, electricity has been expensive in West Germany, but heating oil was only very lightly taxed. Other fuels are also expensive in Denmark: prices for district heat and natural gas follow those for oil closely. Hence, Danes have had no "cheap fuel". They have experienced the greatest upward change in heating fuel prices of virtually any European nation, changes that persisted through the late 1980s.

Thus, we have seen that in an international context Denmark started the 1970s with high residential energy intensities and high living standards, relative to other countries, but finished with moderate or low energy intensities and even higher residential standards. An aggressive energy-efficiency policy that combined high prices with building retrofit programs, thermal codes for new structures, research and development, and an active role of government as coordinator of much of the effort, lay behind this record improvement among OECD countries. It remains to be seen whether the same relative improvements can be realized as part of the new Environment Plan.

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ances bought in Denmark are among the most efficient in the OECD. At the same time, Electrolux Scandinavia (Jonzon 1992) warns that refrigerator size is an important factor, too. Most Danish refrigerators are built to a 55 cm width, and under 160 cm in height, which complicates adding insulation. In all, the reduction in intensity of household appliances in Denmark is so great as to be strongly suggestive of our observation that appliances actually sold there are more efficient than those sold elsewhere, at least in Sweden.

[6] Data based on building codes for all countries except U.S.; U.S. values are from a survey of actual practices (Schipper, Howarth, and Geller, 1990).

[7] The conversion rate tends to lower the value of the *krone*, making Danish household electricity prices appear relatively low. Recall that purchasing power parities take into account that fact that other goods and services in Denmark, and not just energy, are expensive. The conversion factor we use, 8.69 DKK/$ in 1980 money, reflects these relative prices. The market exchange rate was closer to 5.7 DKK/$ in that year, but if other countries market rates were used, Denmark's prices would not shift much relative to Sweden, Norway, West Germany, or France, but would rise by almost 30% relative to Italy and 20% relative to Japan, and by 50% relative to the U.S.

9.2. Manufacturing Sector

Danish manufacturing energy trends are similar in many respects to developments in other nations. A comparison of Denmark, Norway, Sweden, West Germany, France, the United Kingdom, the U.S., and Japan (the OECD-8) (Howarth and Schipper, 1991), found that the impacts of changes in manufacturing output, energy intensity, and industry structure served to reduce final energy use by an average of 18% across nations between 1973 and 1988 (Figure 9-11). Growth in Danish manufacturing output, which averaged 1.5 %/yr over the period, trailed only Japan (3.3 %/yr) and the U.S. (2.8 %/yr) among the eight nations considered (Figure 9-12). Manufacturing output in West Germany and Sweden grew 1.1 %/yr and 1.2 %/yr, while almost no growth occurred in Norway and the United Kingdom.

Energy intensity, adjusted for structural change, fell by 20% to 35% in every nation (Figure 9-13). The Danish improvement of 29% was close to the 28% achieved in Sweden and a bit better than the 20% managed in Norway. Structural change had relatively minor impacts in most nations, lowering energy use by 12% in West Germany while little change occurred in Sweden (Figure 9-14). In Norway, on the other hand, the development of electricity-intensive industries placed strong pressure on sectoral energy use.

Despite these similarities, Danish manufacturing differs substantially from the international norm. The difference is evident in the relatively low proportion of GDP originating in manufacturing—16% in Denmark as compared with the eight nation average of 24%. Also of interest is the low penetration of energy-intensive industries, which account for only 17% of manufacturing output in Denmark as compared against 24% in Sweden and 32% in Norway. These statistics arguably underestimate the true disparity. The energy-intensive industries are not homogeneous, but produce many different products with varying degrees of energy intensity. In Denmark, the chemicals sector accounts for more than half of energy-intensive output, yet the energy intensity of this sector is only 13.4 MJ/1980USD versus 43.5 MJ/1980USD in Norway or the eight nation average of 29.9 MJ/1980USD.[8] The low energy intensity of the chemical sector in Denmark is due to its focus mainly on the production of finished products and less on the production of the chemical building blocks that dominate energy use in most nations.

At an aggregate level, however, the energy/value added ratio of Danish manufacturing is 26% above the level in West Germany, but 9% lower than the U.S., 44% lower than Sweden, and 62% lower than Norway (Figure 9-15). These differences persist for the most part when the aggregate energy intensity of each nation is adjusted to reflect the average output mix across the eight nations (the OECD-8), although the adjustment lowers energy intensity in Sweden and Norway. The raw materials sector is generally less energy-intensive in Denmark than in other nations, presumably because the sector is less concentrated on the most energy-intensive phases of materials processing. For the "other manufacturing" category, however, Danish energy intensity is twice the eight nation average. One potential reason for the difference is the importance of the Danish food industry (ISIC 31), which accounts for 25% of manufacturing value added and 32% of final energy use. While the food sector is less energy-intensive in most nations than

[8] National currencies were converted to USD using 1980 purchasing power parities.

the raw materials industries, it is more energy-intensive than the light manufacturing activities that dominate value added in other nations.[9]

The trend towards increasing electricity intensity in Danish manufacturing is of special significance. Electricity intensity, adjusted for structural change, grew by 50% in Denmark between 1973 and 1988. In no other country was there an increase of more than 13%. Nonetheless, the share of electricity as a fraction of total energy use in Danish manufacturing (23%) is close to the eight nation average of 22%. In Sweden and Norway the electricity shares are much higher (37% and 60% respectively), reflecting the comparatively low electricity prices in those nations. Since Danish manufacturing electricity intensity is close to the international average, the large increase that has occurred does not imply that electricity efficiency is low in Denmark.

An examination of international trends in industrial energy prices provides interesting insights into the determination of energy use. Figure 9-16 shows the development of heavy fuel oil prices measured in constant U.S. Dollars (USD). Industrial oil prices in Denmark are low by international standards, roughly half the level in Sweden and Japan and lower even than the U.S., often regarded as a low-price nation. In each nation, oil prices rose sharply following the 1973 and 1979 energy shocks. By 1988, however, Danish heavy oil prices had receded to the 1973 level. It is interesting to note that the trends towards reduced oil intensity in Danish manufacturing persisted in the mid- to late-1980s even though oil prices fell substantially. This was caused in large part by the entry of gas into the industrial fuel market in 1984.

Figure 9-17 shows the development of industrial electricity prices. In 1988, the Danish price of 0.023 1980USD/kWh matched the level in Sweden but was lower than prices in West Germany and the United States by roughly 50%. Electricity prices in Denmark have been rather unstable over time, rising sharply in the mid-1970s as higher oil prices raised the cost of electricity generation. Since 1980, however, electricity prices have declined by 41%, a change not matched in other nations. The trend towards increased electricity intensity was undoubtedly facilitated by this price reduction.

9.3. The Service Sector

We are just completing our updated report on service sector energy use in nine OECD countries (Schipper and Meyers et al. 1992). At this writing, some preliminary conclusions regarding developments in Denmark compared to other nations can be made.

As in the residential sector, the Danish service sector was highly dependent upon oil heating in the early 1970s. Figures 9-18 and 9-19 show fuel and electricity intensity in Denmark and other OECD countries from 1970 to 1988. Significant reductions in fuel intensity have been observed in almost every country, as has an increase in electricity intensity. Most of the decline in fuel intensity was caused by heat-saving measures. Because of the small share of built space heated with electricity in Denmark (less

[9] The high energy intensity and large output share of the food sector suggest that it might be interesting to separate it from the "other industry" category in the calculations outlined above. We carried out the calculations using both aggregation schemes and found that the differences in the results were minor. To preserve comparability with other nations, we rely on the six sector breakdown as the basis of our analysis. Between 1973 and 1988, the share of manufacturing value added originating in the food sector increased from 20% to 24%. The sector's final energy intensity decreased by 30%, while electricity intensity increased by 73%.

than 4% compared with 25% in the U.S. and over 30% in Sweden and Norway), most of the decline in fuel intensity represents energy saving, although some fuel has been saved as increased use of electricity for non-heating purposes created "waste heat" that warmed buildings. The increase in electricity intensity, on the contrary, appears to represent electrification, the purposeful increase in the number of electricity-using devices per m^2 of building space. While such relative increases have been observed in Sweden and Norway, most of the increase is accounted for by the higher penetration of space heating.

9.4. Passenger Transportation[10]

Denmark has one of the lowest values of per capita energy use for travel of the major countries in Europe, and Danes have a relatively low level of domestic travel using motorized vehicles. One reason for Denmark's low per capita energy use is a clear improvement in the fuel intensity of Danish cars that was unmatched by most other countries in Europe.

The ownership of cars in Denmark lies at 320 per 1000 people, one of the lowest levels in Northern Europe. There are over 400 cars per 1000 inhabitants in Norway, Sweden, Germany, France, and Italy. Among the Northern European countries we have studied, only the ownership level for Great Britain lies close to that of Denmark (Figure 9-20).[11] Danish cars are driven more than cars in any other country in Northern Europe, nearly 17,000 km/year in 1988 (Figure 9-21). But the low number of cars, combined with a load factor that is close to the European average, means that per capita domestic travel in automobiles in Denmark is close to the average among the EU-6.[12]

The small geographical size of Denmark might be one reason that Danes travel significantly less in cars than other Europeans. Indeed, the average automobile trip in Denmark, as estimated from *Transportundersøgelsen-86* (TU-86), lies at around 11 km, slightly less than the values of 13 km and 15 km in Germany or the U.K. Yet even in the U.S., the average trip length in 1990 was only around 15 km, suggesting that country size alone does not determine yearly distance travelled.

Related to the low number of cars in Denmark is the relatively high share of travel provided by rail and bus. The large share of travel in these modes (23% in 1988) helped boost total per capita travel in Denmark to slightly above the average level of the other countries in Europe (Figure 9-22).[13] Yet Denmark is one of the only countries where per capita travel on trains and buses was significantly higher in 1988 than in the early 1970s (Figure 9-23).

Indeed, the share of total travel in Denmark provided by cars in the 1980s was the lowest in the European countries we studied (Figure 9-24). Economic pressures, including high automobile and fuel taxes, were largely responsible. The most obvious pressure is from the high price of fuel (Figure 9-25), but the high price of cars also places severe pressures on Danes to buy small cars. Typically, cars in Denmark cost more than twice what they cost in other Northern European nations (*Automobil-*

[10] Recall that in this report, "car" refers to automobiles and light trucks (*varebiler*) with under two tonnes capacity.

[11] Car ownership in Japan, not shown in Figure 9-20, is well below that in Denmark.

[12] The EU-6 are Norway, Sweden, Germany, France, Italy, and the U.K.

[13] These figures exclude the small contributions of motorcycles, boats, and non-motorized modes.

Importerørernes Sammenslututning 1991). Interestingly, however, the cost of using gasoline per km driven in the average Danish car was only 10% higher in 1988 than in 1972, a situation not too different from most other countries. Although the real price of gasoline in Denmark was significantly higher in 1988 than in 1972, the use of gasoline per km had fallen almost enough to offset this change. Not surprisingly, the use of cars in Denmark has been slowly increasing as it has in other countries, as Figures 9-21 and 9-24 suggest. Thus the main and most persistent difference between Denmark and the other countries portrayed is the low number of cars, not overall mobility.

The vehicle energy intensities of cars in Denmark—2.4 MJ/vehicle-km or 7.4 l/100 km—ranks with that of Italy as the lowest in the 9 countries we have studied (Figure 9-26). France and Norway lie at levels approximately 15% higher. The improvement in Denmark between 1972 and 1988, a reduction of nearly 15%, also stands out for Europe.

If we compare the price of gasoline and the fuel intensity of cars in major countries, we obtain a relationship that approximates a straight line (Figure 9-27).[14] Similarly, there is a relationship between the price of fuel and automobile fuel consumption per capita (also shown in Figure 9-27), although the functional form is less obvious and there is considerably more scatter. In either case, Denmark has the highest fuel prices and nearly the lowest specific fuel consumption. The low energy intensity of cars in Denmark, and the improvement during the period we studied, should not be surprising. The government taxes new cars more than does virtually any other government in Western Europe. These taxes have been progressively increased and there are virtually no company car tax privileges which contribute to the ownership of heavy or powerful cars as in England, Sweden, Germany and Norway. To call Danish cars "efficient" is misleading, however. They are simply small.

Danish modal energy intensities behaved differently from those in most other European countries. Danish automobile travel was about 4% less energy-intensive in 1988 than in 1972. This drop may seem small, but in most other countries, the energy intensity of automobile travel increased because the fuel intensity of automobiles only improved marginally while load factors decreased. The decline of modal intensities for Danish buses since the early 1980s is unusual, while the fluctuations in rail modal energy intensity are typical for Europe. Differences among countries reflect load factors and operations as much as intrinsic differences in vehicle intensity. The downward trend in the energy intensity of Danish air travel is also typical, but the fluctuations are unusual and highly uncertain. In virtually every other OECD country, the energy intensity of domestic air travel declined steadily because of improved aircraft design and increased proportion of seats filled. Energy use per passenger-km thus fell by as much as 40% in Europe and 50% in the U.S.

Figure 9-28 summarizes the difference between travel energy intensities in Denmark and other OECD countries. The first bar for Denmark shows actual energy intensity in 1988, measured in MJ/passenger-km. The second bar shows the figure that would have prevailed in Denmark given the nation's own modal energy intensities but the average modal mix for the OECD. It is clear that travel in Denmark is less energy-intensive than that of most other OECD countries. Moreover, when the average

[14] In this figure, the U.S. is seen in the upper left, then Germany and the U.K., then Japan, then Sweden and Norway, then France and Italy.

OECD modal mix is applied to Denmark's modal energy intensities, the resulting aggregate intensity is significantly higher than otherwise. In other words, Denmark's modal mix is intrinsically less energy-intensive than that for the other nations considered in the figure. Thus both modal mix *and* modal intensities (efficiency) reduce the energy intensity of travel in Denmark relative to its value in other OECD countries.

If we decompose the overall changes in energy use for travel in Denmark into components due to changes in sectoral activity, structure, and intensity, we find results that are rather unusual for the OECD. The increase in per capita travel in Denmark was somewhat below average for the countries we studied. On the other hand, Denmark stands alone as having actually reduced energy use, relative to 1972, because of significant shifts towards bus and rail travel. Indeed, Denmark had the greatest net increase in the share of rail and bus in total travel among the countries studied, although some of that increase was reversed in the past few years.

Energy efficiency in Danish travel showed a slight improvement between 1972 and 1988. Corrected for modal shifts, travel in Denmark experienced marginal decline in intensity of 2% between 1972 and 1988 (Figure 9-29). Most other European countries experienced an *increase* in this important indicator. Indeed, most European countries experienced an increase in energy use per passenger-km for automobiles (Schipper, Steiner, Duerr, An, and Strøm, 1992). Thus the relatively minor improvement in energy efficiency of travel in Denmark is actually rather good for Europe.

These findings can be illustrated in another way. Figure 9-30 shows the contrast between the evolution of per capita energy use for travel in Denmark and in other countries we have studied. The strong decline in the fuel intensity of autos led to a drop in this indicator for the U.S. In Japan and the EU-6, by contrast, per capita energy use for travel increased strongly. The increase in Denmark was much less.

What happened in Denmark? Clearly the impact on energy use of improvements in vehicle efficiency was partially offset by the decline in the load factors of automobiles. Instead, improvements were the result of the combination of slow growth in travel volume and a net shift to rail and bus in the mid 1980s that restrained energy use for travel in Denmark. A combination of higher fuel and travel prices, as well as two periods of economic contraction, reinforced by a tradition of taxation of automobiles, underlay this evolution. The fiscal burden on vehicles and travel in Denmark is one of the highest in all of Europe, hence energy use for travel evolved somewhat differently in Denmark than in other countries in Europe. But the use of automobiles is rising and that of bus and rail is lagging behind. If restraint is important, Denmark will have to work hard to restrain energy use for travel. More important, other countries may have to consider the fiscal stimuli the Danes have become accustomed to if energy use for travel is to be restrained elsewhere.

9.5. Freight Transportation[15]

Freight has played a minor role in driving fuel demand in Denmark and many other countries. But the increasing role of trucks and the worsening of fuel economy of truck freight in North America and

[15] Recall that in this report, "truck" refers to both small and medium-sized trucks (*varebiler* above two tonnes) and all heavy trucks (*lastbiler*).

many European countries, coupled with expectations of greater freight activity after the prospective Single Market, means that energy use for freight is on the rise. Additionally, pollutant emissions from freight vehicles, particularly from trucks, have only been lightly regulated in the past. Hence, future energy use for freight, dominated as it is by trucks, will be of increasing international concern.

In Denmark, the per capita level of domestic freight activity is high compared to other OECD countries in Europe (Figure 9-31).[16] The lack of a large base for raw materials processing in Denmark reduces the natural role of inland shipping and rail freight, which is important in countries where industries like forestry, mining, energy extraction, and ore benefaction play a great role, such as Sweden or the U.S. On the other hand, the importance of agriculture and food processing in Denmark does place large demands on bulk shipping, which compensates for the lack of raw materials processing in Denmark.

The modal mix of freight in Denmark is not unlike that for many countries in Europe, dominated by trucking (Figure 9-31). The rise in importance of pipelines (over 10% of freight in 1988) is also typical for a country with newly discovered oil and gas resources (U.K.), or one in which a significant switch to using gas has been underway (U.S., U.K., France, Germany).

The energy intensities of each freight mode in Denmark lie well within the range we found for other OECD countries. The important exception is trucking (Figure 9-32). Fluctuations in the energy intensity of truck freight are almost universal, a result of real uncertainties in data. Yet the upward trend evident from Danish data is highly unusual. The upward trend in the intensity of truck freight has been observed in many OECD countries, but the rate of increase has been considerably slower; the rise in importance of smaller trucks and the decrease in loading size apparently also has caused the intensity of truck freight to rise in the U.S. Contributing to the high value in Denmark may also be geography: there is simply very little long-distance trucking, measured by distance standards in most other European countries. Only where the vehicle intensity of trucks fell significantly were there large energy savings in this mode. While the clear increase in the energy intensity of trucking per se is not unusual, the rate of increase is cause for concern: either the data are wrong, or the important forces named above are causing an unparalleled increase in energy use for trucks.

The impacts of modal shifts and changes in modal energy intensities on freight energy use are similar to what occurred in most OECD countries. In most nations, the importance of trucks increased during the 1970s and 1980s, raising energy use proportionately. That the aggregate intensity of freight in Denmark increased by 49% (excluding pipelines) stands out as among the highest increases we have observed. When we hold all factors except modal intensities constant, the results for Denmark are dramatic, as Figure 9-33 shows.

The contrasts in energy use for freight in Denmark and other countries are best illustrated in Figure 9-34. While per capita energy use in Denmark is close to that in the remaining European countries we studied, the increase over the period shown was somewhat greater than in other nations. The magnitude

[16] Transit traffic between continental Europe and Scandinavia plays a small role in the total freight shipments of Denmark. We have counted this freight in the total, since we are unable to separate energy use for this freight from that for domestic freight. About half of the "transit" traffic is actually Danish freight headed for other countries by rail or truck.

of the decline in the efficiency of truck freight is the principal reason why Denmark is different.

Finally, many observers expect that one important impact of the possibility of a Single Market will be greatly increased international freight. Trends in truck energy use for freight may be different in this activity, since international trucking is dominated by larger trucks that travel longer distances, mostly on motorways. Still, restraint in energy use in trucking will have to be an important part of any strategy to restrain future energy use.

9.6. Summary: Energy Use in Denmark and Other Industrialized Countries

In this concluding section we summarize the results of our comparison of energy efficiencies in Denmark with those in other countries. We also compare the achievements in energy savings in Denmark with those in other major countries. (See Schipper, Sprunt, Christie & Kibune 1992, Schipper, Howarth & Geller 1990, Schipper, Howarth & Wilson 1990, and Schipper 1988.) We find that the structure of energy use in Denmark is somewhat less energy-intensive than in other important OECD countries. Intensities of energy use in Denmark, on balance, are lower than in other countries. But intensities dropped more in Denmark than in most of the other countries. Thus, in 1972, Denmark was a relatively energy-intensive country. During the ensuing period up to 1988, Denmark's economy and energy use were transformed considerably.

9.6.1. Is Denmark Different?

Figure 9-35 shows per capita primary energy use by sector in five countries (Denmark, Norway, the U.S., West Germany, and Japan) in 1988. The obvious variations arise out of differences in the levels of sectoral activity, the structure of activity in each sector, and the energy intensities of each activity, all of which shape each country's energy use. Differences in fuel mix, which we have not analyzed in detail, play some role as well.

The aggregate figures presented in Figure 9-35 hint at some of the most important differences in energy use that we will encounter. Per capita energy use in Denmark lies near the middle for the five countries shown, well below that of the U.S. or Norway, but close to that of Japan or West Germany. Consumption in some sectors (residential, for example), is greater in Denmark than in most of the other countries.[17] In other sectors, notably manufacturing/other industry and, travel (if Japan is excluded), per capita consumption is considerably less in Denmark. These aggregate comparisons illustrate broad differences between Denmark and the other countries, yet they tell us very little about the real differences among the countries. To understand these, we must consider activity, structure, and intensity in each sector.

Sectoral *activity* differs among the five countries. Since we have normalized by population, part of the difference arising from differences in activity—the effect on the household sector—disappears. Differences in overall economic output as measured by GDP (in industry, or in services) account for some of the differences, too. As the international comparison showed, per capita freight in Denmark is

[17] The U.S. and Norway rank higher because of the high penetration of electricity, which increases the primary energy values shown here.

somewhat higher than in the other countries (except the U.S.). And the fact that Danes travel about as much as Germans or Norwegians, but more than Japanese and far less than Americans account for other important differences in *activity*. In all, these activity differences would tend to lower per capita energy use in Denmark relative to that in the other countries.

The *structure* of energy use in Denmark differs from that of the other four countries in important ways:

• Danish homes are larger than those in every country except the U.S., and the Danish climate is colder than that in every other country shown except Norway. Central heating is more prevalent in Denmark than in any other country shown. Electric appliance ownership lies about equal to that of Norway and West Germany, above the levels in Japan, but below the levels in the U.S. These factors increase household energy use in Denmark relative to values in the other countries shown.

• Danish manufacturing produces less energy-intensive products than does manufacturing in all other countries analyzed. This effect would reduce energy use in Danish manufacturing relative to that in the other countries.

• Denmark has more built area in the service sector, per capita, than all other countries except the U.S.

• The mix of travel modes in Denmark, while considerably more energy -intensive than that of Japan, is still less energy -intensive than the mixes in the other three countries. Danes own fewer cars than Americans, West Germans, or Norwegians, but more cars than Japanese. The affect of this low car ownership on energy use is partially offset by the fact that Danes drive their cars more than all but Americans.

• The mix of freight modes in Denmark is similar to mixes in Japan, West Germany, and Norway, but is far more reliant on trucks than is the mix in the U.S.

A rough weighting of these structural factors suggests that, other things equal, they cause Denmark to consume slightly less energy per capita than the other countries, except for Japan.[18]

The differences in *energy intensities* between Denmark and the other countries are important as they are closely related to energy efficiency.

• Danish space heating in homes and buildings is the most efficient of the countries shown, with Norway and the U.S. close behind. Only homes in Sweden show consistently better thermal performance than those in Denmark. Danish appliances are slightly more efficient than those in the other countries.

[18] Energy use in Japan, although heavily weighted towards industry, has a structure that reduces energy use there relative to all countries shown, because the level of travel (and its structure), and the size of homes (and quantity of equipment) is so low relative to the U.S. and Northern European countries. Similarly, energy use in the U.S., although less influenced by industry than the energy use in many other countries, has a structure that *raises* energy use relative to all countries shown, because of the enormous role of transportation (both travel and freight), and the far greater per capita area of both homes and buildings in the service sector. But Denmark is considerably less dependent on heavy industry than either West Germany or Norway, and has lower levels of both travel and freight. The only sector that stands out as more energy-intensive in Denmark than in other countries is the residential sector. However, if per capita floor area is multiplied by heating degree-days for both Denmark and the U.S., the results are similar. This means that the importance of the colder climate in Denmark is about offset by larger house area in the U.S.

- Danish industry's energy intensities are about average for the countries presented.

- Danish travel is less energy-intensive than travel in every other country, largely because Danes have the least fuel-intensive cars of any country depicted.

- Danish freight is the most energy-intensive of any country we have studied because Danish truck freight is very energy-intensive.

On balance, energy intensities reduce energy use in Denmark slightly relative to the other countries. The greatest differences, however, are in sectors dominated by small consumers, services, homes, and travel, sectors where energy use has been taxed very heavily.

From this brief comparison we can explain why per capita energy use in Denmark was so low in 1988 compared to that of the other countries (except Japan). First, sectoral activity levels are in large part comparable or slightly lower than those in the other countries (again, with the important exception of Japan.) Second, the structure of Danish energy use is *less* energy-intensive than that in any of the other countries except Japan. Third, Danish energy intensities are average or lower than average, except for those for freight. These factors reduce energy use in Denmark relative to most wealthy industrialized countries.

In Chapter 8 we noted that the growth in energy services in Denmark—the combined effects of changes in sectoral activity and changes in the structure of each sector—pushed up energy use in Denmark at a lower rate than the growth in GDP. In other words, the structure of Danish energy use evolved towards less energy intensity between 1972 and 1988. This means that in 1972, Denmark was a more energy-intensive country than in 1988. This change, coupled with the high level of energy savings in Denmark, led to important reductions in energy use there relative to developments in other countries, as discussed in the next section.

9.6.2. Energy Savings Achievements Since 1972: International Comparison

In this section we review the energy-saving achievements in Denmark, comparing them to those we have measured in other countries. In the aggregate, Denmark ranks at the top of the list of energy savings compared to either 1972 or 1988 consumption. But these savings were focused in only a few sectors, which is cause for some concern. In other countries, savings were distributed more evenly about many sectors. Finally, the rate of savings in Denmark has slowed markedly. This observation is consistent with an international trend that reflects changes in both the kinds of energy-using equipment being designed and sold in the largely international market, as well as conditions in each country that affect the adoption of energy-using—and energy-saving—equipment.

Our specific findings are:

- Denmark leads all OECD countries we have studied in savings of heat and electricity in households since 1972. The dramatic decline in space heating intensities is not surprising because Danish households and building owners faced the greatest relative changes in energy prices for electricity and heating fuels of virtually all OECD countries. Moreover, the Danish effort to promote energy savings in households and services was one of the most thorough of any country. This effort continues today with particular focus on electricity in both households and in services.

• Danish manufacturing intensities declined less than those in other countries studied in detail (except Norway), but about average for the six European countries we analyzed (Howarth and Schipper 1991). Danish industry experienced relative price changes similar to those in other countries. But the structure of Danish industry is weighted less towards energy-intensive production, which may explain why the reductions in energy intensities in Denmark were less than elsewhere: energy costs play a smaller role in overall costs there than in the other countries.

• The fuel intensity of cars on the road in Denmark fell by over 15% in the period we studied, one of the largest improvements we measured among European countries. At the same time, the number of people per car decreased somewhat. Overall, the energy required to move a Dane one kilometer was only slightly less in 1988 than in 1972. By contrast, this indicator increased in both West Germany and Japan, fell slightly in Norway, and dropped dramatically in the U.S. Danish drivers saw somewhat greater fuel price increases than did those in the other countries (through 1988), and always faced very high taxes on new cars. This helps to explain the somewhat better performance of this sector than in Japan or West Germany, where neither fuel prices nor car taxes increased as much as in Denmark. Imposition of fuel efficiency standards on new cars in the U.S. is an important reason why so much improvement occurred there.

• Danish freight showed the one of the worst performance of freight of any country we studied. The important role of relatively inefficient truck freight lies behind this result. This is likely related to Denmark's small geographic size and the increasing role of smaller vehicles in the freight system. Haulage in the other countries is more reliant on larger, long-distance trucking, particularly as long-distance traffic shifted from rail to truck.

We summarize the impact of energy savings on energy use in several other countries, including Norway, the U.S., West Germany, and Japan using the same measures discussed in Chapter 8. Energy-saving achievements in Denmark occupy a leading position among those of the countries we have studied. Figure 9-36 shows the impact of changes in energy intensities on primary energy use over time in each of these countries between 1973 and 1988, all other factors held constant. (This is the first method of measuring energy savings discussed in Chapter 8.) For comparison, energy use in 1973 is set to 100. It can be seen that the intensity effect in Denmark was second to that observed for the U.S., and slightly greater than that of West Germany. By contrast, Japan, which is often credited with leading energy savings achievements, lies in fourth place, while Norway shows almost no energy savings. Note the slowdown in the rate of decline of the intensity indicator after 1985 in every country.

Rankings of these changes by sector explain the position Denmark attained. Figure 9-37 compares the energy intensities in 1988 with their 1973 values on a sector by sector basis. As noted above, Denmark leads in energy saving in homes (and buildings), achieved average performance in manufacturing, other industry, and travel, but actually lost considerable ground in the freight sector.

Using the second method described in Chapter 8, we can estimate how much more energy would have been consumed in Denmark and the other countries had intensities not fallen. Figure 9-38 shows the results, portrayed for each country as the amount by which energy use would have differed in any given year had not energy intensities fallen. For Denmark, 31% more energy would have been required in 1988 without energy savings, close to the 29% in the U.S. West Germany lies in third place, at 22%, followed by Japan (17%) and then Norway (3%).[19] The position of Japan may seem odd, given Japan's reputation for energy efficiency. In effect, the improvements in Japan were concentrated into two sectors, manufacturing (with other industry) and freight, that are tied to international competition. Other sectors performed poorly by our measures, hence the overall results for Japan fall behind those for Denmark, the U.S., and West Germany.

We can now compare the importance to the evolution of total energy use of both intensity changes and structural or activity changes in Denmark with developments in other countries. Figure 9-39 shows the activity, structure, and intensity effects for Denmark and the other countries studied. The activity effect in Denmark had a small impact on energy use, far less than that in Japan or the U.S. The structural effect was median; structural changes boosted energy use in Norway and West Germany far more than in Denmark. The intensity effect was second only to that in the U.S.

Figure 9-40 shows the impact of changes in activity and sectoral structure in a different light. We calculate the changes in energy services for each country (Cf. Chapter 8). By this measure, Denmark experienced the *smallest* increase in energy services, 32% as weighted by 1973 energy use patterns. As Figure 9-40 shows, growth in energy services kept pace with that of GDP in the U.S. and Germany but lagged GDP considerably in Japan and Norway. This helps explain the difference between the intensity effect and the change in the actual ratio of energy use to GDP that we have measured in each country. In Denmark the ratio of energy/GDP fell considerably more (27%) than could be explained by the decline in intensities alone (20%). In other words, the ratio of energy/GDP overstates considerably the decline in energy intensities, and therefore the improvements in energy efficiency, achieved in Denmark. This distortion is considerably greater if we consider Japan or Norway, but smaller for the U.S. and negligible for West Germany.

These international comparisons reinforce an important lesson: The ratio of energy use to GDP is poor measure of energy efficiency; changes in that ratio over time give a poor measure of improvements in efficiency over time. This measure distorts the comparison of countries' performances over time. The distortions that arise when this simplistic ratio is used for Denmark are significant, although not the largest among the countries we have studied.

9.6.3. Issues and Implications

This international comparison shows that improvements in energy efficiency in Denmark between 1972 and 1988 had a significant impact on total energy use there. The achievements rank among the greatest of the five countries we have studied in detail. From other evidence (Schipper 1991; Schipper and Meyers et al. 1992) we can assert that inclusion of France, Great Britain, Italy, and Sweden in this comparison would not alter Denmark's position among the leaders in energy saving. But several results from

[19] The base year for other countries we have studied is 1973. To make the comparison with these countries fair figures in this section reflect extrapolation of 1972 trends in Denmark to 1973, for which Danish data were only available for one sector. Figures given in the individual sectoral chapters for Denmark use 1972 as the base year.

this comparison have implications for considerations of future efficiency achievements and energy needs. Given the well-documented potential for further increases in energy efficiency in Denmark, Danish policy makers should focus on the problems named below if they want to harvest that potential.

First, the Danish energy-saving achievements were concentrated in the household and service sectors. Improvements in efficiency in manufacturing kept pace with those in most other countries. Improvements that occurred in the travel sector were minor, albeit better than average for Europe. The energy efficiency of travel in Denmark is now improving over its 1972 level, a better situation than in most countries in Europe or in Japan. The situation with freight, however, raises concerns since the trends towards higher energy intensity are so much more marked than in other countries. Thus, Denmark scores high for energy savings in the aggregate, but this achievement hides the mediocre performance of the travel sector and poor performance of the freight sector.

Second, the slowdown in the rate of improvement of efficiency economy-wide is consistent with what we have found in most other industrialized countries. This slowdown is related to the stagnation or fall in real oil prices, which has influenced most domestic fuel prices as well. Related to this development is the relaxation of efforts by multinational and local firms to improve the energy efficiency of consumer products, although some efforts, such as the coordination of electricity efficiency efforts in Scandinavia, have brought new products to the market. Thus Denmark, like other countries, will have to act with resolution to stimulate both development of more energy-efficient technologies for domestic industries (or in those producing for the world market), as well as to accelerate the uptake of efficiency measures in the Danish economy.

Finally, we showed that *both* structural changes *and* intensity changes helped to reduce energy use in Denmark, both absolutely and relative to economic activity, during the two decades we studied. Whether both kinds of change will continue to lead to restraint in energy use, particularly in a period when energy prices are likely to be relatively stable, is uncertain. In the next chapter, we address some of the issues raised in this report that affect future energy use in Denmark.

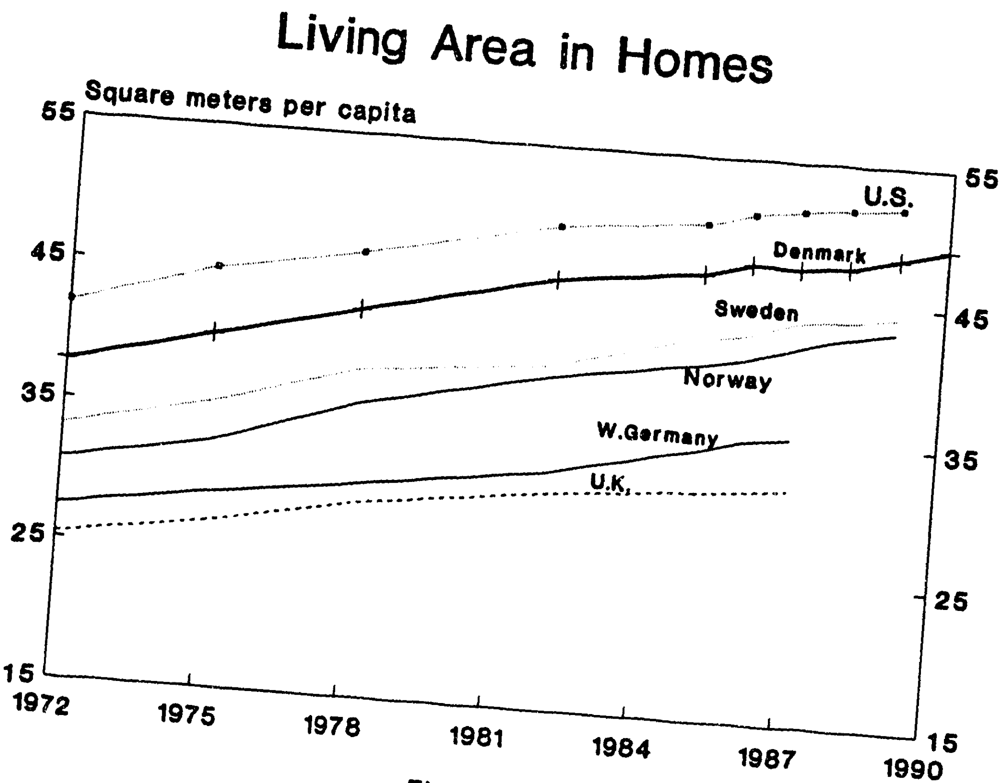


Figure 9-1

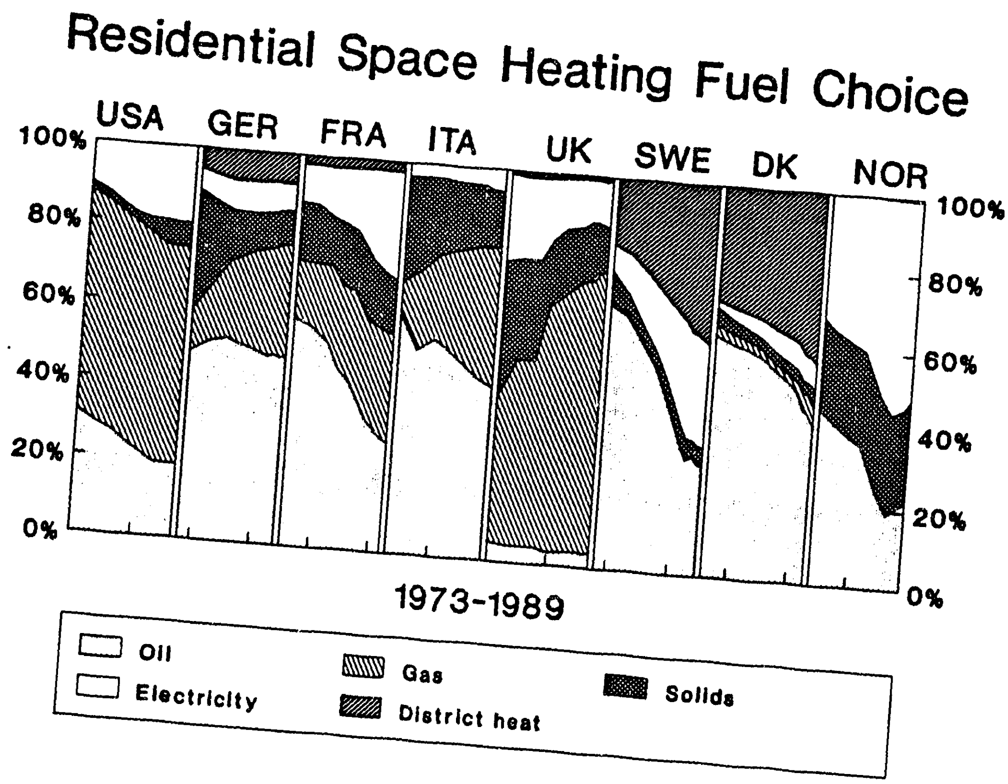


Figure 9-2

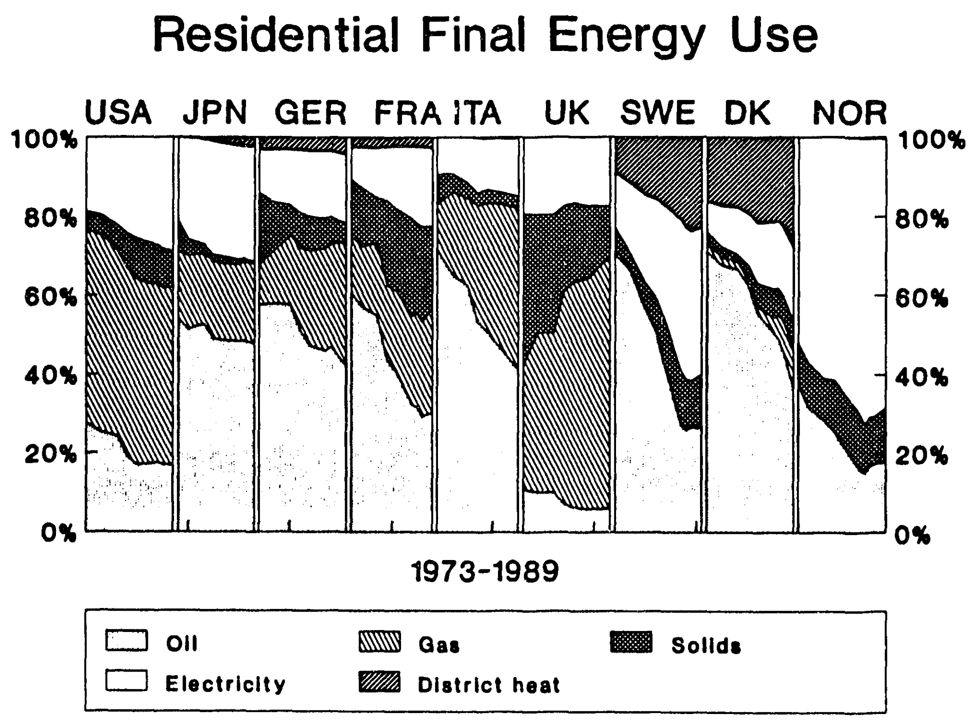
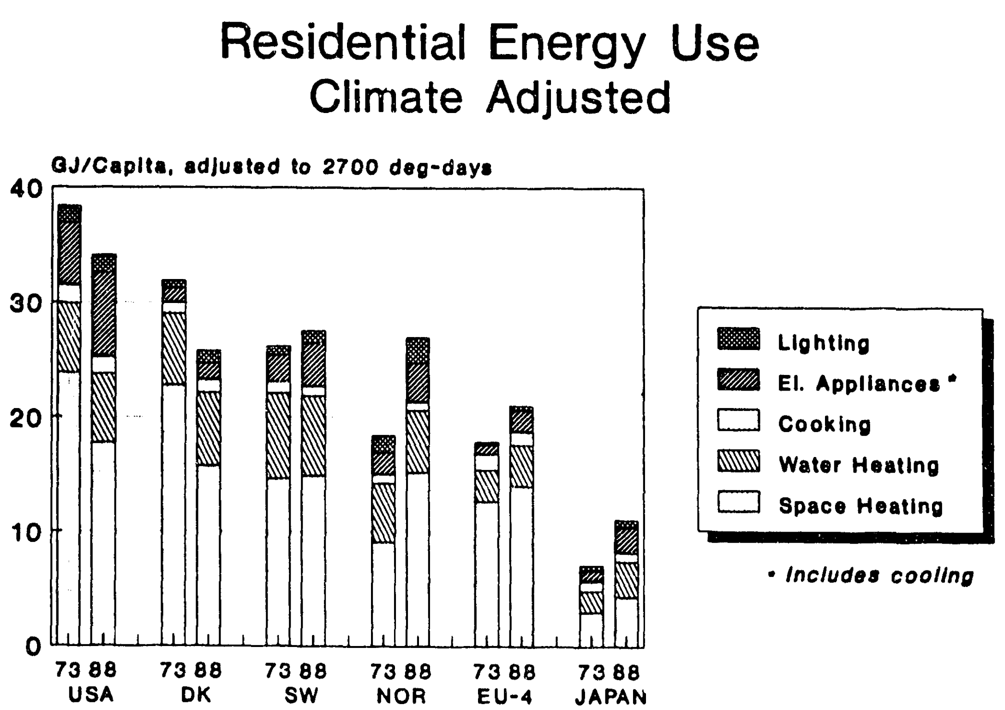


Figure 9-3



EU-4: Ger, Fra, Ita, UK.

Figure 9-4

U.S. and Europe Space Heating Intensity
Useful Energy

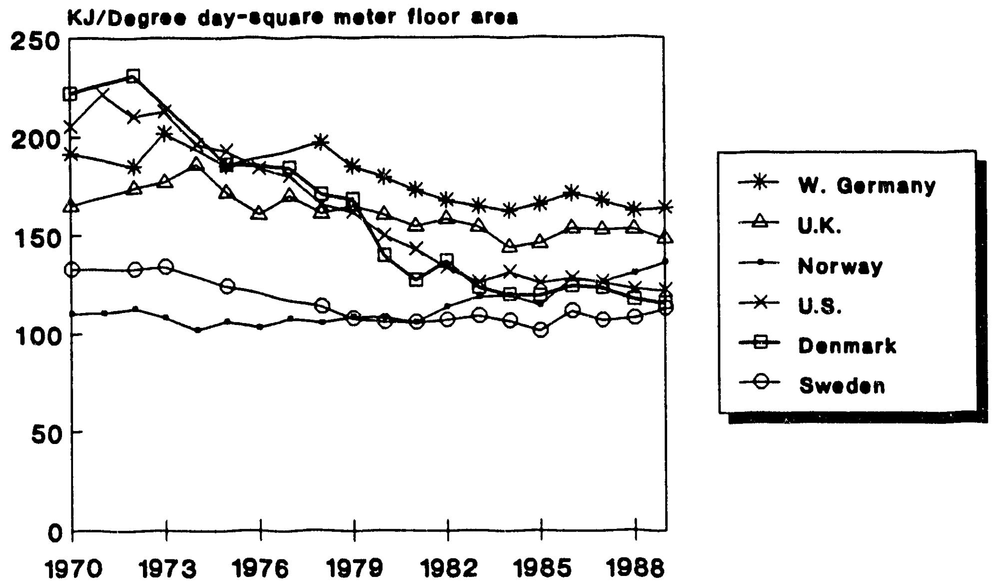
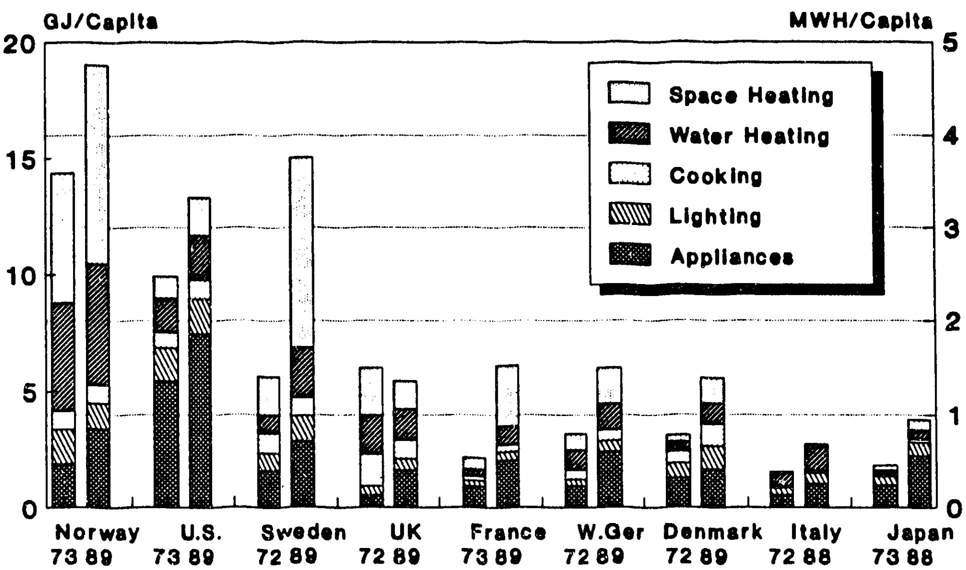


Figure 9-5

OECD Household Electricity Use
1972/3 vs. 1988/9



Norway space heat reduced by 7.5 GJ

Figure 9-6

Energy Use For Appliances and Lighting

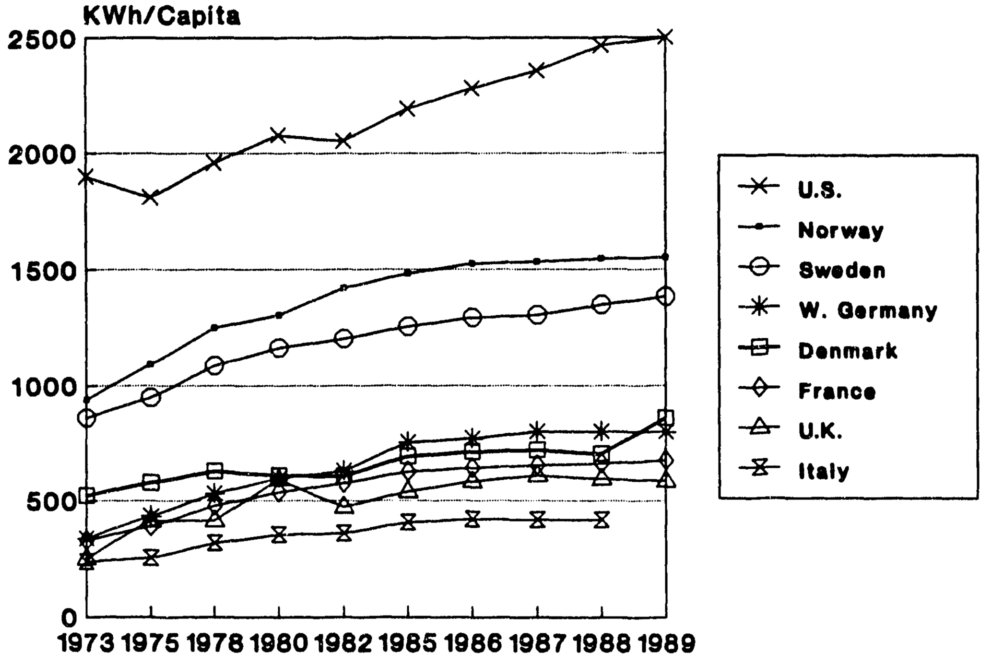
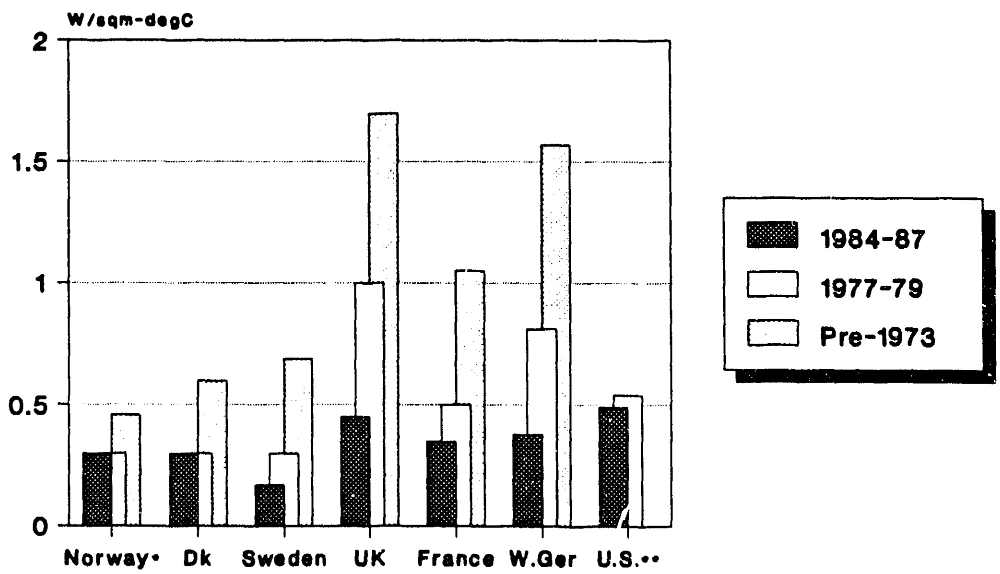


Figure 9-7

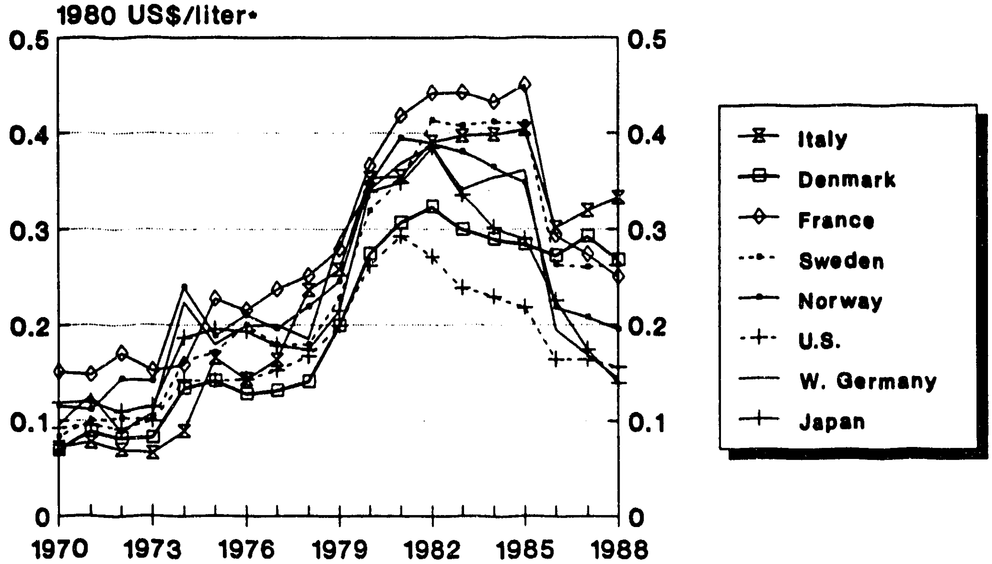
Thermal Performance Standards
Maximum Heat Transmission Values: Walls



* 1987 value for entire wall + windows
** Pre-1973 value not available for U.S.

Figure 9-8

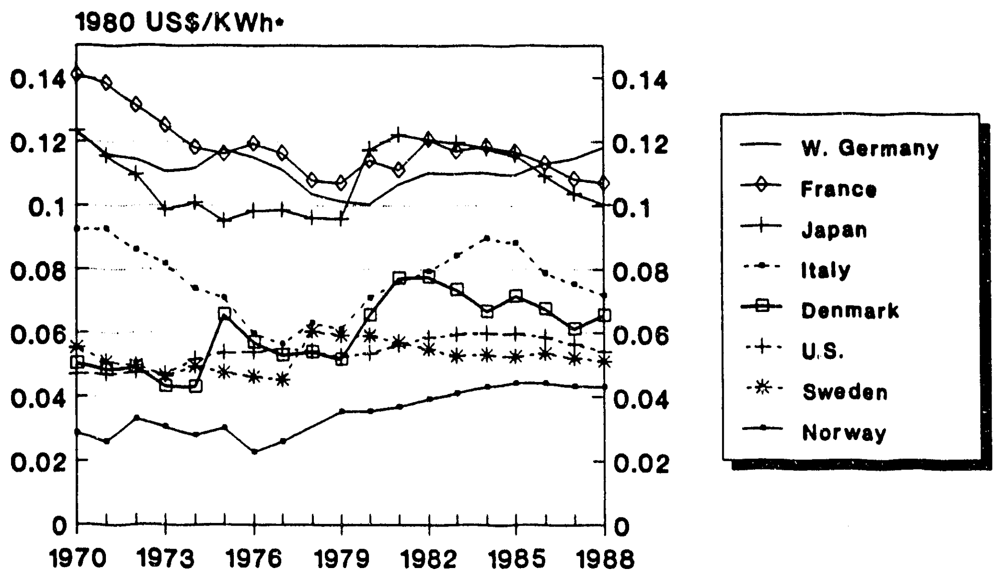
OECD Residential Oil Prices
1970 - 1988



• Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-9

OECD Residential Electricity Prices
1970-1988



• Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-10

Manufacturing Energy Use

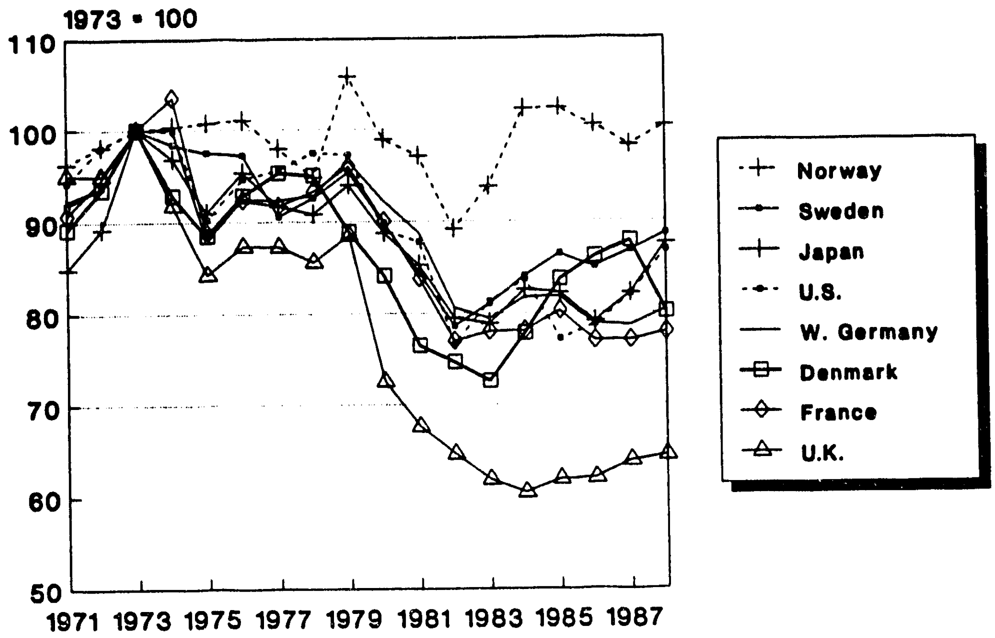


Figure 9-11

Manufacturing Value Added

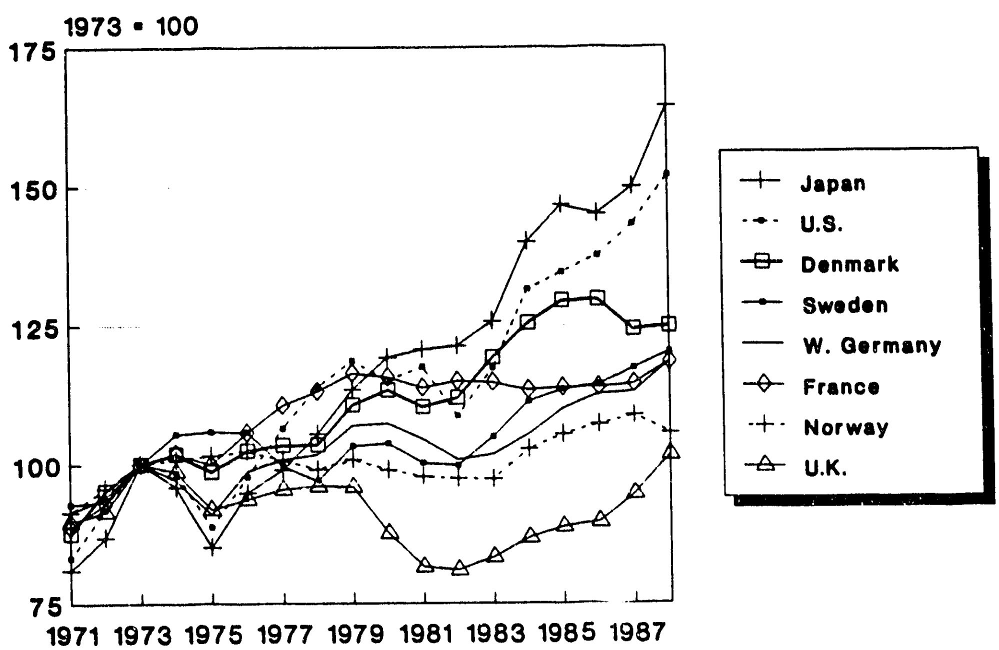


Figure 9-12

Manufacturing Energy Intensity
Constant 1973 Industry Structure

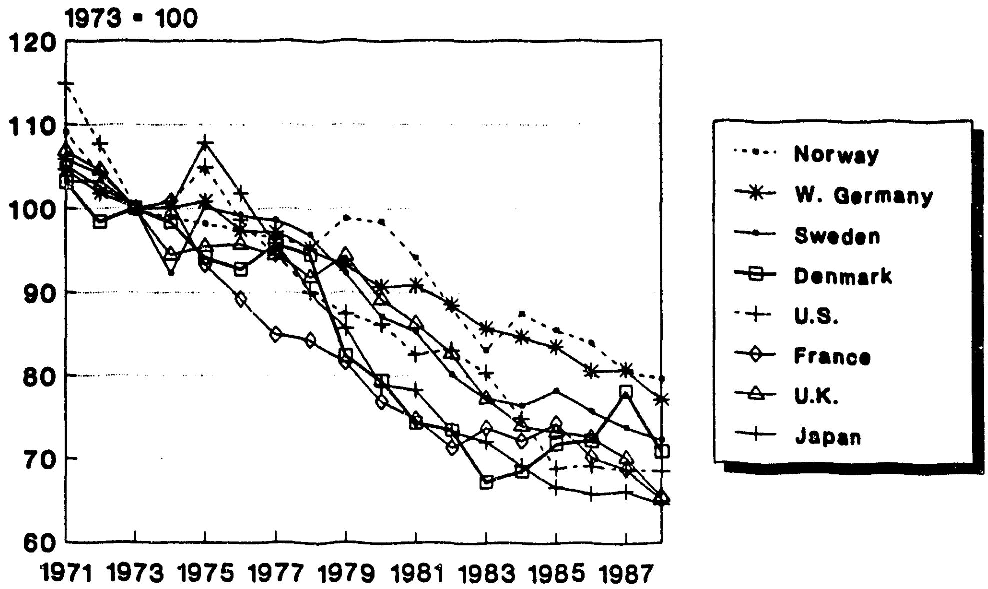


Figure 9-13

Manufacturing Energy Use
Actual Industry Structure
1973 Output and Intensities

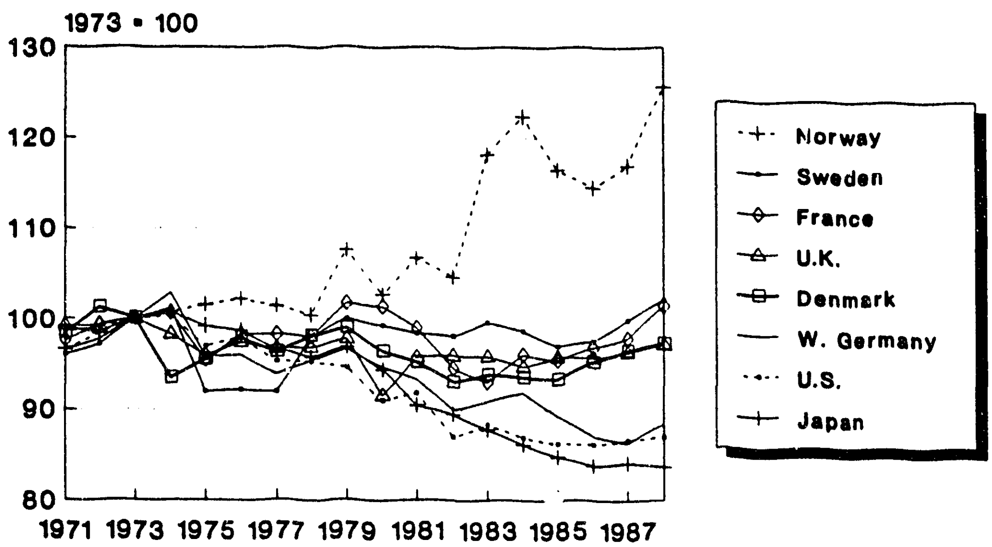
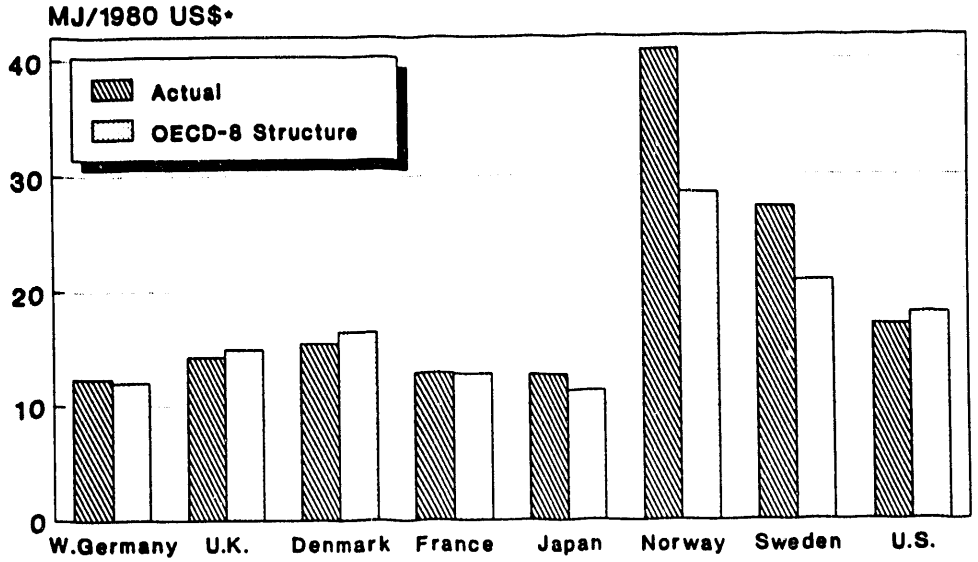


Figure 9-14

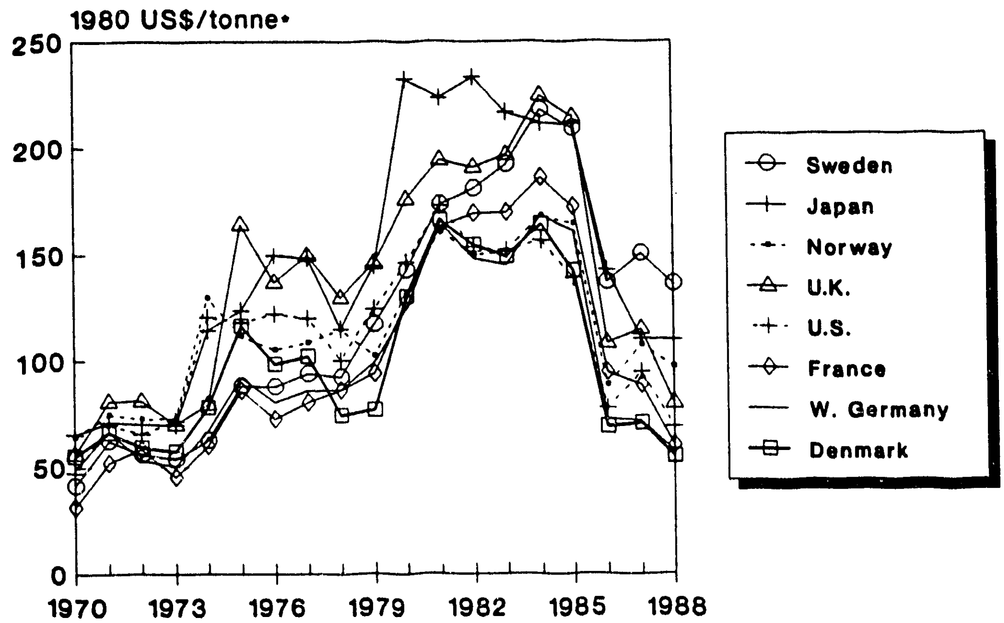
Manufacturing Energy Intensity 1988



* Converted to US$ using Purchasing Power Parity (PPP)

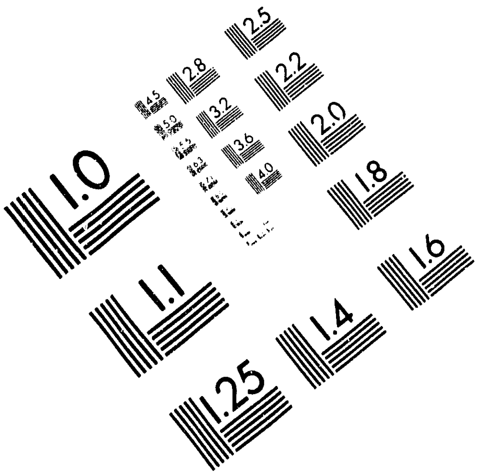
Figure 9-15

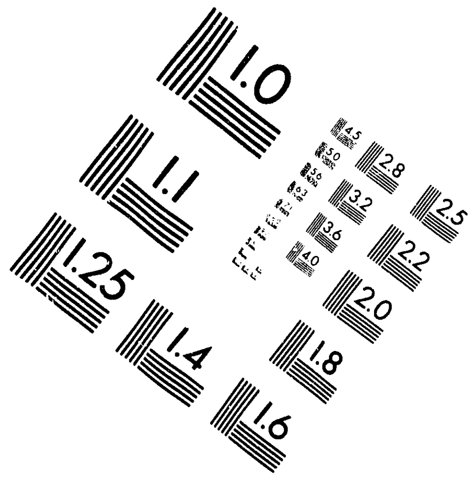
Industrial Heavy Fuel Oil Prices



* Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-16





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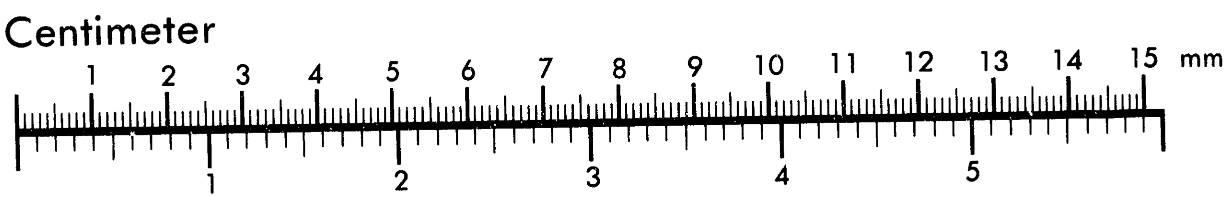

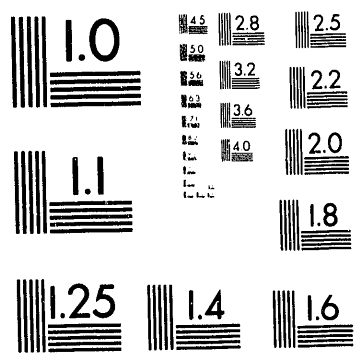

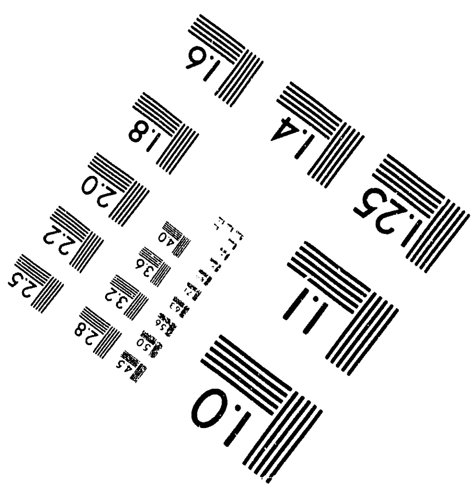

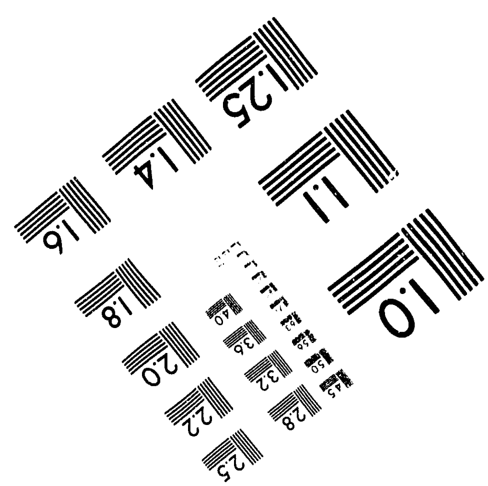

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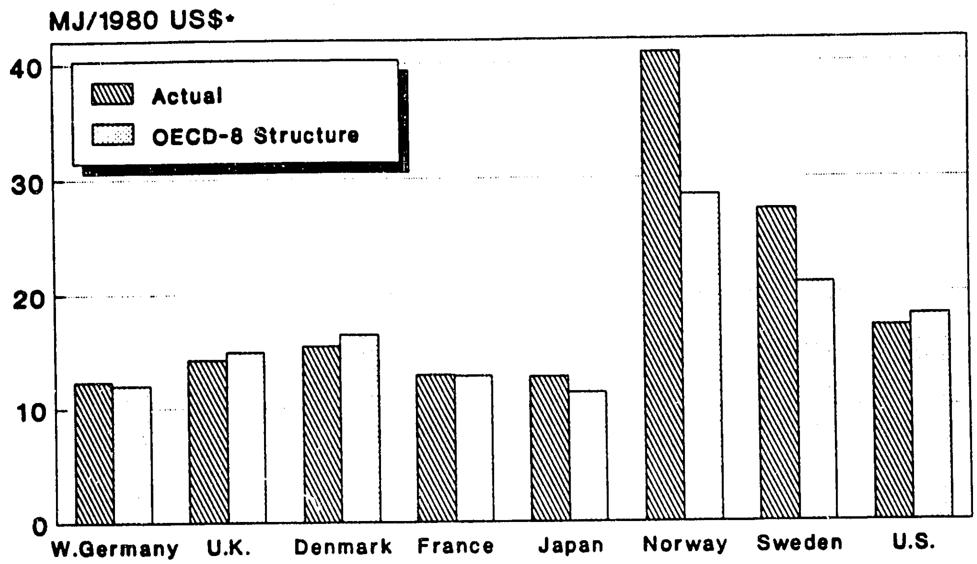
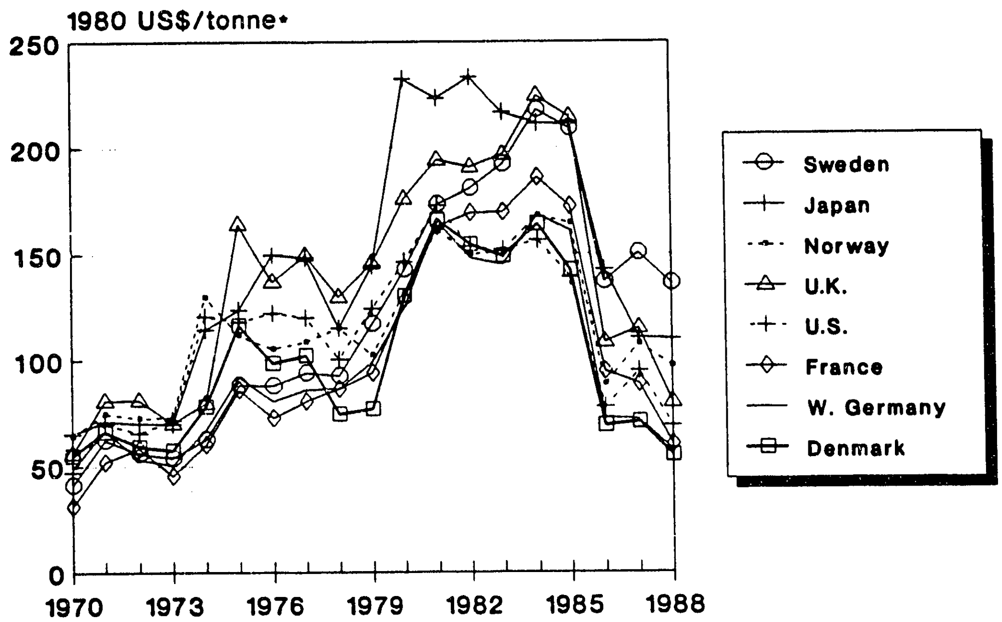
Manufacturing Energy Intensity 1988



* Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-15

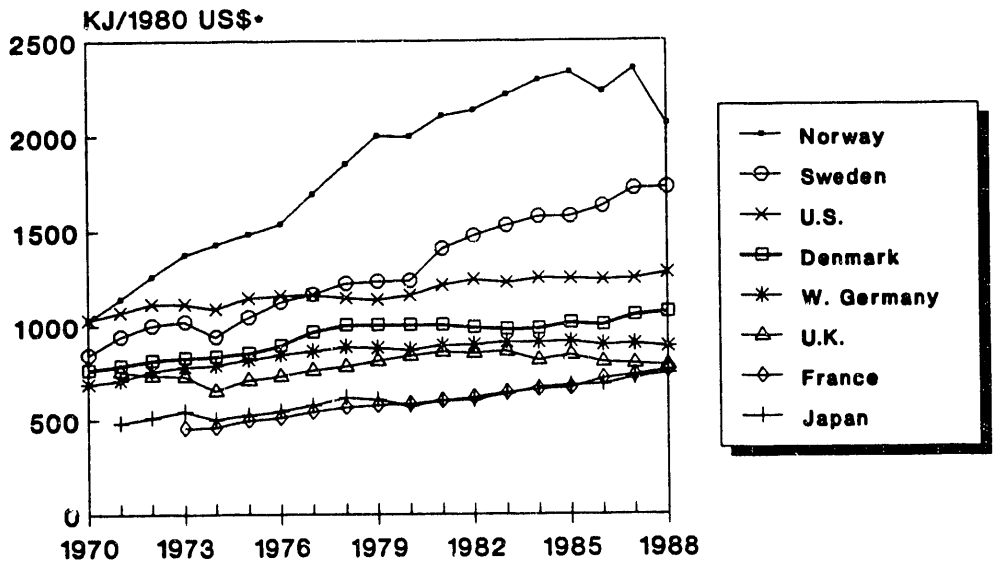
Industrial Heavy Fuel Oil Prices



* Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-16

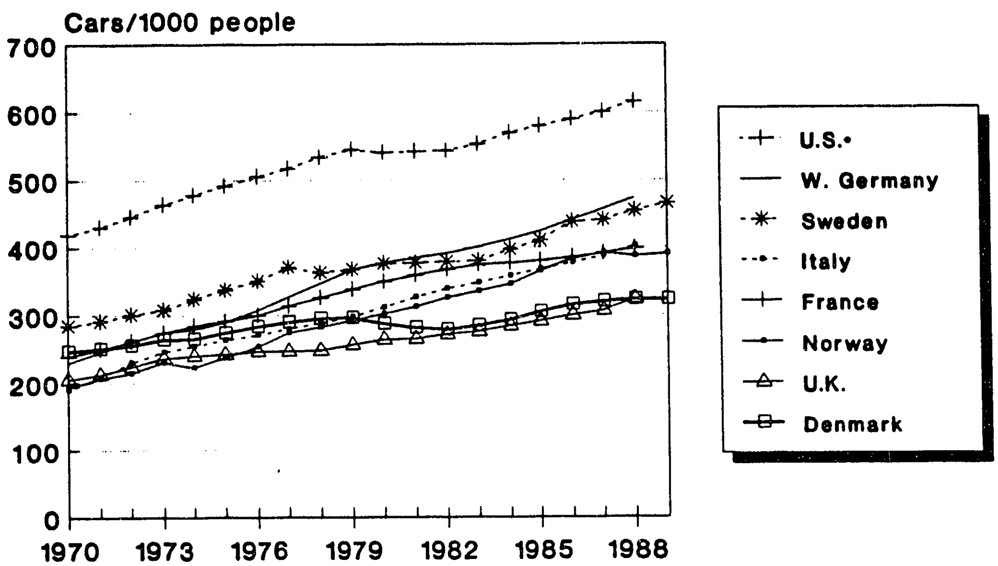
Service Sector Electricity Intensity
Energy Use per Unit of Services GDP



• Converted to US$ using Purchasing Power Parity (PPP)

Figure 9-19

Car Ownership in OECD Countries
1970 - 1989



•Includes personal light trucks

Figure 9-20

Distance Travelled per Automobile

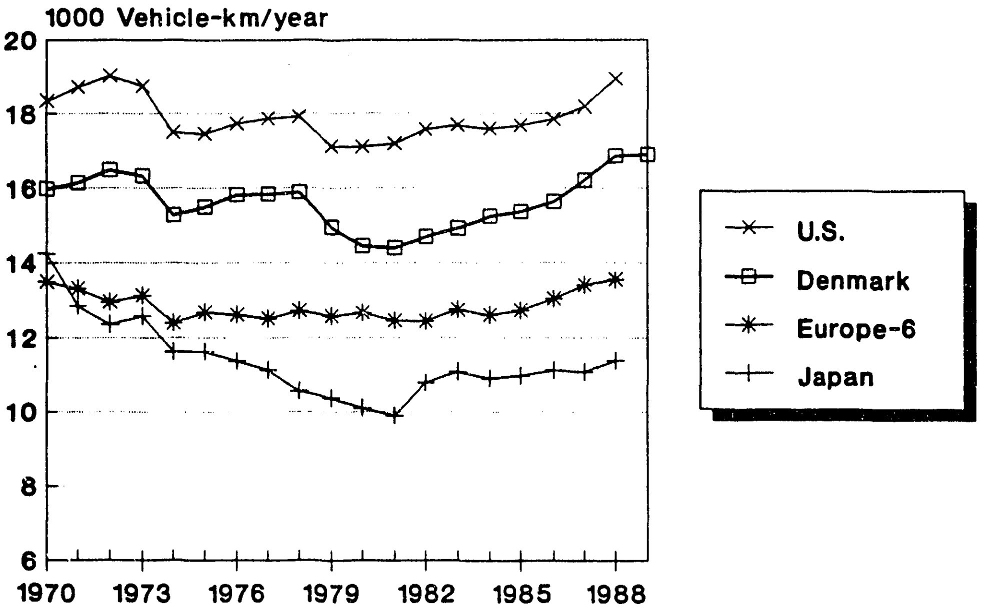
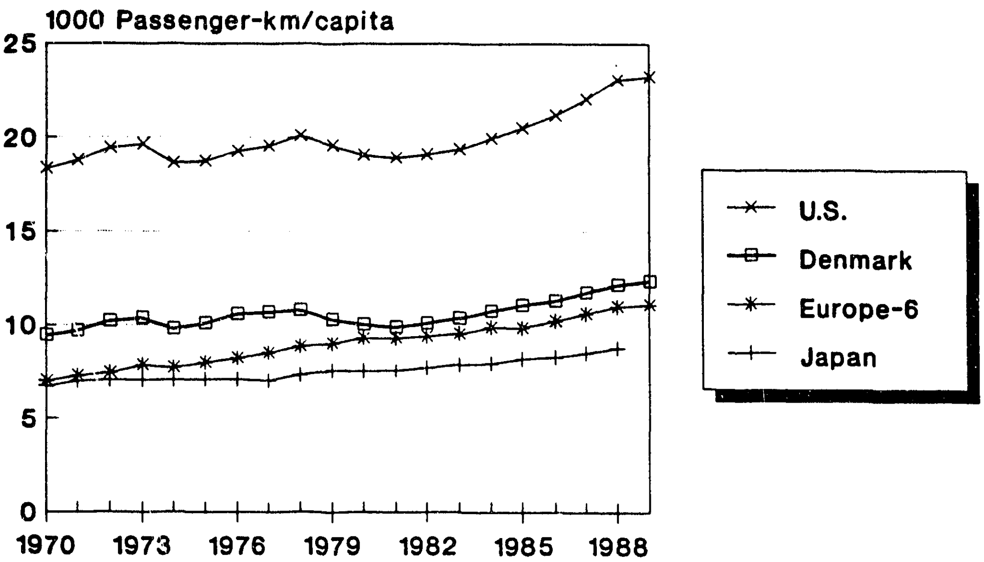


Figure 9-21

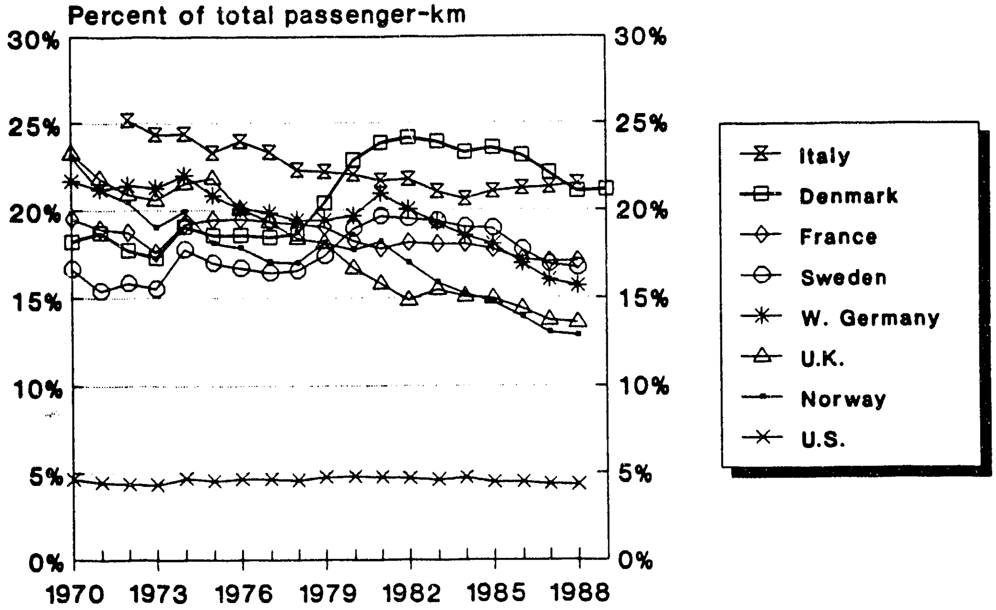
OECD Per Capita Travel 1970-1989
All Modes



US and Europe 1989 preliminary

Figure 9-22

Rail and Bus Travel



Japan share of rail & bus in 1988 was 39.5% down from 55.8% in 1970.

Figure 9-23

Automobile Travel

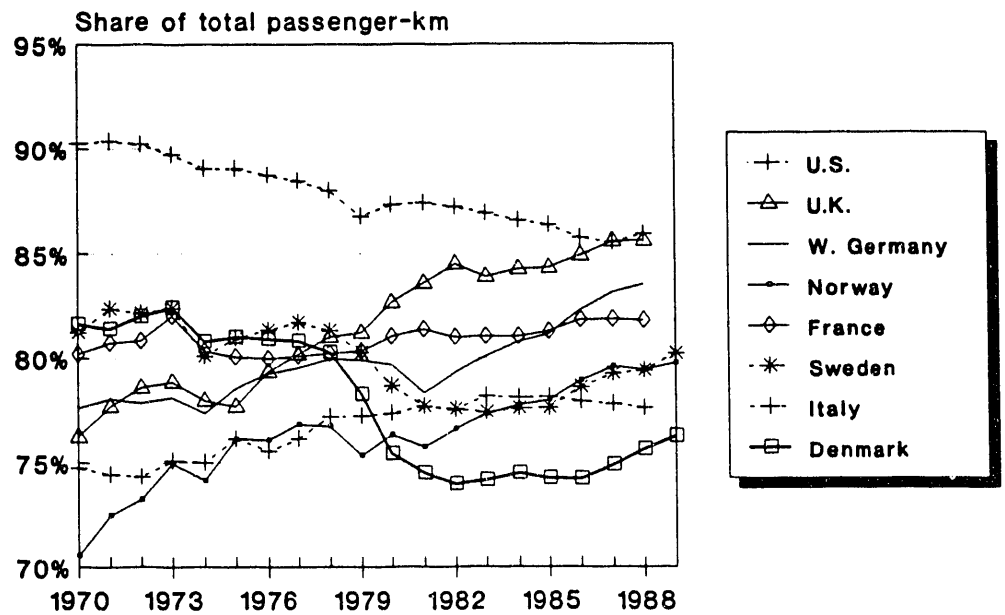


Figure 9-24

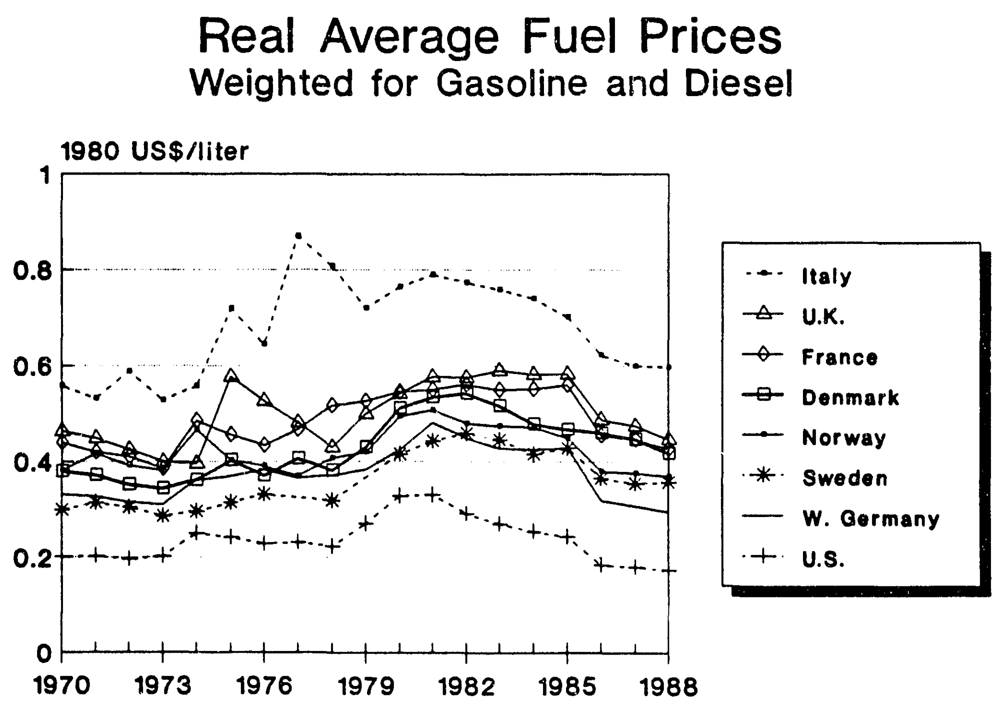


Figure 9-25

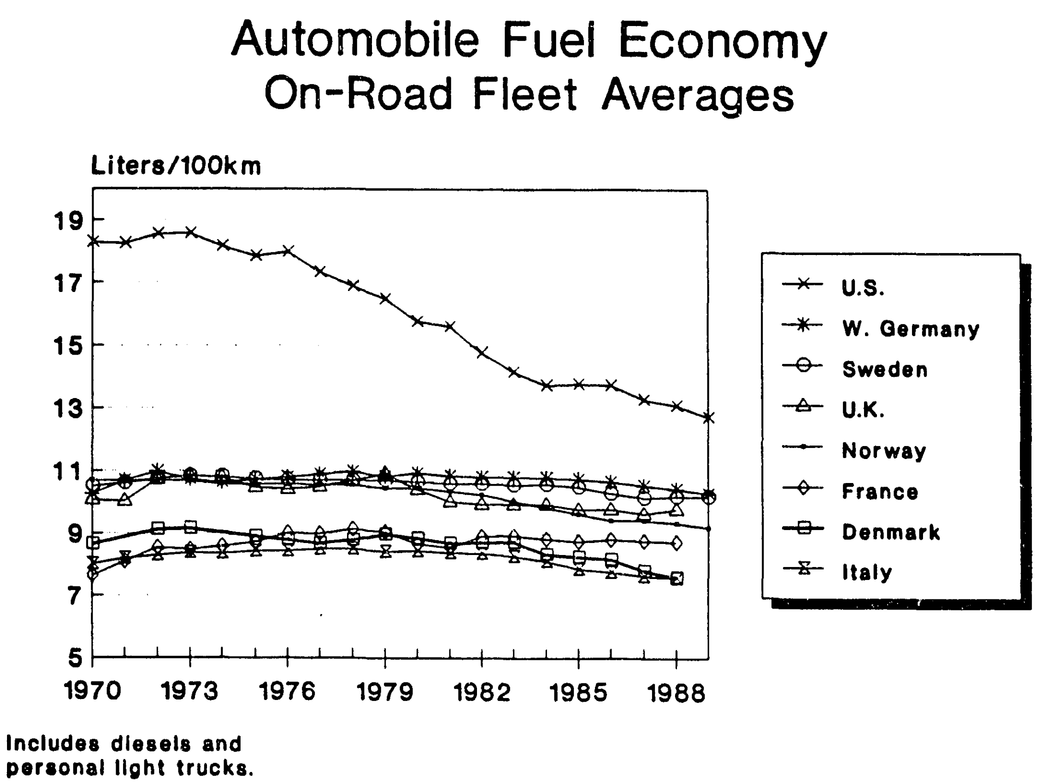


Figure 9-26

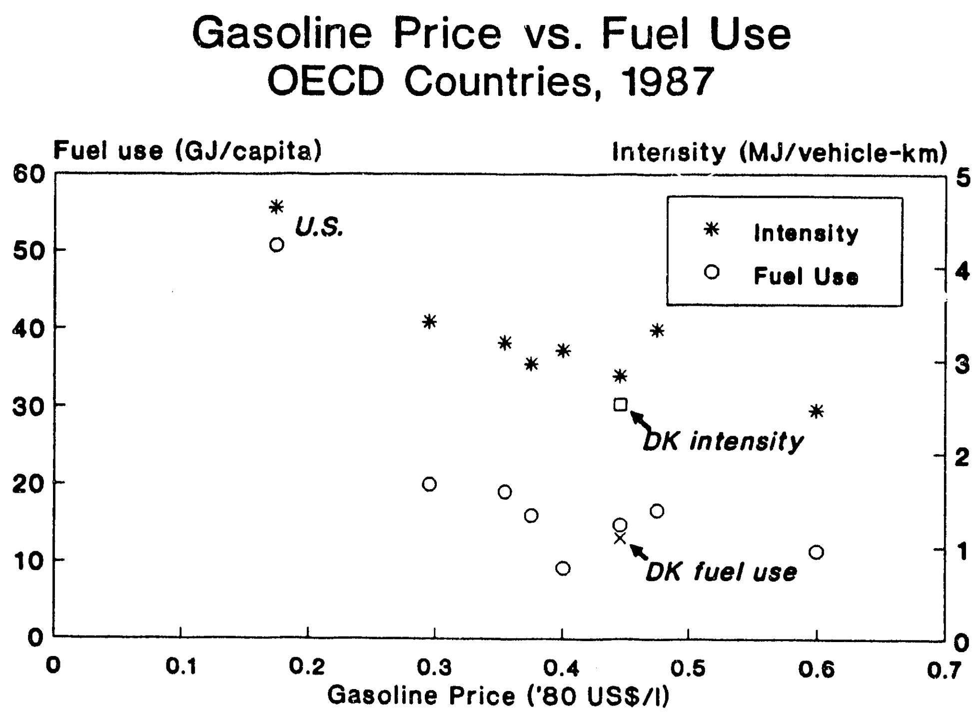


Figure 9-27

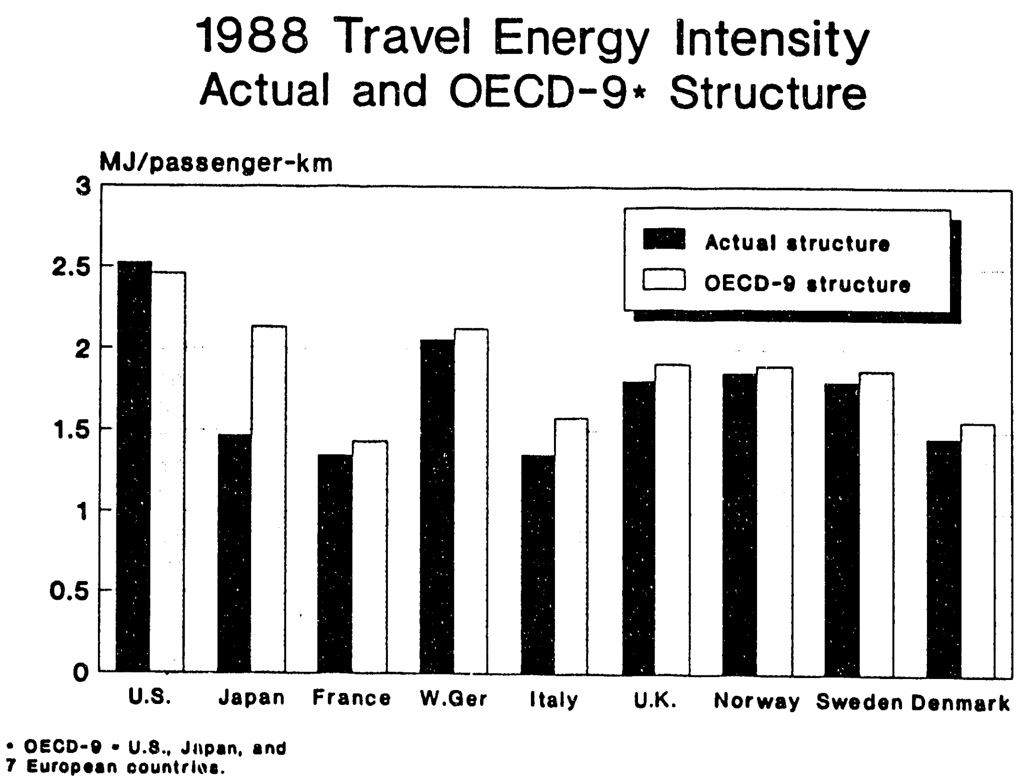


Figure 9-28

Energy Intensity of Travel
Holding Modal Structure Constant

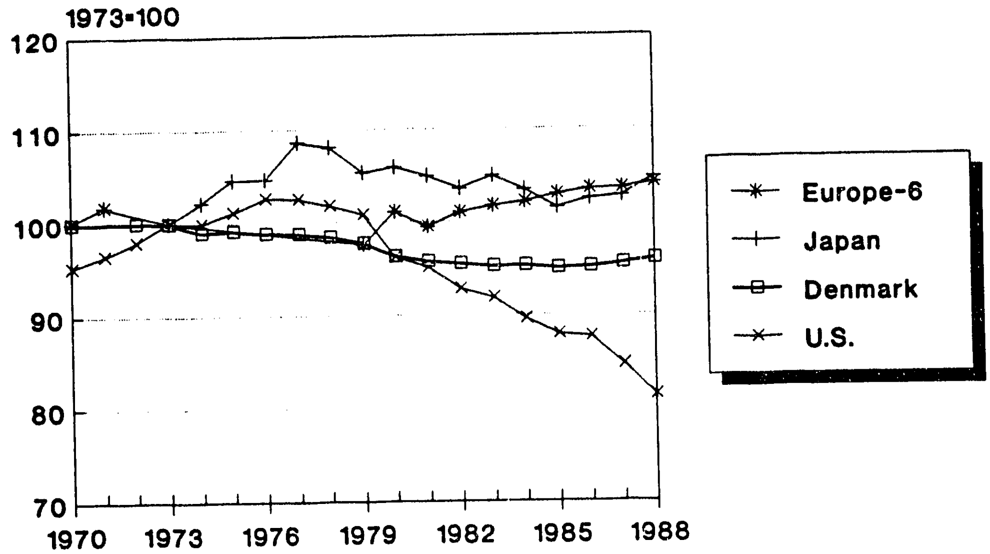


Figure 9-29

Energy Use for Travel

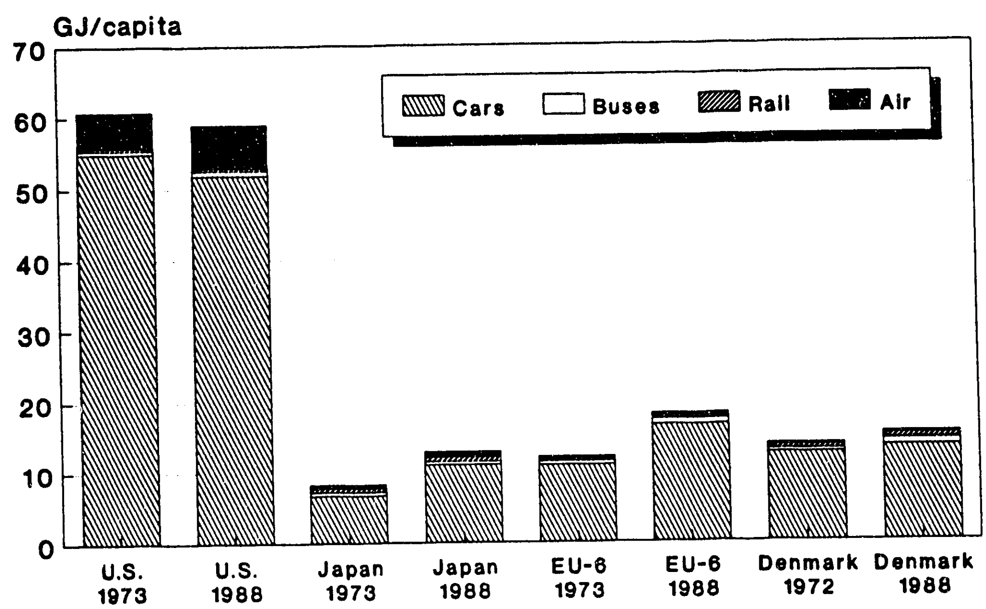


Figure 9-30

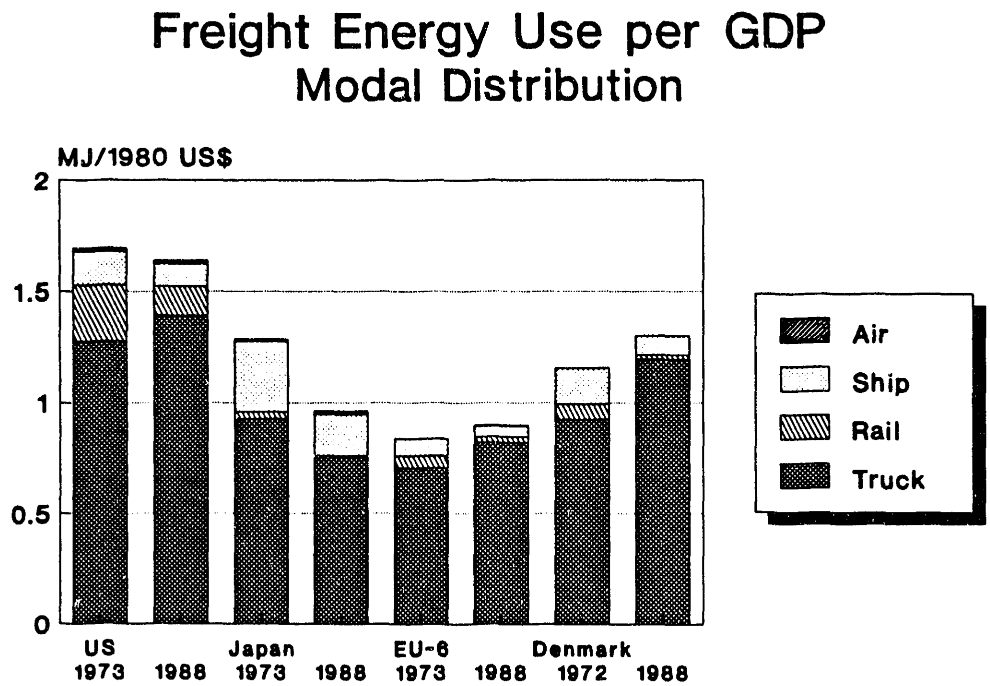


Figure 9-31

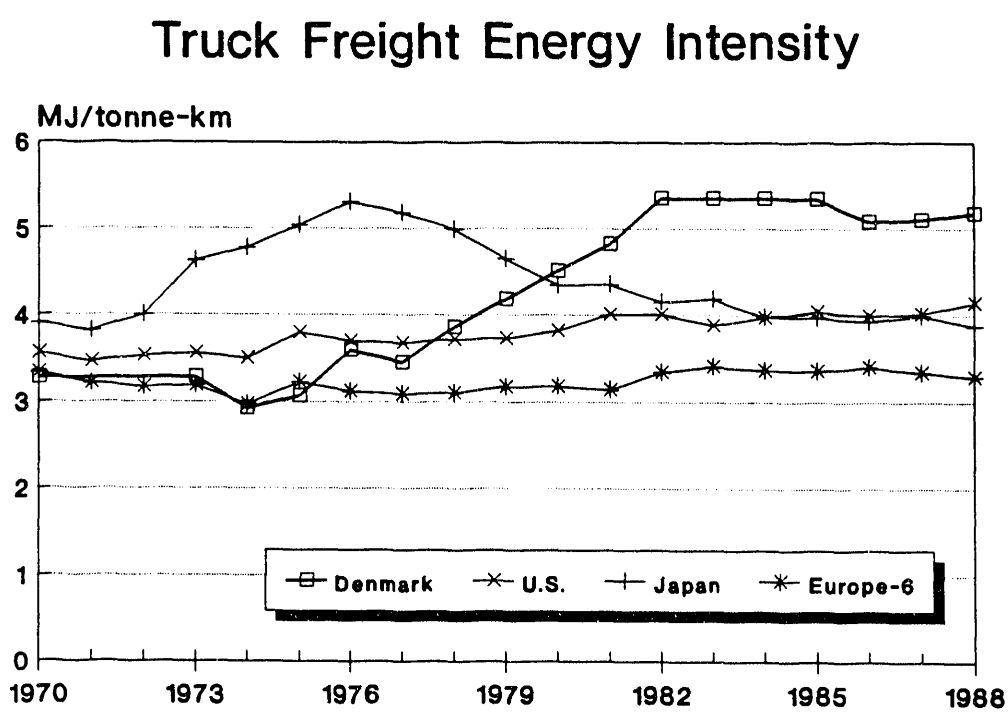


Figure 9-32

Freight Energy Intensity
Holding Modal Structure Constant

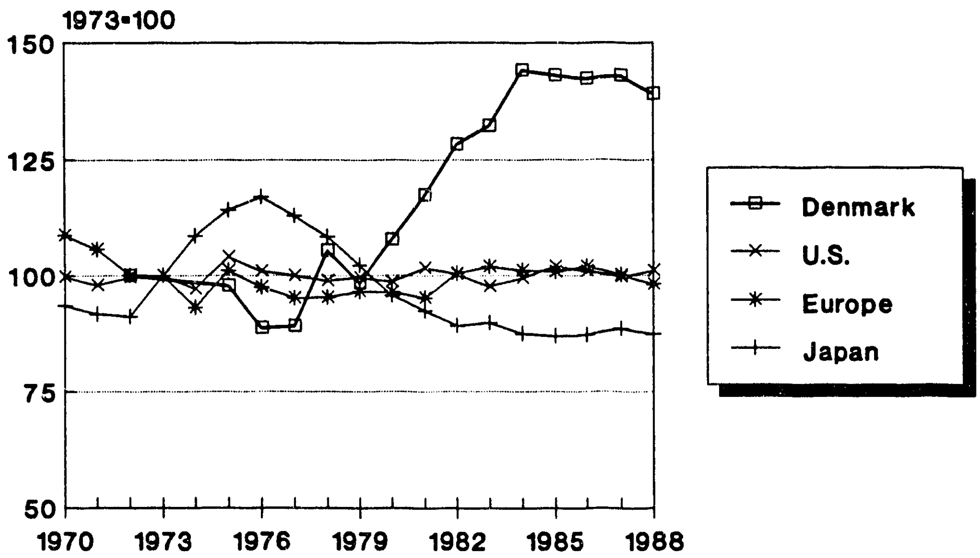


Figure 9-33

Energy Use for Freight

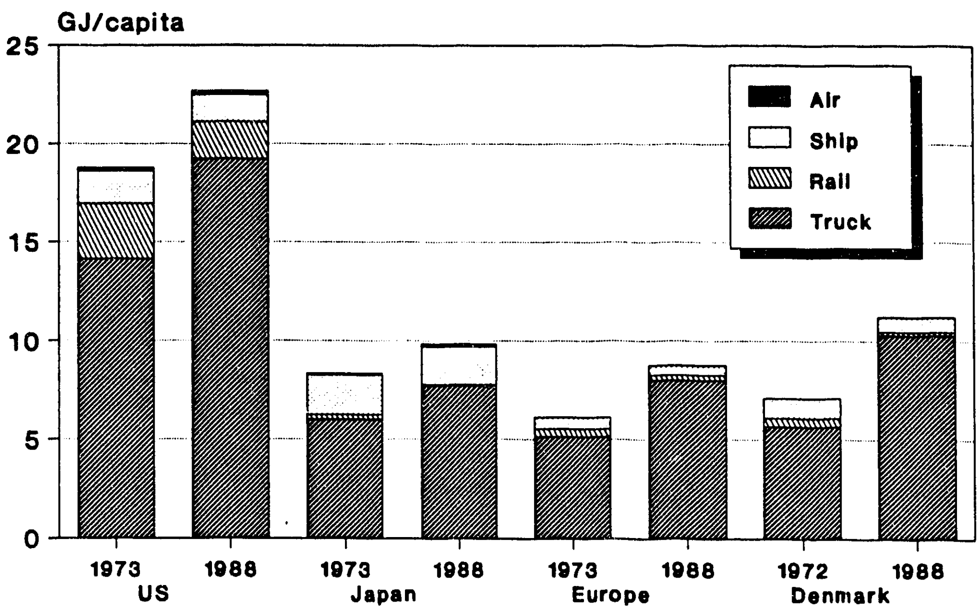
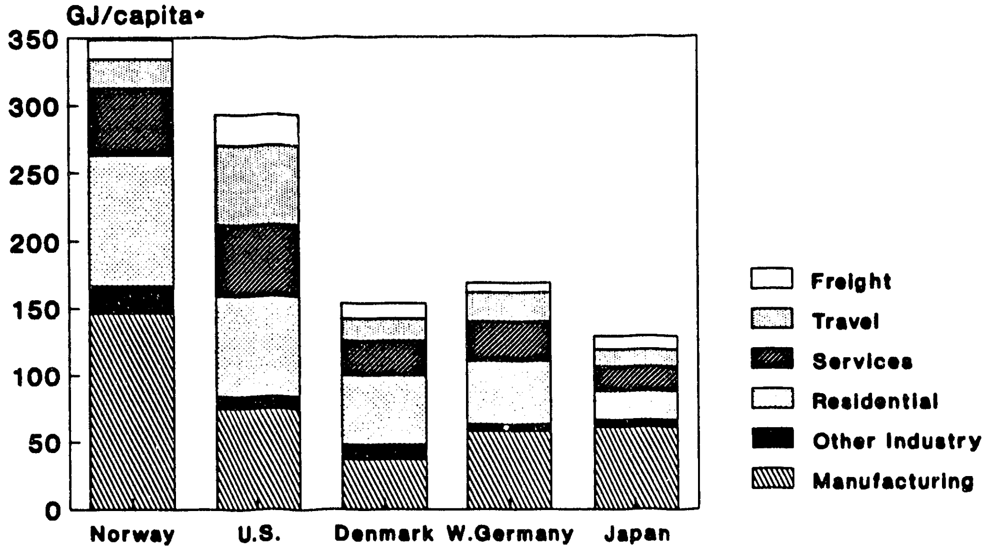


Figure 9-34

Energy Use in Industrialized Countries 1988



* Includes losses for district heat and electricity

Figure 9-35

Total Primary Energy Use Impact of Intensity Changes 1973-88 Six Sectors

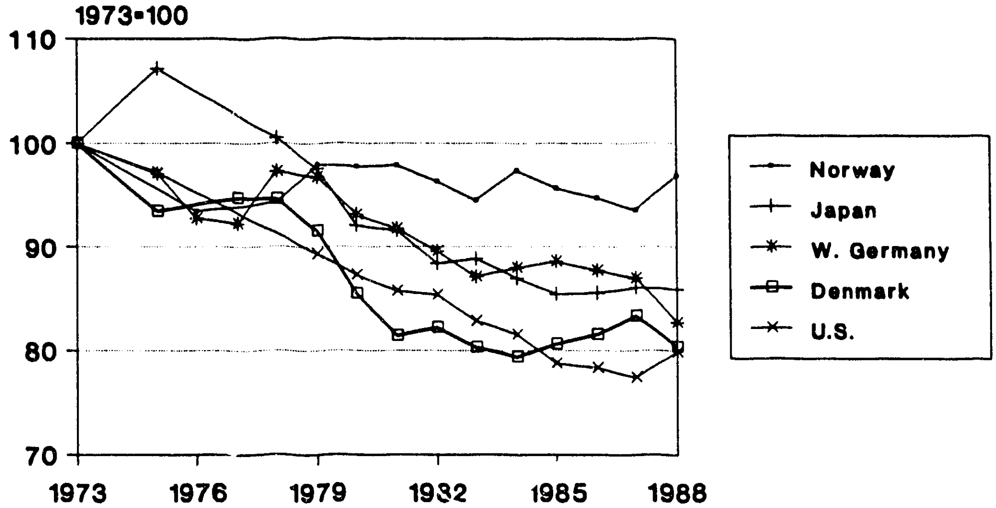


Figure 9-36

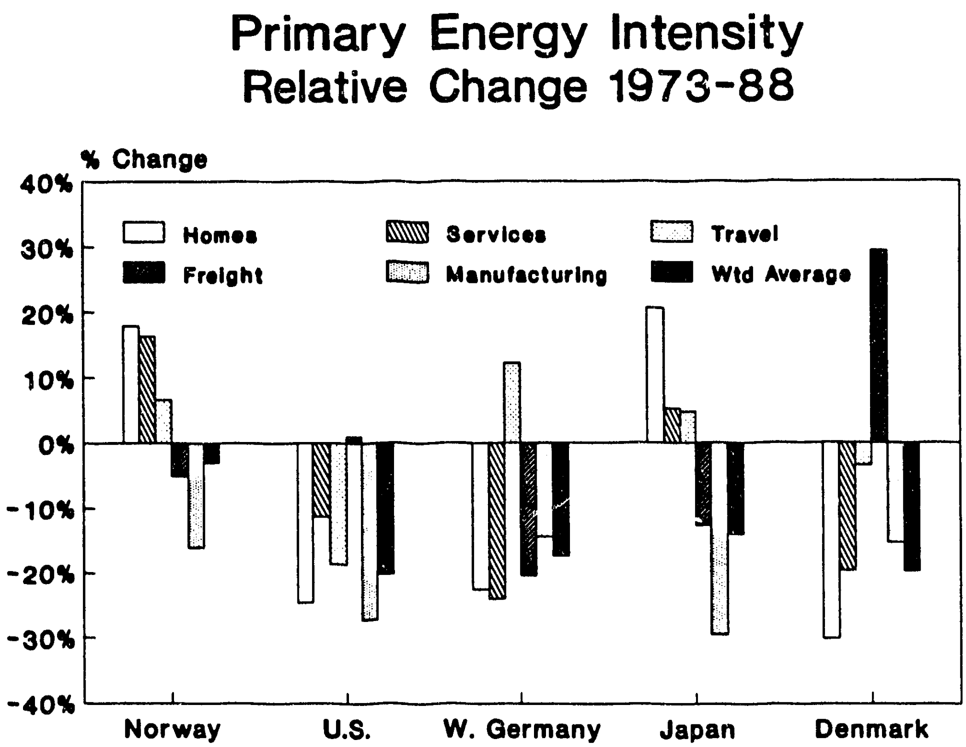


Figure 9-37

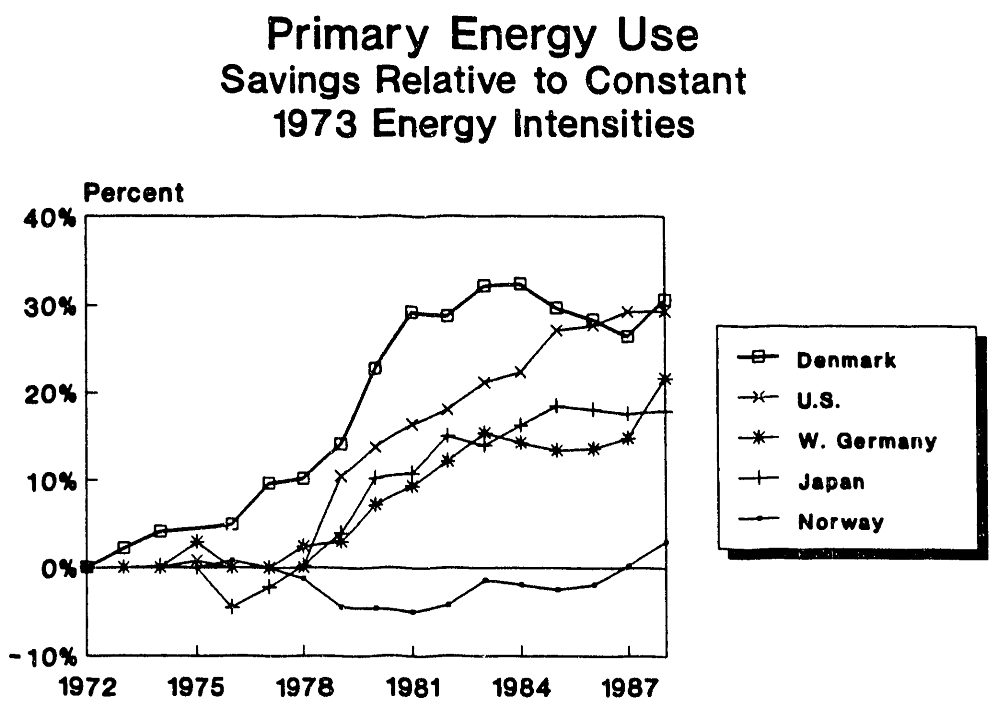


Figure 9-38

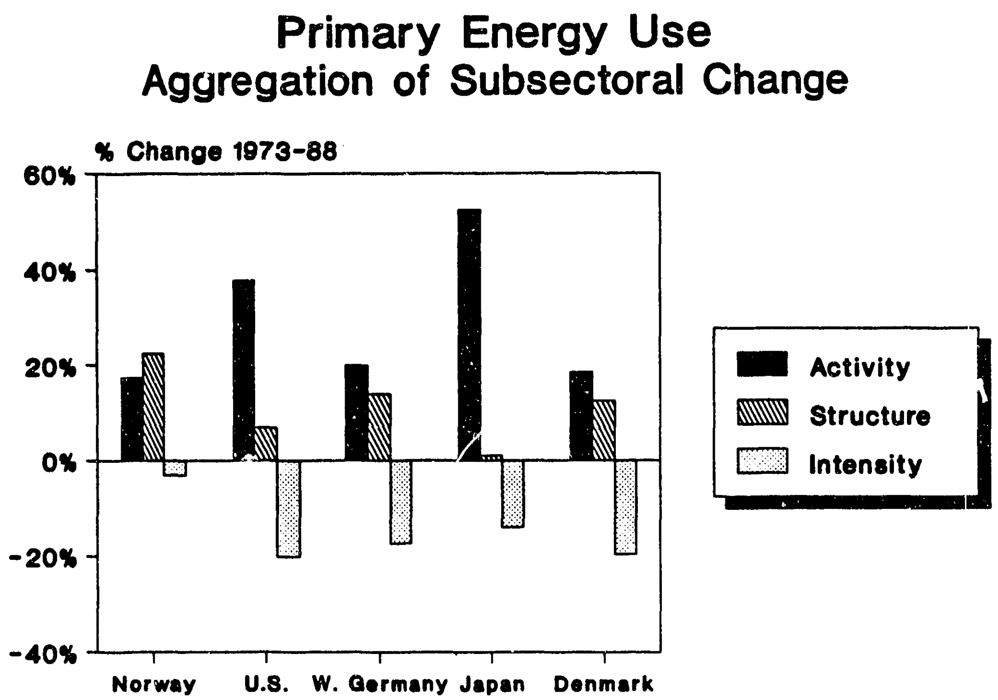


Figure 9-39

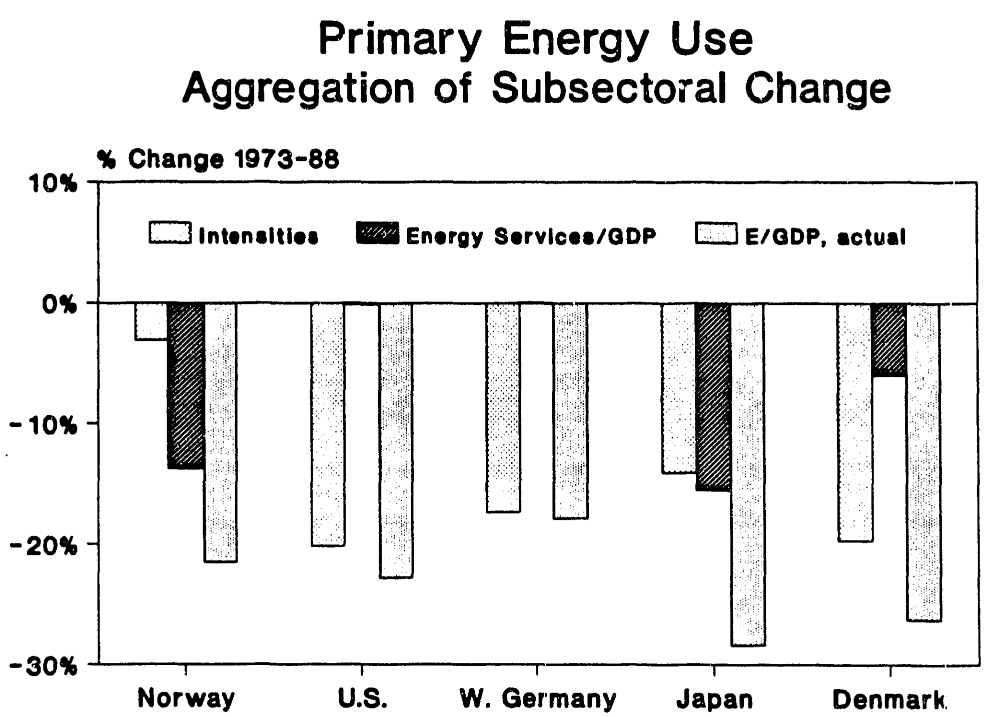


Figure 9-40

10. ISSUES FOR THE FUTURE

Our analysis of energy use in Denmark since 1972 has revealed that both evolution in the structure of energy use and improvements in efficiency caused fundamental changes in total energy requirements. We suggested that the overall level of energy-savings in Denmark was close to the highest we have observed anywhere. The Danish energy scenarios *Energi 2000* (*Energiministeriet* 1990) rely on continued improvements in energy efficiency. Whether these improvements will continue, however, depends on several issues that we raised in our sectoral analyses and international comparisons. We will address these issues here.

10.1. The Nature of Improvements to Efficiency between 1972 and 1988

It is important to summarize the nature of improvements in energy utilization that occurred up to 1988. Understanding these improvements is crucial to judging whether we can expect similar developments in the future.

10.1.1. Technical or Behavioral Changes?

It is possible to estimate the components of energy-savings that are related to technical changes in how energy is used, in contrast to changes caused by behavior. Technical changes have little impact on comfort, behavior, or productivity and output, while behavior changes usually involve "sacrifices" of comfort or mobility, although these "sacrifices", such as those related to lower indoor temperatures or more careful use of hot water, may become routine as individuals become accustomed to more energy-frugal behavior.

Turnover of industrial equipment, buildings and their equipment, and the gradual renewal of the transportation fleet has clearly led to energy savings that can be ascribed to technology. Persistent actions to improve existing heating systems by outfitting them with various controls also count as "technical change". Improved energy-using technology pervades every sector of energy use in Denmark, and appears to have made the largest contribution to energy savings by 1990.

Behavior changes, by contrast, appear to have had an important impact in three sectors, aside from efforts to employ energy managers in factories and buildings. Behavior change led to savings of energy in homes and buildings through adaptation to lower indoor temperatures. Some of the savings of energy in travel—we estimated about half of the reduction in travel-related energy use—arose because proportionately more Danes use buses and trains today than in 1972. But behavioral changes also offset energy savings. Much of the potential energy saving in auto travel was offset by slow changes in the utilization of cars that reduced load factors. And changes in the utilization of trucks led to significant increases in the energy intensity of truck freight and the entire freight system. Roughly speaking, changes in behavior and utilization that reduced energy use appear to have had a slightly larger overall impact than those changes that increased energy use. But behavior and utilization is volatile and subject to rapid swings, caused by changes in prices or incomes or by other factors. How much of the energy savings in Denmark can be considered permanent?

10.1.2. Permanent or Reversible Improvements in Energy Efficiency?

We believe that technological changes that reduced energy intensities are permanent. Reductions in energy intensities so gained will likely never be reversed. In a few activities (production of energy-intensive materials, space heating, driving), reduced energy intensities encourage the very activity for which energy was saved. This "rebound effect", however, is small by most estimates (Schipper and Meyers et al. 1992).

Energy savings gained through behavior change, by contrast, are by no means permanent. We referred to the *ScanTest* surveys that show that Danes were heating to higher temperatures and undertaking fewer energy-efficiency measures in 1990 than in 1981. Certainly the drop in real energy prices and relaxation of energy-efficiency programs lies behind this development. While we do not believe that Danes will soon heat to the high temperatures found in many buildings before 1972, we believe that some of the savings won in the early 1980s by changes in behavior have reversed. This is also true for savings induced by shifts from cars to buses and trains. The share of cars in total travel is rising again. Much of this reversal is a consequence of *both* stagnation in real energy prices *and* the achievement of many efficiency goals, which in turn have permitted Danes to trade savings once based on lower comfort levels to savings now based on technology.

There is clearly a small potential for further reversal of energy savings gained through behavior change. Lower energy costs, particularly during the extremely mild winters that have become "normal" since 1989, permit building owners, operators, or occupants to pay less attention to their heating costs. But at some point, such inattention leads to overheating. In the past, Danes opened the windows to deal with this problem. Hopefully renewed interest in "*Energistyring*" (energy management) will provide an alternative of energy management in large buildings that will enable operators to continue to pay attention to energy costs in spite of stagnation in real energy prices. And a continued proliferation of heating controls for homes, even if slower than in the past, might stem the rise in indoor temperatures in homes that could occur if winters stay mild and prices low.

The trends in the freight system, by contrast, reflect much more fundamental forces at play than merely energy costs, as we noted in our analysis of this sector. Quite simply, there are no energy savings that can reverse with lower energy prices! Our own view, however, is that this behavior represents a trend that has manifest itself in many countries.

10.1.3. Savings That Occurred After 1972: Trend or Break?

We noted that the behavior of energy intensities after 1972 resembled developments in the previous decade in some sectors, but took a new course in others. In manufacturing, the rate of decline of energy intensities increased somewhat after 1972, but the decline had been evident for many years previously. This is consistent with what we have observed in virtually every other country.

By contrast, energy intensities in other sectors were rising before 1972. Part of this rise really reflects structural changes, such as increases in automobile size, home appliance size (or number of features), and comfort levels in homes and buildings. But the post-1972 reductions in energy intensities for these end-uses represent dramatic changes from the pre-1972 period. Clearly, energy prices and energy conservation policies together had an important impact on energy use, particularly in buildings.

10.1.4. Causes: Trends, Energy Prices, or Programs?

The preceding remarks suggest that some of the energy savings that occurred in Denmark after 1972 would have occurred anyway, as part of long-term trends in technological progress. These trends in manufacturing and other industry are universal. Higher energy prices only accelerated what might have occurred anyway, particularly in an open, competitive economy like that in Denmark.

But, unlike manufacturing and industry, Danish building owners, operators, or occupants are not really "competing" with anyone. They see only their own costs. Although technology has made more and more efficient heating systems (and building systems) available in Denmark, the improvements through 1972 were not very evident. That is, there is little evidence of a forceful component of technological progress permitting energy savings in Danish buildings. In Sweden, with a fundamentally different way of financing new construction that favored adoption of many energy-saving technologies, space heating efficiencies were improving at a rapid pace even before 1972 (Schipper, Meyers, and Kelly 1985). But Denmark did not have this kind of home financing system in place. Consequently, the changes in energy use in homes and buildings did not arise gradually because of long-term technological developments. Instead, these changes occurred rapidly when energy prices increased.

Certainly programs contributed to some of these savings, although we argued in Chapter 2 that programs could not be the major reason for improvements in energy efficiency in existing buildings. By contrast, the imposition of building standards and the Heat Plan appear to have forced improvements in the thermal characteristics of *new* buildings beyond what might have occurred with only pressures from higher energy prices. The drive to cut first costs in all forms of construction appears to have been an overriding concern of both private and public building authorities. Fortunately, activist policies in Denmark turned this situation around. New homes in Denmark are among the most efficiently heated in all of Northern Europe.

In the transportation sector it is hard to identify concrete energy-saving policies. One reason is that few vehicles are built or assembled in Denmark. Another reason is that high taxation of new cars in Denmark had already shaped the structure of the car fleet well before 1972. Only recently have authorities begun to consider new forms of taxation that might change the fleet of cars in fundamental ways that specifically decrease fuel intensity. And while traffic and transportation planning has been evident in Denmark for decades, the best that can be said is that such efforts, combined with changes in fuel prices and the prices of using buses and rail, contributed to forestalling the decline in utilization of these systems, and even raised their utilization relative to 1972 shares, something not seen in many other OECD countries.

It is certainly evident that high taxation of motor fuels for private transportation has had an important impact on restraining both travel and fuel use, as well as reducing fuel intensity. But the motivation for such taxation is ages old—fiscal considerations related to both the balance of payments and raising revenue—so it would be unfair to ascribe the savings Denmark experienced in travel-related energy use to "energy policies" per se. At the same time, it is clear that the government can influence energy use for transportation in fundamental ways through careful manipulation of fiscal (and other) policies.

In concluding, we will not try to partition energy savings in Denmark into exact portions permitted by technological trends, or caused by higher energy prices or imposition of energy policies. Clearly all three factors influenced energy use in Denmark. Technology did provide important energy savings in manufacturing even without being provoked by higher energy prices. Denmark also developed the most comprehensive policies promoting energy efficiency in buildings, which has now been extended to saving electricity. At the same time, the Danish government presented its citizens with increases in the prices of heating and motor fuels and household electricity that, relatively speaking, were among the largest experienced by consumers anywhere in Europe. Since the largest contribution to total energy savings in Denmark came from improvements in space heating, it is tempting to attribute most of the savings of energy in that country to higher prices, bolstered by certain energy-saving programs.

It is important to note that energy-saving programs have not disappeared from the Danish energy scene. In particular, there is a great deal of focus currently on electricity savings in all major sectors of stationary energy use. These appear to be effective, if the efforts towards improving home appliances or increasing sales of low-energy compact fluorescent bulbs is any indication. And while some technological trends that are important to energy use are influenced by industries that are not important to Denmark, other developments, particularly those related to appliances and buildings, find Denmark in the lead. This means that even with stagnant energy prices, we can expect building-related technologies to gradually reduce energy intensities in homes and the service sector. Thus, the efficiency of energy use in Denmark can be expected to continue to improve, even if at a slower rate than in the 1980s, because of both energy-saving programs and technological progress. The key question is whether policies (including energy taxes) can increase that rate of savings. The hidden question is whether individuals and companies are prepared to pay higher energy taxes as part of a package to stimulate the improvement of efficiency.

10.1.5. The Plateau of Energy Intensity

The reason for concern over this question is the plateau of energy intensity that is evident in both the building sectors and in industry. Part of the reason for this plateau is the stagnation in most energy prices. While there is still a decline in average energy intensities that occurs when new homes, new cars, or new machines replace older ones, this natural decline is clearly slower than the precipitous fall that occurred during the first half of the 1980s.

To be sure, "stagnation in energy prices" is somewhat misleading. The real cost of heating fuels is so much higher today than in 1972 that the marginal cost of keeping homes or buildings to a given temperature is higher than in 1972, even including the effects of improved efficiency. The improvements in energy utilization in industry, by contrast, appear to have overcome much of the impact of the increase in real fuel prices. And Danish drivers in 1990 paid about the same amount for fuel to drive one kilometer as they did in 1972, once the taxes on gasoline were lowered. Thus the plateau of efficiency is understandable in some sectors. Still, there appears to be a significant potential for reducing heating needs in existing buildings, the most long-lived part of the energy-use system. In the next section, we review prospects for improvements in buildings, and in other sectors, as seen by Danish officials.

10.2. Future Potential and Achievement

In Appendix C we review the detailed scenarios of future energy demand and energy-efficiency potential developed by *Energistyrelsen*. We find that the goals for energy-efficiency improvements in Danish industry are consistent with historical trends. Achieving the potential for improving electricity use in homes and buildings also seems within reach. Goals implied for other sectors, however, are problematical.

For buildings, *Energiforbrug i bygninger* studies three levels of future space heating (and water heating) needs, representing reductions of approximately 25%, 50%, and 75% of present energy intensities (*Energistyrelsen* 1990). The 25% level appears easily attainable, but the other levels appear to be difficult to attain, except in the very long run, and then only if improvements to buildings are made in the normal course of rehabilitation. The problem is not that the proposed strategies will not always pay off, but rather the difficulty of motivating owners, operators, or occupants to make the last marginal investments, for which rates of return are low, say, offering only ten year paybacks. While the study proposes many mechanisms that might raise interest in reaching these low levels of heating, it is by no means clear which strategies will succeed. *We judge that these levels of heating needs will be attained eventually, through rehabilitation and replacement, but we doubt whether the 75% reduction would be undertaken successfully by 2030. However, development of inexpensive means of improving wall insulation could accelerate improvements towards the 50% reduction or even beyond.* The goal set out in *Energi 2000* is for a modest 10% reduction in heating intensity by 2005.

For electricity, the situation is much more favorable. Electricity is more expensive than fuel, but focus on saving electricity for non-heating purposes is a relatively new development. Most of the equipment that uses electricity will be replaced over the next four decades. This presents private parties, as well as public officials, with a attractive opportunity to make significant savings during the process of equipment replacement.

In transportation, i.e., travel and freight, the outlook is mixed. The scenarios by *COWIconsult* (1990a) for the *Trafikministeriet* (Ministry of Transport)[1] consider both technological changes and changes in travel and freight activity, fostered in part by changes in urban structure. But the physical infrastructure in Denmark cannot change too radically over a period of only four decades. And people's travel habits are also hard to change without tough fiscal measures. Indeed, the *COWI* simulation in which traffic on bus and rail is boosted 100% only has a marginal impact on energy use. Hence one has to suggest restraint in activity as part of a package to reduce energy use and emissions from these two rapidly growing sectors. Such measures leave many policy-makers nervous.

Understandably, then, the transport scenarios consider a base case where activity levels grow at historical rates while technology permits some reductions in energy intensities. The results show a significant increases in energy use, and some increase in various emissions, by 2030. The scenario study shows from bottom up calculations that a great improvement in efficiency, such as cars requiring only 2 liters/100 km (vs. approximately 7.5 in Denmark today) would permit an enormous reduction in energy

[1] These were not an explicit part of *Energi 2000*.

demand. But Denmark has little control over developments in the international vehicle market. The prototype autos that use 3-4 liters/100 km have been convincingly tested by their makers, but do not yet appear to have a change to make a significant dent on the world market. Hence they are not readily available for ordinary car purchasers. A more modest drop in fuel intensity, while easily in reach with present developments, would still be swallowed up by increases in overall transportation activity. Thus, while technologies that permit radical energy savings in transportation (here we include trucks and advanced aircraft) are available, world trends are not pointing towards widespread adoption, at least not in the next two decades (Schipper and Meyers et al. 1992). Were a change in the energy intensities of new transportation equipment to appear in the next few years, then it is very likely that most or all of the stock of equipment will be greatly improved by 2010.

The only "solution" appears to be that implicitly proposed by the *COWI* study. That is, a package that includes fiscal measures raising fuel prices, charging for access to cities and parking, and shifting the taxation of new cars to favor fuel efficient and/or low emission vehicles, could restrain energy use for travel both by boosting efficiency and by restraining travel in the automobile. Similar measures would have to be aimed at truck traffic. Admittedly, this solution is uncertain, which is cause for concern. The one bright light is that fuel switching, stimulated by fiscal measures, could reduce certain emissions significantly.

Thus, we find that the realism of the Danish *Energi 2000* study is mixed. We deem the energy savings foreseen for both industry and for electricity uses in buildings as realistic and fully consistent with either historical trends or what we know today about efficient energy and electricity use. We are confident that the *goal* of 10% reduction in intensity can easily be reached. Whether the boldest of the energy saving potentials in older buildings, 75%, can be reached is uncertain, although it is likely that 25% or more can be squeezed from the specific consumption of older buildings.

The real dilemma is in the transport sector. The scenarios foresee only modest improvements in efficiency, coupled with large increases in transport activity. Only a strategy that attacks both efficiency and activity, which involves the lifestyles of Danes, appears able to restrain energy use significantly in this sector. We turn to this sensitive issue next.

10.3. Lifestyles and Energy

A key issue that emerges from the *Scenarios* is the role of lifestyles in shaping future energy use in Denmark. By "lifestyles" we mean the pattern of activities that characterize daily lives of Danes. A variety of studies of time, personal consumption, housing characteristics, and travel behavior all document the changes in the way Danes live that have taken place over the past three decades. This section reviews briefly the implications of these changes for future energy use.

Schipper et al. (1989) studied the link between lifestyles and energy and reached several important conclusions:

• From the 1950s until the present, rapid increases in comfort and mobility, made possible by rising incomes, drove up energy use for these two important services more rapidly than the rise in incomes in most countries. Acquisition of cars and modern heating systems, growth in the size of homes, and increases in both the size and number of features of electric appliances lay behind this increase in what Schipper et al. called "personal energy use".

• People have spent increasing amounts of their time away from the home, either obtaining personal services for family business, or enjoying free time.

• The increase in ownership of household equipment is slowing as a level of saturation is being approached. However, energy consumption depends on the utilization of these systems, not just ownership. Ownership of cars, by contrast, is low by Western European standards, and could be expected to increase in the next twenty years. While it could be argued that utilization of home energy systems cannot increase much more beyond present levels (i.e., people are relatively comfortable), no such argument can yet be made for transportation equipment. Schipper et al. suggest that future free time use will influence heavily future transportation needs.

Schipper et al. noted that energy use per person and per unit of time in homes lies close to that in the service sector. Therefore, spending less time at home and more time away from home would have only a small impact on energy use in buildings as a whole. But energy use per person and per unit of time for transportation is very high, five to ten times its level in buildings. Therefore, increases in the time spent moving around, at the expense of time spent in buildings, could increase overall energy use. Moreover, the costs of a marginal minute spent travelling, particularly in private vehicles, is small. But how and where people spend their time is a function of their incomes and lifestyles. Therefore, the most important changes in energy use in the future could well arise out of future changes in lifestyles if these changes affect mobility.

10.3.1. Future Mobility of Danes

Mobility of Danes increased rapidly after World War II, increasing by a more than a factor of four between 1950 and 1972. According to Danish surveys (Viby-Mogensen, 1990), Danes spent twice as much time travelling in 1987 as in 1964.[2] Their average mobility, measured in passenger-km/capita, increased by about that factor during the same period.

Can these trends continue? The time budget surveys for Denmark (and other countries) suggest there is no immediate time constraint on increased local travel and, as we have discussed, most travel is local. Traffic conditions in Denmark in particular are not as congested as in other countries (except at rush hours in large cities), so there is no real constraint posed by this problem. But Danes have far fewer cars than people in neighboring countries. This is an important consideration.

Historically, what has occurred with travel is simple: Individual travel time has expanded slowly over the past 50 years. What has increased more is the "range", or total mobility, This has occurred because the speed of travel has increased, through the transition from walking and horses to trams and buses, then to cars, and now to aircraft. This transition is by no means finished in Denmark, where

[2] These surveys exclude time spent travelling in or to/from vacation, since the person interviewed cannot be away on holiday or a longer business trip. Thus the time surveys may underestimate the increase in total time spent travelling.

walking, cycling, and collective transit still provides for well over 50% of trips and 30% of mass transit.[3] Denmark, with its low car ownership and travel/capita in cars lying slightly below rest of Scandinavia, could see a marked expansion in travel through increased motorization. The high taxes on cars have simply retarded this development in Denmark relative to neighboring countries. This is precisely what the *Referencescenarier* (Reference Scenario) developed by *COWIconsult* (1990a) implies. Thus the level of mobility in the *Referencescenarier* is *not* implausible.

The kinds of changes that have been occurring in people's behavior in industrialized countries to date have contributed to greater mobility. Fewer working hours raise the number of people commuting to and from work per hour worked. Increases in women working also have raised the total number of people working, and often justified at least one family member driving to work. The shrinking family size, including more single person households, has meant more car use per person. This means that the services of using cars, such as shopping, are shared by fewer people. Older people are surviving to higher ages today than they did 30 years ago, with better health and a reasonable level of social security benefits. This makes them prime candidates for free-time travel, both locally and for vacations. And the post-war generations in Denmark and other developed countries, who have grown up surrounded by personal vehicles, appear to use the mobility cars provide long after they leave the work force. These changes lie behind the simple observation that travel times and distances have increased markedly in Denmark since the 1950s. In short, many of the most marked socio-demographic changes have led to greater travel. Additionally, higher incomes and more free time have led to more time spent away from home, which in turn raises the demand for buildings to visit.

It is not hard to imagine where Danes could go. People's time at home has been relatively constant, but they have spent relatively less time at work (seen in a 50-year perspective) and more time free, either at home or out. And they tend to be spending slightly more time in services now than 20 or 30 years ago. Time spent away from home for free time has been increasing in most Western countries, and with it an increase in the travel time to/from leisure (about 15-20% of leisure time according to Gershuny and Jones (1990), roughly true for Denmark in 1987). There is has been some increase in travel to/from services, too, as opening hours have been liberalized. Here is a key area where Denmark lags behind many other European countries: stores and services are closed evenings and much of the weekend. But liberalization of opening hours in Sweden, Norway, and much of the European continent could become widespread in Denmark. Where such changes have occurred, such as in the U.S., the results have been reflected in most surveys of driving or travel behavior.

[3] B. Vilhelmson (1990) has shown for Sweden that a substitution of cars for present use of buses and rail, with constant travel time, could lead to as much as 40% increase in total travel per capita. This would occur if those in Sweden now without cars obtained cars, which would raise the number there from slightly over 400 per 1000 to more than 525/1000 (the U.S. lies at over 620/1000)! Webster et al. (1986a, 1986b) showed that this motorization—acquisition of cars—is the principal "engine" of this transition. With such motorization comes an increased mobilization, ie. rapidly growing mobility and a drop in the use of buses and the railroads.

10.3.2. Homes and Buildings

We saw in Chapter 2 that the ownership of household equipment and the size and characteristics of homes themselves are a critical determinant of energy use. With rising and falling energy prices, home occupants/owners will adjust both how much comfort they derive from energy used for heating and other purposes, and change the technologies of energy use (i.e., their heating systems, windows, insulation) to save energy. But as home size increases, however slowly, and the stock of appliances in a home is expanded, household energy use can creep up. The study *Energiforbrug i bygninger* recognizes these trends, and assumes that homes will be larger and better equipped in the next century. The overall impact of these assumptions on energy use in homes is rather small, only because present standards are so high. Thus the overall changes in the housing stock related to comfort and lifestyles are small.

It is often contended that there are important uses of electricity that could become widespread in the home. But the only significant potential uses for electricity in homes are related to space- and water heating. Some of these applications have already appeared in limited ways in Denmark. Waterbeds, for example, do consume significant amounts of heating, as to car seat heaters, saunas, or other important applications of electricity to space or water heating. But the heat from waterbeds heats the bedroom as well. Given the high cost of electricity in Denmark, it does not seem likely that Danes will take to a massive buildup of important uses of electricity for heating purposes.

On the other hand, there is a significant potential for increases in the ownership and use of small appliances and electronics, particularly computers. In a study prepared for the U.S. Office of Technology Assessment, however, Schipper (1991c) argued that these applications are *not* important users of electricity for two reasons. Greater concentration of electronic power increases the waste heat in each computer. Improvements in efficiency are essential for continued technological progress. This is because more advanced electronic devices cannot operate if their components are heated. Second, the proliferation of electronic devices and small appliances does not translate directly into electricity consumption, since each is utilized for only a limited time. Moreover, most household tasks are now well mechanized, so the new devices do not present house occupants with major new labor-saving alternatives. Instead, this proliferation really represents an important trend towards specialization, whereby the small appliances (including electronics) are merely more specialized, optimized, and efficient substitutes for older style cooking, water heating, and small tasks previously done by hand.

Physical characteristics of homes are not the only parameters that count. As Schipper et al. (1989) noted, energy use in buildings is not independent of lifestyles. Family size and routines explain roughly half of the variations in energy use in homes of similar construction. Some of these routines are changing in ways that affect average energy use. For example, families are smaller, and fewer people are home during the day, lowering household energy use. As Schipper et al. pointed out, however, these changes either transfer energy use to other buildings, or increase total energy use in homes as the number of homes per capita increases. The key change driving energy use is the continually shrinking family, which drives up the per capita area that must be heated and lighted, as well as increasing the *per capita* ownership of major appliances. Schipper et al. suggested that the shrinkage of families since 1960s in OECD countries has increased household energy use by 25%, other factors being equal.

Physical characteristics of the service-sector building stock are an important determinant of energy use there. Well-heated and well-lit buildings (some would say over-heated and over-lit) may attract more customers. And certain kinds of buildings, notably retail stores, are particularly electricity intensive. Schipper et al. found that shifts in the mix of buildings in the U.S. stock between 1979 and 1986 alone led to a small but measurable increase in energy use in this sector. But this effect was smaller than the overall increase in built area where consumers can go. We suspect the same is true for Denmark. *Energiforbrug i bygninger* assumes only a modest increase in built area. As with the housing stock, growth in the area of the service-sector stock is not expected to be a major source of new energy demand.

Occupancy in the service sector is a determinant of energy use there, just as with the household sector. If people visit restaurants more often in the future (certainly dependent on income growth), restaurants will be more crowded in the short term, or stay open longer. In the longer term, more restaurants will be opened. But at some point, a level of saturation appears, since people who are in restaurants can't be at the movies, too. Since owning or renting space in buildings is not free, particularly if buildings are located in popular spots, the overall space in the built environment where consumers spend time will be limited by the costs of that space, relative to the willingness of consumers to visit that space.

Although the overall growth in the size of the built environment in Denmark is not expected to be rapid, we can foresee a variation whereby people simple stay home more and go out less. This would likely lead to slightly larger homes but less expansion in the service sector, with little net change in the overall use of energy for both homes and buildings. If construction costs (including land, interest, etc.) limited the size of new homes or buildings, and restricted opportunities to increase the size of existing homes or buildings, energy use for most purposes in the built environment would increase less than in the figures presented in *Energiforbrug i bygninger*. The converse is true, too.

What is essential, therefore, is to examine the factors controlling the expansion of the residential building stock. Are there hidden subsidies for borrowing money, or tax incentives to build more? It is certainly not likely that energy and environment policies alone would be used to affect the size and characteristics of the built environment, but important for policy makers to understand whether existing policies might be stimulating changes that increase energy use here just as other policies are promoting restraint.

10.3.3. Summary: Lifestyles Key to Future Energy Use in Denmark

In this brief analysis we suggested that lifestyles, which affect energy use for household purposes, travel, and in buildings people visit, are a key factor determining future energy use in Denmark. Changes in lifestyles related to travel can cause the greatest variations in energy use. Work done for *Energi 2000* reflects this relationship: travel and travel-related energy use outpaces growth in the residential sectors.

The differences in these developments come down to two basic facts. First, the size of the built environment is changing only very slowly, and appears to be approaching saturation. Rapid swings in energy use in both homes and buildings occurs often in response to changing energy prices. These swings affect comfort. But the price changes anticipated in the studies will be slow and affect efficiency more than comfort. Changes in the utilization of buildings that occur over the longer term do not appear to be important in influencing future energy use in buildings, in part because of the tradeoff between consuming energy at home or consuming energy away from home.

The transport sector behaves differently. Changes in the level of mobility occur very rapidly with changes in the cost of that mobility, similar to the situation for comfort in buildings. But whereas longer term changes in energy use in buildings depend on an expansion of the size of the built environment, changes in energy use for transportation can occur with roughly the same stock of equipment, if that equipment is utilized more fully. And since automobiles are relatively inexpensive compared with homes, further changes in travel-related energy use can occur if and when families acquire more cars. Automobiles have much shorter lifetimes than buildings, and the stock of automobiles contracts when economic conditions make ownership and use expensive (such as in 1981-83 and 1990). But virtually no investment is required if consumers want to travel more with existing vehicles. Thus we believe that while the trends towards higher mobility among Danes are not a certainty, they are not implausible.

Breaking this trend is not impossible. The *COWIconsult* scenarios consider simulations of changes in the physical layout of towns, as well as the imposition of policy measures like higher parking fees. Such measures could both reduce the need to travel, and raise the cost as well. But these developments would be working against trends that have appeared in every European country and Japan, trends that point towards the high levels of travel in the U.S. Since the *Referencescenarier* imply that the U.S. level of travel is reached in Denmark, much research is needed to understand whether this level is realistic in a country like Denmark. If the answer is yes, authorities should understand why, in order to consider measures that might allow Danes to enjoy their lives with less growth in mobility. Alternatively, Danish authorities, like those elsewhere, must redouble their efforts to improve the efficiency of vehicles, and reduce emissions as well, so that the effects of increased mobility on the local and global environment are acceptable to all.

11. RECOMMENDATIONS: ANALYSIS AND INFORMATION FOR BETTER POLICIES

In this study, we have examined many sets of energy data for Denmark, and confronted at least two complete revisions of official energy demand data in the process. We uncovered many key uncertainties that cloud both our analysis and, to a certain extent, our conclusions. In this section we set forth three important recommendations for research and data collection that could rectify some of the problems we encountered.

The first recommendation addresses the need for basic energy data as well as information on the sectors where energy is used. The second recommendation addresses uncertainties over how much energy has been saved by individual energy-saving measures. The third recommendation focuses on the poor understanding we have of how individual lifestyles affect energy use.

11.1. Demand-Side Energy Data

Denmark needs a demand-side energy data system. The present system, by which energy suppliers report on the kinds of energy they sell, but leave the nature of the final user up to judgment or rules of thumb, does not provide accurate information on the ultimate disposal of energy in the Danish economy. Only the regular survey of industry by *Danmarks Statistik* gives reliable information on who uses energy in Denmark.

Three major uncertainties we uncovered show why better energy use data is important. The first is the separation of fuel consumption between the residential and service sectors. Uncertainties in dividing up fuels between apartment buildings and service sector buildings are great enough to cloud the picture of how much consumption has changed in these two sectors. Differences in the institutional structures of these sectors, i.e., households vs. firms or service-sector building tenants, make it inappropriate for these kinds of buildings to be aggregated. The second problem arises out of confusion over the allocation of diesel fuels/heating oil between transportation and buildings. The final problem arises because the partitioning of road fuels into distinct sectors, such as cars, buses, or trucks, is itself fraught with uncertainty. These three problems arise because energy suppliers cannot reliably classify their customers for liquid fuels, but problems in classifying customers for district heat and even natural gas arise as well. These problems create uncertainties that can mask changes in energy efficiency and make it difficult for authorities to tell whether a particular energy efficiency policy is succeeding.

To rectify this problem, *Energistyrelsen*, together with *Danmarks Statistik*, should turn to the major energy users, such as airlines, bus companies, trucking firms, large apartment management companies, automobile fleet operators, and, through carefully designed surveys, homeowners/occupants and car drivers, to obtain both data on energy use as well as information on the characteristics of the structures and equipment using energy, and the utilization of that equipment. Fortunately, *Energistyrelsen* and other authorities in Denmark have a tradition of working with ministries and other public authorities close to each of the sectors where energy is used. This tradition should be exploited for improving energy-related data in Denmark.

11.2. Understanding Sectoral Trends to Measure Energy Savings

Understanding energy use in each sector is not the only important step in providing better information on trends in energy demand. It is important that good information on the characteristics of equipment and activity in each sector is coupled to energy data.

Danish authorities made an important step in this direction with the establishment of *Bolig og Bygningregister* (BBR). What is lacking from this data base is information on water heating and cooking equipment and electric appliance ownership.[1] If such information is added to BBR and a survey based on a sample of BBR dwellings that asks detailed questions about actual energy consumption is carried out every few years, then authorities will have a very clear picture of the relationship between the structure of energy use and actual consumption, and thereby be able to estimate the unit consumption of each fuel for each purpose more accurately.[2] A similar survey should be instituted to investigate energy use and equipment in service sector buildings.

To better understand trends in transportation, authorities should pursue extending the various surveys of the Ministry of Transportation (Trafikministeriet 1986) to include information on energy consumption in private modes of transport and the characteristics of vehicles used. Similarly, information gathered from private truckers and trucking companies by *Danmarks Statistik* and other authorities should be extended The same information could be used to monitor energy use in

An important result of such detailed information will be a clearer view of how energy use changes *after* important policy measures are implemented or conservation actions are taken. For example, energy use in buildings where Heat Inspection (*varmesyn*) recommendations have been carried out could be examined to see how much was saved. Energy use in these buildings could be compared to that in buildings where no such measures were carried out. The same information could be used to monitor energy use in recently built homes, particularly *lavenergihus*. A final, and very important task, is to study the relationship between fuel switching and energy use. How much natural gas or district heating is required in homes or buildings formerly using oil? These data are important if authorities are to judge the progress being made towards the heat-saving goals implicit in *Energiforbrug i bygninger*.

Buildings are not the only sector where energy conservation strategies are being pursued. Present data covering modes of travel or freight are too uncertain to permit judgment of the effectiveness of measures to restrain energy use in these sectors, except after several years have passed. Industrial energy use data are reported to *Danmarks Statisitik*, but there is almost no information on energy use and physical production of materials. Given the rising electricity intensity seen in Danish industry, it would be useful to understand both the economic and physical nature of this increase.

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[1] The 1970 Census (*Folk og boligtælling*), for example, contained information on fuels used for cooking but not for heating water.

[2] In the U.S., the Household Survey (*Residential Energy Consumption Survey*, carried out every three years by the Energy Information Administration of the U.S. Department of Energy) asks respondents to give the survey company permission to contact energy suppliers directly to get accurate billing records.

11.3. Energy and Lifestyles

Enhanced energy-use information will also shed more light on the link between lifestyles and energy use. Do those Danes who have low energy use at home use more energy use for transportation? Can we specify better the relationship between energy use for homes and personal transportation and a family's demographic characteristics? These relationships will become more important as household size falls and the average age of the Danish population increases, two factors that will influence future lifestyles in significant ways. Similarly, car ownership is expected to increase, and with it, personal travel. Understanding now how these changes affect energy use will provide useful information for policy makers trying to estimate the impacts of changing Danish lifestyles on future energy use in Denmark.

11.4. What Other Countries Do about Energy-Use Data

The level and quality of energy use data varies among OECD countries.[3] Detailed energy-use surveys covering major sectors of demand are regularly carried out in the U.S., for the Department of Energy's Energy Information Administration, and in France for the *Agence Francaise pour la Matrise d'Energie*. These surveys include information on equipment characteristics, changes in energy use, and energy conservation measures carried out.

Household energy use is carefully studied by regular surveys in France and the U.S. Partial surveys of energy use in homes are carried out regularly in Sweden and Holland, the Swedish surveys examining only heating fuel use, the Dutch surveys focusing only on gas use. Ad-hoc surveys of household energy use have been out in Japan and Norway. Very little information on actual consumption is available for Canada or Germany. Surveys in Britain have been carried out by the electricity and gas industries separately, but there has never been a full survey of both consumption and structural characteristics.

Energy use in the service sector is poorly documented. Part of the reason is that the service sector, together with the residential sector, form a residual of energy consumption once transportation and industrial fuel and electricity use has been accounted for. Complicating the picture for the service sector is the heterogeneity of the building stock and the uses of energy in service-sector buildings, particularly uses of electricity. Only the U.S. carries out a complete survey of building characteristics, actual fuel use, and conservation activities in the service sector. Partial surveys are carried out regularly in Sweden, and have been carried out on an ad hoc basis in Japan, Norway, France, and Holland. In some countries (Canada, Germany, Holland) the total area of service sector buildings is not even well known.

Energy use in industry is recorded in almost every country, but few countries carry out detailed surveys that add information on processes, fuel substitution, energy conservation measures. The U.S. and France are important exceptions.

Transportation energy use is also poorly understood in most countries, where rules of thumb have provided some information on both utilization of vehicles and travel behavior as well as fuel efficiency and fuel use. Almost every country undertakes travel behavior surveys, or freight activity surveys, but

[3] In the course of research over the past dozen years, LBL's International Energy Studies Group has examined energy data from Japan, the U.S., Canada, Holland, France, Norway, Sweden, Italy, West Germany, and, to a lesser extent, Switzerland, Austria, Finland, and Belgium.

APPENDIX A: ENERGY USE IN THE RESIDENTIAL SECTOR

A.1. Analyzing Residential Energy Use Data

There are two basic approaches to analyzing residential sector energy consumption. The ideal approach starts with careful surveys of household equipment and energy consumption (specific consumption) in surveyed households and uses a combination of measurement, regression analysis, and judgement to multiply each kind of equipment by its energy use to get total use by fuel. For Denmark, the survey of building heating carried out by the *Dansk Teknologisk Institut* in the late 1970s (Christensen and Jungmark 1981) made such an approach possible. This approach, combined with Møller's persistent analyses of the use of electricity, information available from gas authorities in the 1970s and early 1980s, and the *Bygnings og boligtællning* (BBR) (*Danmarks Statistik* various years) and omnibus surveys of *Danmarks Statistik* (various years), permits a fairly accurate breakdown of energy use by fuel and end use. We followed this approach in our original analyses of the residential sector (Schipper 1983) and of the service sector as well (Schipper, Meyers, and Ketoff 1986).

Unfortunately, this method cannot easily be applied in the 1990s. This is because the *Dansk Teknologisk Institut* surveys of oil and district heating consumption were never repeated. While experts gained many insights from observing how specific consumption (energy use per sq meter) varied between building types or fuels, the changes in unit consumption by the mid 1980s were so great as to render further extrapolation difficult. The only reliable information on specific consumption comes from a large sample of homes that have had Heat inspections (Budde and Pedersen 1986). But this sample is biased, since inspected homes are likely to be those with unusually high energy costs, and hence unusually high specific consumption levels. Surprisingly, the figures in Budde and Pedersen for 1982 are close to our own estimates.

Given the lack of recent observations of energy consumption in homes, experts have tried a second approach to analyzing the energy consumption of the residential sector. This approach distributes total consumption of each fuel over various end-uses. In principle, this should be done separately for single-family dwellings, multi-family dwellings, and non-residential buildings, but the official data reported to *Energistyrelsen* (1990) do not distinguish between apartments and other large buildings. Hence, oil and district heating consumption levels between homes and services and between home types are uncertain. The best that can be mustered is to use all indicators of specific consumption for heating and hot water by fuel, and use the known area of buildings using each fuel to obtain total energy use by fuel for households, and, as a residual, for the service sector.

A.1.1. Approach Used in This Study

Our method for this report combines these two approaches. We distinguish between single-family dwellings (SFD [*stue-, parcel- , række- og kæde-huse*]) and multi-family dwellings (MFD [*lejliheder, kollegeboliger*]) for estimating specific consumption for heating, water heating, and electricity use for certain appliances. Using extrapolations of information from our original study—measurements and guesstimates of specific consumption, many updated—we build a model that multiplies the number of homes using a given fuel for heating times our estimate of specific consumption per dwelling of that fuel.

The most important energy sources in the residential sector have been oil and district heating. Our method requires us first to separate the residential and service sector portions of the use of these two energy sources, a procedure which we describe below. Then we partition energy use per dwelling into space heating and water heating. Using a few references from the literature (see, for example, Lawetz 1986 and Ketoff and Schipper 1990), we assume a certain specific consumption of each source for water heating. This allows us to separate heating from water heating.[1] We assume that the number of homes using a fuel for central space heating, i.e., district, oil, (as well as gas), is almost identical to the number using the same fuel for water heating. Exceptions are solids and oil, where anecdotal evidence suggests many use boilers only for heat and that some households use electricity for water heating and oil for space heating, since the oil heating system does not produce hot water efficiently for much of the year.

Electricity and gas are treated differently. Electricity use for heating, water heating, cooking, lighting, and six appliances (see below) is estimated using ownership and estimated specific consumption. Use of electricity for secondary heating is estimated separately. Other uses are treated as a residual in this study. We used Møller's most recent data (1991a), but, after discussions with him, removed the apparent smoothing he undertook. We discuss electricity use further under each important end use. Breakdown of uses of city gas follows older information from *Foreningen Dansk Gasværker* (FDG, the Danish Gas Federation), where heating is the residual; unfortunately, no such information exists for natural gas, so our split into heating and water heating is somewhat arbitrary, following the known numbers of homes using natural gas for central heating.

Unless otherwise noted, energy data for the residential sector are corrected to normal climate. This correction is carried out by multiplying actual space heating consumption of each fuel (excluding consumption for other purposes, such as water heating) by the ratio of average to actual degree-days. This differs from the correction formula of *Energistyrelsen*, where half of the variation in degree days is multiplied by consumption of fuels for both heating and hot water. Additionally, *Energistyrelsen* (1990) uses a time series of degree-days that appears to be based on 16°C indoor temperature. We derive our time series of heating degree-days for Denmark by adding 450 degree-days (225 days at a 2°C temperature difference) to the *Energistyrelsen* series to adjust for definitional differences. This means that Denmark has an average of 3141 degree-days measured at an indoor temperature of 18°C in our international data base. For comparison, Germany has 3116 degree-days, Sweden and Norway nearly 4000.

A.1.2. Data Sources

We have relied on *Danmarks Statistik* for data on heating fuels (*Folk og Boligtælling* 1960, 1965, and 1970; BBR 77, 80-90), cooking fuels (1960, 1965, 1970). Data on the structure of fuel use is complemented by information from older *Forening Dansk Gasværker* yearbooks. Some data on heating structure were taken from information provided by Shell (various years) in the mid 1980s. With insights

[1] It is apparent from examining the BBR that there are still a few tens of thousands of homes using oil (kerosene) in room heaters. We have estimated this use over time using information provided by Shell. We also estimated the small use of LPG for cooking, using data from *Dansk Kedelforening* (1978). These estimates are described in our 1983 report. These two uses are separated from remaining oil use, which is then divided into (central) space heating and water heating.

provided by these sources, we estimated the split of non-central heating in apartments (given only for recent years by BBR), covering city gas, kerosene, solids, and electricity.

The main source of data for the structure of electricity use and ownership of electrical appliances is Møller (1991a). We also use the annual reports of *Danmarks Elværkers Forening* (1985, 1987) for data on the number of homes with heating.[2] Most of Møller's data come from *Omnibus* surveys carried out by *Danmark Statistik* (various years).

A.1.3. Splitting Residential And Service Sectors

We separate oil and district heating consumption into the residential and services sectors following the method suggested by *Energistyrelsen* (1990). We note the share of area heated by oil and by district heat in residential and in service sector buildings. We also calculate the share of each kind of building heated by gas. Assuming that specific consumption for each fuel (energy use per sq meter) is roughly similar between homes and service buildings, we partition each fuel according to the share of area in either homes or buildings.[3] Implicit in this method is the assumption that, over the short run, changes in the unit consumption of oil in homes and in buildings are also similar.

Data for relative areas are taken from BBR 1977, 1981, and years thereafter. Data for 1972 were estimated from the share of homes and buildings heated with oil or district heat in 1977 that had been built before 1972, taking into account the fact that some oil-heated homes and buildings converted to district heat between 1972 and 1977.

Using this method, we arrive at a somewhat different partition of gas than *Energistyrelsen* uses, but similar figures for the partition of oil and district heat. When we compare our figures and those of *Energistyrelsen*, the overall differences are small, but our figures appear to lead to smoother and more realistic changes in oil and gas use in the years after 1986. Our figures for total consumption of oil in homes after 1986 do not fall quite as fast as does the consumption given by *Energistyrelsen*.

A.2. Energy Use in Danish Homes: Some Basic Findings

We obtain important results when the procedures outlined above are followed. Total final residential energy use in Denmark remained relatively constant in the 1970s and decreased in the 1980s. The high value, 225 PJ, was passed in 1970, while the low value of 180 PJ occurred in 1984, rising to 186 PJ in 1990 (see Figure 2-2 in text). Corrected for climate (as explained above), consumption reached its highest level in 1972 at 248 PJ, fell to as low as 178 PJ in 1984 and 1985, then fluctuated between 180 PJ and 185 PJ for the remainder of the decade. Part of this reduction occurred because of the gradual increase in the share of district heat and electricity in space heating, water heating, and cooking. Primary energy use, which is another measure of energy consumption that counts both the losses incurred when fossil fuels are burned to provide district heat and electricity and the losses that arise when these fuels are

[2] Defined before 1986 as the number of SFD or MFD with consumption over 10,000 kWh and 6,000 kWh/year, respectively, but after 1986 according to whether the homes actually used electricity for heating.

[3] Survey data comparing similar energy uses in Sweden show that the intensity of fuel use in Swedish homes is close to the intensity of fuel use in buildings, justifying our assumption.

transmitted to customers, behaved differently. Corrected for climate, primary energy use started at 263 PJ in 1970, rose to 297 PJ in 1972, fell back slightly and then recovered to 291 PJ in 1978, fell sharply to 253 PJ in 1982, and then grew slowly to 270 PJ in 1990.[4]

The broadest indicators of energy efficiency in the residential sector show considerable change during this period. By 1990, delivered energy per capita had fallen by 27% relative to 1972, and primary energy use per capita was 12% below its 1972 value. Since the number of people per household fell sharply over the period, energy use per dwelling fell by considerably more than did energy use per capita. If we assume that about 66% of the energy in oil and gas is provided as useful heat to the house, 55% for solids, and 100% for district heat and electricity, then we can measure "useful energy" (the heat and other services delivered by conversion of fossil fuels) per dwelling or per capita. (Using these figures eliminates most of the distortion that occurs when different fuels are aggregated.) We find that useful energy, per dwelling and per capita, declined sharply as well (see Figure 2-3 in text). These declines imply that significant improvements in energy efficiency took place in this sector.

Energistyrelsen (1990) assumes that conversion losses were actually higher in the early 1970s but somewhat lower by the mid 1980s. This does not change our basic conclusions regarding the magnitude of energy savings in the residential (or service) sector. But this assumption does imply that considerable savings occurred because of improvements in design and use of heating systems themselves. We agree with this implication, and thus point out that our figures for useful energy for the 1970s are slightly too high, while those for the late 1980s are slightly too low. But the exact quantification of conversion losses is unknown. Rather than impute information about the changes in conversion losses, we prefer to assume constant figures.

A.2.1. The Structure of the Residential Sector

Important changes in the demographic and fuel consumption characteristics of the residential sector took place. Population, our measure of residential activity, grew by 3%, from 4.99 million people in 1972 to 5.13 million in 1990.[5] The number of dwellings increased by 25%, from 1.89 million to 2.36 million. The share of single family dwellings increased from 55% in 1970 to 60% in 1990. Household size, calculated as the population in dwellings divided by the number of dwellings, declined from 2.76 persons per dwelling to 2.17. Home size increased from 98 m^2 per dwelling to over 107 m^2. The penetration of central heating, including fixed electric heaters as the main heating source, increased slowly over the period from 82% in 1970 to 96% in 1989. The ownership of major appliances increased substantially over the period. Together, these structural factors led to significant increases in the demand for energy

[4] Our analysis of residential energy use is a further development of our 1983 study published in *Energy Policy* (September).

[5] The population estimates are for January 1 of the year cited. The figures used to calculate household occupancy count people in households only. For 1990, for example, we count 2.35 million households or occupied dwellings housing approximately 5.03 million of Denmark's 5.13 million people. The official figure for "*husstande i egentlige boliger*" (households in actual dwellings) is only 2.23 million. It appears that empty dwellings account for the difference, which amounts to about 6%. Since the discrepancy between full population and population "*i boliger*" (in dwellings) is only 2%, this means we have introduced a small error of approximately 3% as an underestimate of household size in homes. This can safely be ignored.

services.

Fuel mix, defined as the share of final consumption provided by each fuel, is driven by the number of homes using a fuel for a given purpose multiplied by the specific consumption of that fuel. The number of homes using a fuel for a given purpose is denoted by fuel choice. Fuel choice is considered a "discrete" variable: either a home uses oil for heating or it does not. However, increasing numbers of homes in Denmark (and elsewhere) use a second fuel for heating as a supplement to their primary fuel. Information about this practice in Denmark is spotty, but it is assumed that much of the solid fuel and a share of kerosene have been used to supplement electricity, according to *Omnibus* surveys of *Danmarks Statistik*. and as much as 300 GWH of electricity (in the cold years 1985-1987) has been used to supplement oil or district heat in key rooms. Additionally, electricity may have been used to provide hot water in the summer, permitting a household to turn off a large oil-fired central heating system.

Figure A-1 shows that the fuel mix in Danish homes changed significantly during the past two decades. For space heating, oil yielded slowly to district heating from the mid-1970s onward. Gas became a serious substitute for oil after 1984. For water heating, oil yielded to district heating, electricity, and then gas. LPG and city gas lost most of their markets to electricity for cooking, although we suspect that natural gas began to appear in some homes in the late 1980s.

A.2.1.1. Space Heating

Oil, which provided space heating for more than 62% of all homes in 1970, lost share slowly through 1985 but still held 50% of homes in that year. District heating and electricity dominated through 1985. By 1990, however, oil's share had plunged to under 37%, yielding mostly to gas and district heating, which reached 45% of homes by 1990 (Figure A-2).

Use of solids as a source of heat increased during the early years of the 1980s, a time when Denmark's economy was facing a severe slowdown. Complementing small uses of coal or petroleum coke were important uses of renewables (*vedvaerande energi*), particularly straw and wood for central heating. Small "*brandeovne*" (heating ovens) became popular in the hard times of the early 1980s, and local trash burning agencies noted a decline in their own collection as citizens found a convenient, if somewhat smelly, source of extra heat. Thus, the main force behind the rise in the use of solid fuels has been fuel choice, both conversions to solid fuels in central or stove heating and increases in the numbers of stoves used for supplemental heating. While the rise in the use of these fuels slowed in the mid 1980s, it has increased once again according to *Energistyrelsen* (1990) figures. Our interpretation of BBR suggests that more people started using small stoves again in 1989 and 1990, and some of this fuel is certainly used in combination with oil or electric heating, as is common in Sweden and Norway.

A.2.1.2. Water Heating

Water heating fuel choices followed similar trends (Figure A-3). As noted in the description of our methodology, we assume that water is heated by the same fuel that provides central space heating (for district heat and natural gas and, for the most part, oil). The two most important fuels for water heating have been oil and district heating, which were found in more than 75% of homes in 1972. A switch away from oil occurred that accompanied that of space heating: District heating increased its share from 30%

to 44% of all homes in the years between 1970 and 1989. By 1990, oil and district heating together held a 75% share of the water heating market.

Gas and electricity provide most of the remaining Danish homes with hot water. From older FDG documents, we know that there were some "*gennomstrmningsapparater*" (point-of-use water heaters) using city gas in apartments, and gas boilers in a few buildings with city gas-based central heat. These have gradually disappeared, particularly as central heating was added during times of building renovation. We assume, however, that natural gas has entered the hot water market along with space heating, reaching a share of perhaps 10% of all homes in 1990. Meanwhile, electricity represents a small but important part of the water heating market. Its share increased from 4% to 12% of all homes during the same period.[6] Consequently, the share of homes with oil-fired water heat lay 2-3 percentage points under that for space heating.

A.2.1.3. Cooking

Cooking fuel choice has followed a somewhat different course (Figure A-4). City gas fueled more than 35% of all homes in 1970. This figure dropped steadily through the mid-1980s, until natural gas began to supplant or substitute for city gas. LPG appears to have lost its share steadily from almost 20% of homes in 1970 (according to *Folk og Boligtælling*) to only 1% of homes in 1990 (our own estimate). The remaining homes use electricity for cooking. Starting at a share of under 50% in 1970, its share rose steadily until it reached 82% in 1990.

A.2.1.4. Appliances and Lighting

Over the years there has been a gradual increase in the level of appliance saturation for the six most important appliances (refrigerators, freezers, refrigerator/freezers, dishwashers, clothes dryers, and clothes washers, all shown in Figure A-5).[7] For clothes dryers and dishwashers, this meant significant increases in ownership from very low levels in 1972. The only appliance that shows a decrease in saturation level is the refrigerator, which has lost market share to combination refrigerator-freezers (combis). Combis, together with clothes washers, show the fastest increase in saturation level, from 9% to 37% and from 35% to 66%, respectively, between 1970 and 1989. The saturation level of combis, clothes dryers and dishwashers will probably continue to grow in the future. In general, the increase in ownership of these appliances, as well as increases in size, drove electricity consumption up, all else equal. These appliances account for about 50% of the electricity use for "Lighting and Appliances".

[6] We assume that every home with electricity as its main heating source also has electric water heating. We assume that some of those heating with kerosene in the early 1970s used electricity for their principal water heat; from anecdotal evidence, it appears that a few percent of homes began to use electricity for water heating even if they possessed an oil-fired combined heat and water-heat boiler. But the difference between electric water heat penetration (Møller (1991a) finds an unusually high figure of 14% in 1990; we believe 13.1% represents full-time users) and electric heat penetration indicates that nearly half of those with electric water heat used a different source for space heating. Møller (1991a) notes that about 12% of those with electric water heaters in their main homes in 1990 said that they only used them in the summer.

[7] We have followed Møller's work at DEFU closely for more than ten years and use his reports as a guide to our understanding of electricity use in general, and electric appliances and lighting in particular.

The remaining electricity use is distributed over lighting and many smaller appliances. Lighting electricity use is subject to many uncertainties. Møller (1991a) estimates that the number of bulbs per household has increased significantly. Other appliances discussed by Møller that are worth mentioning include TVs and other electronics, central heat pumps in detached houses, and many small household appliances. Their numbers have also increased, according to Møller.

A.2.2. Reduced Energy Intensities: Fuel Switching and Changes in Energy Use

Energy intensities for space heating were significantly below their 1972 values by the late 1980s (see Figure 2-4 in text). Energy intensities of cooking and water heating also fell on a per dwelling basis, but only marginally on a per capita basis.[8] Overall, the cuts were so large that homes in Denmark would have used approximately 65% more fuel and 15% more electricity in 1990 if these changes had not appeared.

However we count the various energy forms, we found that primary energy use per capita or per household declined significantly. That is, the energy intensities of the major energy use by major fuel declined, which we explore in the next section. Only a small part of this decline can be attributed to a particular accounting convention. In the next section we discuss the components of this decline.

A.2.2.1. Space Heating

Space heating energy use is calculated for each dwelling and for each fuel by removing the estimated use of that fuel for water heating, cooking, and other end-uses. Although these adjustments are uncertain, the share of space heating in total energy use is so large that uncertainties in the quantity of energy used for water heating and cooking have little impact on the residual space heating.

Space heating fuel use in 1972, corrected to normal climate, was approximately 155 PJ, electricity use 1 PJ, and district heating 34 PJ. By 1990 fuel use had fallen to 74 PJ, while electricity rose to 5 PJ and district heating rose to 42 PJ. In the aggregate, useful energy for space heating declined by 32%. The number of dwellings increased by 25% during the same period, and the area of each home increased by nearly 8%. Useful energy per dwelling thus fell by 45% in the aggregate. The changes indicate that significant improvements in energy efficiency have taken place.

If we examine the individual heating fuels we come to the same conclusion. Our estimates of the delivered energy intensity of each heating source are shown in Figure A-6, along with the aggregate, measured in useful energy/dwelling. Average consumption of oil, per oil-heated dwelling, fell by 47% between 1970 and 1989. During the same period the use of district heating fell by 41%, and that for electricity by approximately 45%. There were no significant shifts in the proportions of homes heated by any fuel that were either single-family (SFD) or multi-family (MFD). At the same time, the average area of a

[8] Recall that cooking energy use is removed by assumption (Møller gives figures for electricity). The assumption that 66% of the energy in gas is "useful" may overestimate the contribution of gas to useful energy for cooking. As a result, the likely rise in gas use that occurred with increased popularity of natural gas appears to raise useful energy for cooking. We assumed deep cuts in water heating intensity from both oil and electricity, but these were almost matched by the drop in people per household. Consequently, on a per capita basis, useful energy for water heating actually increased.

dwelling increased in size. The effects of falling intensities must be real. Summarizing all of space heating by converting solids to useful energy with an efficiency of 55%, and oil and gas with an efficiency of 66%, we estimate that aggregate space heating intensity in the residential sector (i.e., per degree day and per sq meter) declined by 48%![9]

It is essential to point out that the intensities of space (and water) heating have *not* fallen continuously. From earlier *Energistyrelsen* and Shell data we found that the drop in oil and district heating intensities after the 1973 oil price shock wore off by 1978, something we observed in other countries as well (Schipper 1983). The declines that occurred after 1979 were much deeper and appear permanent in 1990. Although data are somewhat uncertain, there appears to have been a slight rebound in 1986 and 1987, followed by a drop back in 1988. And there does not appear much change in intensities during the remaining few years, perhaps because homeowners focused instead on fuel switching. If the various environmental initiatives in Denmark manage to keep heating fuel prices high, in real terms, we do not expect the same rebound we saw in 1987 to occur.

A.2.2.2. Water Heating

Energy for water heating is calculated bottom up, using assumptions about specific use per dwelling by fuel and the number of dwellings using each fuel for heating water (see above). Our estimates of the unit consumption of water heating by major fuel are shown in Figure A-7. Although the figures are clouded in uncertainty, it is hard not to believe that as the combined total (heat + hot water) in homes using oil or district heat fell, that both components declined substantially. When all energy used for heating water is aggregated and converted to useful energy, the result is a clear decline of water heating energy per dwelling fell by over 16%. However, measured on a per capita basis (see Figure 2-4 in text), this improvement was matched by the decline in household size![10] All else equal, water heating intensity should vary with the square root of household size (Schipper et al. 1989). But between 1972 and 1990, water heating energy use/dwelling fell more than did the square root of family size. This means that there was an apparent conservation effect for water heating as well. It is worth noting that the small increase in water heating we show occurs between 1988 and 1990 is caused by the sudden increase in the importance of natural gas, for which we have no data on consumption.

[9] This figure is of course subject to our assumptions about hot water use. But even if we were mistaken in our assumptions about the intensity of hot water use (or its change), the combined heat and hot water figures fell dramatically.

[10] Given the uncertainties in dividing water heating from space heating (see Schipper 1983) we believe it is possible we understated the decline water heating intensity by overstating slightly the decline in space heating intensity. On the other hand, there is no simple way to define the hot water production of a combined oil-fired heating and water heating boiler, because the efficiency of hot water production is actually very sensitive to the overall utilization of the system. In the warm months or summer, this efficiency may fall below 25%.

A.2.2.3. Cooking

Cooking fuel and electricity use is derived by assumptions on unit consumption based on information provided by Møller (1991a) and FDG, as well as our own estimates of use for LPG (See also *Dansk Kedelforening's* (1978) analysis of energy use patterns in 1972). The number of homes using each fuel for cooking is multiplied by the assumed unit consumption of that fuel. Given the many uncertainties, the trends in Figure A-8, both individual or aggregate, cannot be taken too seriously. Up until the mid-1970s total delivered energy use decreased for cooking, a consequence of increased substitution of electricity for gas or even solids. The total turned upward when the penetration of gas appeared to increase in the mid 1980s. *Useful* energy per dwelling fell steadily through the mid 1980s, then began to increase slowly as gas penetration increased.[11] On a per capita basis, however, cooking intensity appeared to increase significantly after the mid-1980s, Part of this effect is real, a consequence of the declining number of household members. Unless better data indicate actual values for the intensities of both electric and gas cooking in recent years, we can draw no conclusions from these findings.

A.2.2.4. Appliances and Lighting

Figure A-9 shows a breakdown of total electricity sales by major end use. Electricity use for household appliances and lighting (those uses that are almost always satisfied by electricity) grew rapidly in the 1970s, then much more slowly in the 1980s. The main reason was a dramatic drop in the electricity intensities of individual appliances. During the entire period, however, appliance ownership levels continued to grow. The overall result was strong growth in appliance electricity use per capita through the mid-1970s, then stagnation and fall through the early 1980s, then slow growth thereafter, as shown in Figure 2-4 in the text.

Electricity use per household for most of the six most important appliances has decreased over the period from 1970 to 1990. This is because the use of electricity *per appliance* fell sharply. (The figures, from Møller (1991a), are given in Figure A-10.) Increases in ownership of combis and washing/drying equipment nevertheless outweighted these improvements, so electricity use per household for these end uses increased.

Møller estimated the electricity use in *new* appliances fell sharply. This improvement was the driving force behind the overall reduction in energy use per average appliance that occurred between 1972 and 1990. Since new appliances still use less electricity than existing ones, average use per appliance continues to fall, albeit more slowly than in the mid 1980s.

According to Møller's estimates, energy use for lighting has been increasing in a slow but steady pace from 2.7 PJ in 1970 to 5.0 PJ in 1990 (750 GWH to 1390 GWH). He assembles information from a variety of sources to track an increased electricity consumption per sq meter of floor area, from 4.28 kWh/sq/year in 1970 to 5.54 kWh/sq m/year in 1990. Our estimates lie close to his, but we believe consumption was stagnant between 1978 and 1981, as electricity prices shot up. (His figures show an increase in lighting energy use per sq meter of household floor space.)

[11] These results are in part a consequence of our imperfect measure of useful energy for cooking.

To be sure, some efficiency improvements in lighting have occurred. It is believed the use of fluorescent tubes and compact fluorescent lamps has increased, but the numbers that Møller (1991b) cites from the 1990 Omnibus, (*Danmarks Statistik*, various years) 0.8 tubes or 0.2 compact fluorescents per homes, are far too low for any impact on lighting energy to be measured. We await concrete results from the Danish utilities currently supporting the spread of such lamps.

The substitution of electricity for fuel in heating, water heating, and cooking was an important cause of growth in household electricity use in Denmark. Other things being equal, this substitution alone increased electricity use in the substitutable markets of heating, water heating, and cooking by 175%. Increases in the ownership of appliances and lighting equipment caused an increase in electricity use for those purposes of 75%. The net result of these changes was that the substitutable markets for electricity increased their share of total residential sales from 33% in 1972 to 45% in 1990.

If we had counted the water heated in washers, the increase in the share of "substitutable" electricity would be even greater. Consequently, we made an important adjustment to our figures for total electricity for lights and appliances when we aggregate electricity with other fuels. We take estimates of water heated by electricity in washers and dishwashers (almost always the case in Denmark) and include this in our overall hot water figures, counting this contribution of electricity to water heating this way. Failure to do this introduces a bias over time, as more families use machines rather than tanks to heat cold water for washing. That is, we should see a decline in hot water preparation from tanks (or from other equipment) and a subsequent rise in the role of electricity for this purpose. By making this adjustment we can more easily compare Denmark to Sweden, where dishwashers accept hot fill from tanks, or the U.S., where both dish- and clothes-washers run on hot fill.

Danish Household Energy Use By Fuel Type

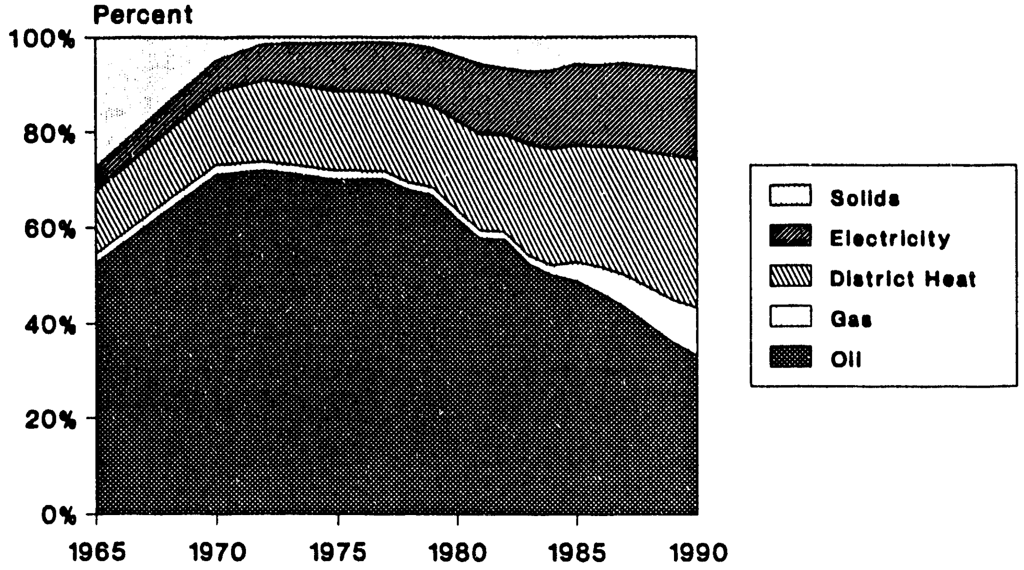


Figure A-1

Household Energy Use In Denmark Space Heating Fuel Choice

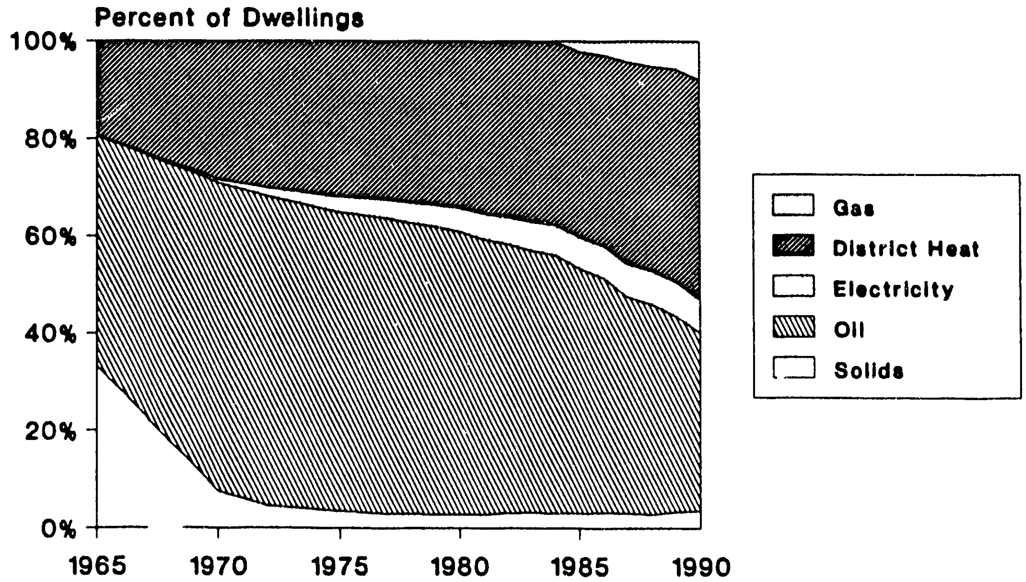


Figure A-2

Household Energy Use In Denmark
Water Heating Fuel Choice

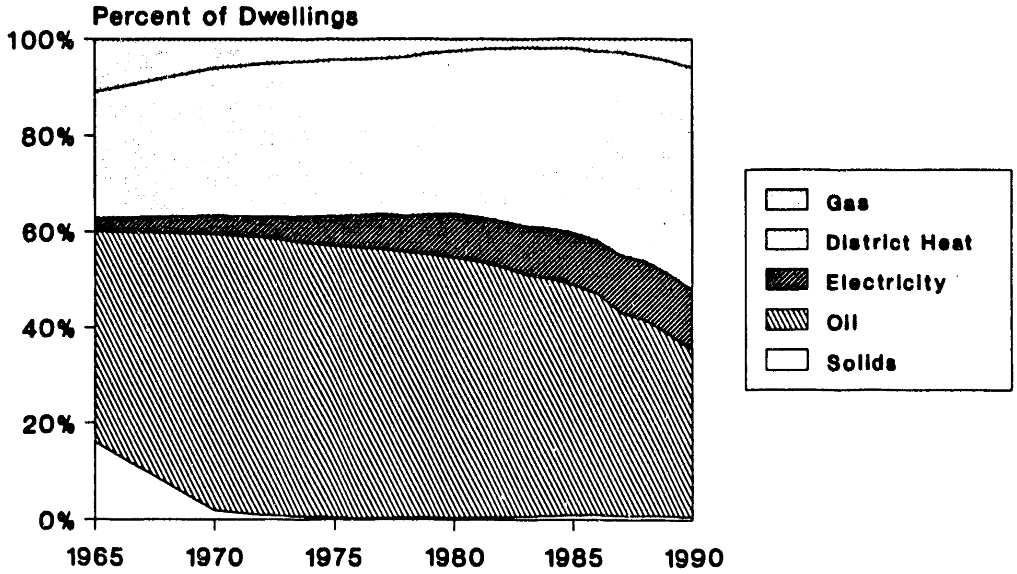


Figure A-3

Household Energy Use In Denmark
Fuel Use for Cooking

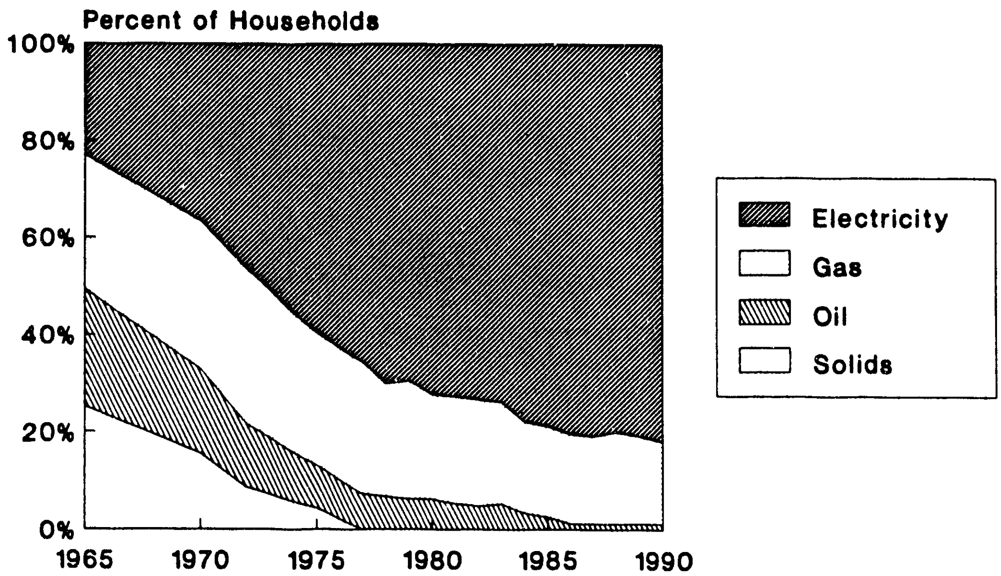


Figure A-4

Household Energy Use in Denmark
Appliance Saturation

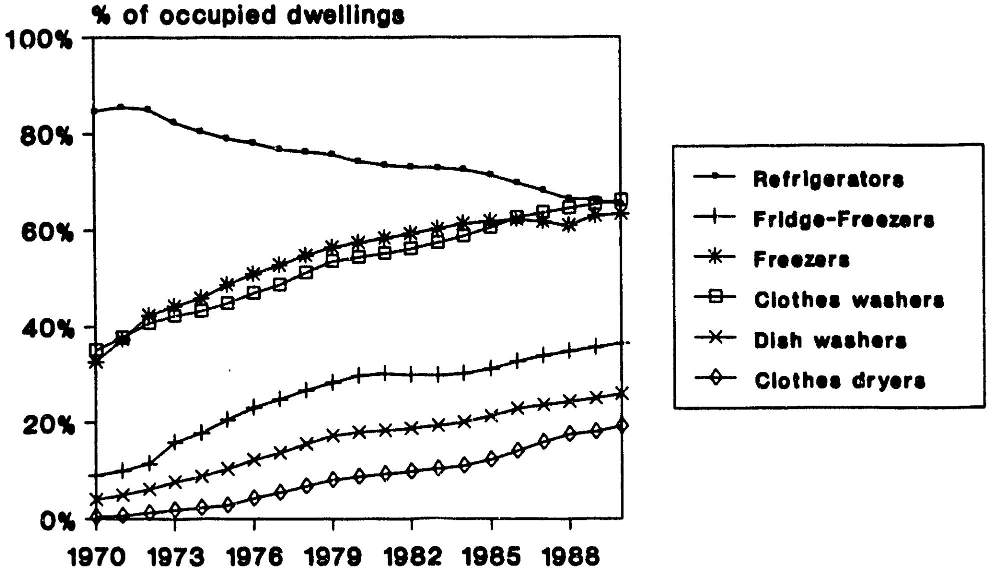
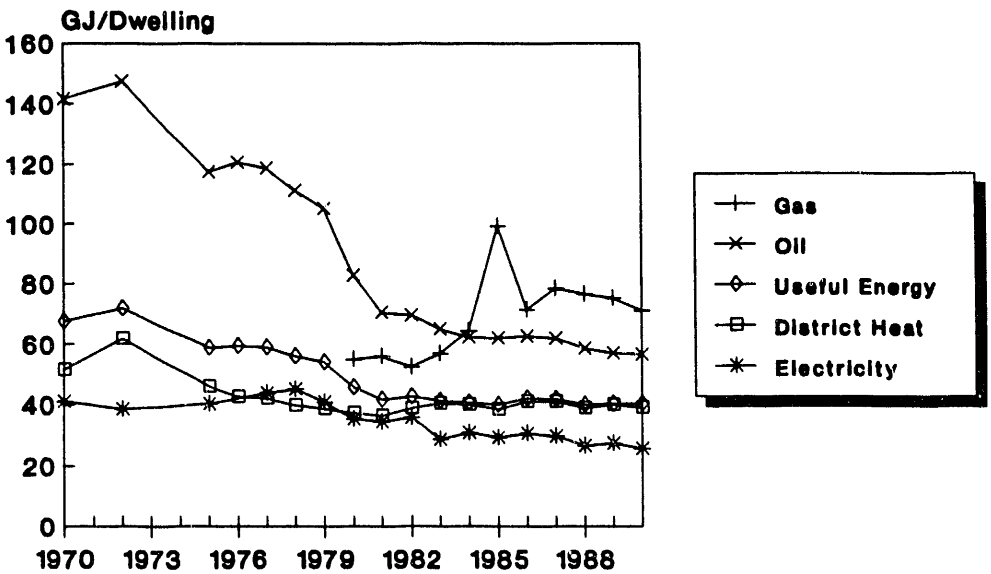


Figure A-5

Household Energy Use in Denmark
Unit Consumption of Heating Fuels



Climate Corrected

Figure A-6

Household Energy Use in Denmark
Fuel Use for Hot Water

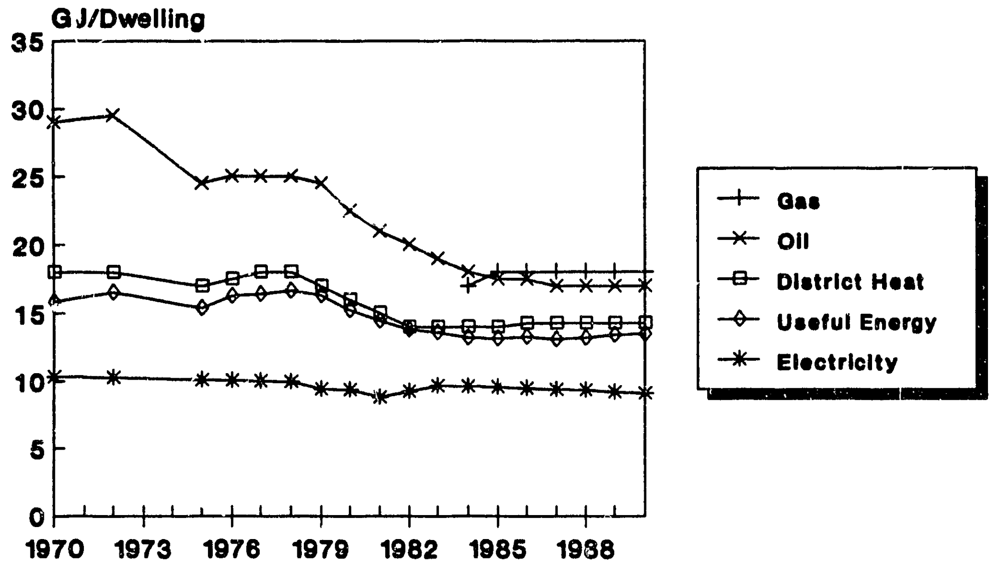


Figure A-7

Household Energy Use in Denmark
Fuel Use for Cooking

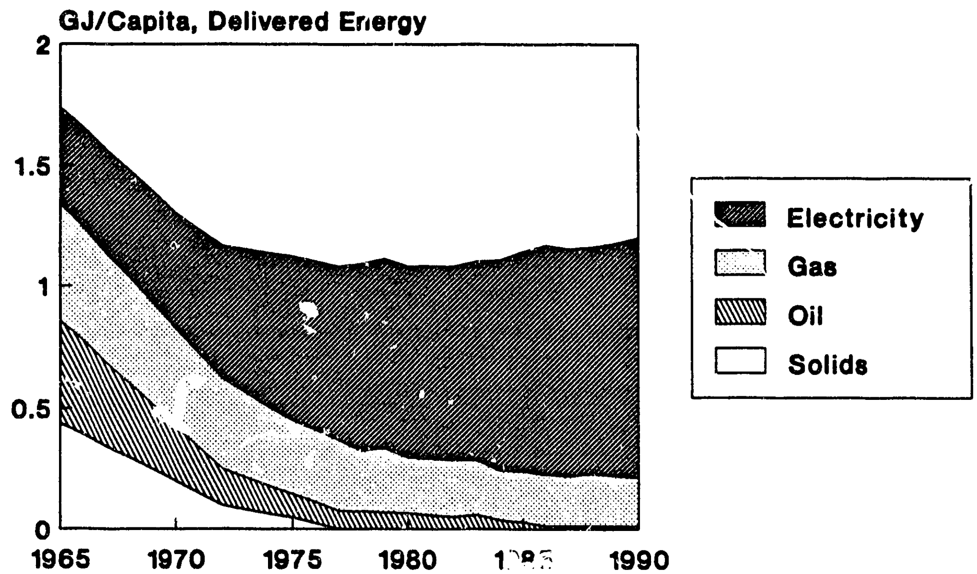
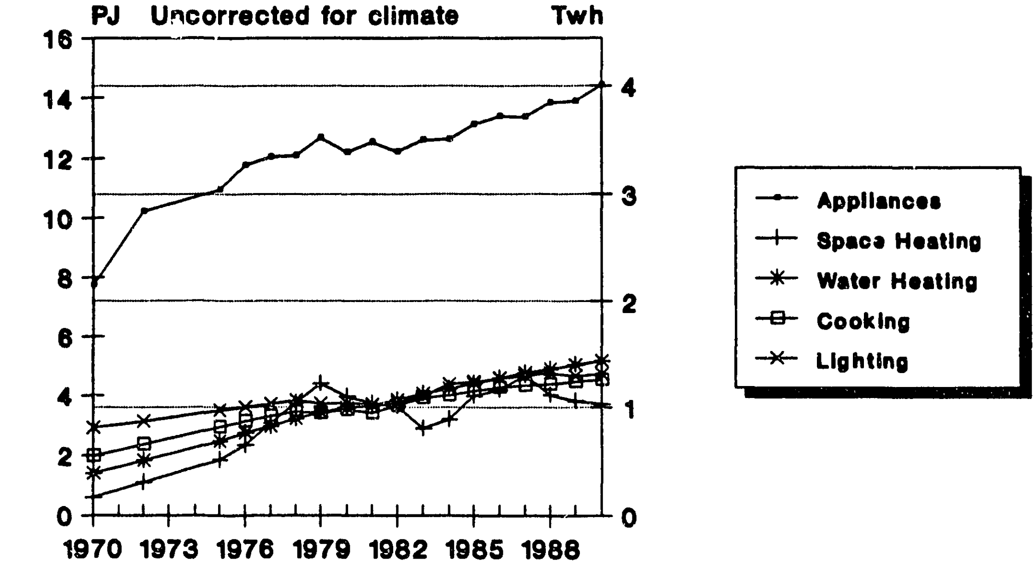


Figure A-8

Household Electricity Use In Denmark
Electricity by End-Use



Water heating includes
hot water for washers

Figure A-9

Household Energy Use in Denmark
Unit Consumption for Appliances

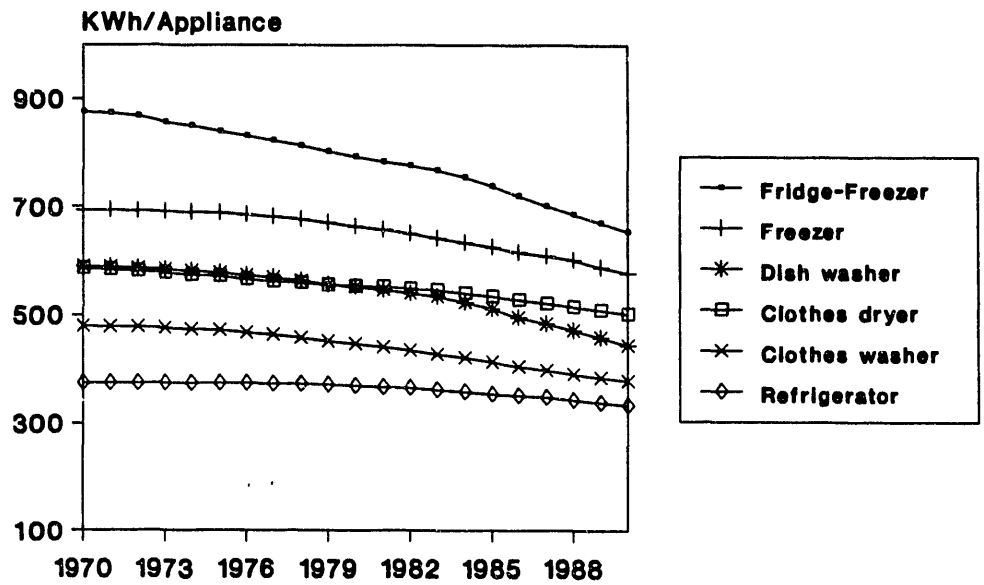


Figure A-10

APPENDIX B: ENERGY USE IN THE TRANSPORTATION SECTOR

In this appendix we explain our analysis of the data for transportation. We place particular emphasis on our reconciliation of data from *Trafikministeriet* (the Ministry of Transport, formerly the Ministry of Public Works, MOA), as provided by Sørensen (1990, 1991),[1] from *Energistyrelsen* (1990),[2] and from other sources named below. After our work and discussions with Danish experts, we have made many important adjustments to transportation-related energy use data. These are noted below.

B.1. Sectoral Overviews: Travel and Freight

Transportation consists of two sectors: passenger travel and freight. Travel activity is measured in passenger-kilometers (p-km), freight activity in tonne-kilometers (t-km). These are further divided into modes: automobile (including taxi and *varebil* [light truck]), two-wheeled vehicles (motorcycle and moped), bus (local city, intercity, and charter), local rail (including the S-bane in Copenhagen), and inter-city rail passenger (including private railroads); trucks above two tonnes, rail freight, domestic shipping, and air for freight.

Certain definitions are crucial to our discussion. Traffic is measured in vehicle-kilometers (veh-km); we often refer to this measure for automobiles and trucks. Vehicle intensity is measured in (energy use)/(distance covered), usually in MJ/veh-km or liters of fuel/veh-km. Travel in cars is almost always estimated by multiplying veh-km by the average number of people in a vehicle, which is called load factor. In measuring air travel, a measure of available seats times distance flown, or seat-km, is also used, and load factor refers to the share of available seats actually filled. From these measures, we form modal intensities by dividing energy use by the level of modal activity, shown as MJ/passenger-km. Modal intensities for freight are measured in MJ/tonne-km.

We exclude walking, cycling, and mopeds/motorcycles because of the uncertainties in data. These are not unimportant modes, since they permit Danes to travel locally at virtually no energy cost, i.e., substitutes for using automobiles for short trips, where energy use and emissions are very high. Mopeds and motorcycles supply important transportation for longer distances as well.

Pipeline transport of oil and natural gas has appeared since 1984. We include this activity in our discussion, but omit it from the calculations of the impact of structural change on freight energy use,

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[1] Sørensen used traffic counts to tabulate vehicle activity data in vehicle-kilometers (veh-km), and information about load factors (people per vehicle, tonnes per vehicle) to estimate modal activity in passenger-kilometers (p-km) or tonne-km (t-km). Sørensen used assumptions about vehicle unit consumption (energy/vkm) and modal unit consumption (energy/p-km or t-km) to arrive at likely patterns of consumption of each fuel for each mode for the years 1972 and 1975-present. Sørensen revised the activity data from 1979 activity completely, but did not revise activity data for previous years. However, the two data sets match fairly well.

[2] *Energistyre :n* provides data for road, rail, air, and sea transport energy use based on information provided by energy supplies. We received revised data from *Energistyrelsen* in August 1991 (Bach 1991), and commented upon these in September, 1991. A final revision was provided in December, 1991. The *Energistyrelsen* data are *not* broken down by mode (i.e., truck, car, etc.). The new data show greater consumption of fuel in the road sectors (i.e., truck, car, bus, miscellaneous), with the residual fluctuating between 4.45 and 8.5 PJ, enough to "smooth" some of the fluctuations we observed in individual intensities. Important odd findings are noted herein (see also Figure B-1, which shows energy use by mode as reported by *Energistyrelsen*.

since there are no data published on energy use in this mode.

Another important activity excluded from our analysis is international air travel. This activity is difficult to allocate to a country, since we do not necessarily know the nationality of travelers embarking or disembarking at Kastrup International Airport. Similarly, allocating the energy sold to foreign air travel is difficult. Finally, we cannot easily find out how far the travellers go, nor how far the energy stretches before planes are refueled. Since fuel for international air travel amounts to roughly 10 times the fuel for domestic Danish lines, this omission is unfortunate.

Finally, we have omitted fuel use and activity for international shipping. Again, this is unfortunate. From an estimate of the tonnes shipped overseas it appears that both the energy used and tonne-km shipped are large compared with the energy used for all domestic freight in Denmark.

There are fundamental problems with the energy consumption data. Between six and ten PJ of oil attributed to transportation by *Energistyrelsen* remained unallocated after the energy use and intensities given by MOA and *Trafikministeriet* tables from 1972 onward were used to derive energy use by mode. Following both *Energistyrelsen* and *Trafikministeriet*, we have allocated this consumption to trucks.

An additional problem complicating our analysis is that *Trafikministeriet* provided no analysis of the pattern of energy use in travel or freight for 1989 or 1990. Because of the uncertainties in the allocation of energy use year to year, it was difficult to extrapolate the patterns of the previous years to 1989 and 1990. Consequently, our detailed discussion of modal intensities covers the period 1972-1988, but the broader discussion of trends in the structure of transportation covers the period from 1950 to 1990.

B.2. Energy Use for Transportation

Total energy use for domestic transportation in Denmark lay at 109 PJ in 1972 (Figure B-2). It then followed a roller-coaster course, falling to 105 PJ in 1975, growing to 123 PJ by 1978, falling back to 110 PJ during the recession that followed the 1979 oil price shock, then growing rather steadily to 139 PJ in the period 1986-8, and reaching 142 PJ in 1989. Energy use per capita followed the same course, growing from over 20 GJ in 1972 to nearly 28 GJ in 1988. The share of energy use for freight increased relative to total transportation energy use, from slightly over 28% to 36% during the same period (Figure B-2). This occurred because energy use per unit of freight activity increased significantly, and because total freight movements increased somewhat more rapidly than did travel.

Passenger and freight activity grew with income (GDP) over time, but the growth rates were significantly different. As Figure 7-1 (in the main text) implied, travel grew more rapidly than domestic freight through 1970; thereafter, it was freight that grew more rapidly relative to GDP, while travel stagnated. By 1990, however, both activities had stabilized and were increasing slowly relative to GDP again.

B.2.1. Passenger Transportation

Trends in energy use for travel depend both on figures for energy use *and* those for traffic and travel. Using various assumptions outlined in a series of memos, Sørensen divided up energy use by fuel into passenger and freight components. Energy use for automobiles (predominantly gasoline) was estimated by *Trafikministeriet*/MOA as a residual after that for other modes was calculated. This is reasonable because automobiles dominate the use of gasoline and gasoline dominate the fuel mix for automobiles. Interestingly, *Dansk Teknologisk Institut* (1987), in their analysis of road transport fuels for 1985 and 1986, arrive at figures close to those provided by *Trafikministeriet*/MOA and close to what is implied by the *Energistyrelsen* figures.

Unfortunately, however, two other significant and possibly greater uncertainties cloud both the basic analysis and its interpretation. First, actual traffic in automobiles is poorly documented. While there are organizations or companies counting the actual distances covered by busses, rail, most truck, and other modes, there are almost no figures covering traffic by private automobiles, taxis or rental cars, and light trucks used as passenger vehicles. Various studies (*Energiministeriet* 1983, *Trafikministeriet* 1988) measure distances people travel in cars as either drivers or passengers. Second, the actual production of travel in automobiles, measured in passenger-km, is poorly known. Passenger-km is derived from vehicle-km and load factor (or passengers/vehicle). In the following analysis, we present both official figures for the level of travel in automobiles, and then our own, calculated from important Danish sources. The alternative calculations give a significantly different result to the development of energy use in travel. In the subsequent discussion here, as well as in the main report, we use the levels of travel we derived from combining *Trafikministeriet*/MOA data on vehicle activity (including *varebiler*) with the new load factors.

B.2.1.1. Domestic Travel Activity

In 1972, the average Dane traveled about 9200 km by motorized means, according to *Trafikministeriet*. Of this, 81% was by automobiles.[3] During the early 1980s, when fuel prices skyrocketed and the economy stagnated, travel fell, particularly the share of travel in cars whose share fell to just 74% in 1982. Walking and cycling, which represent a substantial share of trips, increased. While these modes represent only a small share of distance traveled, they provide key mobility in short trips that would be costly if carried out using cars with cold motors or in congested areas. Using the official figures, travel had risen to over 12600 p-km by 1988, with the share of cars at 76%.

Averaged over the entire period, per capita travel increased by 2% per year. However, since 1981, the rate of growth was more than twice that rate, or 3.8%/year. The fluctuations in the share of automobile travel were mirrored in the role of rail and bus travel which increased during periods of high fuel prices and declined when fuel prices fell and the economy boomed. Similarly, measures of walking and cycling increased with bus and rail, and fell back as the automobile regained its momentum.

We have also calculated total travel in Denmark using an important set of alternative assumptions for the contribution of automobiles. Lund (1975) estimates the structure of travel between 1950 and 1973 in some detail, paying particular attention to the use of automobiles. Using various surveys and estimates, this study finds that in 1970 there were about 2 people in an automobile, on average. This figure lay at 1.9 in 1973. That evolution is consistent with what we have observed in many other countries.

[3] Unless otherwise stated, "automobiles" include taxis, rental cars, and light trucks (*varebiler*) under 2 tonnes. Motorcycles, which accounted for 3% of motorized travel in 1970, falling to about 2% by 1988, are excluded. Cycling, walking, and mopeds account for a significant number of trips, but a very small fraction of total travel.

With these problems in mind, we have re-estimated the load factor in cars. Material provided by *Vejdirektorat* (1981) indicates a load factor of 1.84 in 1981 if children are counted (1.53 without children). To check this estimate, we calculated from *Person trafik i 1975 og 1981* (*Energiministeriet* 1983) the number of trips by trip length made by automobile drivers, automobile passengers, and drivers of light trucks as well. Weekday travel was added to weekend travel. By dividing total passenger-km obtained by total vehicle-km traveled, we derived a load factor. (Note that distance is used in this calculation, not simply number of trips. Longer trips tend to be taken with nearly 2 people in a car.) Carrying out the same calculations on material from *Trafikundersøgelse 1986* (*Trafikministeriet* 1988), we estimated that the load factor in 1986 was only 1.47 without children and 1.74 with children[4] From *Trafikundersøgelse 1986*, we found that total travel reached 46 bn passenger-km, close to the *Trafikministeriet* (1990b) figure, and total traffic of 32 bn passenger-km, considerably higher than the *Trafikministeriet* (1990b) figure for 1986 but not implausible.

A significant number of respondents in *Trafikundersøgelse 1986* did not know the length of their car trips. In our calculations, we estimate the impact of "unknown" trip length. Given that weekend travelers (whose travel is irregular) tended to know trip length less often than weekday travelers (who travel regularly to and from work) that passengers knew trip length less often than drivers, and that passengers tend to travel on longer trips than drivers, we estimate that the "real" load factor for 1986 was somewhat higher. We adopt 1.74 as our figure. We interpolated load factors for the years between 1973 and 1986, assuming that the load factor was constant during the years immediately following the two price shocks but fell approximately 0.05/persons/year in other years. Load factor for taxis and rental cars was assumed to be a constant 1.75, that for *varebiler* a constant 1.4 (following Lund 1975).

These calculations have a fundamental impact on the evolution of travel. When these two load factors (and interpolations) are multiplied by the traffic levels for cars, taxis, rental cars, and *varebiler*, we obtain a *higher* level of car travel in 1970 than given by *Trafikministeriet*/MOA, but almost 15% less in 1988. This change boosts the *share* of rail and bus in later years, but depresses slightly that share in the early 1970s. Total travel in Denmark in 1972 reached 9660 p-km/capita, 5% higher than the *Trafikministeriet*/MOA figure cited above. But total travel lay at only 11000 p-km/capita in 1988, a full 10% under the level estimated by *Trafikministeriet*/MOA. Thus the *growth* in mobility in Denmark is much slower using our alternative calculations about the role of cars. *After careful consideration of the assumptions and data used in all the reports we have studied, we adopt these figures for our analysis. This assumption means that the change in the modal energy intensity of the car between 1972 and 1988 is very small.*

B.2.1.2. Energy Use and Intensity for Travel

Energy use is dominated by automobiles. Since this major use is calculated by *Trafikministeriet*/MOA as a residual after other modes are account for, there is some uncertainty in the value. Hence the energy intensity for automobiles is also uncertain. With this caveat, we find that the on-road, fleet wide intensity of automobiles (and light trucks) appears to have fallen by 0.9%/year

[4] The survey in 1975 contained this information but the results were not published and are not obtainable.

between 1972 and 1988. Vehicle intensity lay at 9.11 l/100 km (for gasoline) in 1972 and fell slowly to 7.6 l/100 km by 1988. This is plausible: the average of the test fuel intensities of new cars (actually the 20 most popular models) weighted by sales figures fell by a greater amount.

There is, however, one element of circular reasoning hidden in these calculations. Fuel intensity, in fuel/km, is equal to fuel consumption for the entire fleet divided by the number of cars and the number of kilometers per car. Thus, the determination of fuel use per km, depends on km/car/year. The present calculation assumes that the distance traveled per car per year rose by 0.1%/year during the same period, to 16900 km/year, one of the highest figures in all of Europe. Given the low penetration of cars in Denmark (320 cars/1000 population, as opposed to close to 400 or higher for Sweden, Norway, Germany, France, and Italy), this distance is not implausible. That is, per capita distance drive is about average for Europe. And the trend towards more driving appears reasonable, although there is some uncertainty as to whether traffic counts really distinguish among the kinds of vehicles being counted, i.e., cars, light trucks, heavy trucks, etc. However, a significant increase in total traffic must imply a significant increase in automobile use and we accept the *Trafikministeriet*/MOA figures for automobile traffic. Thus, the decline in the vehicle intensity of automobiles appears reasonable.

The modal intensities of Danish travel behaved in a mixed fashion, but there are large uncertainties (Figure 6-4 in the main text). Recall that vehicle intensity of automobiles, which is used to derive modal intensity, is calculated as (total fuel consumed)/(total distance driven); since fuel consumed is calculated as a residual after other liquid fuels are allocated to various modes, there is some uncertainty here. Intensities for rail and bus should be reliable, as passenger-km produced and fuel consumed are reported by various regulated operators. The same should be true for air travel, but the fluctuations observed are very difficult to explain.

Using our calculations for load factor, total travel in automobiles grew far less than is the case if the original *Trafikministeriet* figures for travel are used. The modal intensity of cars, in mJ/p-km, rises from 1972 through the early 1980s. After reaching its high point in 1985, this indicator then falls, and winds up slightly under its 1972 value in 1988. The actual highest point is not clear because of uncertainties in fuel use and load factor, but the pattern is clearly a rise and then a drop. That is, the likely fall in load factor is *greater* than the likely drop in vehicle intensity for much of the period we studied. By our measure, then, little energy was saved in the movement of people in cars.

There was a small decline in the modal intensity of busses between 1972 and 1988. However, the modal intensity of bus travel increased suddenly after 1985 to almost 50% above its 1972 value, according to *Trafikministeriet*. There is no obvious change in the traffic (*trafikarbejd*) for any busses, nor a change in the load factors. It appears that the *Trafikministeriet* figures assign about 50% more energy to busses after 1986, which seems unphysical. We have therefore smoothed the figures for the 1986-1988 period to reflect the average of 1984 and 1985. This smoothing leads to a larger decline in intensity between 1972 and 1988 than we would have obtained had we used the original *Trafikministeriet* figures.

The intensity of rail travel, measured in delivered energy, fell 10% over the period we observed. Measured in primary energy (i.e., counting electricity as the fuel required to produce it), the modal intensity in 1988 was 8% below its 1972 value. The difference in these changes suggests that the a small part of the decline in the delivered energy intensity of rail travel was caused by substitution of electricity for oil, as the penetration of electrified rail lines increased.

Our first analysis of energy use for air travel revealed a very unlikely use of diesel fuel in two years, as well as unusual jumps in aircraft fuel in other years. *Energistyrelsen* found the source of some of these jumps, but we smoothed the remaining ones (1985-88) to arrive at figures for air intensity that are consistent with those in other countries. The resulting decline in the intensity for air travel in Denmark was small compared to that observed in almost every other country. Aside from statistical uncertainties, this behavior may reflect the fact that the routes in Denmark are of very short range and were covered by aircraft with piston engines in the early 1970s, with increasingly numbers of turbo-props and jets by the late 1980s. This switch raises energy intensity, even if both turbo-props and jet aircraft have each become more efficient during the entire period.

B.3. Freight Transportation

Energy use for each mode of freight was estimated by *Trafikministeriet*/MOA in the same documents used to estimate that for travel. Freight vehicle traffic (measured in veh-km) and freight shipments and activity (in tonnes, and, for our purposes, tonne-km, respectively) are well documented, since firms are involved. Important uncertainties dominate energy use, particularly that for trucks.

B.3.1. Domestic Freight Activity

Total domestic freight activity (truck, rail, inland, shipping, pipeline, and air, but excluding transit freight shipped over Danish rail or roads) has grown from 10.1 billion tonne-km in 1972 to 13.3 billion tonne-km in 1988. In per capita terms, these levels were 2000 tonne-km/capita in 1972 and 2890 tonne-km/capita by 1988.[5] Pipelines, excluded from the totals above, provided 0.5 billion tonne-km in 1984, rising to 1.5 tonne-km by 1988, or about 12% of the total including pipelines. Including these data raises total freight activity to 14.8 bn tonne-km in 1988. (Figure 7-2 in the text) shows per capita freight with pipelines included.) With this figure we find that freight activity in Denmark grew more rapidly, on average, than did travel, which is unusual among the countries we have studied.

Trucks dominate the modal mix, responsible for almost 70% of the freight in 1988 (including pipelines), up from 65% in 1972. Rail holds a correspondingly small share, 8%, down from 17.7% in 1972, losing almost 4 points to pipelines in the late 1980s. The share carried by ship fell from 17% in 1972 to 12% in 1988, although shipping held over 20% in 1983, before pipelines became important. Air freight is insignificant.

B.3.2. Energy Use and Intensity For Freight

Energy use for freight in Denmark lay at 35.4 PJ in 1972, of which three-fourths went for trucks. By 1988 consumption was close to 57 PJ, and the share of trucks had risen to 92% of this value. Although freight activity excluding pipelines grew less rapidly than travel, energy use for domestic freight climbed more rapidly than that for travel.

[5] Figures quoted for activity here exclude transit freight, but transit freight is included in the calculations of energy intensities.

The intensities of freight in Denmark show mixed trends. Even with the uncertainties considered, truck freight required more energy per tonne-km in 1988, 5.09 mJ., than in 1972, 4.17 MJ/ tonne-km. (Figure 7-3 in the text). The increase from 1972 to 1988 reflects both the general trend towards smaller loads on any sized truck as well as an increase in the role of smaller trucks, possibly for just-in-time applications. The rise in smaller trucks is confirmed separately by data from *Trafikministeriet*.

Other intensities behaved in a mixed way. Energy intensity of rail freight decreased, although the data show wide fluctuations.[6] Energy intensity of ferries and shipping also decreased considerably between 1972 and 1988. The intensities of freight, like those for travel, show considerable fluctuation, which must reflect both uncertainty in activity by mode (particularly for trucks and shipping) and uncertainties in energy use for trucks. However, the differences between 1988 and 1972 for each intensity appear larger than the typical fluctuation. This means that the trends reflect the real situation.

Although there are great uncertainties over the data for freight, it is clear that the trucking system in Denmark has become considerably more energy-intensive. A careful systematic study based on diaries or other survey tools may be needed, not just to clear up the data problems, but to show why freight energy intensity is rising.

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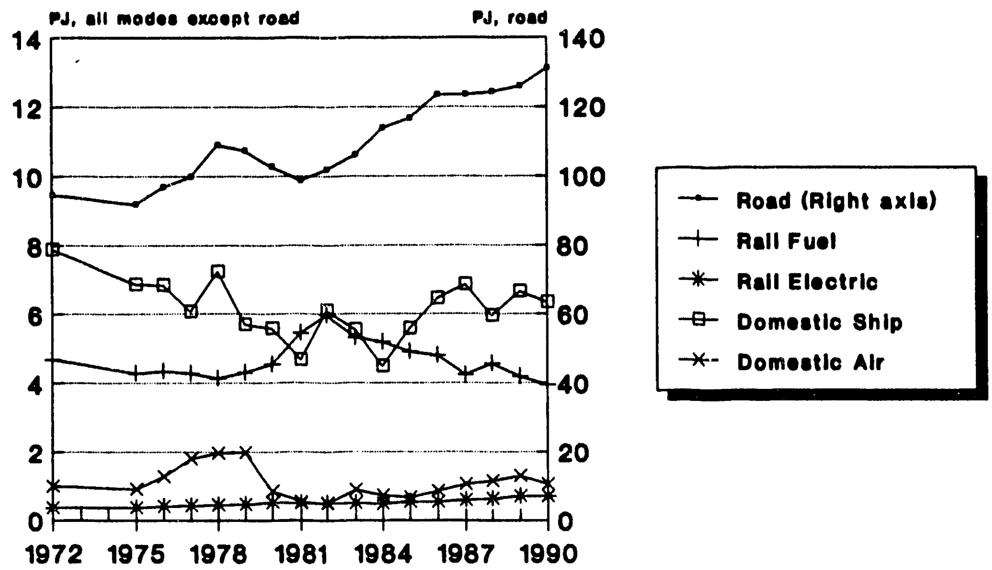
[6] It is presumed that all freight is carried on diesel lines. Since the revised *Energistyrelsen* transportation energy utilization figures did not split passenger and freight fuel use for rail, we used the passenger energy-use figures worked out previously by *Trafikministeriet*/MOA, and assumed that energy not "claimed" by the passenger rail sector was used by freight. This estimate leads to an upward skip of intensities between 1981 and 1983, with a corresponding decline in the intensity of rail travel.

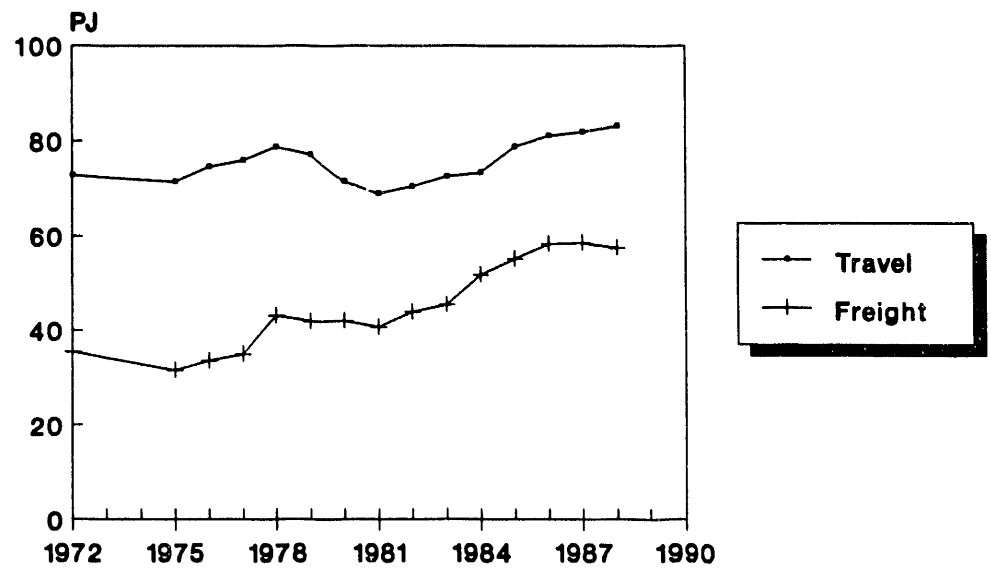
Transportation Energy Use in Denmark
By Main Market



Source: Danmarks Energistroemme, Energistyrelsen

Figure B-1

Transportation Energy Use in Denmark
By Main Market



Source: This report

Figure B-2

APPENDIX C: FUTURE ENERGY USE IN DENMARK: REFLECTIONS ON SCENARIOS FROM *ENERGI 2000*

With our historical analysis as a basis we present brief comments on the scenarios used for *Energi 2000*. These are described in a series of reports issued by *Energistyrelsen* in 1990. Each sector's scenarios are constructed differently, but the published studies permit a straightforward comparison of the reductions in energy intensities built into the scenarios. It is these changes in energy intensity that we discuss below. In this discussion, "savings" refers to the effect of lower energy, fuel, or electricity intensities. We comment briefly on assumptions governing activity and structure in some cases as well.

C.1. Industry (Manufacturing and Other Industry)

The energy scenarios for Danish industry, *Procesenergiforbrug og besparelsemuligheder*, (Risø National Laboratory 1990) are built from three important components: assumptions about growth in output in main industry branches, a reference case that describes the decline in energy intensities of each branch, and a set of scenarios describing improvements in efficiency beyond those built into the reference case. Output is measured by production indices, which are presumably linked to real value added.

The reference case takes account of the historical trend of falling fuel intensities, but foresees a break in the trend of rising electricity intensities. From this starting point, a series of additional savings are proposed. Additionally, the reference case includes the small effects of changes in the mix of industrial output, which appear to depress fuel and electricity use slightly.

The reference case foresees a 25% drop in the ratio of total energy to value added (the "*energifaktoren*"), based on a measure of primary energy consumed by each branch of industry. In the base case, the share of electricity (measured as gross or primary) grows from 41% to 50%, (from 18% to 27%, if electricity is counted at its final-demand value) a continuation of the historical trend towards greater use of electricity in Danish manufacturing.

The decline in aggregate manufacturing fuel intensity foreseen in the scenarios, were the efficiency potentials to be realized, appears reasonable when seen against the increase in real prices and historical trends. The base case represents a decline in fuel intensity of 1.1% per year, or 37% by 2030, compared with 1988. The decline in fuel intensities in the reference case is far slower than observed during the 1970s and 1980s. This decline seems low, given the slow upward march of fuel prices (a tripling of that for liquids, for example). Given the tripling of liquid fuel prices (which draw up gas prices) and likely environmental constraints on switching to solids, we would expect that Danish industry will have to face these higher prices and improve its energy efficiency somewhat more than in the base case.

The conservation scenario represents this improvement. The extra gains in intensity that occur if the potential for fuel saving is captured, an additional 30% decline in fuel intensity between 1988 and 2030, represent a drop of 0.85% per year. The combination of the fall in fuel intensities in the base case and the extra decline from the scenarios reduces the fuel intensity of Danish industry by 2% per year, or by 56% in 2030, compared with 1988. This may seem like a bold step, yet it is less than the rate of improvement observed in the period 1966-1972, 2.1% per year, when prices were falling anyway, and far less than the rate between 1972 and 1988, 3.6% per year, when prices were increasing. In short, the fuel conservation foreseen in Danish industry seems fully within the grasp of Danish industry, given both historical performance as well as the assumptions about output development and energy prices.

Electricity is somewhat different. Between 1966 and 1972, aggregate electricity intensity in Danish manufacturing increased by 2% per year, between 1972 and 1988 by 2.7% per year. In the base case, intensity declines by only 4.5%, or by 0.1% per year. Ignoring the effects of campaigns and non-profitable investments, electricity intensities in the scenarios decline by roughly 25% between 1988 and 2030, or at a rate of 0.7% per year. This decline is not inconsistent with forecasts in other countries. Yet it represents a clean break with trends in Denmark: Can a price increase of less than 1% per year bring on this decline in electricity intensity?

The scenarios also estimated additional electricity savings that might accrue if extra efforts were mounted. These appear to boost the overall savings by about one-third. Whether the extra effort required to capture the remaining decline in intensities foreseen in the scenarios can be mounted is uncertain. However, this "extra effort" is consistent with what Schipper and Meyers et al. (1992) describe as the result of a campaign driven by high-level concerns over CO_2. That is, the extra savings foreseen might be undertaken were it made clear to industrial management that such efforts were necessary for restraining emissions and equally clear that establishments in most other countries were willing to undertake such investments. Put another way, such results might be obtained if both investment policies and vigorous research and development accelerated the supply of electricity saving options and stimulated their adoption.

In summary, we find that the improvements foreseen in the scenarios for fuel use in Danish industry represent a realistic set of goals or end points. The goals set out for electricity intensity, on the other hand, represent a definite break with the past, but by no means an impossible end point.

Table C-1. Energy Savings Forecasts in Denmark
Reductions in Unit Consumption in Industry
(% decline over 1988)

	1990	2000	2015	2030	Notes
Fuel	1/2/2	11/23/19	17/28/25	21/30/41	Solids/Liquids/Gases
Electricity	11	33	38	43	Roughly 50% beyond trends

C.2. Buildings

The reference scenarios for buildings are built somewhat differently from the forecasts for industry. *Energiforbrug i bygninger* (*Energistyrelsen* 1990) models the changes in the housing and building stock based on population, demographics and household format, and income development in benchmark years. In contrast to the industrial scenarios, however, this study assumes that energy intensities for heating will be unchanged in the existing building stock. Against this framework, a series of steps to reduce heating needs has been proposed. For electricity use in homes, the study assumes, quite correctly, that new electricity-using equipment is more efficient than existing equipment. This means that the "base case" contains some improvements in energy efficiency. Finally, the study assumes little change in the use of electricity, per square meter, for non-heating in the service sector. The study then estimates what kinds of changes might be expected here.

Energy use in buildings in Denmark underwent radical changes in the 1970s and 1980s. Between 1972 and 1988, the energy intensities of space heating in homes and in the service sector, averaged over all major fuels, fell by roughly 50%. Given the magnitude of these savings, the issue confronting the analysis is the degree to which additional savings in heating energy use will be realized.

Efficiency of electricity use for non-heating purposes improved considerably in homes, although the improvements were far less dramatic than for heating fuels. There seems no doubt that significant improvements in the future are practical and likely. Electricity use for non-heating purposes in the service sector changed in uncertain ways; all that can be said with confidence is that electricity use per square meter, averaged over all service-sector buildings, increased by over 50% between 1972 and 1988, a far greater amount than could be explained by the small share of space now heated with electricity.[1] Will this trend continue, or will improved efficiency of electricity use lead to reductions in electricity intensities in the service sector?

The scenarios for reductions in heating demand are based on a thorough study of buildings by type and vintage. This study divided savings into levels representing roughly 25%, 50%, and 75% lower consumption of useful energy, per square meter, than was observed in 1988. The study describes the extent and penetration of physical changes to the building stock that must occur for each level of savings to be reduced, as well as describing some policy measures that would be associated with achieving these savings.

Heat-saving improvements (retrofits) to buildings built before 1979 are the primary vehicle of these improvements. The study notes that if the improvements are undertaken at the same time as other building renovations, the marginal costs of saving energy alone fall considerably. From a historical perspective, the 75% reduction scenario appears as a simple extrapolation of the trends that reduced building heating intensities between 1972 and 1988 by more than 4%/year. But these reductions were accompanied by a near 300% increase in the real cost of heating fuels. The increases foreseen for the entire period 1988-2030 lie close to a doubling for heating fuels. This amounts to only 1.6%/year, probably too small to set off a wave of conservation investments. However, these increases do justify further

[1] Increases in lighting levels, computers and other office machines, more ventilation, etc., could account for this increase.

improvements to the Danish building stock.

Energiforbrug i Bygninger estimates that a 25% reduction in space heating is clearly cost effective today, while the 50% reduction is not clearly cost effective and the 75% reduction appears to be expensive. The reductions of 50% and 75% appear expensive even if undertaken together with renovation. Given the low rate of return on savings beyond the 25% level, it is not clear whether individuals *or* authorities will undertake all of these improvements, or whether any occupants will notice the potential gains foregone by not making the extra investments. The marginal gains of aiming for a 50% savings instead of only a 25% savings are small; those inherent in attempting to capture the 75% reduction are even smaller. This does not mean that the potential for savings is either unreasonable or somehow incorrectly calculated.

What these steps represent is the ultimate level to which heat needs can be reduced. Given enough time, new, very efficient buildings will eventually replace old ones. Specific heating demand will fall continually because of this replacement effect, but the gains will be slow. Renovation of existing buildings will gradually reduce heat losses in the older stock, too. The challenge for Denmark, then, is to find a mechanism that will accelerate rapidly the savings in existing buildings to a rate that will capture all of the potential in the Danish building stock.

The situation for electricity savings in buildings is somewhat different and more encouraging. The market for household equipment is increasingly dominated by multinational companies. In an earlier study (Schipper and Hawk 1991), it was found that the interest these companies placed on energy efficiency had relaxed in the late 1980s as goals set a decade early had been met and pressures from rising electricity prices relaxed. But a change in attitude occurred at the end of the 1980s. First, serious agreements to limit the use of CFCs in refrigeration equipment unleashed a fury of research on both new refrigerants and new concepts in refrigeration and cooling equipment. Second, concerns over both local environmental problems and CO_2 emissions caught the attention of major manufacturers like Electrolux and Whirlpool Philips. Some of this interest was spurred by the 1990 efficiency standards set in place in the U.S., standards that will be tightened in 1993 and beyond (McMahon, Turiel, and Schipper 1991). Such standards are being considered seriously in Scandinavia and Holland. Third, electric utilities in Europe initiated serious study of demand-side programs. These programs also caught the eyes of equipment manufacturers. Finally, "golden carrot programs" that reward manufacturers for developing equipment that either improve efficiency in comparison with current "best practices" or overshoot planned efficiency standards have appeared in the U.S. and Sweden. The international and even domestic manufacturers of household equipment have begin to react to these stimuli by offering more energy-efficient equipment than ever before. As a result of all these changes, it is reasonable to expect a dramatic improvement in the energy efficiency of almost all household equipment. The figures shown in the household scenarios appear consistent with those appearing in countless national and international studies (Schipper and Meyers et al. 1992). In our judgement, these savings can be achieved in Denmark provided electricity prices increase slowly, standards are introduced on key household products, and utilities or other actors are encouraged to expand their stimulation of the purchase of energy-efficient household equipment. Since virtually every piece of electricity-using equipment in use in Denmark in the year 2030 will be designed *after* 2000 and bought after 2010, even the boldest ideas for reduced electricity use could be widespread by the early part of the next century, and represent *average* consumption efficiency by 2030.

Electricity use in the service sector could see a dramatic turn. By all estimates there is a large potential for saving electricity in this sector (Fritzel et al. 1991). The interests of utilities and state-sponsored "golden carrot" programs has extended to lighting, ventilation, and even computers for the service sector. This interest is likely to reverse the trends of greater electricity use per square meter we observed in this sector in Denmark. Since much of the equipment used in this sector is replaced regularly there is a large potential for savings whenever replacement occurs. But the overall use of electricity in the service sector also depends on the design of buildings and the integration of many processes. Lighting levels depend on the placement of fixtures and desks, the design of windows to capture natural lighting, etc. Ventilation needs depend both on fresh air needs and on how much waste heat must be moved from overheated parts of buildings. Since roughly 2/3 of the built area in the service sector in 2030 will have been built before 1979, some of the electricity savings that arise from clever design of new buildings will evade owners, operators, occupants of older buildings. It is likely, however, that "*energistyring*", the Danish term for improved electricity use in large buildings, will improve efficiency significantly, although the exact amount is uncertain.

With these comments in mind, we conclude that the ambitions goals of heat savings of 50-75% in Danish buildings may be difficult or costly to achieve by 2030. Savings in the range of 25-50% appear to be more achievable. The greater level of savings will appear eventually as old buildings are replaced. By contrast, the savings suggested for electricity use in homes appear well within reach by the year 2030. And those for electricity use in service sector buildings, while somewhat more uncertain, appear achievable in large part. Efforts currently underway to save both heat and electricity should be monitored carefully to yield both a solid value for savings achieved, as well as a measure of the real costs involved. Only then can the true long term potential be translated into achievement.

Table C-2. Energy Savings Forecasts in Denmark
Changes in Unit Consumption in Buildings
(% decline over 1988)

Sector	1990	2000	2015	2030	Notes
Households					
Heating, Hot Water					2030 Potential
Trend	..	..	..	..	
Moderate	..	..	..	20	
Average	..	..	..	40	
Maximal	..	..	..	60	
Appliances					
Reference	30	60	70	..	"Best" compared with 1988/90
Service Sector					2030 Potential
Heating:					
Moderate	..	..	..	20	Same as homes
Average	..	..	..	40	
Maximal	..	..	..	60	
Electricity					
"*Sparpotential*" (Savings potential)	44/40	48/39	53/36	..	Public/Private sector potentials

C.3. Transportation

Future energy use for transportation is described in *Referencemodel for den danske transportsektor 1988-2030*, prepared by *COWIconsult* for the Trafikministeriet (*COWIconsult* 1990b). In these brief comments we discuss both the assumptions about mix and levels of activity as well as the improvements in energy efficiency. We separate travel and freight.

The reference case assumes an increase in total travel in Denmark, slowing after 2010, but still reaching over 21,000 passenger-km per capita by 2030, only 10% under the present level in the U.S. This level is derived by straightforward regression between income, consumption, prices, and travel. This high level of travel may seem inappropriate for a country as small as Denmark, but it should be recalled that most trips in both the U.S. and Denmark are under 15km. Thus, there is no geographical reason why Danes might not want to travel more. And as the time budget studies suggest, Danes have time to make these trips. Changes in private consumption assumed in the scenarios certainly permit Danes to purchase more automobile fuel (or afford to use other modes); likely changes in the price of transport fuels, combined with improvements in the fuel intensity of each mode, do not present any formidable barrier to this increased travel, either. But it must be recognized that the forecast in the reference case also calls for significant increases in travel for Danes, not only by car but in other modes as well. This implies considerable lifestyle-changes for Danes: far more time will be spent travelling in cars than at present. Thus, we conclude that the basis for these forecasts, a doubling of per capita travel by 2030, is not implausible, but does imply that Danes live differently in 2030.

The reference case calculates changes in energy use per passenger km, the modal intensity of each mode of travel. Related to modal intensities are vehicle intensities, or energy use per vehicle-km. (Modal intensity is vehicle intensity divided by passengers/vehicle.) People per vehicle, or load factors, are assumed to be constant, except for those for automobiles, which fall from 1.8 to 1.7 between 2015 and 2030, after remaining constant at 1.8 through 2015. The only objection that could be raised is that the rather constant (and admittedly high) automobile load factor is likely to fall much more as more families acquire second or even first cars. This development has been observed in virtually every other OECD country with higher car ownership than Denmark. Load factors in aircraft are assumed to be constant.

The reference case assumes slow reduction in the vehicle energy intensities of each mode in Denmark. The declines in vehicle energy intensity for the car fleet (as well as for light trucks), of 15% to 2010 and 15% more to 2030, lie well within the trends reviewed in Schipper and Meyers et al. (1992), and follow the trends we measured for Denmark in the 1972-1988 period. These trends imply that technological improvements in engines and vehicle designs will more than offset the increase in the size, weight, and power of vehicles. For reference it can be noted that the weight of the average car on the road in Denmark grew by only 4.5% between 1972 and 1990. Given the high taxation of cars in Denmark, which is likely to survive EEC harmonization, it is hard to foresee an great change in the characteristics of cars. Instead it is ownership that will increase, which is implied by the more than doubling of distance travelled by cars in the period through 2030.

The domestic aircraft fleet (SAS and others) is based upon short range aircraft (DC9 and successors as well as the 737 series). Improvements are expected in the energy efficiency of these aircraft as engines improve (Schipper and Meyers et al. 1992), because fuel costs continue to be important to airlines. Since the market for aircraft is dominated by three international competitors (McDonnell-Douglas, Boeing, and *Airbus Industrie*), it is likely that these companies will continue to improve new aircraft. In fact, the improvements in air travel modal efficiency foreseen in the Danish scenarios appear small compared with both historical trends and with the outlook in Schipper and Meyers. The assumption of constant load factor may be conservative, as competition forces airlines to fill more seats with special fares.

Trucks represent a significant and growing use of energy in Denmark. Our analysis showed that shifts in the nature of trucking towards smaller trucks, as well as other factors, *raised* the energy intensity of trucking there significantly. The scenarios portray a clear and significant break with these trends, resulting in a reversal of the 1988 energy intensities of trucking, which by 2030 return to their 1972 levels.

The transportation scenarios assume that gasoline and diesel prices double. Given the proposed improvements in efficiency, the impact of these changes on the costs of travel by 2030 are smaller but still significant. For example, gasoline prices rise by 105% in the base price case. Energy use per km falls by 29%, leading to a rise in the price of driving one kilometer by 50%. It is hard to believe that such a price increase would not either lead to lower growth in travel or further increases in vehicle efficiency.

Virtually all vehicles used in Denmark are made by international firms. Danish policies will have little effect on the characteristics of the world market, but can have a major influence on those vehicles imported into Denmark. This is already clear from examining the automobile fleet in 1988, which is lightweight and low-powered by European standards. But if the energy price increases foreseen in the Danish scenarios are realistic, these should lead to significant improvements in vehicle efficiencies world-wide. If that is the case, then the efficiency of automobiles could improve considerably more than in the reference scenario. Similarly, prop-fan aircraft would appear on the market by 2010. And it is likely that high fuel prices would alter the way in which trucks are used.

These possibilities are raised by the variants to the Reference case proposed in the *COWIconsult* report. In the case where travel is reduced radically—approximately 50%—very significant reductions in energy use and emissions in 2030 are achieved. In the other variants, *COWI* models both *ad hoc* changes from the bottom up, such as a 25% reduction in the specific energy consumption for each transport mode, as well changes caused by top-down measures, like parking restrictions or fuel price increases. Each and every one of these results is plausible; what is not clear is by how much a comprehensive package that raises the cost of mobility and stimulates the development and/or acquisition of efficient, new vehicles will restrain total energy use and emissions. This is particularly important when we consider that radical improvements in specific consumption will noticeably lower the marginal costs of moving about for some modes, particularly cars. This change may not on its own "cause" people to move about more, but such an improvement will reduce the incentive to travel less that higher fuel costs could provide. Such considerations appear to have been included in the *COWI* scenarios (1990a).

We conclude, therefore, that the base case scenario for transportation sets out a reasonable basis for both activity and energy use. The only questionable assumption is that of total mobility of the Danish population, which appears high. Against this scenario, it is not unreasonable to imagine that a package of policy measures that raise the cost of mobility and energy significantly would not lead to some restraint in mobility and improvements in efficiency of each mode beyond those in the base case. But it is difficult to say with any certainty whether the ultimate results of applying a package of policies will be consistent with those goals set out in the main *Regerings transporthandlingsplan* (*Trafikministeriet* 1990a). Experience in Denmark during the 1972-1988 period shows that a combination of depressed incomes and significantly higher fuel prices restrained mobility and provoked improvements in efficiency. Whether the same kinds of conditions can be realized in Denmark during the next few decades is unclear.

The other uncertainty in these scenarios, over which Denmark has little control, is the international development of transportation technology. Prototype vehicles that require only 3 liters of gasoline/100 km exist, but there is currently little market for these vehicles. Sketches of even more "efficient" vehicles have been put forward (Schipper and Meyers et al. 1992), but they do not resemble present cars in either size or performance.

Table C-3. Energy Savings Forecasts in Denmark
Changes in Unit Consumption in Transportation
(% decline over 1988)

	1990	2000	2015	2030
Cars	..	..	15	28
Light Truck	..	..	15	28
Truck	..	..	15	28
Bus	..	..	15	28
Pass. Train	..	..	15	28
Freight Train	..	..	10	19
Air	..	..	15	28

Source: *Referencemodel for den danske transportsektor 1988-2030* (Reference model for the Danish transportation sector), *COWIconsult* (1990b).

APPENDIX D: SUMMARY OF DATA USED IN THIS REPORT

We attach as a statistical appendix a summary of the data used in this study, Table D-1. Most figures were derived in this work from official data sources; a few were used with no further processing. The analyses of developments in each sector in the text explain our main assumptions; extra work devoted to the transportation sectors and to the household sector is explained in Appendices A and B. Readers are referred to the Chapters or Appendices for detailed references.

D.1. Summary Energy Balance

This section presents an overview of the production and conversion of energy carriers in Denmark, as shown on the first two pages of Table D-1. All data are based on statistics provided by *Energistyrelsen*. The first category, "Gross Energy Use", provides information on the total use of energy, including conversion and distribution losses. Gross energy use is equal to the sum of domestic production and net imports of energy products.

"Net Use of Oil in Refineries" accounts for the energy used to produce refined petroleum products. "Non-Energy Use of Oil" measures the use of oil products as construction materials, chemical feedstocks, and related items.

The next items give the net use of energy in four types of energy conversion facilities—central heat and power stations, gasworks, district heat plants, and "private producers" (e.g., industrial facilities that produce by-product heat and power). Negative values indicate negative consumption or positive net production of a given energy carrier.

"Net Distribution Losses" represent the quantities of energy lost in the transfer of energy carriers from the point of conversion to the point of end use. The "Efficiency Coefficients" give the total amount of primary energy required to provide one unit of district heat or electricity to end users. "Final Energy Use" is the amount of energy at the point of end use, and is equal to gross energy use minus non-energy uses and conversion and distribution losses. The final category ("Difference, LBL-ENS") gives the statistical difference between the levels of final energy use calculated by adding up final demand across sectors and the "gross energy minus losses" approach.

D.2. End-Use Summary Indicators

This section presents an overview of the structure of energy use and energy-using activities across end-use sectors. Included is information on total energy use, Gross Domestic Product, and population. The figures for primary energy use are calculated by multiplying the use of district heat and electricity by factors of 1.15 and 3.24 to approximate upstream conversion and distribution losses in a manner comparable with other OECD nations. Figures for "primary, Danish" use the conventions of *Energistyrelsen* as reflected in their energy balances.

The section reports figures on actual energy use as well as the so-called "Activity/Structure" and "Intensity" effects. The activity/structure indicators shows the evolution of total energy use that would have occurred if energy intensities in each sector had remained fixed at their 1972 values while energy services followed their actual path. The intensity indicator holds energy services constant at the 1972 levels while energy intensities follow their historical development.

D.3. Manufacturing Sector

This section gives energy use and economic activity (real value added) in six subsectors: paper and pulp, chemicals, nonmetallic minerals, ferrous metals, nonferrous metals, and "other". All statistics are from *Danmarks Statistik*, as referred to in Chapter 3.

D.4. Other Industry

This section gives summary information on energy use and real value-added in the agriculture, fishing, mineral extraction, and construction industries. All data are from *Danmarks Statistik.*

D.5. Service Sector

This section gives data on service-sector energy use and economic activity (real value added). Chapter 5 describes how the energy consumption data were separated from those for the residential sector. No correction for climate is made.

D.6. Residential Sector

The data we used follow closely, but not exactly, those provided by *Energistyrelsen.* Chapter 2 and Appendix A explain how the end-use estimates were derived. No estimates were made for 1973-4 or 1976. "Population" is from *Danmarks Statistik* (various years), a mid-year average. Dwellings and the numbers heated by different fuels are taken from *Folk og Boligtælling 1970* (*FoB* 1970) and *BBR* (with interpolations for the 1970s). "Fuel heated" includes oil, gas, coal, and various renewable solid fuels. Data are from *BBR* (all years) and *FoB* 1970. We interpolated values for 1972-1975. Floor area for homes (*samlade udnyttede etageareal,* or total floor area), is taken from *BBR* from 1977 onward. For earlier years, we used the area of homes built before 1975 or 1970 as measured in 1977. Our figures agree closely with those provided by *Energistyrelsen.* Our degree day figures are derived from those provided by *Energistyrelsen,* as explained in Appendix A.

Energy use for space heating (and total residential energy use) is corrected for climate variations. The space heat indicators are energy (delivered, useful, or primary using the LBL convention) divided by both floor area and yearly degree days. For electricity, actual consumption for space heat is divided by the entire area of the dwelling stock. Similar conventions are used for hot water and cooking.

The ownership of appliances are taken from the work of Møller. Unit consumption refers to stock averages. Figures for refrigerators and combis (combined refrigerator-freezers) are added, and unit consumption averaged.

The various effects (activity, structure, intensity) are calculated as explained in the text.

D.7. Travel

Energy use for travel by mode is derived from work of Sørensen, as well as figures provided by *Energistyrelsen.* These are used to calculate the intensities (MJ/PKM) from the activity levels of each mode, data for which come from *Trafikministeriet.* Stocks of cars (and light trucks) and vehicle-km of car (and light truck) travel also come from *Trafikministeriet,* as modified in this work. The total stock of cars and light trucks was divided by population to calculate the indicator shown.

D.8. Freight

Energy use for freight by mode is derived from work of Sørensen, as well as figures provided by *Energistyrelsen.* These are used to calculate the intensities (MJ/PKM) from the activity levels of each mode, data for which come from *Trafikministeriet.* Considerable uncertainties arise over the use of diesel oil in trucks. These concern the quantities of diesel oil purchased by non-Danish truck drivers or Danes driving abroad and the use of non-taxed trucking fuel for heating purposes.

Table D-1 - Danish Energy Summary

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
SUMMARY ENERGY BALANCE																
GROSS ENERGY USE (PJ)																
Oil			768	632	667	648	656	554	478	450	427	423	436	427	405	375
Gas			0	0	0	0	0	0	1	1	2	7	28	48	62	67
Solids			69	96	149	164	198	272	225	270	266	281	337	344	341	322
District Heat			0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity			-8	3	2	13	11	-4	20	7	15	18	2	0	9	15
Total			828	731	818	825	865	822	723	729	711	730	802	820	817	779
NET OIL USE IN REFINERIES (PJ)			22	21	19	16	18	15	16	15	16	18	19	21	24	25
NON-ENERGY USE OF OIL (PJ)			19	15	20	18	18	16	13	14	14	15	15	15	15	15
CENTRAL HEAT & POWER (PJ)																
Oil			166	118	110	89	79	48	25	18	9	7	13	15	11	13
Gas			0	0	0	0	0	0	0	0	0	0	3	6	3	5
Solids			46	64	110	122	153	226	178	222	217	221	271	277	272	254
District Heat			-23	-22	-25	-27	-29	-31	-32	-34	-37	-39	-46	-47	-52	-53
Electricity			-68	-62	-75	-69	-75	-91	-65	-79	-73	-75	-97	-102	-97	-92
Total			122	99	121	115	127	153	106	127	115	114	146	147	137	128
GASWORKS (PJ)																
Oil			6	5	5	5	5	5	5	4	4	4	2	1	0	1
Gas			-6	-6	-5	-5	-6	-5	-5	-5	-4	-4	-2	-1	-0	-0
Solids			2	1	1	1	1	1	1	1	1	0	0	0	0	0
District Heat																
Electricity																
Total			1	0	0	0	0	0	0	0	0	0	0	0	0	0
DISTRICT HEAT PLANTS (PJ)																
Oil			63	48	53	54	56	49	44	41	35	31	26	16	12	6
Gas				0	0	0	0	0	0	0	0	2	6	12	16	15
Solids			8	9	10	10	11	11	13	15	18	23	27	29	30	30
District Heat			-58	-46	-51	-51	-53	-48	-45	-44	-43	-44	-49	-48	-49	-42
Electricity																
Total			13	12	13	13	14	13	12	12	11	11	11	10	10	8
PRIVATE PRODUCERS																
Oil			1	1	1	1	1	1	1	2	2	2	2	2	2	2
Gas				0	0	0	0	0	0	0	0	0	0	0	0	1
Solids			2	2	2	2	2	2	3	3	3	4	4	4	4	5
District Heat			-0	-0	-1	-1	-1	-1	-1	-2	-2	-2	-2	-2	-2	-3
Electricity			-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2	-2	-2
Total			2	2	2	2	2	2	2	2	2	2	2	2	3	3
NET DISTRIBUTION LOSSES (PJ)																
Oil			0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas			0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solids			0	0	0	0	0	0	0	0	0	0	0	0	0	0
District Heat			20	17	19	20	21	20	19	20	20	21	23	22	23	21
Electricity			4	6	7	7	7	7	7	7	7	6	8	7	7	7
Total			25	23	26	27	28	27	26	27	28	27	31	29	30	28

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
EFFICIENCY COEFFICIENTS																
District Heat																
Gross Eff. (Prod./Fuel Used)			0.98	0.99	0.99	0.99	1.05	1.04	1.00	1.05	1.08	1.01	1.13	1.16	1.18	1.22
Net Eff. (DH Cons/Fuel Used)			0.71	0.72	0.72	0.73	0.76	0.76	0.73	0.76	0.78	0.72	0.81	0.86	0.88	0.91
Gross/Net Efficiency			1.38	1.38	1.38	1.35	1.39	1.38	1.38	1.39	1.39	1.40	1.38	1.35	1.34	1.33
Electricity			2.99	2.88	2.88	2.96	2.97	2.91	2.93	2.84	2.86	2.73	2.73	2.62	2.60	2.60
FINAL ENERGY USE (PJ)																
Oil			490	423	458	465	480	419	374	358	349	349	363	362	348	321
Gas			0	0	5	5	5	5	5	4	4	6	16	25	34	38
Solids			10	20	26	28	32	32	30	30	28	34	35	35	35	34
District Heat			61	51	57	59	62	59	58	60	61	63	73	75	81	77
Electricity			56	60	71	76	80	80	80	81	82	88	92	97	100	102
Total			618	554	617	634	659	595	546	533	525	541	578	594	598	572
DIFFERENCE, LBL-ENS, FINAL ENERGY (PJ)																
Oil			-5	2	-8	-12	-22	-25	-19	-17	-22	-23	-20	-22	-18	-15
Gas			6	5	-0	-0	-0	-0	-0	-0	-0	-1	-0	-1	-1	1
Solids			9	5	4	4	-1	2	2	6	12	12	16	16	19	8
District Heat			3	2	1	0	0	1	1	0	1	2	2	2	2	1
Electricity			-6	-3	-4	-5	-8	-8	-8	-6	-7	-9	-8	-9	-9	-9
Total			7	11	-7	-13	-32	-30	-25	-17	-16	-19	-10	-15	-7	-15

END-USE SUMMARY INDICATORS

ENERGY USE BY TYPE (PJ)														
Oil	485.9	425.5	450.5	453.6	457.5	394.2	354.3	341.0	326.5	326.4	343.2	340.4	329.5	306.1
Gas	5.7	4.9	4.7	4.7	4.9	4.6	4.3	4.1	4.1	5.4	15.5	23.4	33.3	38.5
Solids	19.1	24.1	29.9	32.6	30.3	33.7	31.9	36.7	39.8	46.0	51.1	50.4	54.2	41.5
District Heat	64.1	53.5	57.8	59.3	62.3	59.9	58.8	59.8	62.4	65.0	75.0	77.1	82.7	78.8
Electricity	50.4	57.0	66.8	70.9	71.8	72.4	71.1	74.7	75.5	79.1	84.1	87.8	90.9	92.3
Final Energy	625.2	565.1	609.7	621.1	626.8	564.9	520.5	516.5	508.4	522.0	568.9	579.3	590.7	557.4
Primary Energy	747.8	700.9	767.9	788.8	796.9	736.2	688.7	692.8	686.9	708.9	768.4	787.5	806.8	776.0
GDP (10e9 '80 USD)	30.7	31.6	34.1	34.7	36.3	36.7	36.5	37.7	38.4	40.0	41.5	43.0	43.6	44.2
Manufacturing	20%	20%	20%	19%	20%	20%	19%	19%	20%	20%	20%	19%	18%	18%
Other Industry	18%	15%	14%	14%	13%	13%	13%	13%	12%	13%	13%	13%	13%	13%
Service Sector	47%	50%	51%	52%	51%	51%	52%	53%	53%	52%	52%	53%	53%	53%
Other Sectors	15%	15%	15%	15%	16%	15%	16%	16%	16%	15%	15%	14%	15%	16%
ENERGY/GDP (MJ/'80USD)														
Electricity	1.64	1.81	1.96	2.04	1.98	1.98	1.95	1.98	1.96	1.98	2.02	2.04	2.09	2.09
Final Energy	20.38	17.89	17.89	17.88	17.27	15.41	14.26	13.71	13.22	13.05	13.70	13.48	13.56	12.62
Primary Energy	24.37	22.19	22.54	22.70	21.96	20.08	18.87	18.40	17.87	17.72	18.51	18.32	18.52	17.57
POPULATION (10e6)	4.99	5.06	5.09	5.10	5.11	5.12	5.12	5.12	5.12	5.11	5.11	5.12	5.13	5.13
ENERGY/CAPITA (GJ/Capita)														
Electricity	10.1	11.3	13.1	13.9	14.1	14.1	13.9	14.6	14.8	15.5	16.4	17.2	17.7	18.0
Final Energy	125.3	111.7	119.8	121.8	122.7	110.3	101.6	100.9	99.4	102.1	111.3	113.2	115.3	108.7
Primary Energy	149.9	138.5	150.9	154.7	156.0	143.8	134.4	135.3	134.3	138.7	150.4	153.9	157.4	151.3

 Table D-1, cont.

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
ACTUAL ENERGY USE (PJ, Climate Corrected for Residential Sector)																
Electricity			50.5	57.3	66.9	70.9	71.4	72.3	71.1	74.9	75.8	79.4	83.5	87.7	90.5	92.5
Final Energy			635.4	582.0	615.9	621.4	613.5	559.9	520.1	522.7	517.3	530.7	554.2	575.5	582.3	561.2
Primary Energy			758.4	718.8	774.6	789.1	782.5	730.6	688.2	699.8	696.8	718.7	751.8	783.3	797.1	780.4
ACTIVITY/STRUCTURE EFFECT (PJ, Climate Corrected for Residential Sector)																
Electricity			50.5	53.4	57.0	58.5	60.8	62.0	61.7	62.8	64.4	66.7	68.5	70.6	70.6	71.3
Final Energy			635.4	661.9	707.6	723.5	741.4	742.1	734.5	743.3	759.5	784.1	802.9	828.1	830.1	839.6
Primary Energy			758.4	793.9	849.6	869.7	893.5	897.5	889.5	901.0	921.2	951.7	975.0	1005.8	1008.3	1019.7
INTENSITY EFFECT (PJ, Climate Corrected for Residential Sector)																
Electricity			50.5	54.7	60.8	62.3	60.2	59.6	58.7	61.6	61.1	61.3	62.6	64.0	66.6	67.2
Final Energy			635.4	566.2	563.0	558.0	540.3	495.5	467.3	466.0	452.9	445.3	452.1	455.8	462.8	440.1
Primary Energy			758.4	698.2	708.2	707.2	684.2	639.0	608.3	614.3	600.0	593.0	602.4	609.4	622.6	600.4
SECTORAL BREAKDOWNS			1.15	3.24												
Delivered			125.3	111.7	119.8	121.8	122.7	110.3	101.6	100.9	99.4	102.1	111.3	113.2	115.3	108.7
Residential			47.7	40.2	43.9	44.2	46.1	39.5	36.0	34.9	33.6	33.1	37.6	37.0	37.7	34.4
Services			15.3	13.4	15.0	15.0	15.8	14.0	13.0	13.3	12.5	12.6	14.2	13.9	14.5	14.0
Manufacturing			29.0	27.1	29.0	28.8	26.9	25.4	23.1	22.6	22.0	23.6	25.3	26.1	26.5	24.2
Other Industry			11.6	10.4	10.0	9.8	10.5	9.1	8.0	7.7	8.1	8.3	8.5	9.4	9.5	9.0
Travel			14.6	14.4	15.0	15.5	15.1	14.1	13.6	13.9	14.3	14.5	14.9	15.6	15.6	15.9
Freight			7.1	6.2	6.8	8.4	8.2	8.2	7.9	8.6	8.9	10.1	10.8	11.4	11.4	11.2
Primary, LBL			149.9	138.5	150.9	154.7	156.0	143.8	134.4	135.3	134.3	138.7	150.4	153.9	157.4	151.3
Residential			57.4	50.9	56.1	57.1	59.7	52.6	49.1	48.1	47.1	47.1	52.8	52.6	53.9	50.4
Services			21.1	19.8	22.8	23.4	24.6	22.8	21.9	22.3	21.7	22.1	24.5	24.6	25.8	25.5
Manufacturing			35.4	34.4	37.8	38.2	35.7	34.6	31.8	32.5	31.6	33.8	36.3	37.5	38.3	36.3
Other Industry			14.1	12.7	12.1	11.8	12.6	11.2	9.9	9.8	10.5	10.8	10.9	12.0	12.2	11.5
Travel			14.8	14.6	15.2	15.7	15.3	14.3	13.8	14.1	14.5	14.7	15.1	15.8	15.9	16.2
Freight			7.1	6.2	6.8	8.4	8.2	8.2	7.9	8.6	8.9	10.1	10.8	11.4	11.4	11.2
Primary, Danish			150.2	136.8	148.7	153.1	155.0	141.8	132.7	132.3	131.5	133.9	145.4	146.4	149.2	142.6
Residential			58.3	50.9	56.0	57.1	60.0	52.6	49.1	47.8	46.8	46.2	51.9	50.7	51.7	48.1
Services			21.3	19.5	22.4	23.1	24.4	22.4	21.4	21.6	21.0	20.9	23.2	22.6	23.6	23.2
Manufacturing			34.8	33.3	36.5	37.2	34.7	33.4	30.7	30.9	30.1	31.7	34.0	34.5	35.1	33.1
Other Industry			13.8	12.3	11.8	11.6	12.3	10.9	9.7	9.5	10.1	10.3	10.4	11.4	11.5	10.9
Travel			14.8	14.5	15.2	15.7	15.3	14.3	13.7	14.1	14.5	14.6	15.1	15.7	15.8	16.1
Freight			7.1	6.2	6.8	8.4	8.2	8.2	7.9	8.6	8.9	10.1	10.8	11.4	11.4	11.2
Electricity Use			10.1	11.3	13.1	13.9	14.1	14.1	13.9	14.6	14.8	15.5	16.4	17.2	17.7	18.0
Residential			3.74	4.30	4.95	5.23	5.51	5.35	5.35	5.38	5.45	5.69	6.13	6.32	6.52	6.45
Services			2.36	2.66	3.29	3.52	3.65	3.69	3.72	3.81	3.87	4.02	4.31	4.50	4.76	4.87
Manufacturing			2.79	3.21	3.88	4.15	3.86	4.05	3.84	4.37	4.28	4.55	4.86	5.07	5.20	5.46
Other Industry			1.13	1.01	0.93	0.91	0.93	0.96	0.88	0.94	1.06	1.11	1.04	1.17	1.15	1.10
Travel			0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.12	0.12
Freight			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SECTORAL SHARES																
Delivered Energy																
Residential			38.1%	36.0%	36.7%	36.3%	37.6%	35.8%	35.4%	34.6%	33.9%	32.4%	33.8%	32.7%	32.7%	31.7%
Services			12.2%	12.0%	12.5%	12.3%	12.9%	12.7%	12.8%	13.1%	12.6%	12.3%	12.8%	12.2%	12.6%	12.9%
Manufacturing			23.1%	24.2%	24.2%	23.7%	22.0%	23.0%	22.7%	22.4%	22.1%	23.1%	22.8%	23.0%	23.0%	22.2%
Other Industry			9.2%	9.3%	8.4%	8.0%	8.5%	8.2%	7.8%	7.6%	8.2%	8.1%	7.6%	8.3%	8.2%	8.3%
Travel			11.6%	12.9%	12.5%	12.7%	12.3%	12.8%	13.3%	13.8%	14.4%	14.2%	13.4%	13.7%	13.5%	14.6%
Freight			5.7%	5.6%	5.7%	6.9%	6.7%	7.4%	7.8%	8.5%	8.9%	9.9%	9.7%	10.1%	9.9%	10.3%
Primary Energy																
Residential			38.3%	36.7%	37.2%	36.9%	38.3%	36.6%	36.5%	35.5%	35.0%	33.9%	35.1%	34.2%	34.2%	33.3%
Services			14.1%	14.3%	15.1%	15.1%	15.7%	15.9%	16.3%	16.5%	16.1%	15.9%	16.3%	16.0%	16.4%	16.9%
Manufacturing			23.6%	24.8%	25.0%	24.7%	22.9%	24.1%	23.7%	24.0%	23.6%	24.4%	24.2%	24.4%	24.3%	24.1%
Other Industry			9.4%	9.1%	8.0%	7.7%	8.0%	7.8%	7.4%	7.3%	7.8%	7.8%	7.2%	7.8%	7.7%	7.6%
Travel			9.9%	10.5%	10.1%	10.1%	9.8%	10.0%	10.3%	10.4%	10.8%	10.6%	10.1%	10.3%	10.1%	10.7%
Freight			4.7%	4.5%	4.5%	5.5%	5.3%	5.7%	5.9%	6.3%	6.6%	7.3%	7.2%	7.4%	7.3%	7.4%

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
RESIDENTIAL SECTOR																
ENERGY USE BY TYPE (PJ)																
Oil			170	140	154	153	157	124	105	97	88	82	93	84	81	68
Gas			5	4	4	4	4	4	3	3	3	4	8	11	14	14
Solids			3	2	3	3	5	8	11	12	12	12	12	12	11	11
District Heat			42	35	38	39	41	39	38	39	41	42	49	50	54	51
Electricity			19	22	25	27	28	27	27	28	28	29	31	32	33	33
Final Energy			238	203	224	225	236	202	185	179	172	169	192	189	193	177
Primary Energy			286	257	286	291	305	270	252	246	241	241	270	269	276	258
POPULATION (10e6)			4.99	5.06	5.09	5.10	5.11	5.12	5.12	5.12	5.12	5.11	5.11	5.12	5.13	5.13
DWELLINGS			1837	1962	2031	2061	2088	2115	2133	2151	2169	2191	2211	2234	2258	2279
OCCUPANTS/DWELLING			2.72	2.58	2.51	2.47	2.45	2.42	2.40	2.38	2.36	2.33	2.31	2.29	2.27	2.25
SPACE HEAT (PJ, Climate Corrected)																
Fuel			153	130	135	129	125	103	92	92	86	82	80	83	81	76
District Heat			34	29	27	27	27	27	27	30	32	33	33	37	38	38
Electricity			1	2	3	4	5	4	4	4	4	4	5	5	6	5
Final Energy			188	160	166	160	157	134	123	126	121	119	118	125	125	120
Primary Energy			202	181	196	197	198	172	160	168	161	166	170	191	200	188
Useful Energy			136	116	120	116	114	98	91	93	91	90	90	96	96	93
FLOOR AREA/DWELLING (M2)			100	103	105	106	106	107	108	108	108	108	108	108	108	107
Fuel Choices, shares																
Fuel Heated, %			61.8%	59.7%	59.1%	58.4%	58.0%	57.4%	56.4%	55.2%	54.3%	52.7%	50.8%	49.0%	45.6%	42.5%
District Heated, %			29.2%	31.2%	32.1%	32.5%	32.7%	33.1%	34.0%	34.8%	35.9%	37.1%	38.0%	38.9%	39.8%	41.7%
Electric Heated, %			1.6%	3.1%	3.6%	3.9%	4.3%	4.6%	4.9%	5.1%	4.8%	5.1%	5.3%	6.0%	7.1%	7.7%
DWELLING AREA/CAPITA			36.8	39.9	42.0	42.8	43.5	44.2	44.8	45.3	45.7	46.3	46.7	47.2	47.5	47.7
DEGREE-DAYS (3141 normal, 18C Basis)			2979	2815	3023	3136	3407	3259	3152	2984	2911	2911	3532	3235	3353	3040
SPACE HEAT (KJ/M2/DD)																
Electricity			2	3	5	6	7	6	6	6	5	6	6	7	8	7
Final Energy			319	253	249	235	225	187	168	171	164	159	156	163	162	154
Primary Energy			342	286	296	289	284	240	220	229	217	222	224	249	259	242
Useful Energy			230	183	180	170	163	137	124	127	123	120	119	125	125	119
HOT WATER HEATING (PJ)																
Fuel			30	28	29	29	29	27	25	24	23	21	20	20	19	18
District Heat			10	9	11	12	12	11	11	11	11	11	12	12	13	14
Electricity			2	2	3	3	3	4	4	4	4	4	4	5	5	5
Final Energy			42	40	43	44	44	42	40	38	38	36	36	37	36	37
Primary Energy			47	47	51	53	54	52	50	49	48	48	48	49	49	50
Useful Energy			31	30	33	34	34	33	31	30	30	29	30	30	30	31
FUEL CHOICE Water Heat																
Fuels, % of homes			53.3%	54.4%	54.9%	54.6%	54.4%	53.9%	53.0%	51.7%	50.4%	49.0%	46.7%	45.5%	42.3%	39.7%
District Heat, % of homes			29.2%	31.2%	32.1%	32.5%	33.1%	33.1%	34.0%	34.8%	35.9%	37.1%	38.0%	38.9%	39.8%	41.7%
Electricity, % of homes			2.7%	4.2%	5.4%	5.8%	6.4%	6.9%	7.5%	8.0%	8.6%	9.3%	9.8%	10.5%	11.1%	11.7%
HOT WATER/CAPITA (GJ/Capita)																
Electricity			0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0
Final Energy			8.3	7.9	8.5	8.7	8.6	8.2	7.8	7.5	7.4	7.1	7.1	7.2	7.1	7.2
Primary Energy			9.4	9.3	10.1	10.5	10.5	10.1	9.7	9.5	9.5	9.3	9.4	9.6	9.6	9.7
Useful Energy			6.3	6.0	6.5	6.7	6.7	6.4	6.1	5.9	5.8	5.7	5.8	5.9	5.9	6.0

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
COOKING (PJ)																
Fuel			3.2	2.5	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1
Electricity			2.4	2.9	3.3	3.5	3.4	3.5	3.4	3.7	3.9	4.0	4.1	4.3	4.3	4.4
Final Energy			5.6	5.5	5.3	5.3	5.2	5.2	5.0	5.2	5.4	5.4	5.4	5.5	5.5	5.5
Primary Energy			10.9	12.1	12.7	13.1	12.8	13.1	12.6	13.4	14.2	14.4	14.7	15.1	15.2	15.3
Useful Energy			4.4	4.6	4.6	4.7	4.6	4.6	4.5	4.7	4.9	4.9	5.0	5.1	5.1	5.1
COOKING/CAPITA (GJ/Capita)																
Electricity			0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.9
Final Energy			1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1
Primary Energy			2.2	2.4	2.5	2.6	2.5	2.6	2.5	2.6	2.8	2.8	2.9	2.9	3.0	3.0
Useful Energy			0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
LIGHTING ELECTRICITY (PJ)			3.1	3.5	3.7	3.8	3.7	3.7	3.7	3.8	4.0	4.4	4.5	4.6	4.7	4.8
LIGHTING ELECTRICITY/M2 (MJ/M2)			17	17	17	17	17	16	16	16	17	18	18	19	19	19
APPLIANCE ELECTRICITY USE (PJ)			10.2	11.0	12.0	12.1	12.7	12.2	12.5	12.2	12.6	12.6	13.1	13.4	13.4	13.8
APPLIANCE OWNERSHIP (% of Households)																
Refrigerators & Combis			97%	100%	102%	103%	104%	104%	103%	103%	102%	103%	102%	102%	102%	101%
Freezers			42%	49%	53%	55%	56%	57%	58%	59%	60%	61%	62%	62%	62%	61%
Clothes Washers			41%	45%	49%	51%	54%	54%	55%	56%	57%	59%	60%	63%	64%	64%
Clothes Dryers			1%	3%	6%	7%	8%	9%	9%	10%	10%	11%	12%	14%	16%	18%
Dish washers			6%	10%	14%	16%	17%	18%	18%	19%	19%	20%	21%	23%	24%	24%
APPLIANCE ELECTRICITY INTENSITY (KWH/UNIT)																
Refrigerators & Combis			434	471	484	487	489	491	489	485	480	475	471	469	466	462
Freezers			692	688	681	676	670	663	657	650	642	634	625	616	608	601
Clothes Washers			478	472	464	458	452	447	442	436	429	422	414	406	399	392
Clothes Dryers			581	571	562	559	556	554	552	549	546	541	534	528	522	516
Dish washers			586	578	569	563	556	552	547	541	534	524	512	497	484	472
ACTUAL ENERGY USE (PJ, Climate Corrected)																
Electricity			19	22	25	27	28	27	27	28	28	29	31	32	33	33
Final Energy			248	220	230	226	222	197	184	185	181	178	178	186	185	180
Primary Energy			297	275	292	291	290	264	251	253	251	250	253	265	266	263
ACTIVITY EFFECT (PJ, Climate Corrected)																
Electricity			19	19	19	19	19	19	19	19	19	19	19	19	19	19
Final Energy			248	252	253	254	254	255	255	255	255	254	254	255	255	255
Primary Energy			297	301	303	303	304	305	305	305	304	304	304	304	305	305
STRUCTURE EFFECT (PJ, Climate Corrected)																
Electricity			19	21	22	23	23	24	24	24	25	25	25	26	26	26
Final Energy			248	271	284	293	298	304	309	312	314	318	321	326	329	333
Primary Energy			297	326	343	355	362	369	375	379	382	387	391	398	402	406
INTENSITY EFFECT (PJ, Climate Corrected)																
Electricity			19	20	21	22	22	21	21	21	22	22	23	24	24	24
Final Energy			248	201	199	190	184	161	148	148	143	139	138	142	140	135
Primary Energy			297	252	253	246	240	217	203	203	199	197	197	202	202	196

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
SERVICE SECTOR																
ENERGY USE BY TYPE (PJ)																
Oil			45.5	38.0	41.8	40.2	42.7	33.7	28.6	29.0	24.1	22.5	25.5	22.3	21.4	17.6
Gas			1.0	0.9	0.7	0.9	0.9	1.0	1.0	0.9	1.0	1.6	3.0	4.0	5.2	6.0
Solids			0.5	0.3	0.4	0.4	0.5	0.9	1.0	1.0	0.8	0.8	0.7	0.5	0.3	0.2
District Heat			17.7	15.2	16.6	17.2	18.2	17.3	17.0	17.3	18.1	18.6	21.2	21.0	22.8	22.7
Electricity			11.8	13.5	16.7	17.9	18.7	18.9	19.1	19.5	19.8	20.6	22.0	23.0	24.4	25.0
Final Energy			76.4	67.8	76.3	76.6	80.9	71.9	66.8	67.8	63.9	64.2	72.5	71.0	74.3	71.6
Primary Energy			105.5	100.3	116.2	119.4	125.5	116.8	112.0	114.1	110.9	113.0	125.1	125.6	132.4	131.0
VALUE ADDED (10e9 '80 USD)			14.5	15.8	17.4	17.9	18.7	18.9	19.0	19.8	20.3	21.0	21.8	23.0	23.2	23.4
ENERGY/VALUE ADDED (MJ/'80 USD)																
Electricity			0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1
Final Energy			5.3	4.3	4.4	4.3	4.3	3.8	3.5	3.4	3.2	3.1	3.3	3.1	3.2	3.1
Primary Energy			7.3	6.3	6.7	6.7	6.7	6.2	5.9	5.8	5.5	5.4	5.7	5.5	5.7	5.6
FLOOR AREA (10E6 M2)			48.6	53.8	57.3	59	60.7	61.8	63	64.1	65.3	66.4	67.1	67.8	69.1	70.3
ENERGY/M2 (GJ/M2)																
Electricity			0.24	0.25	0.29	0.30	0.31	0.31	0.30	0.30	0.30	0.31	0.33	0.34	0.35	0.36
Final Energy			1.57	1.26	1.33	1.30	1.33	1.16	1.06	1.06	0.98	0.97	1.08	1.05	1.07	1.02
Primary Energy			2.17	1.86	2.03	2.02	2.07	1.89	1.78	1.78	1.70	1.70	1.86	1.85	1.92	1.86
ACTUAL ENERGY USE (PJ)																
Electricity			11.8	13.5	16.7	17.9	18.7	18.9	19.1	19.5	19.8	20.6	22.0	23.0	24.4	25.0
Final Energy			76.4	67.8	76.3	76.6	80.9	71.9	66.8	67.8	63.9	64.2	72.5	71.0	74.3	71.6
Primary Energy			105.5	100.3	116.2	119.4	125.5	116.8	112.0	114.1	110.9	113.0	125.1	125.6	132.4	131.0
ACTIVITY EFFECT (PJ)																
Electricity			11.8	12.9	14.1	14.6	15.2	15.4	15.5	16.1	16.5	17.0	17.7	18.7	18.9	19.0
Final Energy			76.4	83.6	91.6	94.6	98.7	99.7	100.4	104.4	107.0	110.6	115.1	121.4	122.6	123.5
Primary Energy			105.5	115.4	126.4	130.5	136.1	137.5	138.6	144.1	147.6	152.7	158.8	167.5	169.2	170.4
STRUCTURE EFFECT (PJ)																
Electricity			11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
Final Energy			76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.4
Primary Energy			105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5
INTENSITY EFFECT (PJ)																
Electricity			11.8	12.3	14.0	14.5	14.5	14.5	14.5	14.3	14.1	14.2	14.6	14.5	15.2	15.5
Final Energy			76.4	62.0	63.6	61.9	62.7	55.1	50.8	49.7	45.7	44.3	48.2	44.7	46.3	44.3
Primary Energy			105.5	91.7	97.0	96.5	97.2	89.6	85.3	83.5	79.3	78.1	83.1	79.1	82.5	81.1

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
MANUFACTURING SECTOR																
ENERGY USE BY TYPE (PJ)																
Oil	108.8	107.2	111.4	96.2	97.8	94.1	90.8	81.5	76.2	68.0	63.6	65.0	63.6	62.4	55.8	50.1
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	8.0	13.1	17.0
Solids	13.6	13.7	15.5	21.5	26.9	28.9	24.2	24.4	19.3	22.0	24.2	29.2	32.9	33.4	37.0	25.9
District Heat	3.7	3.6	3.9	3.0	3.1	2.9	2.8	3.5	3.2	3.3	2.7	3.0	3.3	3.6	3.5	2.9
Electricity	13.4	13.5	13.9	16.3	19.7	21.2	19.7	20.7	19.6	22.3	21.9	23.3	24.8	25.9	26.6	28.0
Final Energy	139.4	138.0	144.7	[illegible]	147.5	147.1	137.6	130.1	118.4	115.6	112.4	120.4	129.5	133.3	136.0	124.0
Primary Energy	169.9	168.8	176.5	173.8	192.2	194.9	182.3	177.1	162.9	166.1	161.9	173.0	185.6	191.9	196.2	187.1
TOTAL RAW MATERIALS (PJ)																
Oil	48.7	48.6	51.3	43.3	43.9	36.5	31.3	27.5	24.0	20.8	18.1	18.1	15.9	15.0	13.1	11.9
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	5.2	7.8	8.3
Solids	9.3	9.9	12.1	17.2	21.6	23.3	19.3	17.8	12.7	15.1	14.8	17.3	16.8	16.8	18.4	12.8
District Heat	0.7	0.7	0.8	0.7	0.7	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Electricity	4.8	4.9	5.1	6.1	7.7	8.1	7.1	7.5	6.9	7.8	7.2	7.7	8.5	8.7	8.8	9.2
Final Energy	63.6	64.2	69.3	67.3	74.0	68.4	58.2	53.1	43.8	43.9	40.4	43.4	44.7	46.0	48.4	42.4
Primary Energy	74.5	75.3	80.9	81.1	91.4	86.6	74.0	70.0	59.3	61.5	56.5	60.8	63.8	65.5	68.2	63.0
TOTAL NON-RAW MATERIALS (PJ)																
Oil	60.1	58.6	60.1	53.0	53.9	57.6	59.5	54.0	52.2	47.2	45.5	46.9	47.7	47.3	42.7	38.3
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.9	5.3	8.8
Solids	4.3	3.8	3.4	4.3	5.2	5.6	4.9	6.5	6.6	6.9	9.4	11.9	16.1	16.6	18.7	13.2
District Heat	3.0	2.9	3.0	2.3	2.4	2.3	2.3	3.2	3.0	3.0	2.4	2.6	2.9	3.2	3.2	2.5
Electricity	8.5	8.6	8.8	10.1	12.0	13.1	12.7	13.2	12.8	14.5	14.7	15.5	16.3	17.2	17.8	18.8
Final Energy	75.8	73.9	75.4	69.7	73.5	78.7	79.5	77.0	74.6	71.6	72.0	77.0	84.8	87.3	87.6	81.5
Primary Energy	95.4	93.5	95.6	92.7	100.8	108.3	108.2	107.0	103.6	104.6	105.4	112.2	121.8	126.4	128.0	124.1
VALUE ADDED (10e9 '80 USD)																
Paper & Pulp	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Chemicals	0.2	[illegible]	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5	0.6	0.6	0.7	0.7
Nonmetallic Minerals	0.4	[illegible]	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.3
Ferrous Metals	0.1	0.1	0.1	0.0	0.0	0.1	0.1	[illegible]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nonferrous Metals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	4.7	4.8	5.2	5.4	5.6	5.6	5.9	6.1	6.0	6.1	6.5	6.8	7.1	7.0	6.7	6.7
Total	5.5	5.6	6.1	6.3	6.7	6.7	7.1	7.3	7.1	7.2	7.7	8.1	8.3	8.3	8.0	8.0
ELECTRICITY (PJ)																
Paper & Pulp	0.7	0.7	0.7	0.8	0.7	0.8	0.8	0.9	0.8	1.0	1.0	1.0	1.1	1.3	[illegible]	[illegible]
Chemicals	1.5	1.4	1.6	2.1	2.6	2.4	1.9	2.4	2.6	2.9	2.4	2.7	3.0	3.2	3.2	3.5
Nonmetallic Minerals	2.0	2.0	2.3	2.1	2.6	2.7	2.4	2.1	1.6	1.9	1.9	2.0	2.1	2.1	2.5	2.0
Ferrous Metals	0.5	0.6	0.4	1.0	1.7	1.9	1.8	2.0	1.7	1.8	1.8	1.8	2.1	1.9	1.6	2.3
Nonferrous Metals	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Other	8.5	8.6	8.8	10.1	12.0	13.1	12.7	13.2	12.8	14.5	14.7	15.5	16.3	17.2	17.8	18.8
Total	13.4	13.5	13.9	16.3	19.7	21.2	19.7	20.7	19.6	22.3	21.9	23.3	24.8	25.9	26.6	28.0
FINAL ENERGY (PJ)																
Paper & Pulp	6.4	6.4	6.3	5.7	4.9	5.5	5.5	5.3	4.8	4.9	6.0	6.2	6.3	7.4	7.8	6.0
Chemicals	9.7	10.6	13.1	18.2	22.0	12.2	8.0	8.9	10.0	9.1	8.4	9.5	9.6	9.4	8.8	9.7
Nonmetallic Minerals	39.4	38.3	43.2	35.6	39.2	41.6	35.9	31.8	22.8	24.3	21.4	23.1	23.7	24.3	26.8	21.8
Ferrous Metals	6.9	7.9	5.8	6.7	6.4	7.7	7.2	6.0	5.3	4.7	3.8	3.8	4.6	4.5	4.4	4.5
Nonferrous Metals	1.1	1.0	0.9	1.0	1.4	1.4	1.5	1.1	1.0	0.9	0.7	0.8	0.6	0.5	0.5	0.4
Other	75.8	73.9	75.4	69.7	73.5	78.7	79.5	77.0	74.6	71.6	72.0	77.0	84.8	87.3	87.6	81.5
Total	139.4	138.0	144.7	137.0	147.5	147.1	137.6	130.1	118.4	115.6	112.4	120.4	129.5	133.3	136.0	124.0

ANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
RIMARY ENERGY (PJ)																
aper & Pulp	7.9	8.0	7.8	7.6	6.5	7.3	7.2	7.3	6.5	7.1	8.2	8.5	8.7	10.3	10.7	8.7
hemicals	13.0	13.8	16.7	23.0	27.8	17.6	12.3	14.3	15.8	15.5	13.7	15.6	16.3	16.5	16.0	17.5
onmetallic Minerals	44.0	42.9	48.4	40.2	45.0	47.8	41.3	36.5	26.4	28.7	25.6	27.6	28.4	28.9	32.5	26.2
errous Metals	8.1	9.2	6.7	9.0	10.2	12.1	11.3	10.4	9.2	8.8	7.8	7.8	9.3	8.8	8.1	9.8
onferrous Metals	1.5	1.4	1.1	1.4	1.9	1.9	2.0	1.5	1.4	1.3	1.2	1.3	1.1	1.0	1.0	0.9
ther	95.4	93.5	95.6	92.7	100.8	108.3	108.2	107.0	103.6	104.6	105.4	112.2	121.8	126.4	128.0	124.1
otal	169.9	168.8	176.5	173.8	192.2	194.9	182.3	177.1	162.9	166.1	161.9	173.0	185.6	191.9	196.2	187.1
LECTRICITY/VALUE ADDED (MJ/'80 USD)																
aper & Pulp	6.0	5.8	6.1	7.4	5.4	5.5	4.9	5.6	4.8	6.4	5.3	5.1	5.8	6.6	6.3	6.1
hemicals	7.3	6.6	5.6	6.0	6.5	5.8	4.2	4.9	5.3	5.8	4.2	5.0	5.1	5.1	4.8	4.8
onmetallic Minerals	4.6	4.7	4.8	5.0	5.7	6.1	5.0	5.3	4.5	5.6	5.4	5.6	5.9	5.3	6.9	5.8
errous Metals	9.8	10.9	5.2	20.8	42.7	36.4	28.8	27.0	24.6	32.1	27.3	22.8	25.3	23.5	20.2	26.1
onferrous Metals	6.4	5.4	4.4	5.9	8.6	11.2	8.9	5.2	7.1	10.3	6.4	7.0	7.2	11.2	11.6	9.1
ther	1.8	1.8	1.7	1.9	2.1	2.3	2.1	2.1	2.1	2.4	2.3	2.3	2.3	2.5	2.7	2.8
otal	2.4	2.4	2.3	2.6	3.0	3.2	2.8	2.8	2.8	3.1	2.9	2.9	3.0	3.1	3.3	3.5
FINAL ENERGY/VALUE ADDED (MJ/'80 USD)																
aper & Pulp	58.1	54.1	53.9	53.0	37.5	38.7	34.3	34.0	29.7	31.5	33.1	31.9	33.8	36.7	38.7	29.7
Chemicals	47.8	48.4	46.5	52.1	55.9	29.5	17.9	18.5	20.4	18.7	14.9	17.3	16.3	15.0	13.3	13.4
Nonmetallic Minerals	89.5	88.7	90.4	86.8	87.2	92.5	75.1	79.2	64.6	69.7	62.1	63.9	66.2	62.4	74.0	63.8
Ferrous Metals	133.5	142.6	77.0	136.0	164.5	144.0	116.0	83.1	75.1	82.6	59.1	49.5	54.7	54.2	54.7	50.8
Nonferrous Metals	41.2	35.6	36.2	36.5	53.9	70.8	54.9	29.3	39.7	46.8	21.7	24.1	18.3	26.6	27.0	22.3
Other	16.2	15.4	14.6	12.9	13.1	14.1	13.4	12.5	12.4	11.7	11.1	11.2	12.0	12.4	13.1	12.3
Total	25.3	24.5	23.6	21.6	22.2	22.1	19.3	17.8	16.7	16.0	14.7	14.9	15.6	16.0	17.0	15.4
PRIMARY ENERGY/VALUE ADDED (MJ/'80 USD)																
Paper & Pulp	71.8	67.3	67.6	69.7	49.6	51.1	45.4	46.6	40.5	45.9	45.1	43.4	46.9	51.4	52.9	43.4
Chemicals	64.3	63.3	59.3	65.6	70.7	42.7	27.4	29.5	32.2	31.8	24.4	28.5	27.8	26.4	24.1	24.3
Nonmetallic Minerals	99.8	99.4	101.4	98.1	100.0	106.1	86.3	91.1	74.8	82.2	74.2	76.5	79.4	74.2	89.5	76.7
Ferrous Metals	155.6	167.2	88.7	182.7	260.4	225.7	180.4	143.6	130.3	154.7	120.4	100.6	111.4	106.9	99.9	109.2
Nonferrous Metals	56.1	48.1	46.4	49.9	73.5	96.3	75.0	41.0	55.5	69.9	36.0	39.8	34.6	52.1	53.3	42.9
Other	20.4	19.5	18.6	17.2	18.0	19.4	18.2	17.4	17.3	17.1	16.3	16.4	17.2	18.0	19.2	18.6
Total	30.9	29.9	28.8	27.4	28.9	29.3	25.6	24.3	23.0	23.1	21.1	21.5	22.3	23.0	24.5	23.3
ACTUAL ENERGY USE (PJ)																
Electricity	13.4	13.5	13.9	16.3	19.7	21.2	19.7	20.7	19.6	22.3	21.9	23.3	24.8	25.9	26.6	28.0
Final Energy	139.4	138.0	144.7	137.0	147.5	147.1	137.6	130.1	118.4	115.6	112.4	120.4	129.5	133.3	136.0	124.0
Primary Energy	169.9	168.8	176.5	173.8	192.2	194.9	182.3	177.1	162.9	166.1	161.9	173.0	185.6	191.9	196.2	187.1
ACTIVITY EFFECT (PJ)																
Electricity	12.5	12.8	13.9	14.4	15.1	15.1	16.2	16.6	16.1	16.4	17.4	18.3	18.9	18.9	18.2	18.2
Final Energy	130.1	133.2	144.7	149.9	157.1	157.3	168.2	172.2	167.6	170.1	181.1	190.4	196.6	196.8	188.8	189.5
Primary Energy	158.6	162.4	176.5	182.8	191.6	191.9	205.1	210.1	204.4	207.5	220.8	232.2	239.8	240.0	230.2	231.1
STRUCTURE EFFECT (PJ)																
Electricity	13.7	13.7	13.9	13.7	13.9	14.1	14.1	14.0	14.0	13.8	14.0	13.9	13.9	14.1	14.3	14.4
Final Energy	143.1	142.3	144.7	138.1	140.2	141.8	142.4	137.8	136.0	134.0	134.5	133.8	133.1	135.9	137.2	137.5
Primary Energy	174.4	173.6	176.5	169.5	171.9	173.9	174.6	169.8	167.9	165.6	166.4	165.5	164.8	168.0	169.8	170.4
INTENSITY EFFECT (PJ)																
Electricity	15.3	15.0	13.9	16.3	19.7	20.3	17.5	17.8	17.2	19.9	18.3	18.3	18.9	19.4	21.0	21.6
Final Energy	157.7	153.5	144.7	140.0	143.1	142.3	123.9	118.6	110.8	109.8	100.0	101.4	106.5	107.2	116.1	105.2
Primary Energy	192.5	187.6	176.5	177.0	187.5	188.1	163.5	158.9	149.8	154.9	141.4	142.7	149.1	151.1	163.5	153.9

DANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
OTHER INDUSTRY																
ENERGY USE BY TYPE (PJ)																
Oil	51.4	51.0	51.5	47.0	45.8	44.7	48.1	40.9	34.8	32.6	32.7	31.5	30.6	34.3	33.5	32.0
Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.4	1.6
Solids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	1.5	2.6	4.0	5.8	4.9	5.5	4.5
District Heat	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1.3	1.5	2.3	2.4	2.4
Electricity	4.9	5.2	5.6	5.1	4.7	4.7	4.7	4.9	4.5	4.8	5.4	5.7	5.3	6.0	5.9	5.6
Final Energy	56.8	56.7	57.7	52.6	51.0	49.9	53.4	46.4	40.8	39.4	41.5	42.5	43.3	47.8	48.7	46.1
Primary Energy	67.8	68.4	70.4	64.1	61.7	60.4	64.1	57.5	50.9	50.3	53.8	55.4	55.5	61.6	62.3	59.1
VALUE ADDED (10e9 '80 USD)	4.9	5.2	5.6	4.8	4.9	4.9	4.7	4.9	4.6	4.7	4.4	5.1	5.2	5.6	5.6	5.6
ENERGY/VALUE ADDED (MJ/'80 USD)																
Electricity	1.0	1.0	1.0	1.1	1.0	0.9	1.0	1.0	1.0	1.0	1.2	1.1	1.0	1.1	1.1	1.0
Final Energy	11.5	10.8	10.4	11.1	10.5	10.1	11.3	9.4	8.8	8.4	9.4	8.4	8.3	8.5	8.7	8.2
Primary Energy	13.7	13.1	12.7	13.5	12.6	12.3	13.6	11.6	11.0	10.7	12.1	10.9	10.6	11.0	11.1	10.5
ACTUAL ENERGY USE (PJ)																
Electricity	4.9	5.2	5.6	5.1	4.7	4.7	4.7	4.9	4.5	4.8	5.4	5.7	5.3	6.0	5.9	5.6
Final Energy	56.8	56.7	57.7	52.6	51.0	49.9	53.4	46.4	40.8	39.4	41.5	42.5	43.3	47.8	48.7	46.1
Primary Energy	67.8	68.4	70.4	64.1	61.7	60.4	64.1	57.5	50.9	50.3	53.8	55.4	55.5	61.6	62.3	59.1
ACTIVITY EFFECT (PJ)																
Electricity	5.0	5.3	5.6	4.8	4.9	5.0	4.8	5.0	4.7	4.8	4.5	5.1	5.3	5.7	5.7	5.7
Final Energy	51.3	54.3	57.7	49.4	50.7	51.1	49.1	51.2	47.9	48.9	46.1	52.8	54.2	58.2	58.2	58.2
Primary Energy	62.5	66.3	70.4	60.2	61.8	62.4	59.9	62.5	58.4	59.7	56.2	64.4	66.2	71.0	71.0	71.0
STRUCTURE EFFECT (PJ)																
Electricity	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Final Energy	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7
Primary Energy	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4
INTENSITY EFFECT (PJ)																
Electricity	5.5	5.5	5.6	6.0	5.4	5.2	5.6	5.5	5.4	5.7	6.8	6.2	5.7	5.9	5.9	5.6
Final Energy	63.9	60.2	57.7	61.4	58.1	56.3	62.7	52.2	49.1	46.5	52.0	46.5	46.0	47.4	48.3	45.7
Primary Energy	76.3	72.6	70.4	74.9	70.2	68.1	75.3	64.7	61.3	59.3	67.4	60.6	59.0	61.1	61.8	58.5

·NISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
·SSENGER TRANSPORT SECTOR																
·ERGY USE BY TYPE (PJ)																
·il			72.4	72.4	76.1	78.6	76.7	71.7	69.0	70.6	72.5	73.4	75.7	79.0	79.4	81.0
·ectricity			0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
·inal Energy			72.8	72.8	76.5	79.0	77.2	72.2	69.5	71.1	73.0	73.9	76.2	79.6	80.0	81.6
·imary Energy			73.7	73.7	77.4	80.0	78.3	73.3	70.6	72.2	74.2	75.0	77.4	80.8	81.3	83.0
·HICLE STOCK, CARS /(10e3)			256.1	273.5	289.5	294.6	295.8	287.3	281.3	278.6	284.0	293.1	304.5	314.5	319.3	322.5
HICLE-KM (10e9)																
·itomobiles & Light Trucks			21.1	21.4	23.3	23.9	22.6	21.2	20.7	20.9	21.7	22.8	23.9	25.1	26.5	27.9
·SSENGER-KM (10e9)																
·itomobiles & Light Trucks			41.1	40.9	43.5	43.8	41.0	38.5	37.6	38.0	39.1	40.7	41.7	42.7	44.8	46.9
·torcycles			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
·ises			5.1	5.7	6.3	6.6	6.8	7.2	7.4	7.7	8.1	8.4	8.8	9.1	9.2	9.2
·il			3.1	3.1	3.2	3.3	3.7	4.4	4.6	4.7	4.7	4.7	4.8	4.7	4.8	4.9
·ter			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6
·ir			0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.5
·tal			50.1	50.5	53.9	54.6	52.3	51.0	50.5	51.4	52.8	54.6	56.1	57.5	59.8	62.0
·ERGY/PKM (MJ/PKM)																
·itomobiles & Light Trucks			1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.5
·torcycles			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
·ises			0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
·il			1.0	1.0	1.0	1.0	0.9	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
·ter			4.6	4.8	4.7	5.1	4.5	4.7	4.1	5.4	4.2	4.4	4.6	5.4	5.1	4.6
·ir			3.8	3.4	3.2	3.6	2.9	2.2	1.6	1.2	2.7	2.0	1.7	2.0	2.3	2.3
·tal			1.5	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3
·TUAL ENERGY USE (PJ)																
·lectricity			0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
·inal Energy			72.8	72.8	76.5	79.0	77.2	72.2	69.5	71.1	73.0	73.9	76.2	79.6	80.0	81.6
·imary Energy			73.7	73.7	77.4	80.0	78.3	73.3	70.6	72.2	74.2	75.0	77.4	80.8	81.3	83.0
·TIVITY EFFECT (PJ)																
·lectricity			0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5
·inal Energy			72.8	73.4	78.3	79.3	76.0	74.1	73.3	74.6	76.7	79.3	81.6	83.6	86.9	90.1
·imary Energy			73.7	74.3	79.3	80.3	77.0	75.0	74.2	75.6	77.7	80.3	82.6	84.6	88.0	91.2
·RUCTURE EFFECT (PJ)																
·lectricity			0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
·inal Energy			72.8	72.2	71.9	71.6	71.2	70.1	69.7	69.5	69.3	69.4	69.2	69.3	69.5	69.9
·imary Energy			73.7	73.1	72.8	72.6	72.2	71.4	71.1	70.9	70.7	70.7	70.5	70.5	70.8	71.1
·TENSITY EFFECT (PJ)																
·lectricity			0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
·inal Energy			72.8	72.8	72.4	74.4	76.6	75.1	73.5	74.2	74.1	72.3	72.9	74.6	71.7	70.3
·imary Energy			73.7	73.7	73.3	75.4	77.4	75.9	74.2	74.9	74.9	73.0	73.7	75.4	72.6	71.1

ANISH ENERGY SUMMARY	1970	1971	1972	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
REIGHT TRANSPORT SECTOR																
IERGY USE BY TYPE (PJ)																
il			35.4	31.5	34.9	43.0	41.9	42.0	40.6	43.8	45.4	51.8	55.1	58.3	58.5	57.5
ectricity			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
inal Energy			35.4	31.5	34.9	43.0	41.9	42.0	40.6	43.8	45.4	51.8	55.1	58.3	58.5	57.5
imary Energy			35.4	31.5	34.9	43.0	41.9	42.0	40.6	43.8	45.4	51.8	55.1	58.3	58.5	57.5
NNE-KM (10e9)																
ucks			1.4	1.5	1.8	1.9	1.9	1.7	1.6	1.6	1.6	1.7	1.9	2.0	2.0	2.0
il			0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2
ip			0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.3	0.4	0.4	0.4	0.4
peline			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.3
r			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tal			2.0	2.1	2.5	2.4	2.5	2.4	2.2	2.2	2.3	2.4	2.7	2.9	2.9	2.9
IERGY/TKM (MJ/TKM)																
ucks			4.2	3.4	3.2	3.9	3.8	4.2	4.4	4.7	4.8	5.4	5.3	5.4	5.3	5.1
il			1.1	0.9	0.9	0.8	1.0	1.0	1.6	1.8	1.4	0.9	0.7	0.6	0.4	0.8
ip			2.8	2.5	1.8	2.6	1.8	1.7	1.3	1.4	1.4	1.7	1.7	1.6	2.0	2.1
peline			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
r			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
tal			3.4	2.9	2.7	3.4	3.1	3.3	3.5	3.7	3.7	4.2	4.2	4.2	4.2	4.3
TUAL ENERGY USE (PJ)																
ectricity			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nal Energy			35.4	31.5	34.9	43.0	41.9	42.0	40.6	43.8	45.4	51.8	55.1	58.3	58.5	57.5
imary Energy			35.4	31.5	34.9	43.0	41.9	42.0	40.6	43.8	45.4	51.8	55.1	58.3	58.5	57.5
TIVITY EFFECT (PJ)																
ectricity			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nal Energy			35.4	36.9	43.8	43.5	45.2	42.8	39.3	39.9	41.5	41.5	44.4	47.4	46.7	45.2
imary Energy			35.4	36.9	43.8	43.5	45.2	42.8	39.3	39.9	41.5	41.5	44.4	47.4	46.7	45.2
RUCTURE EFFECT (PJ)																
ectricity			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nal Energy			35.4	36.7	37.5	37.7	37.7	36.6	37.1	36.8	36.9	37.2	37.3	37.3	37.5	38.9
imary Energy			35.4	36.7	37.5	37.7	37.7	36.6	37.1	36.8	36.9	37.2	37.3	37.3	37.5	38.9
TENSITY EFFECT (PJ)																
ectricity			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nal Energy			35.4	29.3	26.6	32.8	30.6	33.3	35.1	38.2	37.7	41.2	40.7	40.4	40.7	39.8
imary Energy			35.4	29.3	26.6	32.8	30.6	33.3	35.1	38.2	37.7	41.2	40.7	40.4	40.7	39.8

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