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Authors
Schipper, Lee
Howarth, R.
Wilson, D.

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A LONG-TERM PERSPECTIVE ON NORWEGIAN ENERGY USE

Lee Schipper, Richard Howarth and Deborah Wilson*

International Energy Studies Group
Energy Analysis Program
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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ABSTRACT

Norway is the home country of the leader of Brundtland Commission, which recommended that nations reduce their energy use through increased energy efficiency. In order to better understand the potential for such a reduction in Norway, the Norwegian Oil and Energy Department, along with Oslo Lysvaerker, asked the International Energy Studies Group at the Lawrence Berkeley Laboratory to analyze the changes in the level and structure of Norwegian energy demand that have developed since 1950. The long time horizon of our analysis allowed us to examine the evolution of the energy use of each major sector of the economy.

The results of our analysis show that energy efficiency has not improved as much in Norway as in other countries since 1973. Two factors lie behind this finding. First, electricity and wood have been cheap and abundant in Norway, and oil, although priced for international markets, has not been perceived as a scarce fuel. Indeed, the burgeoning revenues from the oil sector provided Norwegians with access to more cars and more travel, larger and more comfortable homes, and other amenities so that energy use increased even after 1973 while the citizens of other nations were cutting back on energy use. The second, more subtle factor, is that the use of energy in Norway reached maturity only quite recently, as the ownership of the principal energy-using equipment of each sector began to approach saturation. The maturation of energy demand in Norway implies that the significant potential for energy resource conservation can now be exploited. If energy prices should rise significantly in Norway, we expect that the energy efficiency of the Norwegian economy could improve dramatically in the future.

SUMMARY FINDINGS

1. Between 1950 and the early 1980s, the structure of the Norwegian economy evolved towards a progressively more energy-intensive mix of activities in manufacturing, transportation, and households. This evolution proceeded relatively unaffected by the two oil price shocks; indeed, the income provided by the oil shocks stimulated this evolution more than the increase in oil prices retarded it. Consumers were acquiring the means to comfort, convenience, and mobility during the period of high energy prices. During this time, Norwegians appear to have paid little attention to available opportunities for fuel conservation.

   The trends in the structure of energy use in Norway differ from those of many other industrialized countries, where the structure of the manufacturing sector has begun to evolve towards a less energy-intensive product mix. The trend in other countries was accelerated by the two oil shocks. Similarly, the rise of ownershipn and use of the automobile and the increase in the comfort and convenience of homes came to a head in Norway only during the 1970s, considerably later than in North America or the other Scandinavian countries. As a result, overall energy demand in Norway behaved as if no oil crises had occurred, except for temporary adjustments immediately after the two oil price increases. By contrast, energy demand in the United States, Sweden, Denmark, and West Germany responded dramatically after both 1973 and 1979.

2. Some gains in energy efficiency did occur in the economy after 1973, but these were offset by growth in energy-using activities. Automobile fuel economy has improved by about 10 percent since 1973, but the number of cars increased by more than 50 percent over the same time period. In the residential sector, building shells became tighter, but the energy intensity of space heating, measured in terms of delivered heat per square meter of floor area, continued to rise even after 1973. Furthermore, the average amount of space per person increased by more than 10 percent, and indoor temperatures and the share of total floor area heated increased. In the manufacturing sector, modest efficiency improvements were realized in most industry groups, but the proportion of output generated by energy-intensive industries increased so that aggregate sectoral energy intensity remained roughly constant.

   In many other OECD* countries, consumers reduced space heating demand per household by more than 20 percent while achieving increases in comfort (i.e., increased central heating); industries reduced energy intensities by some 30 percent; and building managers reduced intensities in service buildings. As a result, total energy demand for heating, manufacturing, and in some cases the service sector and automobile transport was *lower* in 1986 than in 1973. Thus, the energy intensity trends in Norway ran counter to trends in most other countries, except in the automobile fleet, where the small improvements in Norway were consistent with those in the rest of Europe.

* "OECD" is an acronym for the Organization for Economic Cooperation and Development.

3. Low electricity prices and the availability of wood for space heating allowed most Norwegian households to sidestep the effects of higher oil prices in the 1970s and early 1980s. And when oil prices collapsed, consumers reacted by substituting oil back for wood and, in some cases, electricity. In manufacturing, persistently low electricity prices also restrained interest in conservation. If electricity prices continue to increase as they have in the last few years for residential customers, substantial conservation may occur.

   In most other OECD countries, sharp increases in oil prices precipitated strong short-term reductions in oil intensity and, over the longer term, reductions in the energy intensities of most activities. Even in Sweden, where electricity prices remained relatively constant in real terms after 1973, the oil price shocks, reinforced by taxes on heating oil, caused overall reductions in energy intensities as well as shifts to electricity. And while substitution to electricity and wood began almost immediately after the 1973 and 1979 oil price shocks in Norway, substitution to other alternatives such as gas, coal, and to a lesser extent district heating was markedly slower than in other countries.

4. Perhaps the most remarkable result of our analysis is the finding that the ratio of energy to gross domestic product in Norway has decreased since 1973 even though the energy intensities of each major end-use sector (homes, services, passenger transport, freight transport, and manufacturing) for the most part remained constant or increased! In other words, the drop in the energy/GDP* ratio was caused not by energy saving, but by changes in the relative importance of different sectors as well as the increase in GDP generated by growth in the oil sector.

The challenge for Norway, as we see it, is to achieve the broad goals set out by the Brundtland Commission through the implementation of concrete policies. New sources of electricity in Norway will be more expensive and more polluting than hydropower. And increased use of fossil fuels, particularly for transportation, brings additional costs in the form of pollution and carbon dioxide production. If the government and Norwegian people want to minimize the ultimate costs of using more energy and electricity, then policy decisions will have to be made that will likely lead to higher energy prices. These changes in policy could be accompanied by programs designed to support and facilitate investments in energy-efficient technologies. If, by contrast, the current approach to energy (and especially eletricity) pricing is maintained, we do not expect that energy efficiency will improve very rapidly.

* "GDP" is an abbreviation for Gross Domestic Product.

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The results of our analysis show that energy efficiency has not improved as much in Norway as in other countries since 1973. Two factors lie behind this finding. First, electricity and wood have been cheap and abundant in Norway, and oil, although priced for international markets, has not been perceived as a scarce fuel. Indeed, the burgeoning revenues from the oil sector provided Norwegians with access to more cars and more travel, larger and more comfortable homes, and other amenities so that energy use increased even after 1973 while the citizens of other nations were cutting back on energy use. The second, more subtle factor, is that the use of energy in Norway reached maturity only quite recently, as the ownership of the principal energy-using equipment of each sector began to approach saturation. The maturation of energy demand in Norway implies that the significant potential for energy resource conservation can now be exploited. If energy prices should rise significantly in Norway, we expect that the energy efficiency of the Norwegian economy could improve dramatically in the future.

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A LONG-TERM PERSPECTIVE ON NORWEGIAN ENERGY USE

1 INTRODUCTION

Norway is rich in energy resources. Domestic hydroelectric power provides over 40 percent of national energy use, and the rich oil and gas deposits of the North Sea could support current use levels of those fuels well into the foreseeable future if they were reserved strictly for domestic consumption. Norway will be a net exporter of fuels and electricity for some time to come; as a result, the nation is less vulnerable to the impacts of future energy shocks of the sort that occurred in 1973 and again in 1979 than are most other OECD nations.

Domestic energy policy has in the past focused principally on the exploitation of the natural resources of the nation. Most important has been the development of the cheap hydro capacity that has fostered electricity prices that are very low by international standards and correspondingly heavy reliance on this renewable energy source throughout most sectors of the economy. For these reasons, it may appear that raising the efficiency of Norwegian energy use is unimportant to the future welfare of the nation.

But a range of realities now confronts the nation that compels the reconsideration of this supposition. While existing hydroelectric facilities produce electricity at low average cost, the availability of new sites and environmental considerations sharply constrain the development of additional hydro capacity. As a result, future electricity use will require increased utilization of fossil fuel and/or nuclear technologies, and the marginal cost of electricity is today well above the price charged to current customers. Higher prices and improved energy efficiency could therefore yield substantial net benefits to the Norwegian economy.

Second, Norway is surrounded by energy-poor nations, and the use of fuels and electricity at home bars their export to foreign consumers who may be willing to pay much more to use them. Household electricity prices in Norway, for example, are roughly half those in Denmark.[1] Industrial electricity prices in Norway appear to be the lowest in Europe, held down by long-term contracts. While electricity price reform might cause economic dislocation in some sectors — particularly in industry, which is strongly dominated by electricity-intensive raw materials processing — the long-term gains in economic efficiency could be quite substantial. In an increasingly international economic environment, Norwegians would do well to reconsider policies that promote the inefficient use of their natural resources.

Finally, energy utilization lies at the heart of a range of environmental problems including urban air pollution, acid deposition, and climate change induced by fossil fuel combustion. Many of these problems are regional or even global in scale, and each nation must contribute its share if the problems are to be resolved. Future increases in Norwegian electricity production will most likely rely on natural gas with its associated carbon dioxide production. Official policy seems to be turning towards decreasing Norway's contribution to the global environmental burden.[2]

Energy savings policies may be called for as a way of ameliorating many of the dilemmas outlined above. But the design and implementation of effective energy policies for Norway will require a firm understanding of past energy-use trends and the identification of opportunities for future progress. Towards that end, we have prepared a detailed study of Norwegian energy use from 1950 to 1986.[3]

The reasons for the long time horizon of our study are several. First, forty years is a sufficiently long time to replace half of the housing stock, replace the vehicle stock two times over, and to replace or retrofit most industrial facilities. The structure and performance of the Norwegian economy changed considerably over the period of the analysis. We were thus able to capture the true long-term evolution of Norwegian energy use rather than short-run responses to transient economic conditions. A second consideration was also important: To gauge the impacts of the energy shocks of the 1970s on post-shock energy use patterns, one must first evaluate the trends unfolding before 1973.

The following sections present an overview of the evolution of Norwegian energy use along with the principal findings of our study. Sections 4 through 7 discuss the details of our work and the findings for the residential, service, manufacturing, and transportation sectors. An appendix and the references are presented at the end of section 7. The figures are grouped at the end of the section in which they are first referenced.

2 ANSWERING THE KEY QUESTIONS

Before we review the evolution of Norwegian energy use in each major energy end-use sector, we outline the questions we set out to answer.

2.1 How Has the Structure of Energy Use in Norway Evolved Since 1950?

Since 1950, energy use in Norway has passed through three important phases. In the 1950s, manufacturing growth drove energy demand. In the 1960s, manufacturing energy use spurted, but so did energy demand for automobiles. In the 1970s, growth in energy demand for transportation continued, but growth in the demand for comfort and convenience in the residential and service sectors pushed energy use even higher. The overall impact of this evolution was to cause energy demand to rise steadily at an average annual growth rate of 4.1 percent between 1950 and 1973 and 1.9 percent between 1973 and 1986.

We can summarize our findings using two sets of aggregate indicators, which are indexed to the year 1973. Figure 2.1 shows the indices of the aggregate output or activity levels of each sector as developed in our analysis* as well as real GDP. Heated floor area kept pace with GDP throughout the period of analysis. The level of passenger travel, in contrast, grew faster than GDP through 1973, then slowed (particularly after the 1979 price shock), but grew with GDP after 1983. The volume of domestic freight, which grew more rapidly than GDP before 1973, fell behind GDP growth in the early 1970s but has kept pace in the 1980s. Manufacturing output grew more rapidly than GDP up to 1973 but has since remained almost constant.

One important change in the composition of the GDP in the 1970s was the rapid rise of oil sector activity. In 1986, petroleum extraction accounted for 17 percent of GDP, rising from just one percent in 1973. Service sector activity, as shown in the figure, has also grown rapidly, although not as fast as GDP. Together, oil and services accounted for 80 percent of the growth in GDP after 1973. The break in the

* These are manufacturing value added, freight (tonne-km), passenger travel (passenger-km), services GDP (data for which extend farther back than the estimates of services floor area), and heated residential floor area.

indicators of freight activity and manufacturing output after 1973 appears to be related to the shift towards oil sector activity. By the mid 1970s, these indicators had stabilized or resumed slow growth.

Figure 2.2 summarizes the evolution of aggregate sectoral energy *intensities* — or energy use per unit of activity — that complement the activities summarized above. The energy intensity of manufacturing rose between 1950 and 1967, fell between 1967 and 1978, and has since fluctuated. The energy intensity of freight transport fell between 1950 and 1973, as electricity backed coal and oil out of railroads, but has since risen as the share of trucks, particularly for short trips within cities, increased. The energy intensities of home heating and passenger transport rose during the entire period.

From these summary indicators we may conclude that no dramatic reductions in sectoral energy intensities occurred as a result of increased oil prices in 1973 or 1979. By the mid 1970s, these indicators had stabilized or resumed slow growth. The energy/GDP ratio in Fig. 2.2 fell because of increases in oil sector GDP and because of a shift from oil to electricity in certain applications such as the provision of space heat.

When we divide sectoral energy use even further, we find an additional and important conclusion hidden in the aggregate figures. We separate energy demand into that for producers (including manufacturing, other industry, freight, and business services) and consumers (including homes, personal services, and passenger transportation) in Fig. 2.3. The figure shows that the share of energy used for consumers was constant or decreasing until the mid 1960s, when this share began to rise. The share of energy demand for producers behaved in a complementary manner. Once the major consumer goods that use energy (automobiles, central heating or its equivalent, and major appliances) approach saturation, energy demand "matures".

Such maturity means that consumers have acquired the most important means to comfort, convenience, and mobility. In many other countries, particularly Germany in the 1960s, and Japan and the United Kingdom in the 1970s and 1980s, we have found that income-driven growth in ownership and use of cars, heating systems, and appliances seems to proceed rapidly with little regard for energy efficiency. Only when the major uses are in place do consumers seem to be receptive to improving the efficiency of energy use. This behavior is unfortunate, because it is often less costly to start with efficient technologies than to substitute or retrofit later.

This shift towards the consumer indicates something significant about energy use with important ramifications for the future prospects for energy efficiency. For one thing, energy-use decisions will be spread over more households and individuals, with each decision generating only a small impact on aggregate energy use. Moreover, producers and consumers approach energy-use issues differently. Producers tend to watch their energy costs carefully and calculate how they can best use energy and other resources in the production process. Consumers pay less attention. They can be expected to watch for ways to improve their heating comfort while reducing heating energy use, and to pay some attention to the price of gasoline when selecting their next auto (or driving their next kilometer). But consumers generally focus excessively on the initial cost of energy-using equipment, underweighting future energy costs, and their interest in investing in energy-saving technology is generally weak.

Even if consumers do pay some attention to the energy efficiency of their heating systems or automobiles, they pay less attention to the energy consequences of the *size* of their homes, the comfort in the places they visit away from home, or the overall *distances* they drive (or more recently, fly). To be sure, this latter group of "structural" parameters grew with incomes in the past. But in the future, it is possible that consumers will elect to use their homes and cars differently than in the past.[4] The choices we foresee will be less constrained by income levels than was the case before homes and buildings had high comfort levels or consumers had access to automobile and air travel. As a recent review[5] shows, there may be a wide range in the mix of activities in which future consumers in Norway (or other countries) choose to participate. Future energy demand in Norway may become increasingly sensitive to these choices. So although the *ownership* of energy-using equipment may approach saturation, the *utilization* of that equipment may increase, driving energy use higher over time.

2.2 How Do Short-Term Reactions to Changes in Energy Prices Differ from Long-Term Trends?

Figure 2.4 shows the long-term trends in the real prices of energy products sold to industry in Norway; Figure 2.5 shows the evolution of prices paid by consumers for energy products. As can be seen, the most significant shocks that occurred fell on the prices of kerosene and heating oil; prices for these fuels shot upwards in 1973/4 and 1979/80 but decreased slowly in the mid 1970s and rapidly in the mid 1980s. Note that as a consequence of the high taxes already placed on gasoline, its price as measured in real terms did not move rapidly in either direction. From 1980 until 1984, electricity was cheaper than oil for heating homes and buildings. These changes in relative prices caused many short-term changes in energy use, but their long-term impacts are less certain.

The main short-term reactions to the 1979/80 shock included a rapid switch by home and building owners from oil to electricity. A similar switch occurred in industry, particularly when interruptible electricity ("tilfaeldig kraft") was available. The level of passenger travel fell in 1980 and 1981 when fuel prices jumped, reducing transportation energy use slightly. But all of these changes were reversible, and some are already reversing. (Travel sprang back by 1984, for example, while oil use moved upward after the price collapse of 1986.)

Without a doubt, the oil price shock of 1973/4 had a short-term and temporary impact on driving and home heating. The shock of 1979/80 had more lasting effects. Yet the growth in the underlying structure of energy demand in Norway proceeded with little interruption induced by the increase in oil prices. This short-term responsiveness did not give way to significant improvements in industries, homes, and buildings, suggesting that high energy prices during a short time period would not by themselves affect much significant change in energy efficiency in Norway. Below we will argue that a more fundamental, long-term reaction could appear if energy prices rise and if other forces are brought to bear on energy demand.

2.3 How Do the Structure and Evolution of Norwegian Energy Use Differ from Trends in Other Industrialized Countries?

Energy demand in Norway stands out from that of other countries in several important respects. The Norwegian fuel mix is the most heavily reliant on electricity among the OECD countries. This is a consequence of the availability of low-price hydroelectricity, which encouraged the evolution of manufacturing production towards a mix of electricity-intensive products and processes, and the highest penetration of electric space and water heating of any country in the OECD. The intensity of wood use for heating is also high. The structure of Norwegian energy use is significantly influenced by these features, and any strategy to increase energy efficiency must deal with the institutions and political pressures that this decades-old pattern has shaped.

There are other differences between Norway and other countries that have important consequences for energy demand patterns. The climate in Norway is colder than that of most other countries in the OECD. The cold climate, however, justifies more attention to saving heat in buildings than would a warmer climate.[6] Norwegian homes are larger than those in Central Europe, but still slightly smaller than those in Sweden or Denmark, and considerably smaller than those in North America. Norway's geography favors sea travel in freight over other modes, and the spread of the population has driven automobile use to one of the highest levels in Europe, close to 14,000 km per automobile per year. Another consequence of Norway's unique geography is the importance of domestic air travel, measured in passenger-km/capita, far greater than is the case in West Germany or Sweden. A final consequence of both geography and economic history is that a significant amount of Norway's freight is funneled into foreign trade and is therefore not easily counted in our comparison. Yet this freight (including shipments of oil) is dominated by the transport of raw materials with a high weight per unit of value, and therefore costly in terms of energy to ship. Thus the *structure* of the Norwegian energy economy is more energy-intensive than is that of most other industrialized countries.

We can also compare the *efficiency* of energy use in Norway with that of other countries. Today, Norwegian building shells are relatively efficient compared to those in most other countries (i.e. their thermal transmission values are low), although less efficient than those in Sweden. Thermal requirements for new buildings are comparable to those in Sweden and Denmark, although it appears that many of the newest homes in Denmark and Sweden exceed requirements by a wide margin. Although there are few real measurements, indoor temperatures in Norway appear to be comparable to those in Sweden, and higher than in Denmark, West Germany, or North America. Household appliances in Norway are about average for efficiency. Lighting levels, by contrast, are by far the highest in the OECD, and commercial buildings are amongst the most well (or perhaps even over-) heated. Automobiles are slightly larger and more fuel-intensive than the European average, but less so than those in Sweden or North America.

The historical development of the structure of energy demand in Norway is also different from that in other countries. In other industrialized countries (e.g. Sweden, Denmark, West Germany, or the United States), the saturation of household equipment, per capita raw materials production, and in some cases even transportation activity, began to appear before the first oil crisis, and certainly earlier than in Norway. In these countries, a wave of fuel and electricity conservation in space heating occurred after the oil shocks. Significant energy savings in manufacturing, and, in the case of the U.S., a drastic improvement in automobile fuel economy, also occurred. Because key energy uses were still growing to maturity in the 1970s in Norway, few signs of energy efficiency improvement were exhibited in the nation.

2.4 What Are the Most Important Factors Affecting Long-Term Energy Use in Norway?

We have alluded to several factors that have shaped the evolution of energy use in Norway. The most obvious are the low price of electricity and the presence of other natural resources that led to the development of energy-intensive raw materials industries. But unlike Sweden, where an engineering industry developed to take raw materials to their final stage as tools, automobiles, appliances, and other capital and consumer goods for both domestic use and export, a large proportion of the output of the raw materials industries in Norway is exported. At the same time Norway imports a large portion of consumer goods, making these expensive and often objects of taxation. This would explain the fact that it took Norwegian households longer to acquire heavy appliances and cars than their neighbors in Sweden.

Then, too, Norway's GDP, while growing at nearly 4 percent per year for most of the post-war period, spurted rapidly after the discovery of oil. This fed consumer spending, which grew more rapidly than disposable income in some years as consumers used up savings or borrowed money to acquire larger cars and appliances or travel abroad. Thus the Norwegian economy bloomed late for consumers, who "caught up" with the energy standard of consumers in other countries when those other consumers were busy reacting to higher oil prices. What these observations mean is that the development of energy demand in Norway was *different* than in other countries, but by no means illogical.

The development of the manufacturing sector in Norway has been particularly important to the long-term evolution of energy use. Because of natural endowments of raw materials and rivers that provide cheap electricity, the structure of Norwegian industry has become increasingly energy-intensive over time. In other words, the share of manufacturing production arising in the raw materials industries increased from 14 percent in 1950 to 26 percent in 1986. There is nothing wrong with this development, as long as it is agreed that the low price of electricity, an important stimulus to this development, is "correct". But if new power prices rise significantly, then it is probable that these industries will *not* expand. The present evidence suggests that the current price structure is an important reason why the energy and electricity intensities of most industry groups in Norway fell only slightly after 1973. If electricity prices remain low, output from will probably expand with world markets, and little incentive would exist for serious energy efficiency improvements. If prices increase, industry will most likely find ways to reduce energy intensities; some energy-intensive facilities would presumably lose their comparative advantage and shut down. Together, these processes would contribute to significant energy savings.

Certainly the discovery of oil and the subsequent dramatic increase in oil-related income in Norway after 1973 is an important factor shaping energy demand. The discovery of oil may have had less of a direct impact on the long-term structure of the economy already in place. But oil spawned services and brought an important international status to Norway and Norwegian business that was previously unknown. And the legacy of oil certainly adds to the perception that Norway has more than enough energy (and raw materials) to prosper.

2.5 Which End-Use Sectors in Norway Appear to Hold the Greatest Potential for Enhanced Energy Efficiency or Reduced Energy Use?

The foregoing analysis shows that the evolution of energy demand in Norway has not undergone major long-term changes related to fuel and electricity conservation. This evolution is consistent with the development of energy prices and with many features of Norway's natural resources. Nevertheless, the energy future of Norway may be different than the recent past.

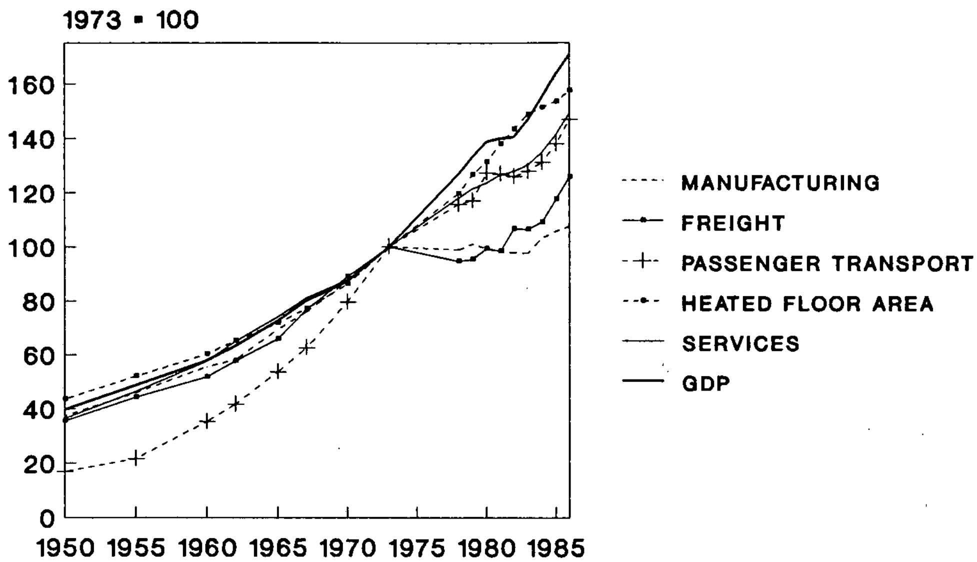
For one thing, certain energy uses may be approaching saturation. Energy use in homes has nearly saturated; with proper price signals and incentive programs, building owners and occupants could probably be induced to make significant investments to save fuel and electricity in existing and new buildings. Expansion of built space in the service sector, driven in part by oil-related private activity and public services fed by oil revenues, may slow. Automobile ownership and use has not saturated, but future growth could be limited, and growth in gasoline use cut.

The lack of significant and measurable reductions in energy intensities since 1973 suggests that manufacturing and households are sectors that would be very receptive to energy resource conservation efforts if energy prices were to increase. Although we have not analyzed the service sector in great detail, its intensive use of electricity suggests this sector should also be receptive to conservation efforts. If energy prices increased and conservation programs were in place (such programs might include loans for insulation, labeling of appliances, advice and consulting to owners of buildings and industrial facilities, etc.), the results probably would be apparent after a short time. Together these efforts might reduce the growth in total energy delivered to these three sectors to almost nil for the remainder of the century.

Enhanced efficiency in the transportation sector is a more difficult matter. We noted that the fuel efficiency of cars in Norway increased by only about 10 percent since 1973, consistent with developments in most other European countries. Far greater improvements are possible. These could be stimulated both by fiscal measures that the national government could undertake, as well as by changes in the local incentives and disincentives to travel. But travel demand is still relatively unsaturated, as both air travel and car ownership and use show considerable growth potential. We therefore expect some growth in energy use for transportation even if the efficiency of certain modes increases.

In the manufacturing sector, on the other hand, there are significant opportunities for improved energy efficiency. But these improvements will be realized only through sound policy management. Sectoral output has been stagnant since the development of Norway's oil resources in the 1970s, and this stagnation has been a major factor in the stabilization of manufacturing energy use at the current level, and certainly in the lack of any interest in far-reaching conservation investments. Should the manufacturing sector resume its growth, its energy use would presumably grow as well. But long-term manufacturing energy use trends in Norway have been driven not only by sectoral output by also by energy — particularly electricity — prices. With prices as low as they are, Norwegian manufacturing has grown towards an energy-intensive product mix, and there has been little incentive for efficiency improvement. As we noted above, further reductions in manufacturing energy intensity will probably come only with the restructuring of electricity prices to more accurately reflect the marginal social cost of domestic electricity use. While the impacts of such reform could have dire consequences for the most electricity-intensive sectors, it may be an unavoidable consequence of economically efficient resource utilization.

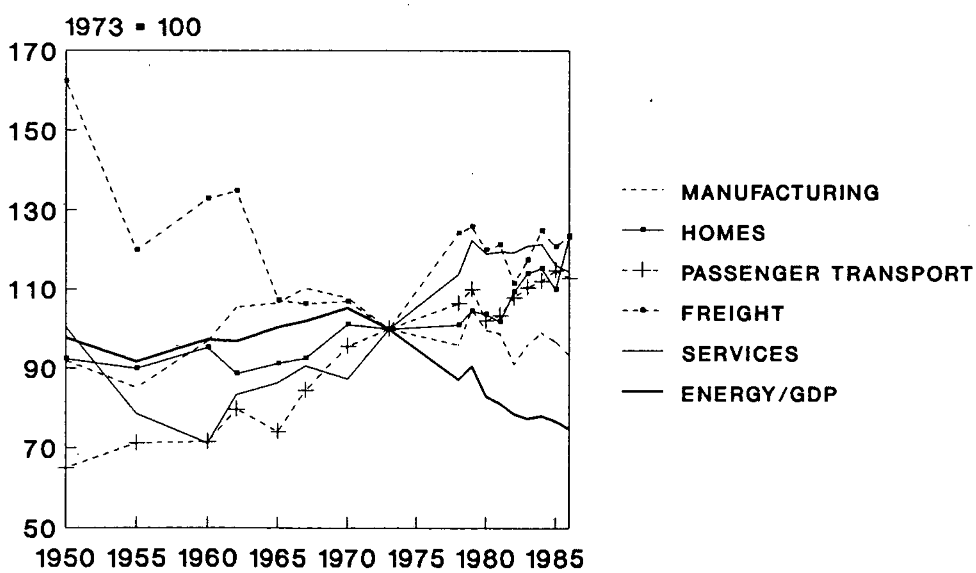
FIGURE 2.1
NORWEGIAN ECONOMIC STRUCTURE 1950-1986
KEY ENERGY-USING ACTIVITIES



Value added, tonne-km, pass-km, home floor area weighted for central heat

c1strindx

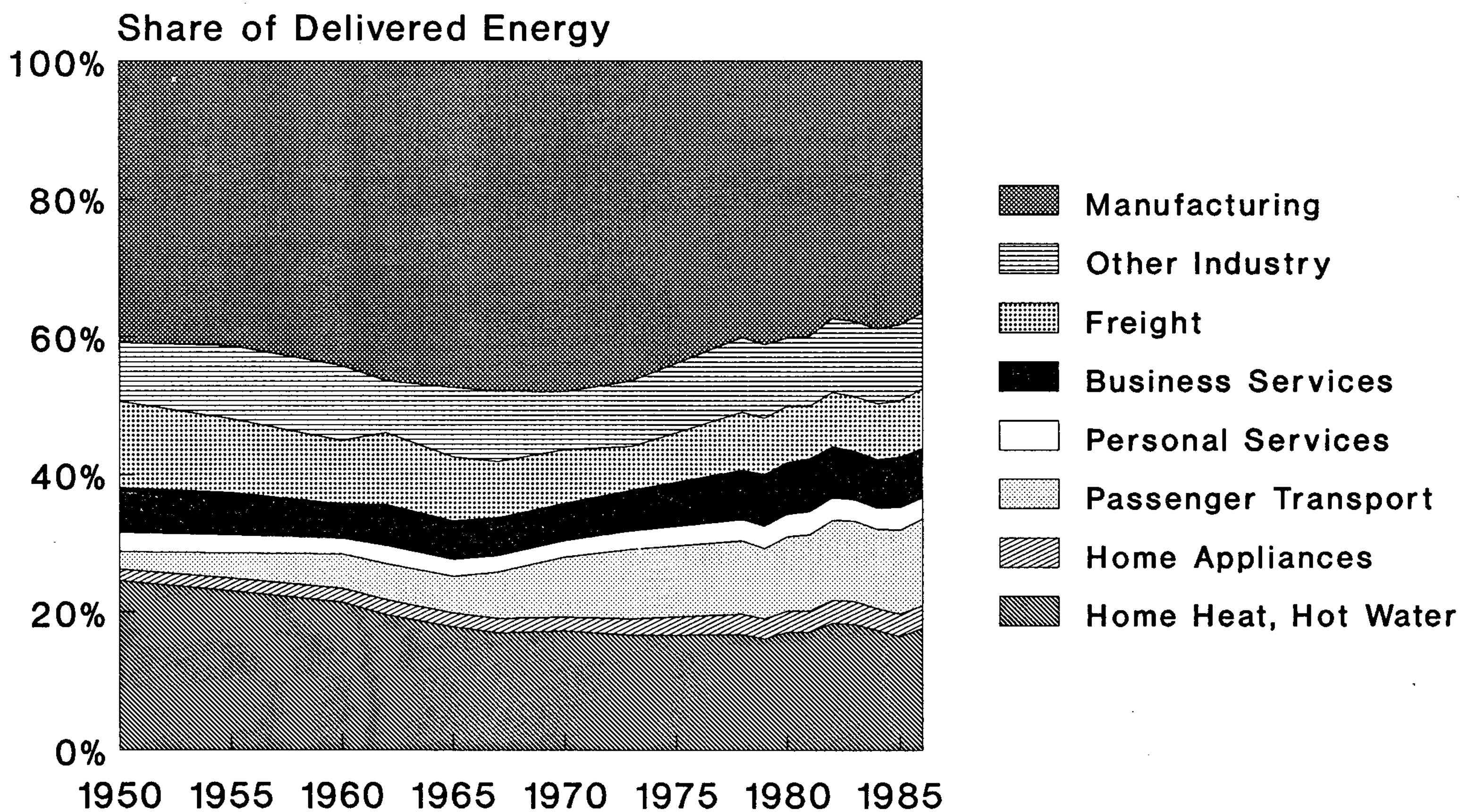
FIGURE 2.2
NORWEGIAN ENERGY INTENSITIES
KEY ENERGY-USING ACTIVITIES



Energy/value added, energy/tonne-km, energy/pass-km, useful energy/sq.m.

c2intndx

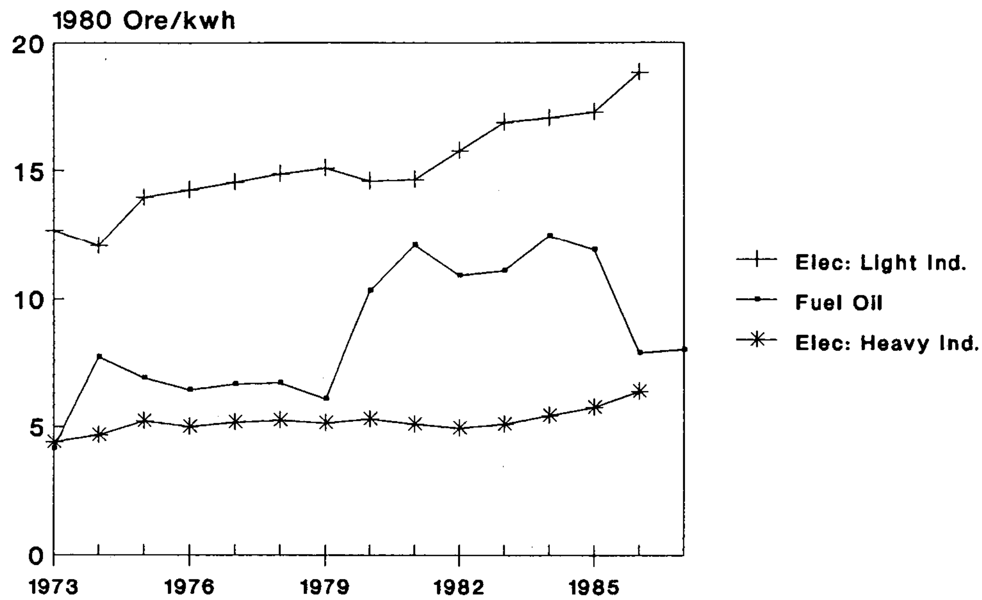
FIGURE 2.3
EVOLUTION OF ENERGY DEMAND IN NORWAY
PRODUCER AND CONSUMER SHARES



Consumer share is for homes, passenger transport, and personal services

c3endus

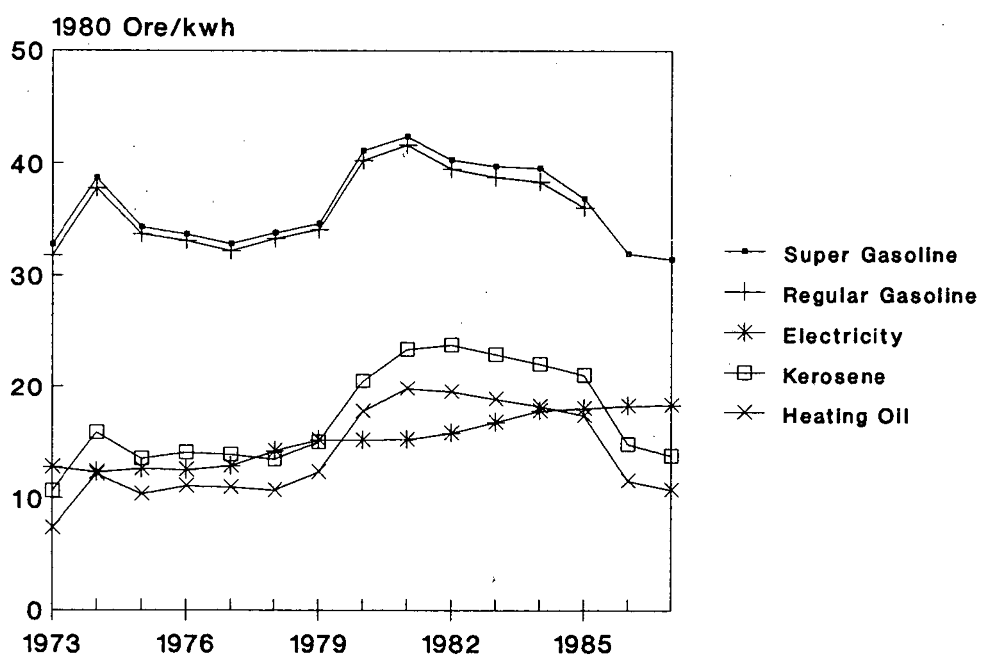
FIGURE 2.4
INDUSTRIAL ENERGY PRICES IN NORWAY



Heavy industry includes smelters, chemicals and paper & pulp

c4inprl.6/90

FIGURE 2.5
CONSUMER ENERGY PRICES IN NORWAY



c6consp

3 AGGREGATE FINDINGS AND OBSERVATIONS

Norwegian primary energy use grew at an average annual rate of 4.2 percent between 1950 and 1962, 4.7 percent between 1962 and 1973, and 3.1 percent between 1973 and 1986. This growth was fed principally by oil and hydroelectricity (Fig. 3.1). Given the high efficiency with which the potential energy of water stored behind a dam is converted to electricity, only a small fraction of Norwegian primary energy is lost in energy transformation processes (Fig. 3.2). Total final energy demand grew somewhat less rapidly at 3.8 percent per year from 1950 to 1962, 4.4 percent per year from 1962 to 1973, and only 1.9 percent per year from 1973 through 1986. The year-to-year changes varied with weather, energy prices, and economic activity. The percentage breakdown of energy use by sector (Fig. 3.3) reveals that the dominance of industry has diminished since 1973 as the remaining sectors — particularly transportation — have grown in importance.

Driving the increase in aggregate energy use was the growth in GDP (including the oil sector), which averaged 4.0 percent per year during the 1950 to 1986 period. The overall energy/GDP ratio for Norway remained constant in the 1950s but increased by 0.8 percent per year in the 1960s, only to fall by 2.1 percent per year in the 1970s and 1980s (Fig. 3.4). Substitution of electricity for fuel in many applications was one factor that fostered the decline of this ratio after 1973, but the ratio of primary energy/GDP also declined by 1.2 percent per year, suggesting that real reductions in the overall energy intensity of the economy may have occurred. But if the oil sector — which has a very low final energy/output ratio — is excluded from the GDP, the energy/GDP ratio of the Norwegian economy falls only slightly in the 1970s and 1980s. These ratios fell more markedly in most other countries, both before 1973 and more recently, as the energy efficiencies of many activities increased. At the aggregate level Norway exhibits less evidence of increased energy efficiency than do other countries.

To facilitate comparisons with other nations, Fig. 3.4 also presents Norway's primary energy/GDP ratio with electricity weighted by a thermal input factor of 2.89 units per unit of electricity produced, a ratio close to the average for all OECD countries. The overall trends in Norway are the same no matter which conversion convention is used, but the overall ratio of primary energy use to GDP is significantly higher using the OECD convention than using the Norwegian convention. *What we will show in the following sections, however, is that all of these aggregate ratios hide the dynamic transformation of the structure and intensity of energy use in Norway.* In order to see how energy and economic activity interact in Norway, we therefore turn to detailed analyses of each major end-use sector, focusing on sectors that account for about 90 percent of final demand.*

* Data limitations forced us to omit analysis of the agriculture, fishing, construction, utilities, and mining sectors, which together account for 11 percent of final demand; and the own-use of the energy sector, which accounts for 10 percent of primary energy use.

FIGURE 3.1
PRIMARY ENERGY IN NORWAY
FUEL INPUTS

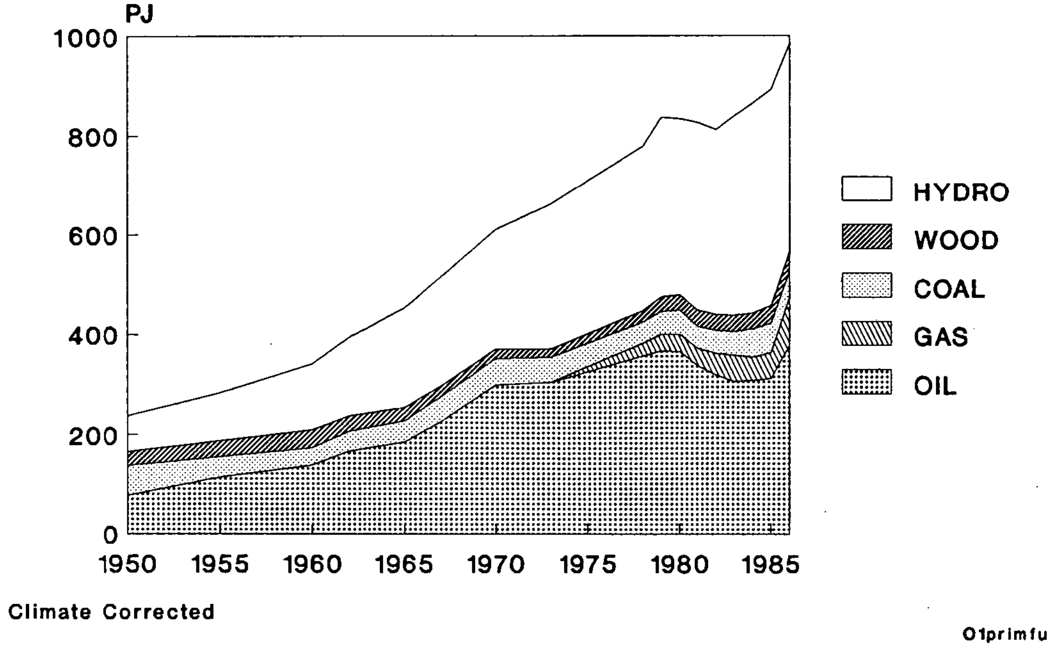


FIGURE 3.2
NORWEGIAN PRIMARY ENERGY USE

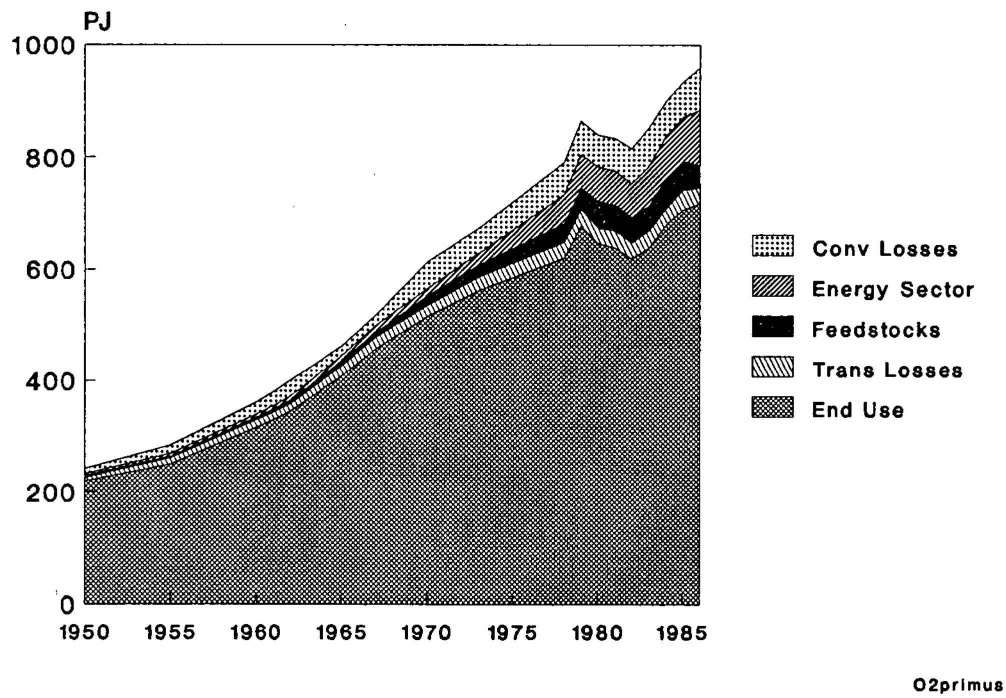
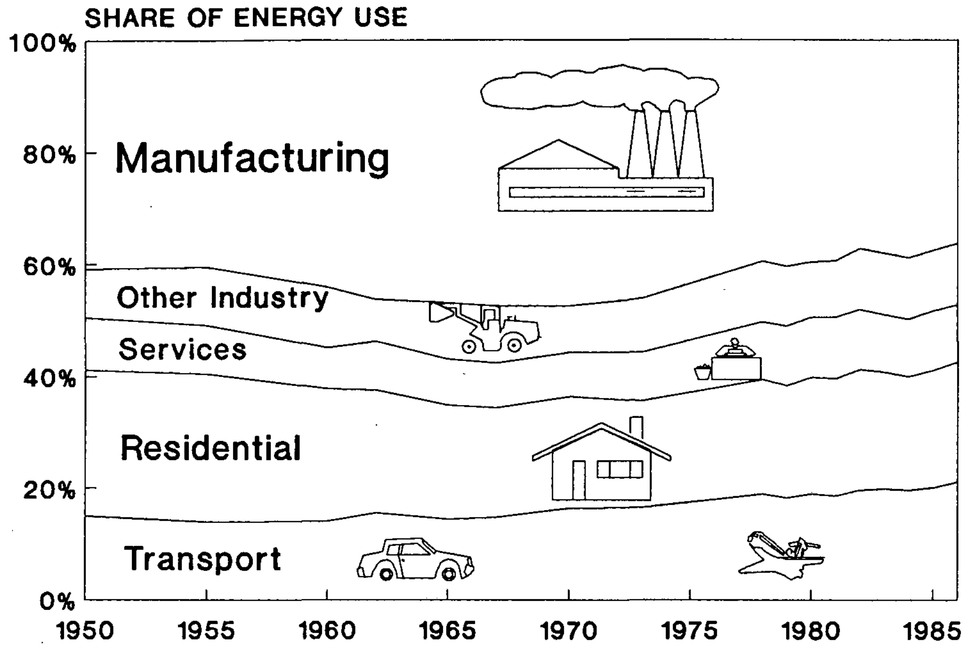
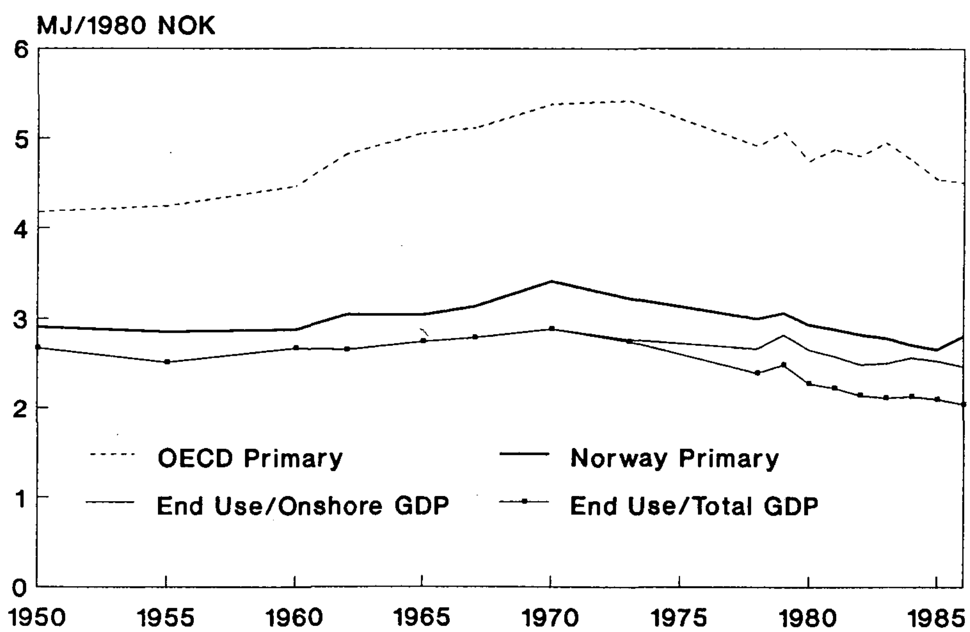


FIGURE 3.3
NORWAY: SECTORAL ENERGY USE BREAKDOWN



03endsec

FIGURE 3.4
NORWAY: ENERGY/GDP RATIOS



Uncorrected for Climate Variations

o4egdp1

4 RESIDENTIAL SECTOR

Because of Norway's cold climate (over 4000 degree-days C),* energy use for heating homes has always played an important role in the country's energy use patterns. Today, household energy use in Norway supports one of the highest indoor living standards in the world. Energy demand in the residential sector in Norway has been marked by three outstanding characteristics: (1) Steady growth through the mid 1980s in the apparent levels of comfort and convenience, as measured by heated space per capita and ownership of major appliances; (2) steady growth in energy demand per home for most uses; and (3) a high reliance on electricity to provide energy services provided by gas or oil in most other countries. This section analyzes these characteristics and what they imply for future fuel and electricity conservation.

4.1 Activity, Structure, and Fuel Use

Population and total floor area represent the two most important indicators of activity in the residential sector. Energy demand for heating is driven by floor area, while demands for other end uses tend to follow the number of people in a home and the saturation of equipment for the other end uses.[7] Figure 4.1 displays historical trends in household size and floor area. The size of homes has increased continually while average family size has decreased at an even greater rate. Together, these changes led to a near *doubling* in space per person. During this time, ownership of appliances increased from low levels, which also had an important affect on electricity use. Finally, the share of farmhouses and semidetached homes declined, while that of detached single-family dwellings increased. The share of apartments remained below 20 percent between 1960 and 1980. The decline in the role of semidetached housing increased slightly the ratio of surface to floor area in the stock, increasing slightly the heat losses per square meter of floor area.

Total household energy use increased steadily from 1950 to 1987 (Fig. 4.2).[8] In the 1950s and 1960s there was continual substitution from solids (wood, coal, coke, and peat) to oil and electricity; in the 1970s and 1980s electricity and wood were substituted for oil. The current fuel mix includes the highest share of electricity — over 65 percent — of any OECD country with significant heating requirements.

Space heating accounts for about 60 percent of the energy delivered to Norwegian homes. Figure 4.3 shows the space heating fuels in use between 1960 and 1985.[9] The combined use of wood, coal, or coke and electricity that was popular in the 1950s yielded to heating oil and kerosene in the 1960s and early 1970s. This pattern was reversed after 1973, when oil lost its share of residential heating to both electricity and wood. Electricity is now the principal heating source and is also used in most homes that rely on wood or kerosene to provide supplemental heating. Central heating, in which heat is carried by hot water or air circulating from a boiler using oil or even electricity, never reached more than 13 percent of homes (25 percent of apartments, but fewer single-family dwellings). This is because cheap electricity permits the installation of high efficiency room-by-room heating systems at low capital cost. The use of electricity in most rooms of Norwegian households today provides comfort levels as high as those obtainable with central heating systems for as many as 90 percent of all homes.**

* This is based on the SSB/ANNA average for 9 months at base 17 C, adjusted to the base 18 C. By comparison, Canada has 4685 degree-days, Denmark has 3316 degree-days, West Germany 3163 degree-days, Sweden 4017 degree-days, and the United States 2699 degree-days according to this scheme.

** In 1983, only 10 percent of all homes had neither central heating nor electricity as either the main source or a secondary heating source. These homes used either solid fuels or kerosene or some combination of the two for space heating. In 1970, about 15 percent of all homes fell into this class.

There are virtually no data on the choice of fuels used for cooking or heating water. Based on discussions with NBI, Energidata, and other experts, we estimate that electricity is used to heat water in about 95 percent of all homes, up from 85 percent in 1970 and 60 percent in 1960. The share of homes using oil to provide hot water fell from 10 to 5 percent between 1973 and 1986 as many homes switched to electric water heaters, using oil only to provide space heat. Virtually all homes used electric ovens and ranges in 1986, but some 5 to 10 percent probably used wood as late as 1970 (not all households reported owning "elkomfyr" as late as 1982), and about 1 percent used city gas in the 1960s and early 1970s.

Electricity also powers most major household appliances. Although many of these were introduced only in the 1960s in Norway, they have become very popular and have grown in size and sophistication. Fig. 4.4 shows the trends in major appliance ownership between 1960 and the present.* According to Electrolux (L. Sunden, private communication), Norway and Sweden have the highest appliance ownership levels and quality standards in Europe. Thus while the indoor comfort and convenience standard in Norway was low compared to many countries in 1970, Norway now ranks among the most advanced countries in the world.

4.2 Intensity and Efficiency

Based on assumptions and estimates of ownership levels and unit energy consumption by fuel for each type of equipment, we divided up the use of electricity, oil, and wood by end use for purposes other than space heating. While the energy intensities of water heaters and appliances in Norwegian households are uncertain, we used published estimates[10] to calculate the energy use per household for water heating, cooking, lighting, and appliances.** For lighting, we estimated that electricity use rose from 1000 kWh per dwelling in the 1970s to 1600 kWh per dwelling by 1986.***

Utilization efficiencies vary considerably from one fuel to another. To account for these differences, we assumed, based on observations from Norway and a number of other countries, that approximately 55 percent of the thermal energy in wood or coal and 66 percent of the energy in oil and gas is actually converted to useful heat for space and water heating. Electricity and district heating are counted as 100 percent efficient.**** Using these assumed conversion efficiencies, we calculated the *useful* energy

* The sources of the data are the same as those for heating systems. 1960 data were extrapolated based on conversations with Philips. The data represent ownership. As many as 95% of all households have "access" to washing machines, according to Boforholdundersoekelse 1981 (extrapolated to 1986), but electricity to run those machines in washrooms is *not* counted in residential, but rather as part of "eiendomsdrift".

** These estimates differentiate between electricity and oil intensity for water heating in single-family and multi-family dwellings. A single estimate was used for electricity use and wood use intensity for cooking stoves and appliances. Intensities were also assumed for lighting and each major electric appliance. These intensities all varied over time.

*** The lighting electricity estimates were based on information supplied by Philips and by A. Ljones of Energidata based on sales of light bulbs. The implied lighting levels are much higher than those of any other country including Sweden, which has a similar annual cycle of natural light.

**** Others in Norway put the efficiency of wood use between 40 and 60 percent, and that for oil between 60 and 70 percent. We chose the figures above as compromises, and for compatibility with our calculations for other OECD countries. Note that electricity used for lighting and appliances is assumed to have a 100 percent conversion efficiency for purposes of analysis. While the actual efficiencies of such devices are substantially lower, at least some of the waste heat produced serves to provide an indirect source of space heat. In addition, we have taken manufacturers' estimates of the energy used to heat water in dishwashers and washing machines and counted this energy towards water heating. While these assumptions presumably introduce errors into the analysis, we believe that the magnitude of such errors is small. In fact, the conversion efficiencies for providing space heat and hot water probably increased during the study period. This increase means that the impact of combustion losses for each fuel was less in 1986 than previously, or, alternatively, that the increase in useful energy per dwelling was even more rapid than shown. Thus our figure gives the lower limit to the increase in useful energy provided to homes in Norway over period.

employed in each end use. Figure 4.5 presents a first approximation of the evolution of useful energy and on-site conversion losses per household over time.

Our analysis indicated that useful energy per dwelling grew more rapidly than delivered energy per dwelling. This is because the steady substitution of electricity for fuels coupled with the near perfect end-use efficiency of electricity drove down the share of delivered energy lost as waste heat. Note that both measures indicate steady growth in energy use per household over most of the period of analysis. In contrast, the measures fell sharply following the oil shocks of 1973 and 1979 in almost every other OECD country. Why was Norway different? To answer this question, we look further into the changes that have occurred since 1973.

4.3 Changes between 1973 and 1986

The most important change in Norwegian residential energy use that has developed since 1973 has been the increased reliance on electricity, which took over at least half of the space and water heating market formerly held by oil and kerosene, today providing these services to at least 80 percent of new homes. Norwegian households turned to fuel substitution to hold down energy costs as oil prices exploded during the energy shock. A second important development was the saturation of the ownership of cooking and water heating equipment and of household heating standards. Finally, the ownership of electric appliances grew significantly. What effect did these changes have on total household energy use and intensity?

The intensity of space heating increased steadily throughout the period of analysis with no permanent pause after 1973 or 1979. Thermal transmission requirements for new homes were tightened in 1979 and again in 1987. These improvements reduced heating requirements in new homes. But household energy use is still determined largely by the characteristics of houses and appliances already in place by 1973. Together, such households comprised more than 80 percent of the housing stock in 1986. While there is ample evidence that the thermal performance of homes increased during this period,[11] much of this improvement was used to obtain higher comfort standards rather than to reduce the level of energy use, particularly in older homes that were previously poorly heated, with some rooms not heated at all.

The estimated energy intensities of all other end uses except cooking grew steadily. By 1986, however, most end uses were approaching saturation, with significant growth occurring only in ownership of and energy use for dryers and dishwashers. Some of this additional energy use served indirectly to heat homes.

Figure 4.6 traces the growth in population, total dwellings, total dwelling area, useful energy for heating, and useful energy for other purposes since 1973. Each parameter is indexed to its 1973 value. The growth in total area was the most important factor driving the growth in useful space heat; the difference between the growth in total area and in space heat represents the increase in heating intensity. It is clear from this diagram that population growth is no longer a driving factor. But the growth in the number of dwellings, and the more rapid increase in total area (i.e., the increase in area per dwelling) continue to propel space heating energy use upwards. Similarly, the use of energy for all other purposes has also grown faster than floor area (or population). In other words, the energy intensity of household energy uses grew steadily after 1973, and before that time as well.

Figure 4.7 presents indicators of end-use energy intensity. The space heating intensity indicator (useful energy/area) grew by about 33 percent over the study period. While comfort standards (average indoor temperature and number of rooms heated) rose considerably during the same period,[12] reductions in heat losses in homes restrained the growth in the intensity indicator. Indicators of water heating and appliance energy-use intensity (both measured in useful energy/capita) have grown much more. But these indicators appear to be approaching saturation too. The indicator of cooking has declined, principally because of reduced cooking in the home.

We conclude that the major uses of energy in Norwegian households are approaching saturation. Increases in efficiency in the future could reduce these energy intensities, possibly enough to reduce even total energy use in the residential sector. National surveys[13] indicate that Norwegians believe they have achieved high comfort standards as indoor temperatures range from 19 to 21 C in most rooms. The ownership of major appliances except dryers and dish-washers is close to saturation.* Energy use per household is the highest ever, as is the potential for energy-saving investments. This means that decision makers in Norwegian households should be more interested than ever in improving the efficiency of energy use.

4.4 International Comparison

The behavior of household energy use in Norway is different from that of most other OECD countries. Steady growth occurred in most of the Norwegian intensity indicators throughout the period of analysis, driven by increases in comfort levels, water heating, and appliance ownership. These increases, which reflect real increases in comfort, were driven in part by the boom in oil revenues. In other countries, the same indicators grew more slowly in the 1970s and 1980s: either the growth in energy intensive household activities had already slowed by the 1970s, or efficiency improvements offset the impact of increases in the level of delivered energy services. We explore reasons for these differences in this section.

Norwegians enjoy about 40 square meters of living space** per person. While this is slightly below the level of 45 sq.m. in Denmark and Sweden and over 50 sq.m. in the U.S., it is well ahead of the level of floor area per capita in Central Europe and Japan. Central heating penetration is low in Norway in the formal sense, but if we count decentralized electric heating systems as central heating, we find that only about 15 percent of Norwegian homes have neither electric radiators in most rooms nor actual central heating. That is, this small share of homes has essentially only manually operated sources of room heat. This means that heating standards in Norway are now on par with those in Denmark, Sweden, the United States, and Canada and are thus amongst the highest in the world. As we noted above, the same is true for appliance ownership. This parity, however, was achieved only after 1979, as the growth in oil

* Electricity use for the automation of dishwashing is small compared to the electricity used to heat the water, so increased use of dishwashers will not significantly increase household electricity use unless automation leads to increased hot water requirements. Electricity use for drying represents a significant potential increase in electricity use, but condensing dryers could reduce net heat utilization substantially. Freezers could grow in size, and combination refrigerator/freezers will likely increase their market share at the expense of refrigerators. These changes represent the major growth factors in household electricity use for appliances.

** "Boligareal". We have taken the revised figures presented by Energidata (which take into account more than just "nettogulvareal"). Energidata estimated the average area per home to be 100 sq.m. in 1985. Previous SSB figures showed only 87 sq.m. We applied the difference between these figures and the older figures to historical series of floor area, in order to make the values for Norway comparable with the gross area figures that represent other countries.

revenues led to the increased per capita income. The rapid catch-up process was one reason why no lasting drop occurred in household energy intensities after 1973 in Norway.

Our analysis indicates that space heating intensity in Norway grew from a low level in the 1960s to rough parity with Sweden and Denmark at present. Water heating intensity appears to be close to that in Sweden or the U.S. for homes with electric water heaters, and comparable to that in Sweden, Denmark, or the U.S. for those homes heating with oil. Cooking energy use, which is now dominated almost entirely by electricity (vs. 95 percent in Sweden and less in every other country) has fallen as in every other country, due to reduced family size, the preparation of simpler meals, and the reduction in the proportion of meals eaten at home.

Figure 4.8 shows electricity use per dwelling for electric appliances in the Scandinavian countries. Electricity use is even with that of Sweden and close to the level in the U.S. Danish homes have somewhat lower appliance electricity use, and other European countries trail even farther "behind" Norway. Differences in ownership levels and size account for the higher consumption in Norway. Unit consumption for major appliances is similar to that in Sweden because Norwegians use the same appliances in many of the same ways as the Swedes do. But unit consumption for lighting is significantly higher than in Denmark or Sweden (Fig. 4.9).

All in all, Norwegian energy use per household is about average for the OECD, but electricity use per household is much higher than in other nations. As Fig. 4.10 shows, the high penetration of electric space and water heating, encouraged by low electricity prices, is the main reason for the high level of electricity use in Norwegian households.

Certain international trends in the improvement of household energy use-efficiency are reflected in Norway as well. Figure 4.11 shows the maximum thermal transmission values permitted for walls and ceilings in new homes in four Nordic countries, based on the two most recent building codes. These values illustrate the changes in requirements and practices over time. While the Norwegian values are low, they are not as low as those in Sweden. The low Swedish values are motivated by concerns over higher electricity prices and other problems that might arise when nuclear power is phased out.[14] Nevertheless, the Swedish values represent reasonable targets for Norway, given the many similarities in standards and construction practices.

International trends, driven in part by policies in West Germany, have forced appliance manufacturers to improve the efficiency of most appliances. As a result, new appliances in Norway are less electricity-intensive than older ones. The orderly replacement of older ones by newer ones will reduce electricity needs for a given appliance, everything else being equal.[15]

The increases in Norwegian household energy use are not unique. Schipper *et al.*[16] found that household energy trends in Japan and Great Britain followed a similar path. Rising standards of indoor comfort were not held back by higher fuel prices, and substitution provided an alternative to cutting back during short periods of very high prices. And the low price of electricity in Norway, like the low price of natural gas offered to homes in Britain and Holland, has encouraged increased heating levels. Subsequent increases in the price of gas in Holland provoked significant and steady decreases in the intensity of use for space heating there. Perhaps a similar development will occur in Norway.

4.5 Conclusions

The evolution of energy demand in Norwegian households has been marked by continual growth in energy use and energy services, with no permanent interruptions arising from the two oil shocks. Fuel substitution, rather than conservation, constituted the most important change in household energy use. With this steady growth in energy demand, Norwegian households reached a high level of indoor comfort by the early 1980s. The efficiency of space heating increased continually, but much of this improvement was translated into greater comfort — i.e., more heat in the home for a given consumption of fuel and electricity — rather than reductions in energy use per home. And while international market trends have forced electric appliance efficiency to increase during the past 15 years (spilling over to Norway), there is little evidence that energy efficiency has played an important role in the choice of water heating and cooking equipment or electric appliances. In other words, the growth in comfort and the acquisition of appliances were so important to consumers in the 1970s and early 1980s that they paid little attention to opportunities to raise the efficiency of energy utilization. The impact of fuel and electricity conservation programs (ENØK in Norwegian) so far has been to reduce growth in energy demand per home or per capita, but not to reduce aggregate demand per household, as happened in the U.S., France, Denmark, and Sweden. Thus we find no great wave of conservation similar to that which occurred in homes in most other countries.

The future may be different. Attaining increases in comfort levels no longer appears to pose a barrier to increased energy efficiency in the residential sector in Norway. Higher energy use for all purposes translated into greater expenditures for energy, which justifies greater investments in better building shells and windows, heat recovery, improved water heating insulation, and more efficient electric appliances. Norwegian building owners today are more likely, therefore, to respond to energy price increases by adopting efficiency measures than they were in the past.

Since the efficiency of new appliances sold in Norway has increased steadily over the past 10 years, new appliances use less electricity than existing ones. Replacement alone will reduce electricity needs for appliances, or at least restrain the growth caused by slow increases in ownership. Lighting represents a significant potential for electricity savings in Norwegian households. While some of the heat from this use indirectly provides useful space heat, much goes wasted.* We believe that a campaign to encourage the use of high-efficiency flourescent light bulbs and moderate lighting levels could save at least 50 percent of this electricity. Higher electricity prices would heighten interest in such a conservation strategy.

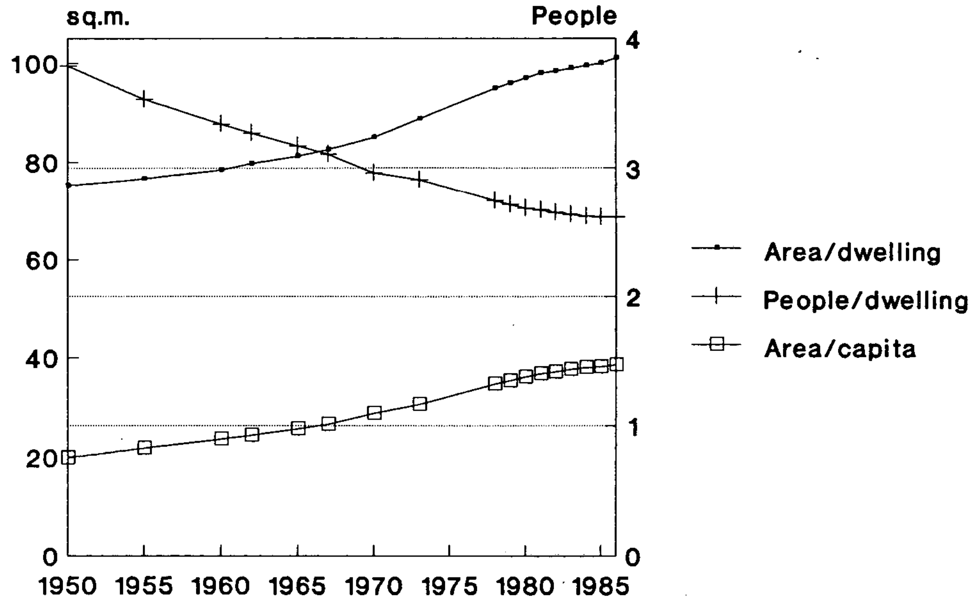
Improved efficiency of household energy use in Norway will not come automatically with higher energy prices. Many factors documented elsewhere[17] hinder orderly investment in more efficient building shells and equipment. The first step is for the government to carry out a detailed assessment of household energy use and equipment. This survey would determine actual energy utilization patterns for different end uses in the residential sector. The U.S. Residential Energy Consumption Survey[18] could serve as a useful model survey. The survey should cover ownership of equipment, use of equipment, hours the home is occupied, and so forth. Such a survey will allow better determination of the ENØK potential than is possible with today's limited knowledge of the sector. From this survey, the government (and an increasing number of concerned electric utilities) could determine the kinds of homes where efficiency

* While some portion of the waste heat from lighting should be credited to the energy and economic balance of the house, lightbulbs are an expensive form of heating panels. Also, as the heat losses of a home are reduced, the heating season becomes shorter, and the value of the heat given off by lights, water heaters, and other appliances diminishes.

improvements could be profitably undertaken.

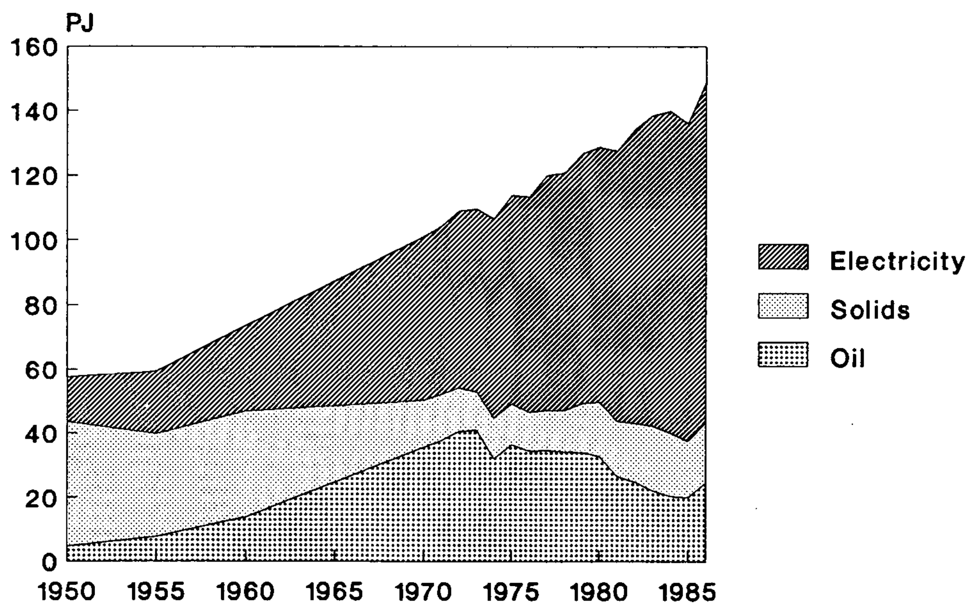
Other steps might be taken to accelerate efficiency improvements. The government should consider minimum efficiency standards for appliances, including cooking and water-heating equipment. The heat transmission values in the building code could be further reduced to the levels now in place in Sweden. National or local authorities could reward purchase of particularly efficient appliances or light-bulbs through rebate schemes such as those underway in the United States. An energy certificate that reveals the thermal performance properties of all homes for sale could be made a requirement of sale, as is the case in Denmark.[19]

FIGURE 4.1
NORWEGIAN HOUSING STANDARDS
1950 - 1986



r1house

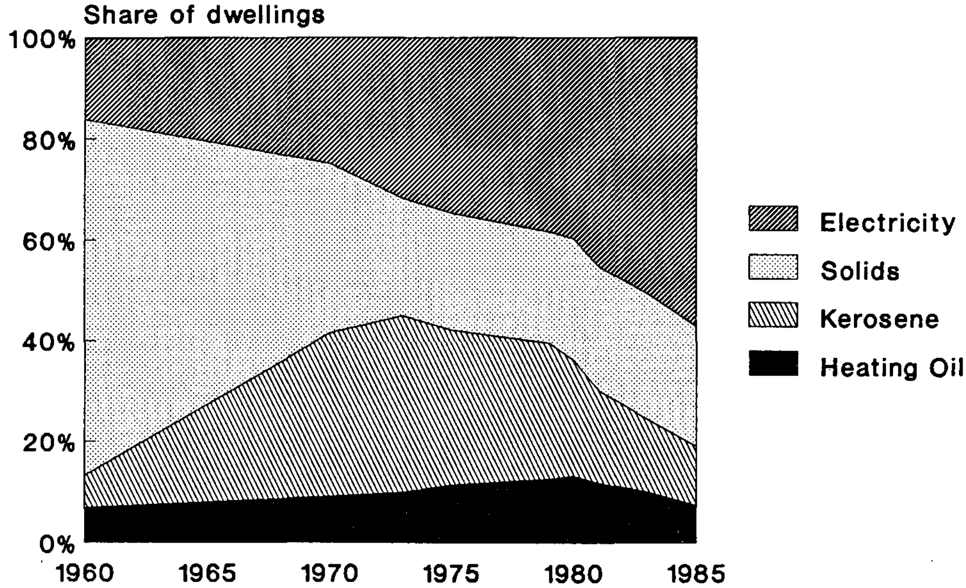
FIGURE 4.2
HOUSEHOLD FUEL USE IN NORWAY



Climate corrected; city gas and district heat (not shown) less than 1 PJ/year

r2hhfuel

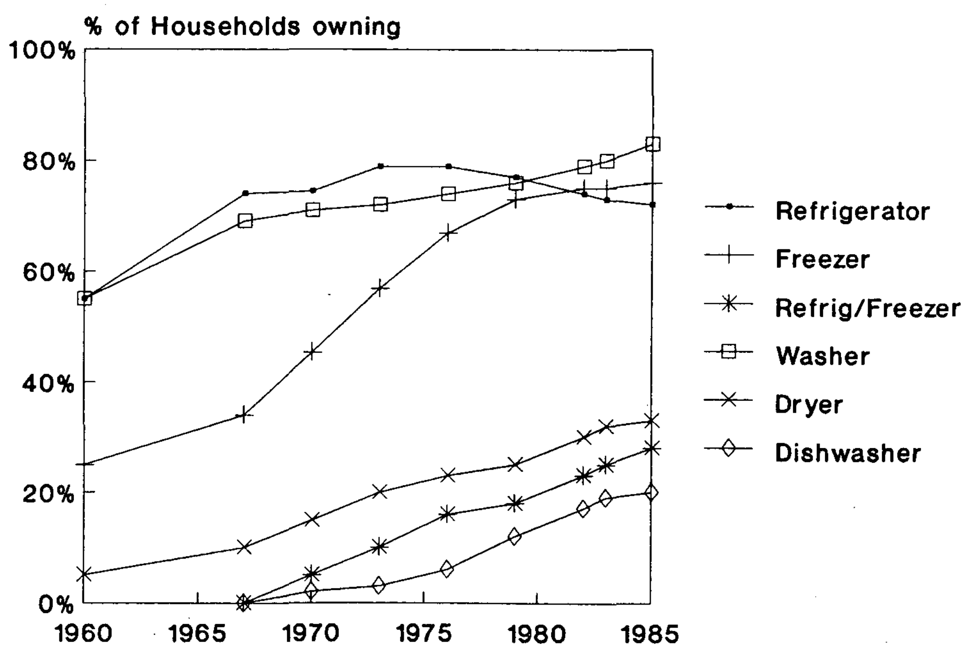
FIGURE 4.3
PRINCIPAL HOME HEATING FUELS IN NORWAY



Most wood and kerosene heated homes also use significant amounts of electricity.

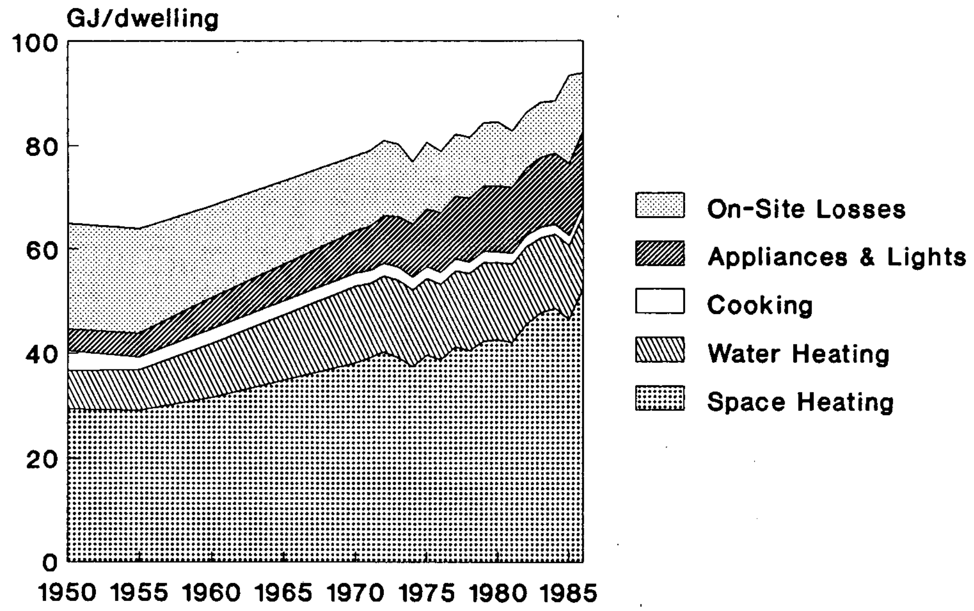
r3heatst

FIGURE 4.4
NORWEGIAN APPLIANCE OWNERSHIP



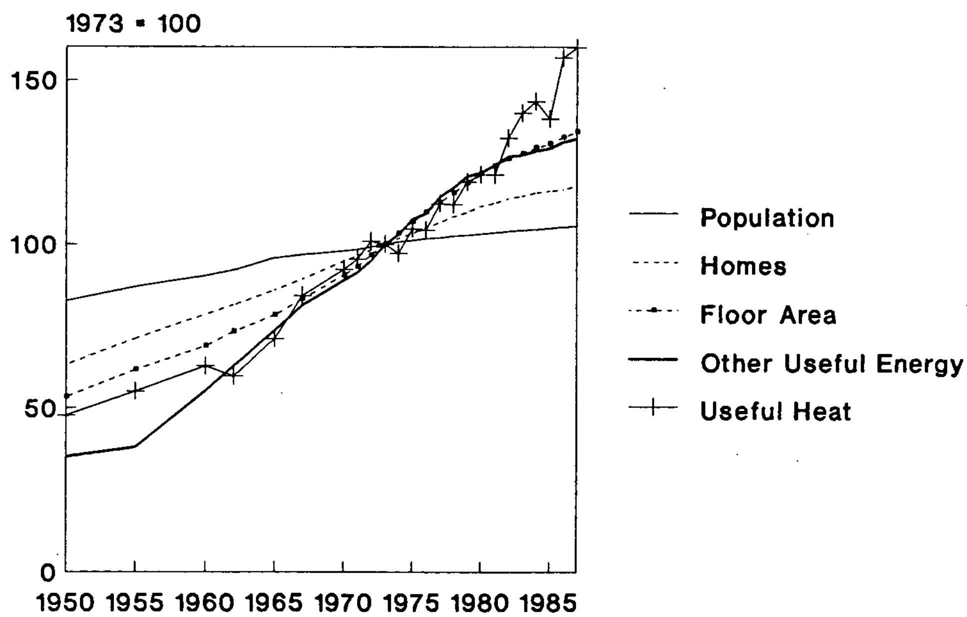
r4hheqpt

FIGURE 4.5
NORWAY: DELIVERED HOUSEHOLD
ENERGY BY PURPOSE



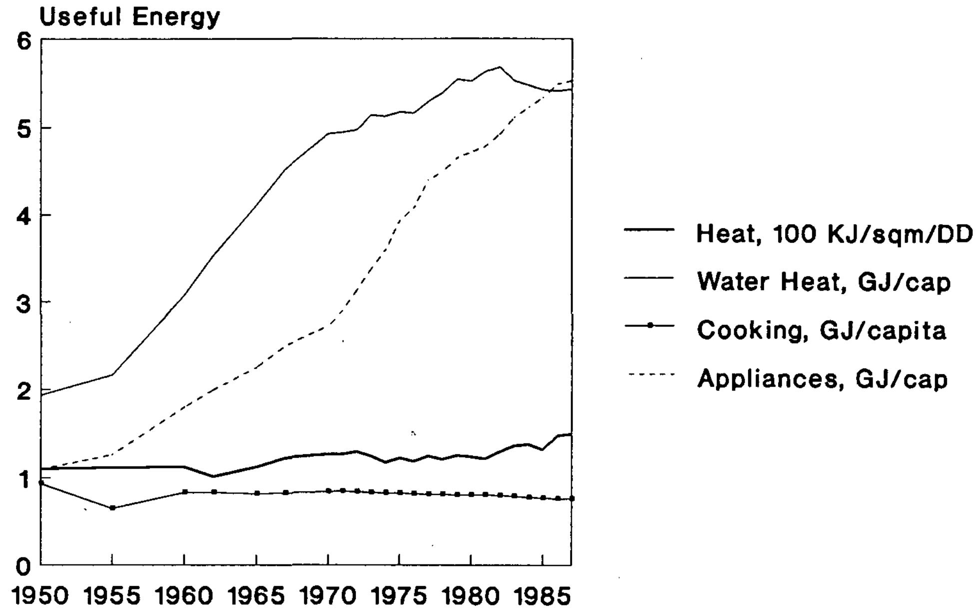
r5nrgydw

FIGURE 4.6
HOUSEHOLD ENERGY USE IN NORWAY
PRINCIPAL INDICATORS



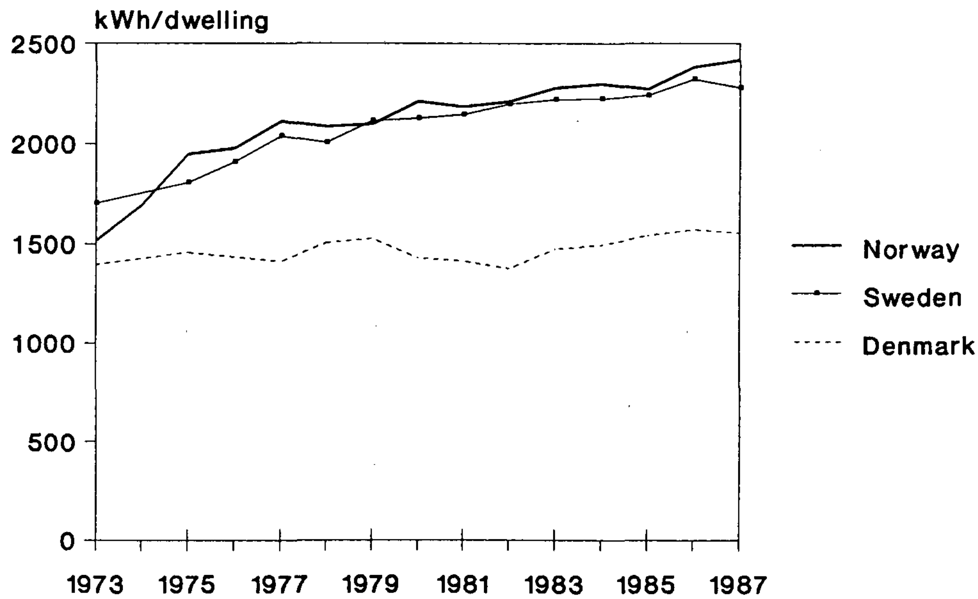
r6heat73

FIGURE 4.7
HOUSEHOLD ENERGY USE IN NORWAY
KEY INTENSITY INDICATORS



r7hhinds

FIGURE 4.8
APPLIANCE ELECTRICITY USE
SCANDINAVIA



Excludes hot water for washers

r8appl

FIGURE 4.9
LIGHTING ELECTRICITY USE IN SCANDINAVIA

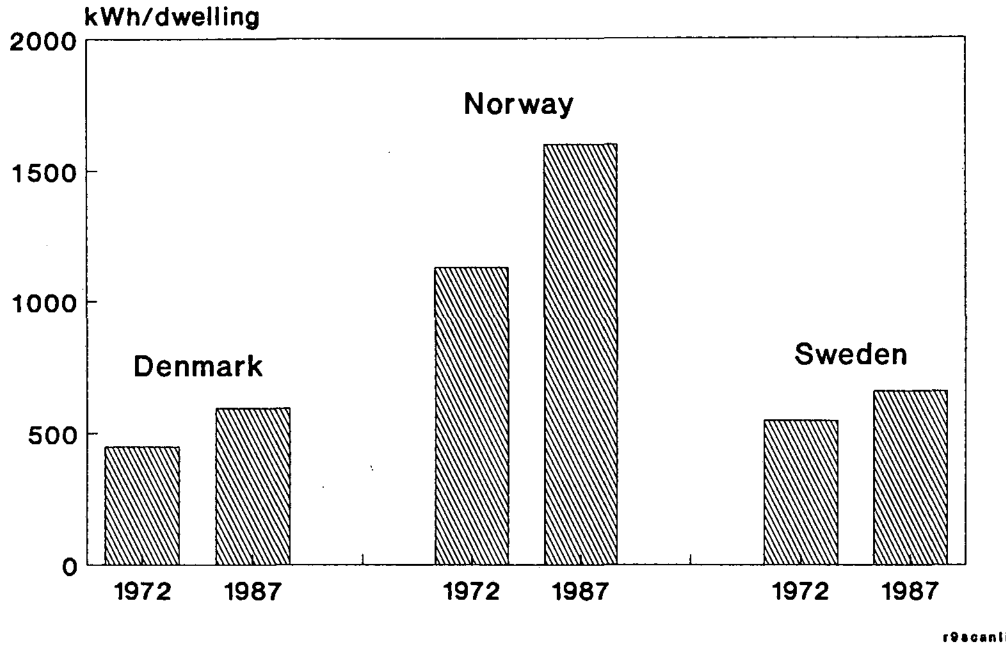
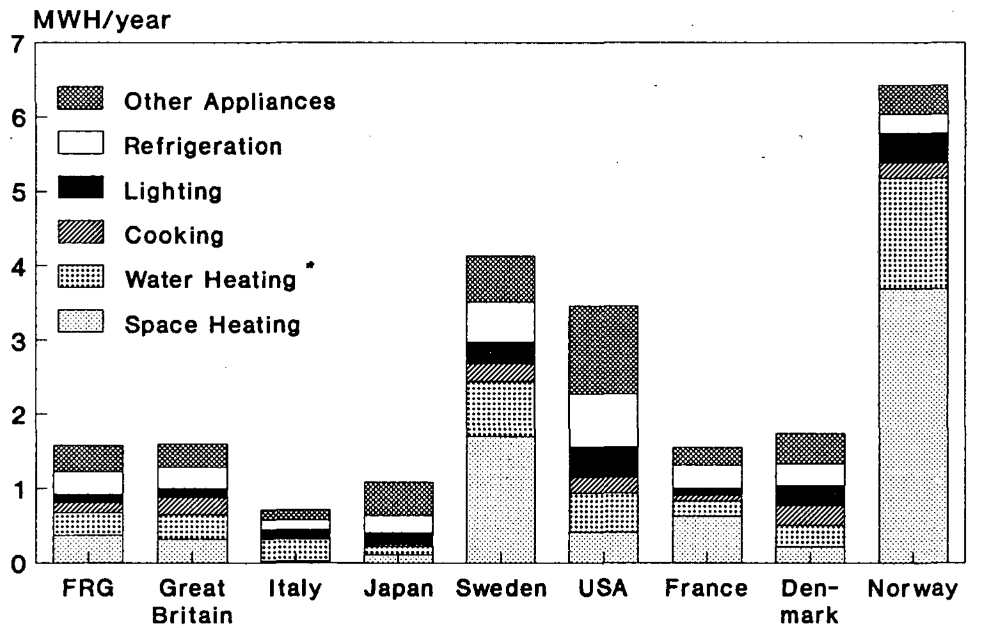


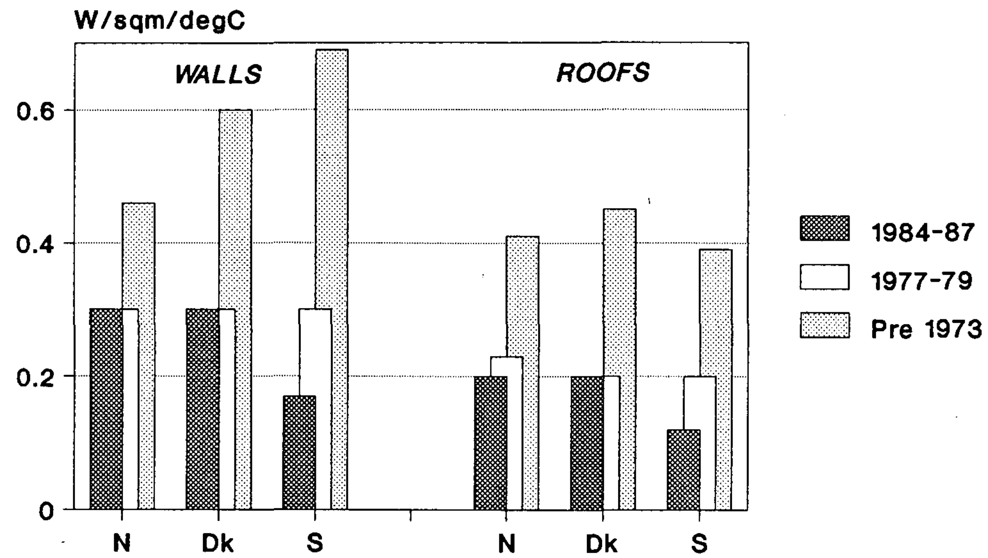
FIGURE 4.10
ELECTRICITY USE PER CAPITA IN 1986



*Including hot water for washers

r10elcap

FIGURE 4.11
BUILDING CODES IN THE NORDIC COUNTRIES
MAXIMUM HEAT TRANSMISSION VALUES



1987 Norwegian wall value is for
entire wall, including windows

r11codes

5 SERVICE SECTOR

The energy use and physical activity indicators of the Norwegian service sector were poorly documented until quite recently.* Data we used include service sector value added; estimates of the floor area of service buildings between 1965 and 1973 made by Sagen;[20] estimates of heated floor area by Energidata for 1975, 1980, and 1985; and the single year energy use surveys of Foyn for 1977[21] and Sagen for 1984 and 1985.[22] The service sector has grown more rapidly than most other sectors in Norway as in other countries and presents important opportunities to conserve oil and electricity. In spite of the data difficulties, then, we present a brief analysis of this sector.

5.1 Activity, Structure, and Fuel Use

Services value added, which is one measure of sectoral activity, accounts for roughly 50 percent of Norwegian GDP. This measure has grown at a steady rate of 3.3 percent per year since 1965. Service sector floor area, as estimated by Sagen, grew less rapidly than value added at an average annual rate of 2.4 percent over the same period.** In 1985, there were approximately 64.3 million square meters of net service floor area, as estimated by Sagen. By this measure there were about 16.1 square meters of floor space per capita in 1985, up from an estimated 12 square meters in 1973. Sagen suggests that some 10 percent of this total was unheated.

During this time, climate-corrected sectoral energy use grew from 31.7 to 72.7 PJ, corresponding to growth rates of 5.4 and 3.1 percent per year for the periods 1965-1973 and 1973-1986, respectively (Fig. 5.1). Significantly, the fuel share for electricity, which lay close to 41 percent in 1965, had risen to 42 percent by 1973 and 74 percent by 1986. Much of this electricity was used to heat buildings.

The heating structure of the service sector is similar to that of the residential sector. Twenty eight percent of all floor area is heated using only electricity while 11 percent is heated by oil alone. Twenty percent is heated using a combination of direct electricity and central oil heat; 13 percent by combined oil/electric boilers; 9 percent by other combinations or by district heat; and 17 percent had three systems, almost all including electricity. All in all, 95 percent of all service floor area is heated at least partially by electricity vs. 55 percent for oil. While 64 percent of all users consider electricity their most important source of space heat, only 30 percent identify oil as their most important heating fuel. In short, electricity dominates the heating of service buildings in Norway.

* The service sector includes International Standard Industrial Classification (ISIC) sectors 6 through 9, which include mainly commercial and government buildings. Energy use data for the sector are often lumped in with the residential and agricultural sectors, while some portion of the electricity use of the construction and utility sectors is apparently included in the service sector energy balances before 1976. As a result, our analysis will be based mainly on the period after 1965, and in particular after 1976.

** While accurate floor area data exist only for 1977 and 1985, it appears that the ratio of value added to floor area varies substantially amongst the various subsectors of the service sector. This variation is not surprising since some service activities such as education require large areas but generate relatively little value added, while others such as business and public administration generate substantial value added while using only limited floor area. Our analysis indicated that there were no major changes in the structure of the service sector over the period of analysis. Note also that some service related activities such as transportation services and real estate utilize energy that is attributed in part to other sectors (transportation and residential, respectively). Thus service sector value added is not in general an adequate indicator of sectoral activity for purposes of energy analyses, and we use physical floor area as our principal activity indicator.

While an exact percentage breakdown is not available for Norway, service sector energy use is dominated by space and hot water heating, air conditioning, lighting, and miscellaneous equipment. We can estimate the approximate disposition of this energy utilization by comparing use in buildings that do or do not use a given source for heating.* When this comparison is made (see below), we find approximately 47 PJ used for space heating (about 40 PJ useful energy), 7 PJ for water heating (about 5 PJ useful energy), and 29 PJ for cooking and non-substitutable uses of electricity.

It is also possible to disaggregate energy demand by building type. While Sagen and Energiregnskap do not totally agree for the year of Sagen's study (1984) on the disaggregation by building/service type, the totals for all of services are very close. Retail stores use more than 25 percent of delivered energy, followed by schools (19 percent), health services (18 percent), public administration (9 percent), offices (6 percent)**, and hotels and restaurants (5 percent).

5.2 Intensity and Efficiency

Sagen gives detailed data on the energy intensities, measured in MJ/sq.m. of net floor area, of various subsectors of the service sector. With the exception of personal services (personlig tjenesteyting), his data show that total energy intensity — the sum of all energy used in all buildings of a given type divided by total net floor area in those buildings — lays between 750 and 1318 MJ/sq.m., depending on building type. Buildings with oil heat used about 730 MJ/sq.m. of oil and 574 MJ/sq.m. of electricity. Many buildings with oil-based heat also used some electricity for heating. Buildings using no electricity for *heating* used 414 MJ/sq.m. of electricity, which we assume was representative of the non-heating electricity intensity of all service-sector buildings. Buildings with electricity as the principal heating source on a room-by-room basis or in central boilers used between 924 and 975 MJ/sq.m., respectively. After subtracting off the 414 MJ/sq.m. for other purposes, we obtain the figures 510 and 561 MJ/sq.m. of electricity for heating.

Let us assume that this non-heating electricity intensity is constant across buildings regardless of their heating fuel. Comparison of electricity use in buildings *with* and *without* supplemental electric heating gives the approximate use of electricity for heating given above. If we compare the same figure with the intensity of electricity use in buildings with oil heat (about 570 MJ/sq.m.), we find from the difference that approximately 157 MJ/sq.m. of electricity is used to provide supplemental heat in buildings with oil heating systems. If heating oil is used at 66 percent system efficiency then the useful energy supplied as space heat in oil-heated buildings (including the electric supplemental heat) is approximately 640 MJ/sq.m. as compared to 570 to 675 MJ/sq.m. in electrically-heated buildings.

* We assume, based on our survey of practices in other countries, that 15 percent of oil and district heat is for water heating (mainly in schools, hotels, hospitals, and other residence-like buildings), that 5 percent of electricity is for water heating, 42 percent of electricity for space heating, and the remaining electricity for lights, machines, fans, cooking, etc.

** Bank og forsikring, foretningsmessig tjenesteyting.

5.3 Changes between 1973 and 1986

If we make a few assumptions about the proportion of each fuel's total service sector consumption used to provide space heat* we can estimate the development of energy intensity in this sector (Fig. 5.2).** In spite of the uncertainties in data, we see a clear pattern of saturation in space heating, with a slight drop after 1979. Non-heating electricity use also seems to be saturating.

The energy/value added indicator of energy intensity shows a somewhat different behavior, because service sector value added grew more rapidly than floor area. Figure 5.3 shows how service sector GDP, delivered energy intensity, and useful energy intensity changed over time. These measures also show that intensity increased until 1979. Both intensity measures stabilized or began slight declines following the 1979 price shock.

The limited disaggregation of data by Sagen and Energidata permit an interesting commentary on the progress in the energy efficiency of Norwegian service-sector buildings. Energy use for buildings built after 1981, according to Sagen, was 865 MJ/sq.m., while that in buildings built between 1955 and 1981 was 1040 MJ/sq.m. But 27 percent of energy used by the older buildings was oil, vs. only 7 percent in the newer buildings. Allowing for these differences, the newer buildings still use less net energy — 15 percent less per square meter — than the older ones. But Energidata disaggregates these figures by building types. They find that intensity in hospitals and hotels built after 1981 is lower than in older buildings, while intensity in stores, schools, and "other buildings" is *higher* in the new buildings. Thus the decrease in intensity in newer buildings may be due in part to the evolution of the mix of buildings erected after 1981 towards those that use less energy per unit area.

5.4 International Comparison

Using LBL data for a number of OECD countries,[23] Sagen points out that the total per capita service sector floor area in Norway is somewhat below the level of 18 sq.m. per capita observed in Denmark and Sweden and significantly lower than the United States level of 24 sq.m. per capita. Through rapid growth, per capita service floor area in Norway has caught up with the levels reached in many other countries.

The service sector in Norway is far more reliant on electricity than is the case in any other country. Even in Sweden, only 22 percent of all area is heated with electricity (8 percent fully, 14 percent partially);[24] instead, district heat is the heating source of choice amongst service sector consumers. In the United States, as much as 20 percent of service sector floor area is heated by electricity, mainly in areas with warm climates where the high capital costs of natural gas systems are not justified by the low estimated fuel savings. All factors considered, Norway has by far the most electricity-intensive service

* The assumed heating shares were 85 percent for oil, 100 percent for solids, 85 percent for district heating, and a rise for electricity from 25 percent in the 1960s to 42 percent in 1986. Our assumptions take into account results of Sagen's survey. If 58 percent of electricity goes for non-heating purposes in 1985/6, this works out to give approximately the same value per sq. meter as Sagen finds for electricity intensity in buildings with *no* electric heat.

** Sagen shows that the actual energy intensities of buildings depend on both their heating systems and their structure and function. Aggregate intensity therefore depends on the relative area found in different kinds of buildings. The shares of service sector value added by subsector, which are related to the distribution of floor area by function, have not varied significantly over the study period. We therefore assume that the effects of changes in the relative areas of buildings is small. In fact, the share of area built for retail trade reached nearly 50 percent of all service structures built between 1975 and 1985, although the share of trade in total building area in 1985 was only about 30 percent. But the energy intensity of trade, according to Sagen, was close to the average of all buildings in 1985.

sector of any country.

One consequence of this high reliance on electricity is that the service sector has a relatively low delivered energy intensity, particularly for heating, in comparison with other countries. The approximate intensities for useful heating are slightly higher than those in West Germany, Sweden, and Denmark. The drop in Denmark and West Germany after 1979 was more marked than the apparent drop in Sweden or Norway, where the importance of district heating and electricity blunted the overall impact of the oil price rise. During most of the 1970s until the mid 1980s, electricity was cheaper than oil in Norway as a source of space heat at an assumed system efficiency of 75 percent for oil units. Thus the service sector in Norway could escape the full impacts of the rise in oil prices through reliance on electricity for heating.

The apparent intensity of electricity use in the Norwegian service sector for purposes other than space heating is high by international standards. Total electricity use per square meter in Germany, Denmark, and France (countries with little electric heating) lay between 188 and 280 MJ/sq.m. in 1983. If lighting electricity use is as high in the service sector in Norway as it is in the residential sector, then lighting is an important reason for the high electricity intensity of this sector.

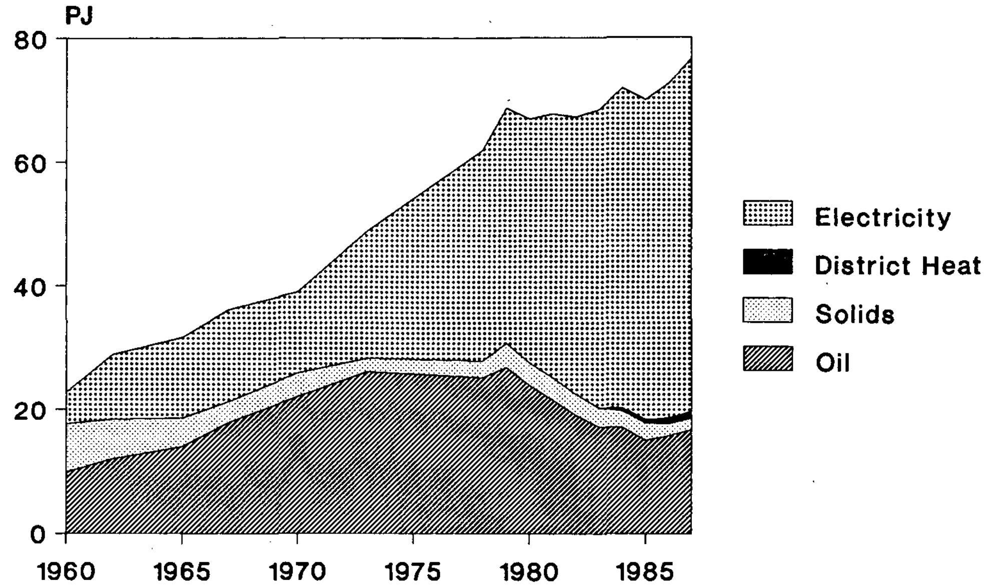
5.5 Conclusions

The broad trends in the evolution of energy use in the Norwegian service sector parallel those of the residential sector. A gradual flattening of energy intensity occurred as comfort levels reached saturation in the early 1980s. Expansion of built area in the sector drove energy use even further upwards, so that the service sector share of final demand grew to nearly 11 percent by 1986. Electricity dominates the fuel mix in this sector.

Comparison of the development of service sector energy and heating intensity with similar figures from other countries shows that the "conservation shock" which occurred in many nations failed to materialize in Norway, although the energy price increases of the early 1980s did stop the growth in the intensity of space heating. As with the residential sector, the evolution of the service sector suggests that there is a significant potential for reductions in space heating energy use as well as lighting and possibly other building related uses of energy. If the price of electricity increases, we expect building owners and users will show heightened interest in saving energy.

To better grasp the potential for energy savings, the survey **Energiundersøkelsen 1985**[25] should be reanalyzed for detail showing differences in heating and non-heating energy use by building type and vintage. Then the survey should be repeated to better establish the real pattern of fuel and electricity use by end-use and building type and to calibrate more carefully the potential for more efficient energy use. Attention should be paid to lighting and to energy use for information technologies. Ventilation is also an important area where efficiency improvements might be achieved.

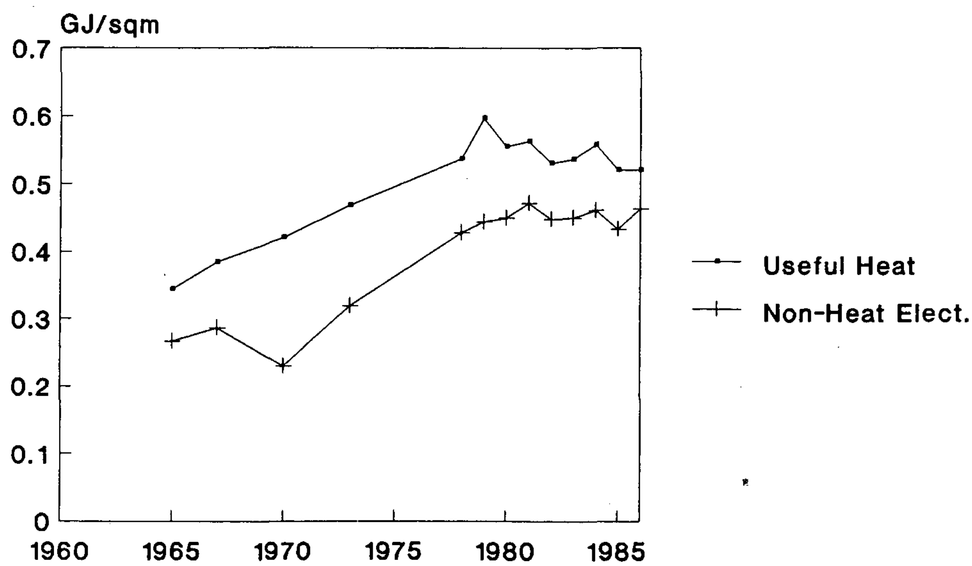
FIGURE 5.1
NORWEGIAN SERVICE SECTOR
CLIMATE CORRECTED ENERGY USE



Pre-1965 data very uncertain

s1serven

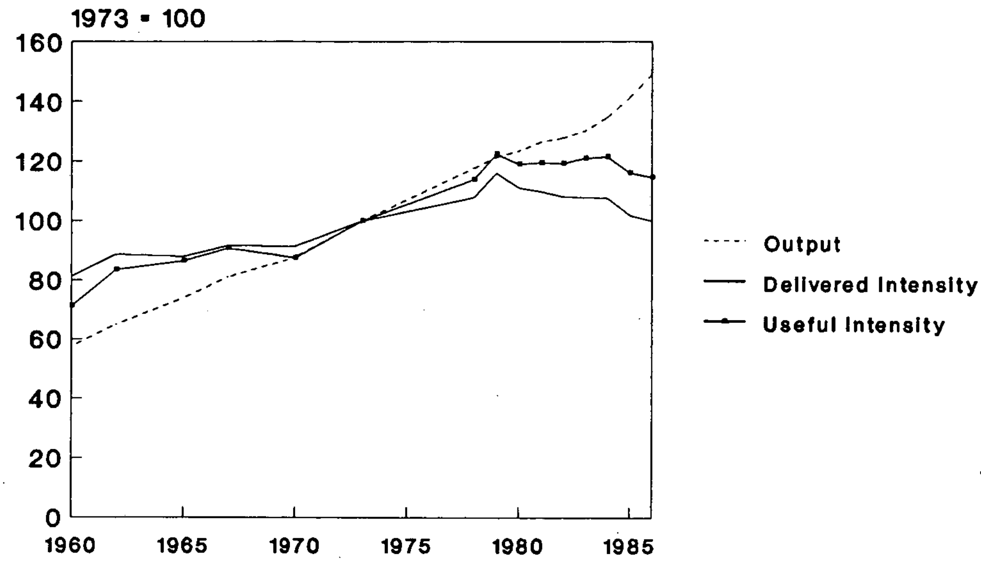
FIGURE 5.2
NORWEGIAN SERVICE SECTOR
USEFUL ENERGY INTENSITIES



Area estimated; 1970 energy uncertain;
Heat includes hot water and cooking

s2servin

FIGURE 5.3
NORWEGIAN SERVICE SECTOR
OUTPUT AND ENERGY INTENSITY



Output is service sector value added;
intensity is energy/value added

s3servtr

6 MANUFACTURING SECTOR

The Norwegian manufacturing sector is an important consumer of energy products that accounts for some 36 percent of final energy demand. The sector provides both substantial opportunities and significant challenges for fuel and electricity conservation. A relatively high proportion of Norwegian industrial activity consists of energy-intensive raw materials production, a substantial fraction of which is exported.

The efficiency improvements that have occurred in Norwegian manufacturing following the energy shocks of the 1970s have been less substantial than those observed in other nations. Instead, the ready availability of cheap electricity has fostered growth in electricity-intensive industries and lessened the impacts of rising fuel prices. Significant energy savings in the manufacturing sector will probably come only when the price of electricity charged to industrial users is raised to more accurately reflect the opportunity cost of producing additional electricity or selling electricity for export to other nations.

6.1 Activity, Structure, and Fuel Use

The output of the manufacturing sector in Norway as measured by real value added grew at an annual rate of 4.2 percent in the 1950s and 1960s as the economy matured and the infrastructure was put into place. But in the 1970s the domestic economy approached maturation and the boom in the oil sector drew capital away from industrial production. As a result, manufacturing value added stabilized at about 44 billion 1980 NOK, and the per capita production of principal raw materials leveled off (Fig. 6.1). The share of raw materials exported remained high, however, demonstrating that the output of energy-intensive industries* was decoupled to a large degree from domestic demand.[26]

The long-term trend in manufacturing energy use closely mirrors the path of manufacturing production (Fig. 6.2). Sectoral energy use rose at a rate of 4.6 percent between 1950 to 1973 before leveling off at about 260 PJ. The implication is that the aggregate energy intensity of Norwegian manufacturing remained more or less constant, suggesting that changes in output were the principal factor driving sectoral energy use over the period of analysis.

But while the analysis of aggregate manufacturing activity and energy intensity as the determinants of long-term energy use patterns provides some useful insights, this approach overlooks a central characteristic of manufacturing energy use. The manufacturing sector is composed of a variety of heterogeneous industries, the energy intensities of which vary substantially. As a consequence, the structure or output mix of the manufacturing sector may have significant impacts on energy use, and analyses of sectoral energy use should account for the interrelated but logically distinct impacts of aggregate sectoral output, industry structure, and the energy intensities of the component sectors.

* "Energy intensive industries" in this report include iron & steel (ISIC 371); non-ferrous metals (ISIC 372); non-metallic minerals or stone, clay & glass (ISIC 36); basic chemicals (ISIC 351); and paper & pulp (ISIC 341). All other industrial output and energy use is aggregated. We count wood and related wastes used in the paper-making process. We include interruptible power. Note that "kraft intensiv industrier" in Norway include non-ferrous metals, iron and steel, and raw chemicals only.

Analyses for the United States, West Germany, Sweden, France, the United Kingdom, Japan, and Norway[27] have shown that the impacts of changing structure and energy intensity on manufacturing energy use may be gauged by disaggregating the sector into six industry groups: the five energy-intensive raw materials sectors, including iron and steel, nonferrous metals, chemicals, stone, clay & glass, and paper & pulp; and a residual category ("other"), encompassing the range of less energy-intensive industries.

As Figure 6.3 shows, the proportion of manufacturing value added originating in energy-intensive industry groups grew from 14 to 26 percent over the period of analysis. Particularly strong growth occurred in iron & steel, nonferrous metals, and chemicals production. Since the energy intensities of these sectors are eleven times as great as those of non-energy-intensive manufacturing output, the shift towards energy-intensive production placed significant upward pressures on sectoral energy use.[28]

Our analysis of the manufacturing fuel mix in Norway also yielded illuminating results. Of greatest interest was our finding that the share of sectoral energy provided by electricity grew from 36 to 58 percent between 1950 and 1986 (Figure 6.2). This explosive growth in electricity use apparently occurred mainly in response to growth in electricity-intensive industries; the nonferrous metals, chemicals, and iron & steel sectors are over twelve times as electricity-intensive as all other industries combined. The growth of these sectors was presumably driven in large part by the low electricity prices faced by industrial users.

While long-term growth occurred in the use of coal, wood, and gas, the use of oil rose moderately in the 1950s and 1960s before leveling off in the 1970s. Following the second oil shock in 1979, manufacturing oil use fell by 49 percent over a five year period. But the weakness in oil prices that developed in the mid 1980s has led to a resurgence in sectoral oil demand.

6.2 Intensity and Efficiency

The impacts of changes in energy intensity (measured by energy per unit of real value added) and related changes in energy-efficiency on long-term trends in Norwegian manufacturing energy use are rather difficult to characterize. As is shown in Figure 6.4, obvious long-term energy intensity reductions occurred in the chemicals sector, where energy intensity fell by more than 89 percent over the period of analysis. While improvements were also realized in most other sectors, the rate of improvement was not as consistent over time. In the stone, clay & glass sector, for example, energy intensity fluctuated until 1970 but has since fallen by 46 percent. The energy intensity of ferrous metals production fell by 35 percent in the 1950s but has since remained relatively constant. The energy intensity of the nonferrous metals sector fell by 50 percent between 1965 and 1979 but was stable both before and after this period. In the paper & pulp sector, intensity apparently increased in the 1950s and then began a 49 percent reduction between 1962 and 1986. In the non-raw materials sector there was little change in energy intensity over time.

To what extent are these changes due to changes in energy efficiency? The energy intensity of a given sector may change because of changes in process efficiencies, the mix of processes used to produce given outputs, or because of changes in the mix of outputs produced within that sector. It is difficult to disaggregate these effects without analyzing detailed data on the production and energy intensities of particular physical commodities.

Data on physical production and energy use from 1976 to 1986[29] provide some insights regarding this matter. The reduction in the energy intensity of the paper & pulp sector, for example, was due to intensity reductions of 39 percent in chemical pulping and 24 percent in the production of cardboard and paper. The energy intensities of the principal physical commodities produced by the nonferrous metals sector fell by 6 to 17 percent over the period. The energy intensity of cement and chalk manufacture decreased by 29 percent while the intensities of a range of chemical products fell by 49 to 83 percent over the period, suggesting efficiency increases in the stone, glass & clay and chemicals sectors. The energy intensity of iron and steel production fell by 18 percent between 1976 and 1984 but shot back up to 1976 levels as energy prices eased in 1985 and 1986.

This cursory analysis suggests that modest efficiency improvements were achieved in most sectors of Norwegian manufacturing. In some sectors, the improvements were rather substantial.

6.3 Changes between 1973 and 1986

The relative impacts of changes in manufacturing activity, industry structure, and energy intensity on sectoral energy use are shown in Figures 6.5. This figure depicts the evolution in energy use that would have arisen due to the variation in each factor if the other two had remained constant at base year (1973) values. As we noted above, growth in sectoral output drove energy use upwards in the 1950s and 1960s before stabilizing in more recent years. Between 1950 and 1986, structural change would have driven up energy use by 67 percent if sectoral output and the energy intensities of each component industry had remained constant at their 1973 values. No apparent changes in the rate of structural change were induced by the energy shocks. Reductions in industry-by-industry energy intensities, all else equal, would have yielded significant energy savings between 1950 and 1973. But the trend towards decreasing energy intensity slowed considerably following 1973; while the energy intensity index shown in Fig. 6.5 fell by 16 percent between 1980 and 1983 in the wake of the second energy shock, little change was recorded in the 1973-80 and 1983-86 periods. Over the long term, changes in structure and intensity have largely cancelled each other out so that energy use has closely followed the path of sectoral output.

Figures 6.6 and 6.7 show the effects of changing structure and intensity on fuel and electricity use taken separately. As can be seen, the trends in structure-adjusted fuel and electricity intensity are remarkably similar; the major difference is that electricity intensity remained relatively constant over the 1980-3 period while fuel intensity fell by 10 percent. Structural change at 1973 output and industry-by-industry intensity would have driven up electricity use by 101 percent and fuel use by a more modest 38 percent between 1950 and 1986. Together, these trends are consistent with the view that low electricity prices were a leading cause of structural change in Norwegian manufacturing.

These results suggest that the response of the manufacturing sector to the energy shocks of the 1970s were rather limited in scope. While sectoral oil consumption fell by 61 percent between 1973 and 1984, it has since increased to 58 percent of its 1973 value as oil prices have declined. The use of other fuels and electricity exhibited relatively little change. Meanwhile, the proportion of output produced in energy-intensive industries continued to rise.

6.4 International Comparison

As we noted above, there have been only modest reductions in the structure-adjusted energy intensity of Norwegian manufacturing since the onset of the energy shock, and shifts in the output mix towards energy-intensive industries would, all else equal, have driven up sectoral energy use by 17 percent between 1973 and 1986. Ongoing LBL research[30] shows that post-energy-shock manufacturing energy trends in Sweden, West Germany, France, the United Kingdom, Japan, and the United States stand in stark comparison. For the countries in question, structure-adjusted energy intensity decreased by 24 to 38 percent between 1973 and 1986.* Structural effects, while smaller in absolute terms, would have reduced manufacturing energy use in these countries by 2 to 15 percent following the energy shock if sectoral output and energy intensity had remained constant. In no country except Norway did structural change serve to increase energy utilization.

The evolution of the energy intensity of Swedish manufacturing by industry group provides a useful yardstick against which Norwegian trends may be compared.[31] An examination of recent trends shows that energy intensity in Sweden has decreased steadily since 1970 for every branch of industry except nonferrous metals, and even this sector managed a modest improvement over the long term. The overall reductions were 29 percent in paper & pulp; 40 percent in chemicals; 38 percent in stone, clay & glass; 42 percent in iron & steel; and 10 percent in nonferrous metals. Unfortunately, differences in the definitions of the sectors and in the mix of activities within each sector precludes the direct comparison of sectoral energy intensities between Swedish and Norwegian energy intensities.

Although there has been strong relative growth in Norwegian raw materials production, the share of manufacturing output generated by energy-intensive industries is not extraordinarily high in the country. The stone, clay & glass; iron & steel; nonferrous metals; chemicals; and paper & pulp sectors account for 26 percent of Norwegian manufacturing output — inside the range of 16 to 28 percent observed in the countries noted above. Moreover, the strong growth in oil sector income has caused the share of Norwegian GDP generated by the manufacturing sector to fall to only 14 percent as compared to the more typical 20 to 30 percent observed in other nations. But the structure of Norwegian manufacturing is nonetheless an important determinant of its high energy use. Much of Norway's energy-intensive output is produced for export, including a third of its pulp, two-thirds of its paper, and nine-tenths of its primary aluminum.[32]

What caused the observed differences between Norway and other nations with respect to industry structure and energy intensity? Probably most important were the low electricity prices paid by industrial customers in Norway in comparison with other nations. Norwegian industry on average paid only 13 øre per kWh in 1986, electricity-intensive industries considerably less, while Swedish, West German, and U.S. industry paid 2 to 4 times that rate. These differentials are not a recent development but have persisted since the 1950s. As a result, electricity now provides almost 60 percent of Norwegian manufacturing energy use in comparison with 17 to 35 percent in the other nations considered in our international manufacturing energy study.

* The most recent U.S. data are for 1985.

The high reliance on electricity in Norwegian industry probably also accounts for the lack of a major reduction in energy intensity of the sort witnessed in other nations in response to the energy shocks of the 1970s. Electricity prices did not increase as rapidly as the prices of purchased fuels (Fig. 2.4), so there was little incentive for electricity-intensive firms to cut back on energy use, although some oil conservation clearly did occur.

6.5 Conclusions

It is clear that the special circumstances of Norwegian energy supply — namely, the availability of electricity to industrial users at a fraction of the price paid in other nations — is the driving force behind the structure and energy intensity of Norwegian manufacturing. The average electricity price of 13 øre per kwh is clearly below the price which could be obtained through the export of electricity to other nations, and it is even below the long-run marginal cost of electricity generation in Norway. Painful though it may be, it is time for the government to reevaluate the practice of maintaining electricity prices at very low long-term contract rates to industrial users. Long-term electricity contracts written in the 1950s during which hydro power was cheap and abundant no longer make sense as Norway heads into the 1990s. This policy is economically inefficient and results in the misallocation of scarce energy resources, along with the environmental degradation energy use entails.

We understand fully the implications of this policy recommendation. While higher energy prices have been greeted in other nations through enhanced efficiency and improved "housekeeping" practices which, in some cases, actually reduced production costs, the transition to higher electricity prices in Norway might entail not only improved efficiency but also a significant reorganization of the structure of the manufacturing sector. Inevitably this will be a difficult process which will cause stagnation and unemployment in certain sectors of the economy and in certain districts of the country. But the social gains to be won through this restructuring should be more than sufficient to implement job retraining programs and other policies designed to reduce the losses of the most vulnerable members of society. As in other policy areas, the apparent conflict between efficiency and distribution may be reconciled through thoughtful policy planning.

The output of raw materials in Norway is "mature", but could grow if world markets continue to expand for energy-intensive products. Significant changes in energy demand and efficiency are tied to industrial policy questions beyond the scope of this report. Future energy demand in Norwegian manufacturing will grow under present industrial and energy policies. But higher industrial electricity prices would likely unleash significant structural change away from heavy industry. This stimulus, if coupled with policies designed to ease the social impacts of significant changes in the level of production of raw materials, could lead to a dramatic change in industrial electricity (and energy) demand.

FIGURE 6.1
RAW MATERIALS PRODUCTION IN NORWAY
1955 - 1986

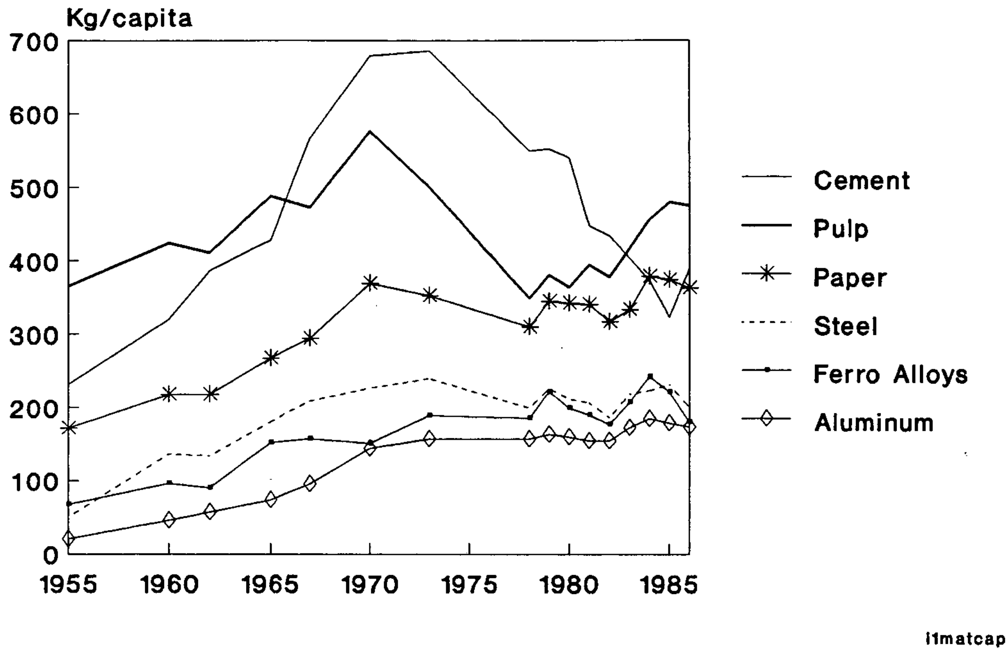


FIGURE 6.2
NORWEGIAN MANUFACTURING
ENERGY USE BY FUEL

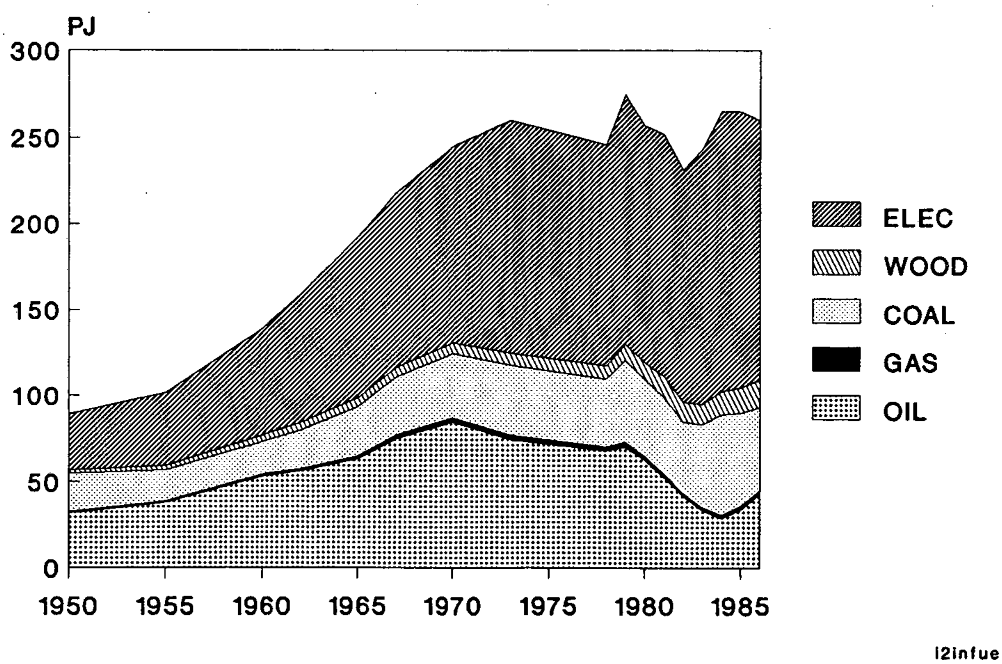
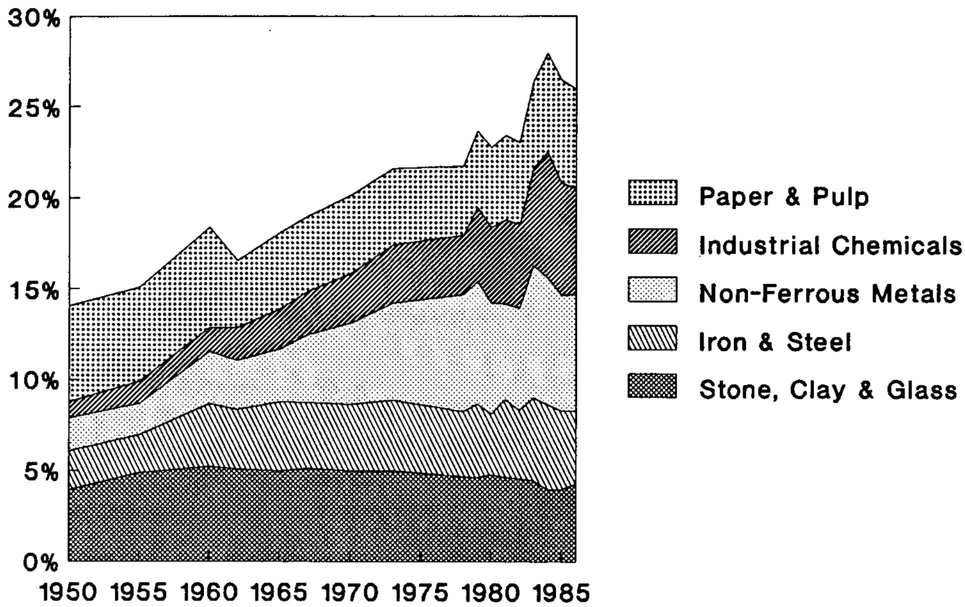
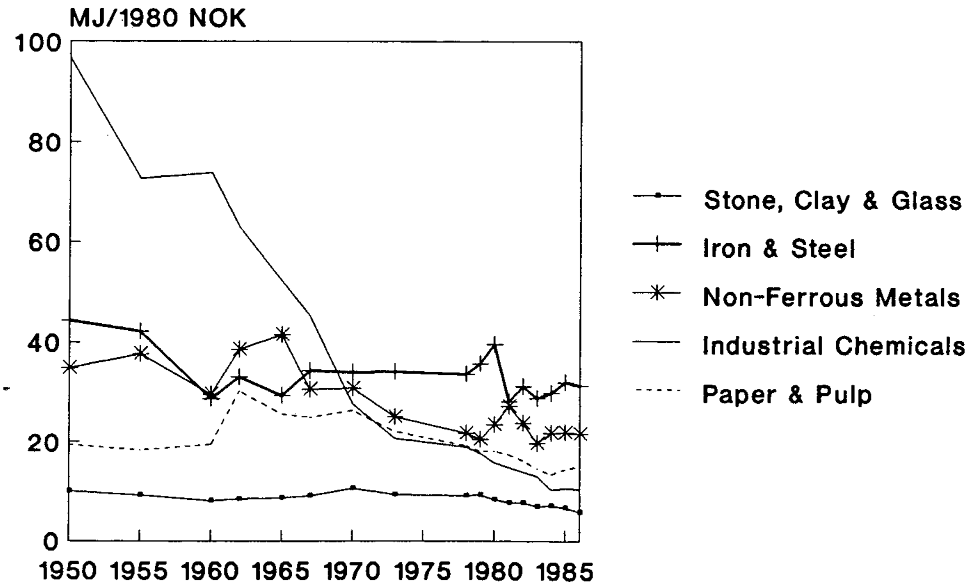


FIGURE 6.3
SHARE OF ENERGY-INTENSIVE MANUFACTURING OUTPUT IN NORWAY



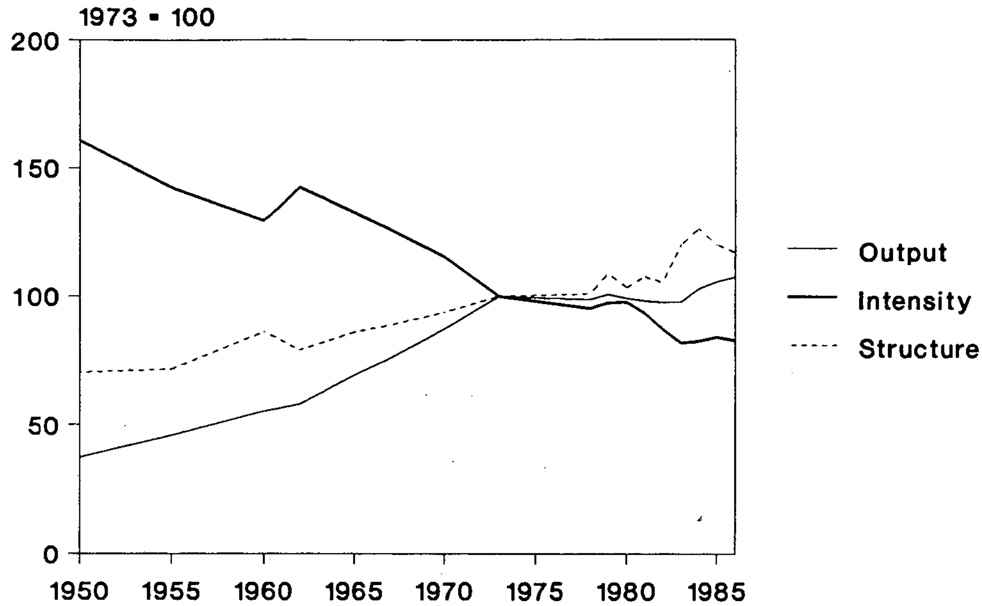
13instru

FIGURE 6.4
NORWEGIAN MANUFACTURING SECTORAL ENERGY INTENSITIES



14indint

FIGURE 6.5: EFFECTS OF CHANGING OUTPUT INTENSITY, AND STRUCTURE ON NORWEGIAN MANUFACTURING ENERGY USE



i5entrnd

FIGURE 6.6: EFFECTS OF CHANGING OUTPUT, INTENSITY, AND STRUCTURE ON NORWEGIAN MANUFACTURING FUEL USE

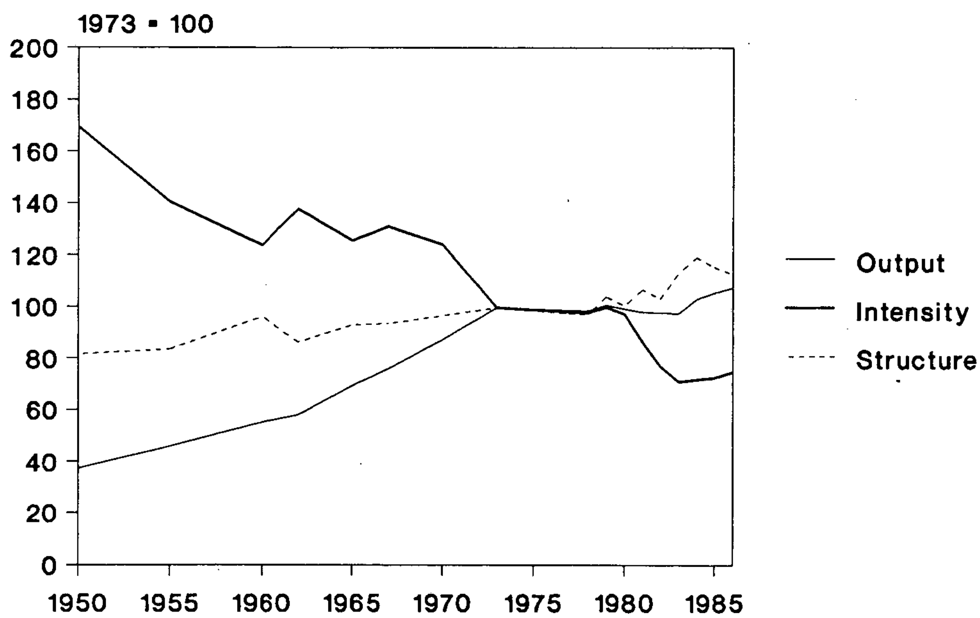


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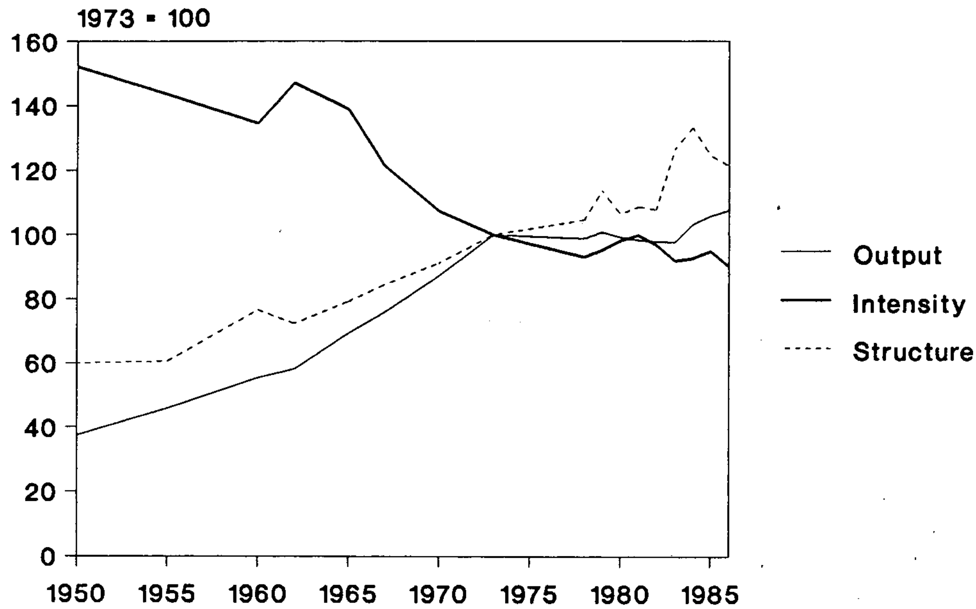
FIGURE 6.7: EFFECTS OF CHANGING OUTPUT, INTENSITY, AND STRUCTURE ON NORWEGIAN MANUFACTURING ELECTRICITY USE



I7eltrnd

7 TRANSPORTATION SECTOR

Because of its nearly complete dependence on oil, the Norwegian transportation sector receives a great deal of attention in energy policy discussions. The geographical outline of Norway makes long distance travel important as a means of unifying people living as far as 1000 kilometers apart, although automobile and truck transport over short distances has grown strongly in the recent past. While Norway is self-sufficient in the oil that fuels sectoral energy use, the impacts of transportation on urban congestion and air pollution are very significant. Since the effluent emitted by vehicles is, all else equal, proportional to fuel use and because both fuel use and congestion are driven largely by traffic volume, environmental concerns have led to increasing debate over the structure of the transportation sector and its energy utilization. In this section we review the most important characteristics of the level and structure of transportation energy use.[33]

7.1 Activity, Structure, and Fuel Use

Transportation activity and energy use may be disaggregated logically into three distinct categories: passenger traffic; freight; and miscellaneous activities such as private boating and the movement of heavy equipment on farms and forests. Because this third category is something of a residual and data on it have been sporadic and inconsistent over time, our analysis focuses on activity and energy use trends in passenger and freight transportation. But since these two activities account for almost 90 percent of transportation energy use, our analysis captures the most important long-term influences on transportation energy use.

Passenger travel, measured in passenger-km, grew at an annual rate of 7.1 percent between 1950 and 1973 and 2.6 percent thereafter, compared with GDP growth rates of 4.0 and 4.1 percent. Freight activity, measured in tonne-km, grew by 4.6 and 1.8 percent during these same periods. Both activities grew more rapidly than population, and passenger transport grew almost twice as fast as GDP during the 1950s and 1960s. As a result, transportation energy use became a progressively more important component of national energy demand, and energy use for passenger travel surpassed freight energy use by 1964.

Figures 7.1 and 7.2 show the evolution of passenger and freight activity. The structure of each activity was transformed radically over the past 40 years. In both areas the mix of modes has shifted to those that require more energy per unit of activity. In passenger transportation, rail and bus traffic yielded to the automobile by the mid 1960s, while the share of passenger transport on air carriers grew from 0.3 to 4.8 percent between 1950 and 1986. And although fuel-efficient marine shipping carries almost 60 percent of domestic freight, road transport via truck has grown more rapidly than any other mode, today accounting for approximately half of freight energy use. Short-haul trucking, which uses more energy per tonne-km than long-haul trucking, is growing the most rapidly within this mode. Finally, while international shipping carries significant quantities of freight to and from Norway, this activity and its associated bunkers are not counted in most energy and freight statistics. As a result, the importance of freight to total energy use is understated by existing statistics.

The most dramatic change in the structure of the transportation sector has been the rapid rise of the private passenger car. As Fig. 7.3 shows, the number of autos per 1000 people grew more rapidly than both trucks and disposable income from only 60 in 1960 to nearly 400 in 1986. Driving distance per car increased slowly through 1973, fell for about ten years, and then resumed its march upward.[34] The automobile came to dominate both travel activity and transportation energy use. Because of the congestion and pollution that accompanies automobile use, there is considerable interest in Norway concerning the role of automobiles in the transportation system of the future. Gasoline is by far the most important fuel in the fleet.

Figure 7.4 shows energy use for selected modes of passenger and freight transportation as well as for the miscellaneous category described above.[35] The rapid rise of energy use by the automobile is unambiguously clear. At the same time, the relative importance of rail energy use declined due to both the decline in passenger and especially freight rail transport (Figs. 7.1 and 7.2) and the transition from solid fuels to oil and electricity which raised the end-use efficiency of locomotives.

7.2 Intensity and Efficiency

The energy intensities of the various modes of transportation behaved somewhat erratically over the period of analysis.* The intensity of rail transport (measured in MJ/pass-km or MJ/tonne-km) fell as coal yielded to oil and electricity. The energy intensities of other modes generally increased over time as load factors fell. The fuel economy of automobile travel, which we estimate from data provided by Esso, decreased as cars became larger and more powerful. After 1973, automobile fuel economy increased, but automobile load factors fell more rapidly. These changes led to continued increases in the energy intensity of automotive travel. A similar trend developed in trucking, where a substantial number of small trucks entered the fleet to provide local delivery service, thereby yielding increased energy intensity. The net effect of these changes was to increase the energy intensity of freight and passenger transport through most of the period of the study, even after the onset of the energy shock in 1973.

7.3 Changes between 1973 and 1986

We can summarize the developments in this sector with three diagrams. When the total volume of passenger and freight activity is compared against GDP (Fig. 7.5), the increase in the relative importance of passenger transport is clear. The pause in this growth in the late 1970s and early 1980s was related both to the growth in oil sector GDP and the real stagnation in passenger activity for a few years after the 1979 oil shock. More recently, the growth in the ratio of passenger traffic to GDP appears to have resumed. The ratio of freight activity to GDP, in contrast, was relatively stable over the period of analysis although it fell by 15 percent between 1973 and 1980. Thus by 1986 energy use for passenger transport was significantly more important than freight, which it overtook in 1964.

Figure 7.6 shows the ratio of energy use for each purpose to activity. The steady increase in the intensity of passenger travel reflects the increasing importance of autos, and later even air travel. On the freight side, the increasing role of truck freight has pushed up the intensity of freight transport steadily since 1973. Finally, Figure 7.7 shows the resulting ratio of transportation energy use to GDP for freight and passenger energy use. These curves illustrate how the rising importance of automobile and truck activity have driven transportation energy use upward, during many periods more rapidly than GDP.

* The energy intensity of transportation activities is defined in terms of energy per passenger-km for passenger transport or energy per tonne-km for freight. Fuel economy refers to the intensity of vehicle activity, measured in liters of fuel per vehicle-km.

Figure 7.8 shows the relative impacts of changes in the activity level, modal mix, and modal energy intensities of the passenger transportation sector on sectoral energy use between 1950 and 1986. The figure shows the evolution in energy use for passenger transport (excluding air travel) which would have occurred due to the independent variation of each factor while the other two remain constant at base year (1973) values. The figure clearly illustrates how changes in the energy intensity and structure of passenger transportation both contributed to to the substantial increase in sectoral energy use which arose since the early 1960s.

The changing role of the automobile during this period bears further comment. While there are no actual data, information from transportation experts suggest that cars became heavier and more powerful during the period of analysis, particularly as oil revenues and easy credit drove up consumer spending in the late 1970s and early 1980s. While the distance driven by each car did not change considerably after 1973, the breakdown of car trips by purpose has changed. According to national surveys[36] the shares of driving for shopping and commuting — purposes which contribute more than proportionally to urban congestion and air pollution — have increased from 33 percent to 39 percent of kilometers driven since 1980. Moreover, load factors fell during this time, in part because of the rising importance of driver-only commuting. Finally, the average length of trips has decreased. Since short trips mean the car is running proportionately more on a cold engine, fuel economy declines. And because load factors have fallen, the overall energy intensity of automobile traffic has increased.

The fuel economy of Norwegian passenger cars has changed only slightly since 1973. Since annual driving distance and total gasoline sales to private cars are not easily determined, estimates of automobile fuel economy must be guarded. But according to Esso (G. Aas, private communication) and TØI[37] on-road fuel economy for all cars improved by some 12 percent between 1975 and 1986 to about 9.3 l/100 km.* The fuel economy of new cars, estimated as the weighted sum of the tested fuel economy of the ten most widely-sold cars[38] improved from 9.5 l/100 km to 7.5 l/100 km between 1975 and 1986. The changes in the driving cycle noted above, and associated congestion, probably reduced the impact of these theoretical improvements considerably.

7.4 International Comparison

To put Norway's transportation energy use into perspective, we compared passenger transport and freight activity levels with those of other countries with similar incomes. Figure 7.9 shows per capita passenger travel in Norway and several other countries in 1986. The dominance of the automobile in all four countries is striking. While the higher volume of travel in the U.S.[39] (almost 50 percent more per capita) is obvious, the position of Norway as the second most travel-intensive country (tied with Sweden) is surprising given that Norwegians traveled far less than Swedes or West Germans as recently as 1970. More detailed analysis shows that the breakdown of travel by purpose is weighted more towards free-time and vacation travel than that in Germany. The U.S. towers above both countries, with more automobile travel in all categories. As we noted above, travel for shopping and commuting have both increased in recent years, increasing urban congestion and driving down load factors. Domestic air travel is also more important than in most other European countries, a consequence of the geographic layout of the nation.

* 8.3 l/100 km according to TØI.

A comparison of the structure of freight transport in 1986 (Fig. 7.10) reveals that Norway has the highest share of sea-going domestic freight, and the lowest share of truck freight, among Scandinavian countries and West Germany. Since geography and the types of goods shipped is an extremely important determinant of the mix of freight modes appropriate to a country, it would be inappropriate to call the Norwegian mix "energy-efficient" because of the lesser role of trucks. Nevertheless, the mix of freight modes in Norway is less energy-intensive than in the other countries shown. But in all these countries, the importance of truck freight is increasing, and with that increase, the energy intensity of freight.

How does the fuel economy of cars in Norway compare with that of other countries? Comparing first fleet averages (Fig. 7.11), we see that the slight decrease in fuel use per km is consistent with the small changes observed in Germany and Sweden, but far less than the dramatic improvements in the U.S. Comparing the fuel economy of new cars (Fig. 7.12), we see slight improvements in Sweden and Norway against dramatic improvements in the U.S. The improvements in the U.S. surprise no one; American cars were enormous and inefficient in 1973. Note in fact that differences in the fuel efficiency of new cars narrowed by the mid 1980s. The internationalization of both manufacturing and markets caused this narrowing. But why do the fuel economy figures for Norway, with high gasoline prices and automobile taxes, show so little improvement?

The most obvious reason is that cars have become more powerful and larger.* Another reason is that increases in urban driving served to reduce fuel economy. But why have Norwegians not reacted to high gasoline prices (among the highest in Europe) and the high taxes on cars? The real price of gasoline in Norway (Fig. 2.5) has not varied by more than 25 percent over a long period of time, and stands today below its 1960 value. Additionally, we believe that the income tax system, which permits the deduction of some driving costs as well as the interest on money borrowed to buy a car, permits Norwegians to drive larger cars farther than otherwise. Also important is the pervasive "company car" phenomenon, where employers purchase or loan cars to their employees in lieu of higher wages and salaries. Because these transfers of wealth are not fully taxed, both parties come out ahead. But the practice represents an important government subsidy to automotive transport which increases fuel consumption, congestion, and urban air pollution.

7.5 Conclusions

The great increase in transportation energy use which occurred between 1950 and 1986 was driven principally by the rapid increase in passenger mobility. Passenger travel per capita was low by European standards in the 1960s but now ranks near the top. The automobile bore the bulk of this increase while air transport also increased. Because of the high energy intensities of these transport modes, energy use for passenger traffic grew even more rapidly than passenger mobility. Much of the increase in transportation energy use occurred after 1973 even as gasoline prices were on the rise.

Energy use for freight transport grew less rapidly than than for passenger traffic. Because of the high volume and low energy intensity of marine shipping, Norwegian freight transport is relatively energy-efficient, but the rise of the truck in the last 15 years has steadily increased overall energy intensity of freight.

* In Germany, average horsepower was about 33% higher in 1987 than in 1973.

Transportation activity and energy use does not appear to be saturated yet in Norway. While Norwegian reliance on automotive transport is high by European standards, car ownership has not yet approached saturation, as many women and some working men have yet to gain access to cars. Our preliminary analysis suggests that driving could increase for all major purposes — work, leisure, and shopping. Thus we expect increases in gasoline demand in Norway unless measures are taken to alter the trends we have sketched or stimulate improvements in fuel economy. And where automobile use may decrease — vacation travel — air transport, which is even more energy-intensive, promises to grow at a rapid rate.

We believe that Norwegian transportation energy use can be reduced, or at least that its growth can be constrained. But to achieve this objective, measures must be taken to reduce the level of transport activity and the reliance on energy-intensive transport modes. And substantial increases must be achieved in the energy efficiency of all vehicles.

One way to reduce the growth in gasoline demand would be to encourage the use of relatively lightweight, small-engine cars. This has been achieved through the increased taxation of automobiles on a weight basis. The private use of company cars and interest payments on auto loans could be taxed more, and the nation might impose fuel economy standards on new automobiles.*

In the very long run, careful attention to the geographical distribution of urban development might reduce the demand for travel somewhat. Low off-peak fares for bus and local rail services (as in Gothenburg or London) would encourage switching to these modes from cars for shopping and leisure travel. Careful attention to the location of shops and public facilities could also reduce the need to move about. The use of tolls to enter large cities, particularly during peak hours, would certainly discourage some car use and thus reduce congestion and pollution levels. This approach has been implemented in Bergen, Singapore, and Hong Kong, and is now being tested in Oslo.

Norway could also take measures to reduce the energy intensity of freight. Mandating the use of wind spoilers on long-distance trucks is one realistic option, and penalizing the empty return of trucks is another. For short haul freight, whose role in total movements is increasing, the most important contribution that the government could make would be to reduce congestion in cities. If the use of city tolls reduced traffic in cities, trucks would operate more efficiently.

* Such an approach might be viewed as a potential restraint of foreign trade by car exporting nations, but we believe the approach is viable.

FIGURE 7.1
NORWEGIAN PASSENGER TRANSPORT BY MODE

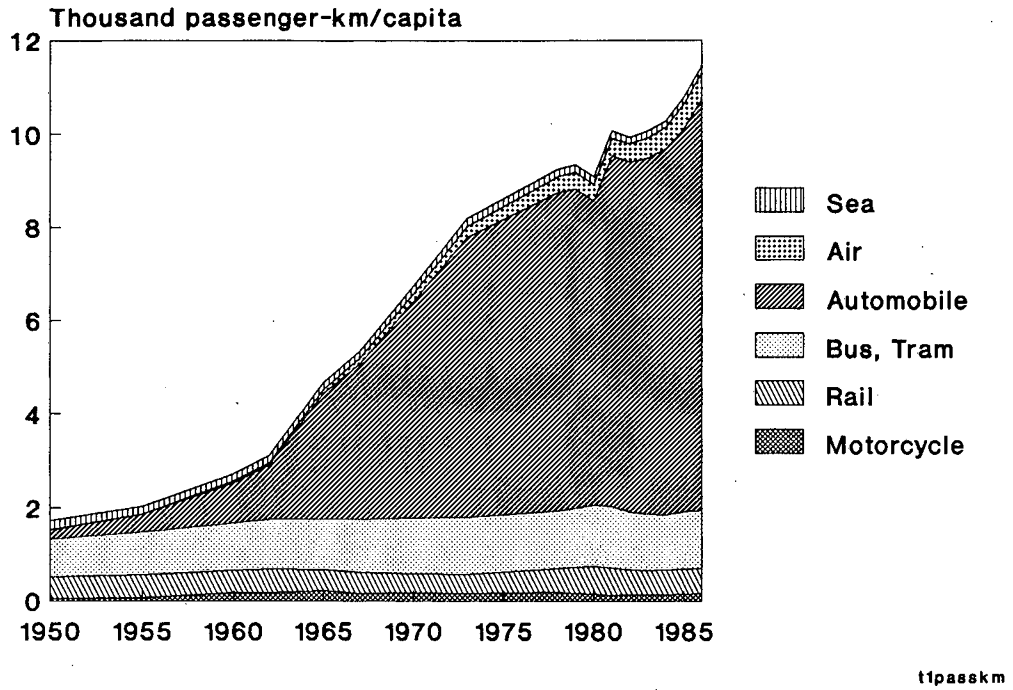


FIGURE 7.2
NORWEGIAN FREIGHT TRANSPORT BY MODE

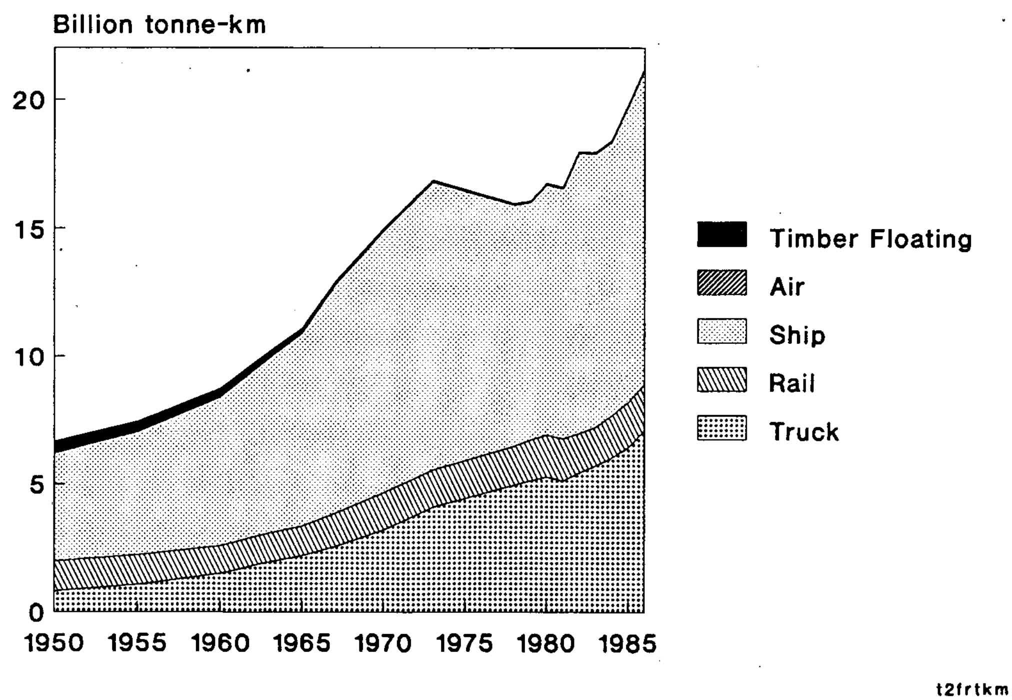
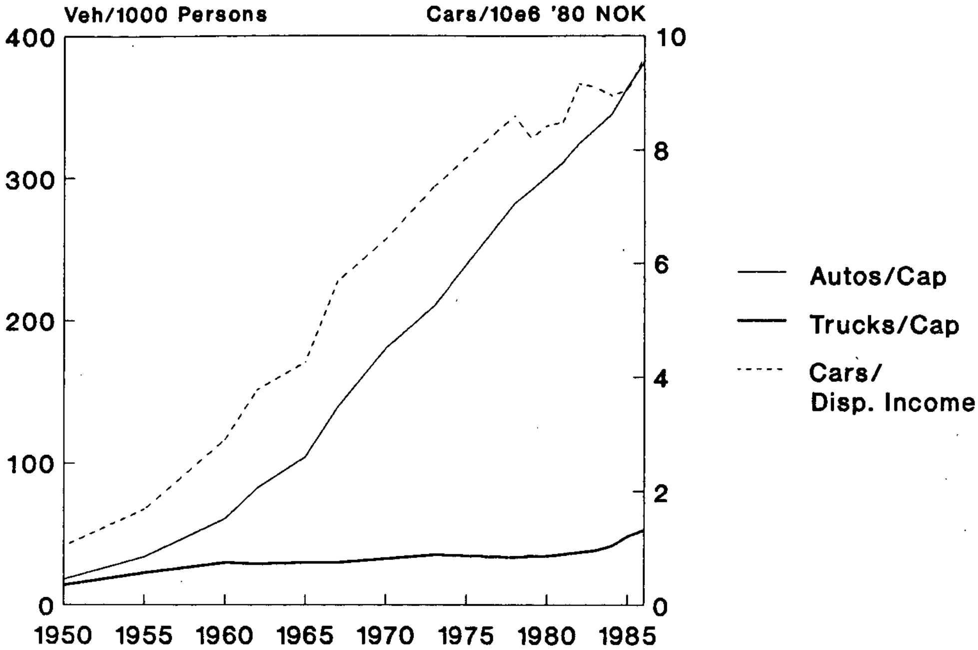
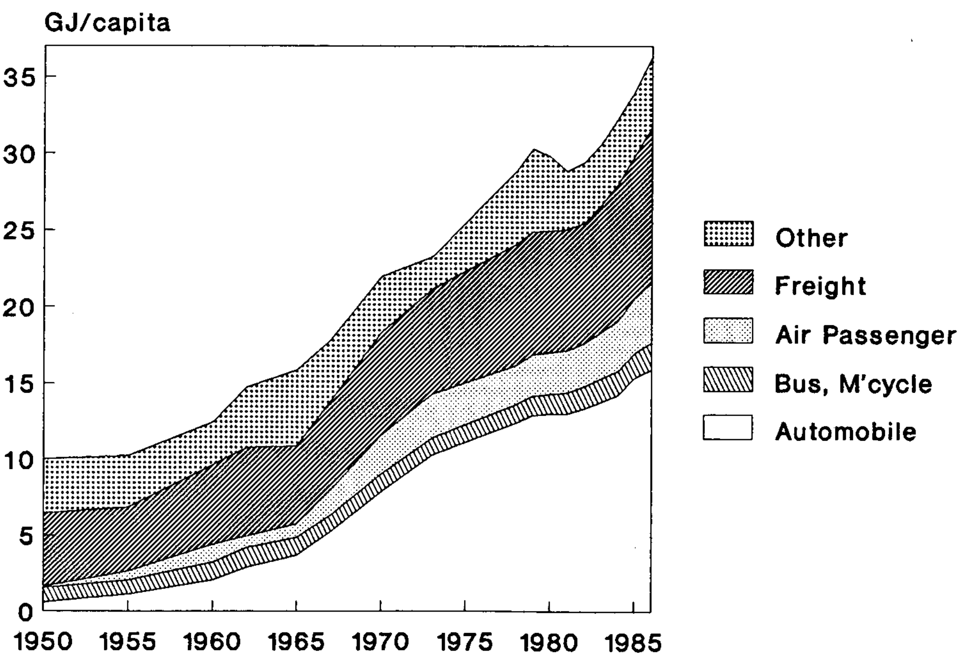


FIGURE 7.3
MOTOR VEHICLES IN NORWAY



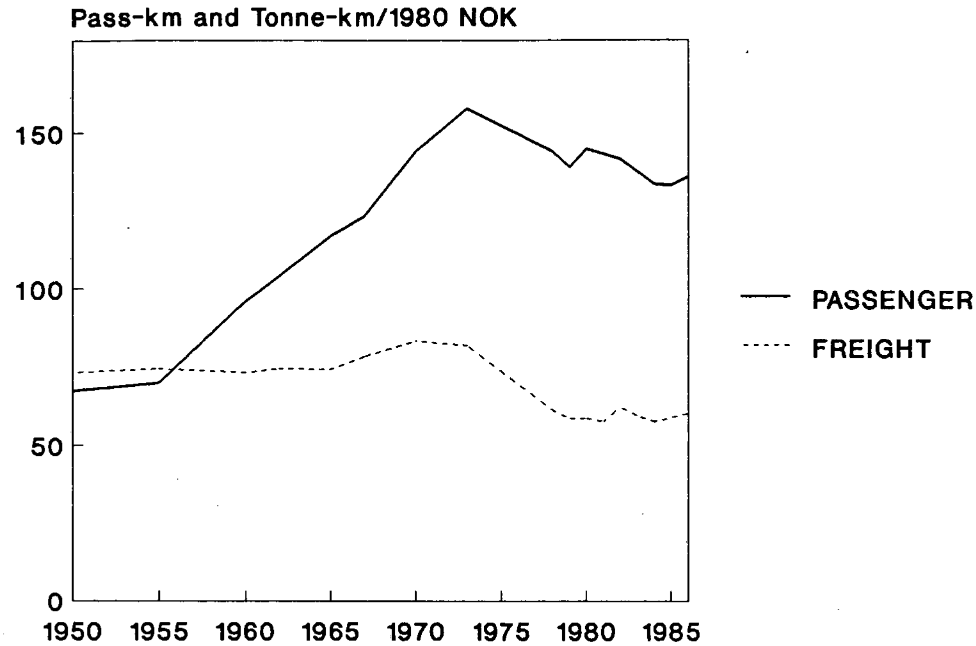
t3vehcap

FIGURE 7.4
NORWAY: TRANPORTATION ENERGY USE BY MODE



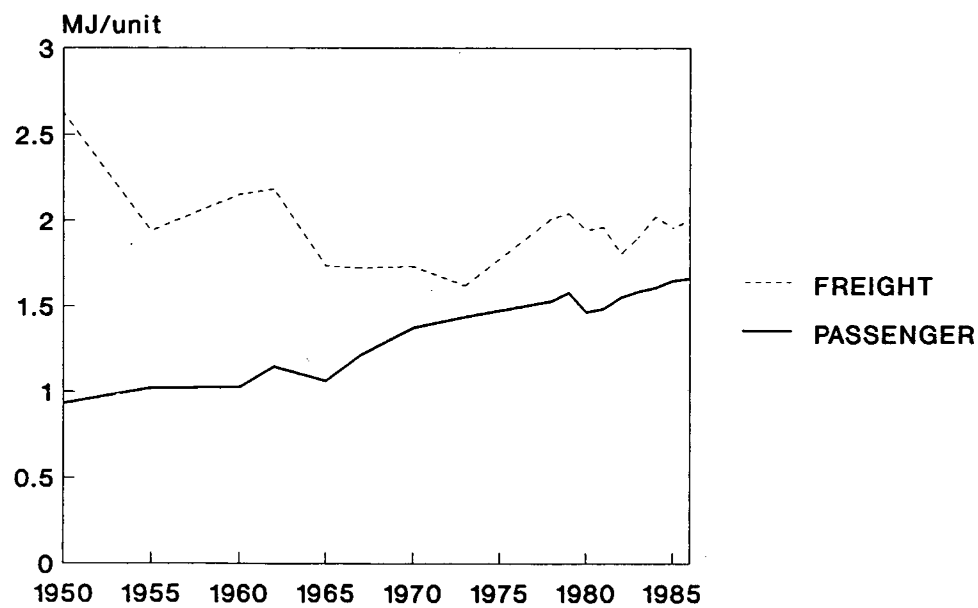
t4tepen

FIGURE 7.5
NORWAY: TRANSPORTION ACTIVITY/GDP



t5tspgdp

FIGURE 7.6
NORWAY TRANSPORTATION ENERGY INTENSITIES



Passengers: MJ/pass-km
Freight: MJ/tonne-km

t6tspin

FIGURE 7.7
NORWAY: TRANSPORTATION ENERGY/GDP

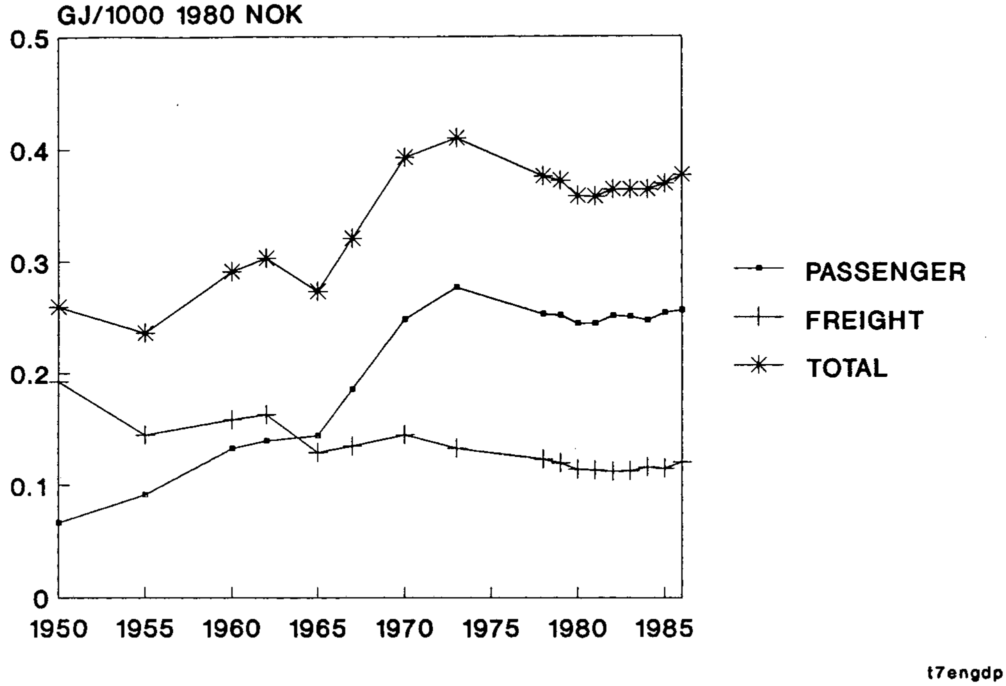


FIGURE 7.8: EFFECTS OF CHANGING VOLUME, INTENSITY, AND STRUCTURE ON NORWEGIAN PASSENGER TRANSPORTATION ENERGY USE

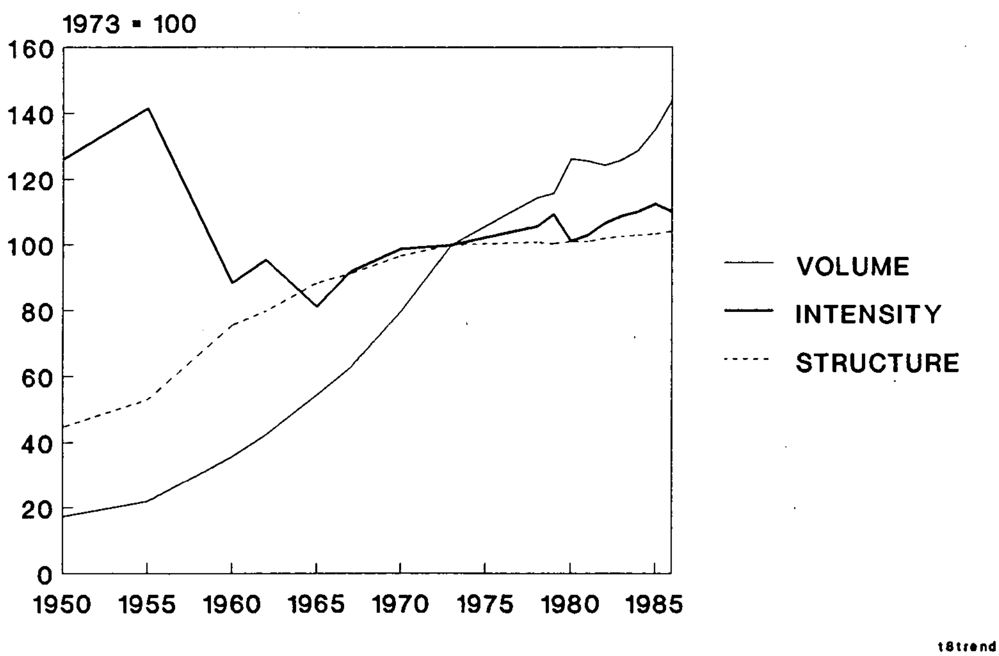


FIGURE 7.9
PASSENGER TRAVEL IN SELECTED COUNTRIES

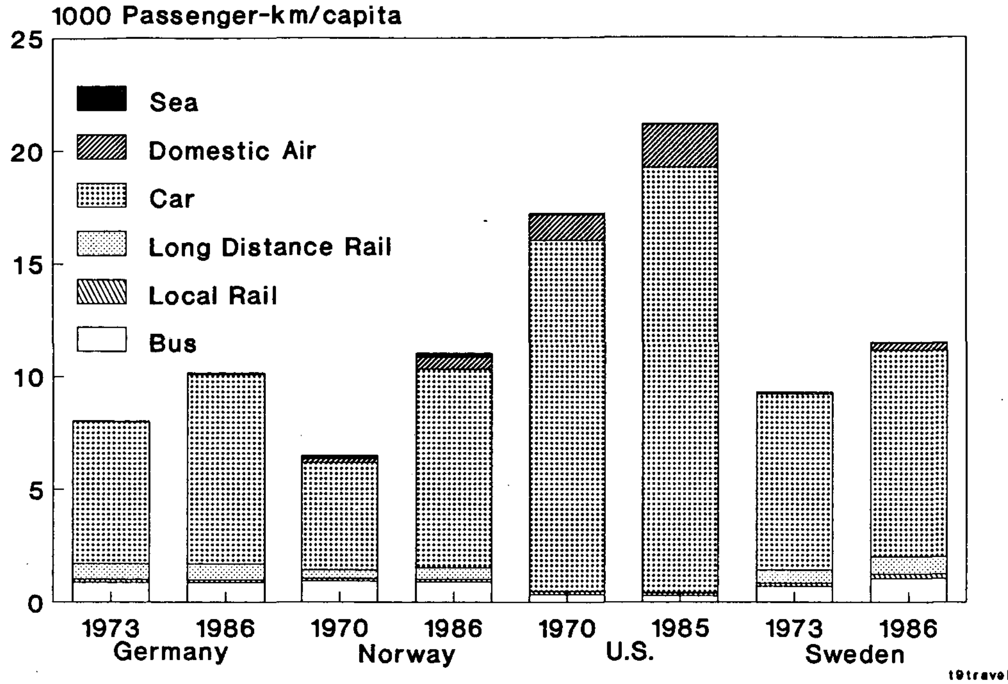


FIGURE 7.10
FREIGHT TRANSPORT IN SELECTED COUNTRIES

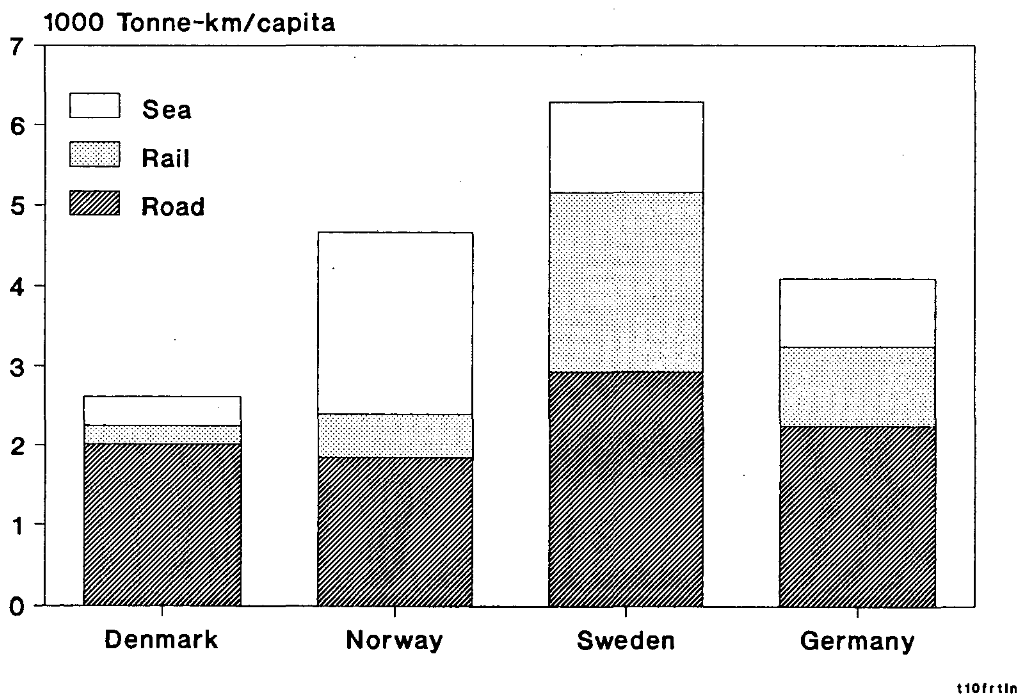


FIGURE 7.11
AUTOMOBILE FUEL ECONOMY
ON-ROAD FLEET AVERAGES

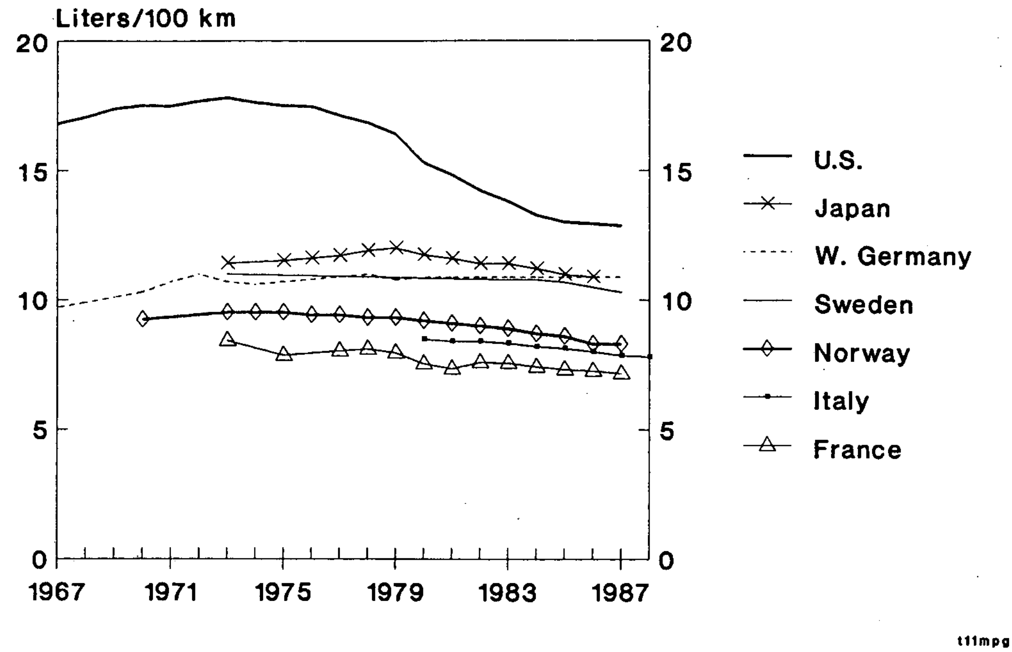
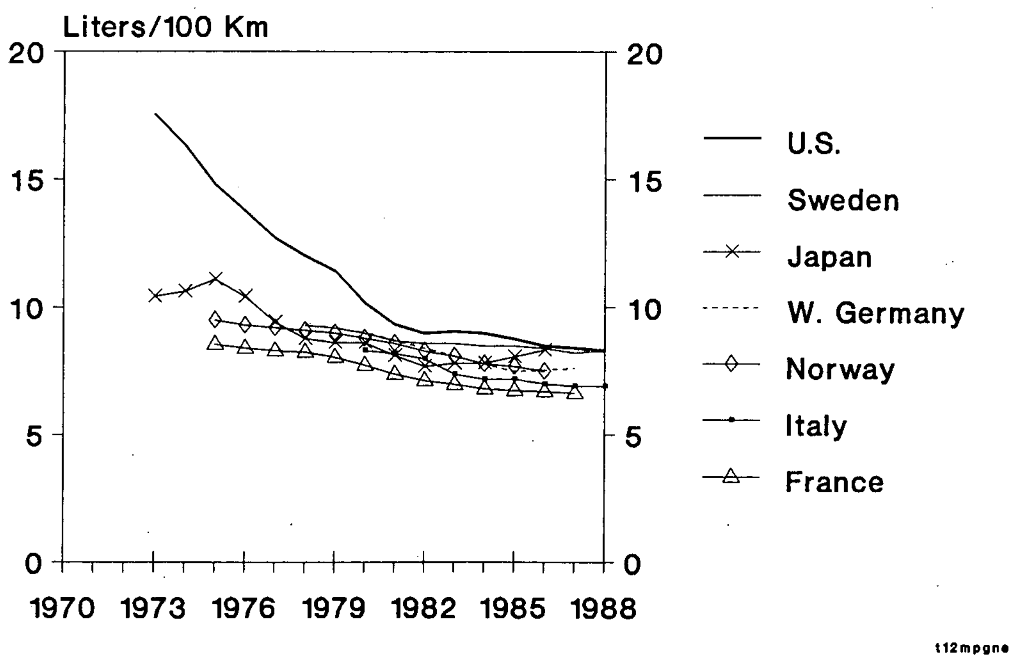


FIGURE 7.12
AUTOMOBILE FUEL ECONOMY
NEW CAR FLEET AVERAGES



APPENDIX: A NOTE ON THE DATA

We outlined our principal data sources as appropriate in the text. Here we offer a more detailed explanation of certain sources, procedures and assumptions. The data were gathered by the authors with the special assistance Haji Semboja (OED) and Jan Moen (Oslo Lysvaerker), to whom we are most grateful.

We collected a wide variety of data on energy demand and energy using activities in Norway. Most of our data are from Statistiska Sentralbyraa's published and unpublished files. Data included energy use and GDP disaggregated by sector; physical measures of production; ownership levels and characteristics of energy-using equipment such as appliances, automobiles, and heating systems; and activity indicators such as residential floor area and passenger mobility. Data on transportation activity were provided by Transportøkonomisk Institutt and Esso. Estimates of the characteristics of the residential sector were developed by this project.

We were required to calculate Norway's energy balances in uniform units for benchmark years between 1950 and 1986. Our main data sources included **Resursregnskap, Energistatistikk, Industristatistikk,** and **Elektrisitetsstatistikk.** Haji Semboja developed a series of Lotus-123 matrices to transform SSB data into common units. Although the **Energiregnskap** from SSB show considerable detail, data are only available from 1976 onward, and have only been fully evaluated for the 1976-1980 period. Since one goal of this project was to produce time series from 1950 onward, we decided to use the older **Energistatistikk** and make comparisons with **Energiregnskap** where possible. The transformation diskettes are available from Jan Moen of Oslo Lysvaerker.

Residential and Service Sectors

Residential, service, and agricultural sector energy use are only distinguishable in official statistics from 1976 onward. We therefore compared the estimates of Sørensen (from 1950), NPI (from 1960) and various time series from SSB in order to estimate the use of each fuel by the residential sector. Using estimates from Sørensen and Energistatisistik on electricity and oil use in the agricultural sector, we separated out this sector. The residual was considered taken to be service sector energy use. The estimates up to 1976 corresponded to the post-1976 data rather well and also closely matched the data on service sector energy use assembled by Sagen (private communication). Thus while there are some uncertainties in our analysis, the sum of residential, service sector, and agricultural energy use as represented in our study equals the sum that obtains from the historical energy balances plus an additional amount that reflects the use of wood in the residential sector. This extra wood was also added to our estimate of total energy use.

Transportation Sector

The energy balances list fuel use for transportation divided into the traditional categories "road", "rail", and "air". In addition, we believe that these statistics may include the fuel use of some farm and forestry equipment. Inspection of the balances with reasonable estimates concerning the fuel use of each major transport mode left a residual of diesel fuel presumably used by these activities. From internal calculations carried out by Esso and TØI, we broke down transportation energy use further by mode. The

Esso data distinguished the energy used by light and heavy trucks; buses; tractors and certain other off-road equipment; private boats; and a variety of other types of transportation equipment. Using these calculations for the 1970s and 1980s, we were able to show how energy use may have varied by mode from 1950 onwards by making assumptions concerning the evolution in the energy intensity of each type of equipment. The data for air travel were unreliable because of the lack of data on the breakdown between military and civilian uses, and further separation of the latter into domestic passenger use, bunkering of SAS and Norwegian charter flights, and bunkering of foreign carries was not possible.

Manufacturing Sector

Data on manufacturing energy use were obtained from **Energistatistikk** and, for certain industries (stone, clay & glass and industrial chemicals), **Industristatistikk**. We attempted to include the petroleum refining sector but discovered that the data on refining energy use were unreliable, showing unlikely jumps for several years of the analysis. We therefore kept refining energy use in the energy sector, although its value added is counted under manufacturing. We kept mining separate, as in the energy statistics, and also kept the losses in the energy sector, as well as non-energy uses such as feedstocks, separate. Thus we treat manufacturing in considerable detail, but did not analyze the remaining energy uses in industry or in the energy sector. Value added data were obtained from **Nasjonalregnskaper**. The split between industrial chemicals and refining, and between ferrous and non-ferrous metals for the years 1950 - 1962 was not available and was estimated based on trends and the 1962 data.

Energy Units

The basic energy units of our work are Joules (J). A petajoule (PJ) is defined as 10^{15} Joules, a gigajoule (GJ) as 10^{9} Joules, a megajoule (MJ) as 10^{6} Joules, and a kilojoule (KJ) as 10^{3} Joules. One Million tonnes of oil equivalent, another common energy unit, is equal to 41.87 PJ. Electricity is generally reported in either kilowatt hours (kWh) or terawatt hours (tWh). One kWh is equal to 3.6 MJ, and one tWh is equal to 3.6 PJ. The conversion factors used to transform physical quantities of fuel into these energy units are given in the various **Resursregnskaper** and other SSB sources.

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8. These data were derived from Sørensen, **Boligers Energiforbruk og Energikostnader**, Norges Bygeforskning Institut (1986); NPI (private communication); and the yearly energy balances published by Statistisk Sentralbyraa, which we used to estimate the components of energy use in homes, services, and agriculture. See also Tyler and Schipper, *op. cit.*; and A. Ljones, **Utvikling av Energiforbruket 1975-1985**, report to Olje og Energidepartementet, A/S Energidata (1988).

9. These data are based on SSB surveys taken in 1960, 1967, 1973, 1980, 1981, and 1983; and private surveys by Esso for 1970 and 1975. The 1985 distribution is extrapolated from trends.

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