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DISCLAIMER

The Structure and Intensity of Energy Use:

Trends in Five OECD Nations[1]

Richard B. Howarth,[2] Lee Schipper,[2] and Bo Andersson[3]

This paper examines trends in the structure and intensity of final energy demand in five OECD nations between 1973 and 1988. Our focus is on primary energy use, which weights fuels by their thermal content and multiplies district heat and electricity by factors of 1.15 and 3.24 to approximate the losses that occur in the conversion and distribution of these energy carriers. Growth in the level of energy-using activities, given 1973 energy intensities (energy use per unit of activity), would have raised primary energy use by 46% in the U.S., 42% in Norway, 33% in Denmark, 37% in West Germany, and 53% in Japan. Reductions in end-use energy intensities, given 1973 activity levels, would have reduced primary energy use by 19% in the U.S., 3% in Norway, 20% in Denmark, 15% in West Germany, and 14% in Japan. Growth in national income parallelled increases in a weighted index of energy-using activities in the U.S., West Germany, and Denmark but substantially outstripped activity growth in Norway and Japan. We conclude that changes in the structure of a nation's economy may lead to substantial changes in its energy/GDP ratio that are unrelated to changes in the technical efficiency of energy utilization. Similarly, changes in energy intensities may be greater or less than the aggregate change in the energy/GDP ratio of a given country, a further warning that this ratio may be an unreliable indicator of technical efficiency.

INTRODUCTION

In the controversy over the importance of restraining energy-related emissions of carbon dioxide to reduce the threat of global climate change, two issues have consistently arisen: How much will CO_2 emissions grow in the U.S. and other nations in the absence of policy action? And what will it cost to restrain emissions relative to the expected baseline? Aggregate models of the relationship between energy and the macroeconomy have been applied extensively in the analysis of these questions (Manne & Richels, 1991; Jorgenson and Wilcoxen, 1991). While the details differ from case to case, these models project expected energy and economic trends

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targets. The models suggest that although the marginal cost of CO_2 emissions abatement is currently low, costs are expected to rise over time as the economy grows and the cheapest opportunities to reduce emissions are exhausted. Over the long term, the reduction of CO_2 emissions to 20% of their current level could cost several percent of national income.

Juxtaposed against such pessimistic findings are assessments of the technical potential to save energy. The ongoing process of innovation has led to the development of many technologies that offer both energy and cost savings as compared against the existing stock of equipment. As the equipment stock ages and is replaced, improved energy efficiency could yield CO_2 emissions reductions of nearly 40% with zero or negative economic costs given appropriate price signals and policies to overcome the market failures that impede the adoption of low-energy technologies (Ruderman et al., 1984; National Academy of Sciences, 1991; Howarth and Andersson, 1992).

The tension between these two approaches has fanned a heated debate. Although their results appear on the surface to be contradictory, in fact they are complementary, addressing fundamentally different aspects of the problem under consideration. The macroeconomic models allow for autonomous (non-price related) improvements in energy productivity as technology improves over time and examine the impacts of a carbon tax given existing market failures and institutional barriers to the improvement of energy efficiency. The technical potential studies provide a gauge of the rate at which new technologies could restrain future energy use and point to the opportunity to improve market performance through the removal of market barriers.

Missing from the debate, however, is a thorough analysis of the relationship between the ongoing process of economic development and the activities that drive energy use. While energy analysts have developed extensive data on the levels of energy-using activities, they have used such data mainly to establish the potential to reduce energy use while providing a constant set of energy services. Much less effort has been devoted to projecting future activity levels and their energy implications. If growth in energy-using activities exceeds the rate at which efficiency improvements may be achieved in practice, it follows that a reduction in energy services — a real cost to the economy — will be necessary to achieve CO_2 emissions restraint.

Nor have macroeconomic studies adequately broached the subject. The most widely cited model provides no details regarding the structure of energy use but models energy demand using a one sector, aggregate production function framework (Manne & Richels, 1991). Other models provide considerable disaggregation in the production sector of the economy but present energy demand for households and personal vehicles as an aggregate function of prices and income (Jorgenson and Wilcoxen, 1991). Since such uses account for some one-third to one-half final energy demand (depending on the nation), the implications of this aggregation scheme cannot be ignored.

This paper addresses both the structure and intensity of energy demand by presenting a descriptive history of the coupling between energy and economic activity in five nations: the United States, Norway, Denmark, West Germany, and Japan (see Schipper et al., 1990a, 1990b, 1992a, 1992b; Schipper and Meyers et al., 1992). The time frame of our analysis, 1973 to 1988, allows us to examine the trends that prevailed during periods of both increasing and decreasing energy prices. We decompose and analyze the changes in the level of energy end use to estimate the contribution of changes in both energy intensities and the corresponding activities that drive energy use. While we do not explicitly examine the role of price changes vs. so-called "autonomous" effects in driving the trends, we believe that our work yields insights that are useful in understanding the determinants of energy use.

METHODOLOGY

This paper focuses on the use of fuels and electricity to provide energy services to end users. Both purchased and nonpurchased fuels are considered, including for example the use of waste biomass in industry. We do not include the use of fuels for non-energy purposes such the use of hydrocarbons as construction materials or as feedstocks in the chemicals sector. Nor do we explicitly examine the losses that occur in petroleum refineries, district heat plants, electricity generation, and the distribution of energy carriers.

Because energy carriers vary substantially with respect to their physical properties and economic productivity, changes in the mix of energy products have significant implications for the structure and intensity of energy use. The most important differences are between fuels and electricity. Our basic unit of account is primary energy use, which weights the use of fuels by their thermal content at the point of end use. District heat and electricity are weighted by factors of 1.15 and 3.24 to account in an approximate way for the thermal losses associated with the production and distribution of these energy carriers. (The electricity coefficient assumes a conversion efficiency of 33.2% with 7% distribution losses.) These conversion factors do not correspond directly to actual conditions in the energy sectors of each nation. In Norway, for example, virtually all electricity is produced from hydropower at a conversion efficiency of about 85%. The approach is useful, however, because it allows for standard comparisons between nations.

The basis of our analysis may be described as follows. We decompose energy use into a range of separate categories according to the sector and/or context in which it occurs. These categories are outlined in detail in the following sections. Examples include the use of energy in the provision of space heat in residential buildings, the production of iron and steel, and the operation of automobiles. For each category we define an indicator that measures the activity associated with the energy use. Our activity indicators conform to established conventions in the energy literature. For residential space heat, for example, activity is defined as heated residential floor area. For the iron and steel sector, activity is measured in terms of real value added, while passenger-kilometers are used for automobile transportation. For each category, we then define energy intensity as the ratio of energy use per unit of activity.

Let E_t be energy use at date t, A_{it} be the level of activity i, and I_{it} be the corresponding energy intensity. Then $A_t = (A_{1t},\ldots,A_{nt})$ and $I_t = (I_{1t},\ldots,I_{nt})$ are the vectors of activity and energy intensity at date t, and the level of energy use is $E_t = A_t \cdot I_t$ by definition. While this formula is of little interest in itself, it provides the basis for performing interesting thought experiments. Let $E(A_t,I_0) = A_t \cdot I_0$ and $E(A_0,I_t) = A_0 \cdot I_t$ where A_0 and I_0 are the activity and intensity vectors for some base year. Then we define the activity effect

$$\%\Delta E_A = \frac{E(A_t,I_0)}{E_0} - 1 \qquad (1)$$

as the change in the proportional level of energy use relative to the base year that would have occurred over time given constant energy intensities but the actual development of activities. Similarly, the intensity effect

$$\%\Delta E_I = \frac{E(A_0, I_t)}{E_0} - 1 \quad (2)$$

is the relative change in energy use that would have occurred given constant activity levels but variable intensities. Given the algebraic relationship between the activity and intensity vectors, these effects sum to the actual change in energy use only with the addition of an interaction term (Howarth et al., 1991):

$$\%\Delta E = \%\Delta E_A + \%\Delta E_I + \frac{(A_t - A_0)\cdot(I_t - I_0)}{E_0}. \quad (3)$$

Nonetheless, the approach provides a readily interpreted and conceptually powerful method to understanding the nature of energy demand trends. The methodology may be applied to changes in total energy use or to the analysis of trends in a particular end-use sector.

The following sections provide an overview of the classification scheme used to disaggregate energy use. At an aggregate level, we divide energy use between six end-use sectors — the residential, service, manufacturing, other industrial, passenger transport, and freight sectors — with further disaggregation in most cases. Our data are based mainly on official national statistics and detailed analyses carried out by experts within each country. For a discussion of the data, see Schipper and Meyers et al. (1992).

Residential Sector

Energy use in the residential sector is broken down into five categories: the provision of space heat, electricity use for appliances, water heating, cooking, and lighting. For space heating, activity is defined as heated residential floor area. For appliances, activity is defined using an index of appliance ownership levels per capita weighted by unit electricity consumption in the base year. Because there is no direct measure of hot water use, cooking, or lighting services, the definition of activities that correspond to these uses is problematic. Past research, however, has shown that these uses grow in proportion to the total number of households multiplied by the square root of the number of occupants per household (Schipper et al., 1985 and 1989). We therefore use this product as our activity indicator for these energy services.

Manufacturing Sector

Analyses of the industrial sector have found that its energy use is highly concentrated in the processing of basic materials by thermal, mechanical, and chemical means. Five energy-intensive manufacturing industries — paper and pulp (ISIC[4] 341); chemicals (ISIC 351-2); stone, clay, and glass (ISIC 36); iron and steel (ISIC 371); and nonferrous metals (ISIC 372) — typically account for two-thirds of energy use although they account for only one-fifth of industrial production measured in terms of value added (Howarth and Schipper, 1991). We

[4] International Standard Industrial Classification.

partition industrial energy use between each of these sectors and a residual category, "other manufacturing". According to this framework, petroleum refining is part of the energy conversion sector and is thus omitted from the manufacturing sector. For each industry group, activity is measured in terms of real value added.

Other Industry

In addition to manufacturing, energy is used in a number of other industrial activities including mining, construction, agriculture, forestry, and fishing. These sectors typically account for only about 5% of final energy demand, and the breakdown of energy use between each class of activity is difficult to achieve given existing data. We therefore consider the energy use of these industries only in aggregate terms, taking total real value added summed across sectors as our activity indicator.

Service Sector

As in the residential sector, service-sector energy use is dominated by the provision of building energy services — space conditioning, water heating, lighting, and the operation of electrical equipment. Although there is a wealth of studies of the technical potential to save energy in certain service-sector activities, the breakdown of energy use by end use or subsector over time is not available in most nations. We thus examine service sector energy use only in aggregate terms. Sectoral activity is defined in terms of real value added or contribution to national income (Schipper et al., 1986).

Passenger Transport

We disaggregate the energy used for passenger transportation into four modes: personal vehicles, including automobiles and light trucks; rail; buses; and airplanes. The rail and bus categories include both local and intercity traffic. The energy use of motorcycles and water transport systems is small in magnitude and thus safely ignored. The definition of modal activity levels is somewhat problematic. In an abstract sense, travel by car and travel by train are not equivalent; nor even are travel in subcompact vs. full-sized cars. For comparative purposes, however, we use passenger-kilometers as our indicator of transportation activity for each mode. For a further discussion of this issue, see Schipper et al. (1992c).

Freight Transport

We divide the energy use of the freight sector into four separate modes: road, rail, ship, and air freight. The "road" category is dominated by trucks, including local delivery vans and long-distance tractor-trailers. Although there are significant differences in the energy intensities of different types of road freight carriers, it is generally not possible to achieve a further degree of disaggregation. For each mode, activity is measured in tonne-kilometers (Schipper and Meyers et al., 1992, Ch. 4).

RESULTS

The development of primary energy use in the five nations under consideration between 1973 and 1988 is shown in Figure 1. As the figure indicates, energy use grew strongly in Norway (37%) and Japan (27%), with little net change in the other countries. Generally speaking, energy use declined somewhat following the oil price shocks of 1973 and 1979, but grew steadily in the late 1970s and mid to late 1980s. An exception to the rule was Norway, where the growth in energy use was virtually uninterrupted.

Per capita energy use increased in Japan, West Germany, and especially Norway but showed little change in the U.S. and Denmark (Figure 2). In 1988, primary energy use per person was highest in Norway, dominated by the production of energy-intensive raw materials and the provision of space heat using electricity. This disparity was caused in part by the availability of low-price hydroelectricity to Norwegian energy users (Figure 3). The level of energy use was also high in the U.S., especially in the residential, service, and transportation sectors. West Germany, Denmark, and Japan used 42%, 48%, and 56% less primary energy per capita than the U.S. in 1988.

The ratio of primary energy use to gross domestic product fell by 17% in West Germany, 20% in Norway, 23% in the U.S., 26% in Denmark, and 28% in Japan (Figure 4). But while the relative changes were broadly similar among nations, their sources were rather different. Figure 5 shows the development in energy use that would have occurred if energy-using activities had remained frozen at their 1973 levels while energy intensities followed their actual paths. The data indicate that energy intensities were relatively constant in Norway while reductions of up to 20% occurred in the other nations. For the U.S. and West Germany, the change in real energy intensity (the index of changes in individual intensities weighted by base-year activity levels) closely matched the change in the energy/GDP ratio. In Japan, however, real intensity fell by just 14% — only half the reduction in the energy/GDP ratio. A smaller gap (20% vs. 26%) was observed for Denmark.

Where they occurred, energy intensity reductions were most rapid in the late 1970s and early 1980s, a period marked by high and unstable oil prices (Figure 6). In most cases, the trend slowed or reversed by the mid-1980s as real energy intensity approached an apparent plateau. This pattern was observed first in Denmark, where energy intensity was relatively stable after 1981.

Figure 7 shows the development in energy use that would have occurred if energy intensities had remained fixed at their 1973 levels while energy-using activities followed their actual course. The provision of "energy services" grew significantly in all five nations; the total growth was 33% in Denmark, 37% in West Germany, 42% in Norway, 46% in the U.S., and 53% in Japan.

Figure 8 shows the change in energy services relative to GDP. The ratio of total energy-using activities (weighted by their corresponding 1973 energy intensities) was relatively constant in West Germany and the U.S. but fell by 4% in Denmark, 17% in Norway, and 13% in Japan. Thus structural change — shifts in energy-using activities relative to the aggregate economy — caused essentially all of the decline in the Norwegian energy/GDP ratio and half of the decline in Japan.

Detailed information on 1973-1988 developments in energy intensities and energy-using activities in the major end-use sectors is given in Table 1. These calculations, which are based on our definition of primary energy use, show considerable variation among countries and sectors. Table 2 presents the same set of calculations for developments in delivered energy use, which counts energy carriers (including district heat and electricity) based on their thermal content at the point of end use without adjusting for upstream conversion and distribution losses. The differences in the results for the primary and delivered energy measures are principally attributable to increases in the share electricity relative to total energy use (Table 3).

A detailed comparison of the developments in each end-use sector is beyond the scope of this paper (see Howarth and Schipper, 1991; Howarth et al., 1991; Schipper et al., 1986, 1989; Schipper and Meyers et al., 1992). Here we sketch the main trends that occurred in each of the five nations.

United States

In United States, growth in energy-using activities in the residential and service sectors outstripped the increase in GDP between 1973 and 1988 (Schipper et al., 1990a). While total manufacturing production, measured in terms of real value added, kept pace with GDP, a shift away from energy-intensive industries in the late 1970s and early 1980s caused the growth in industrial energy services to lag behind national income — a pattern also observed in passenger and freight transportation.

Energy intensity fell substantially in the manufacturing, residential, and passenger transport sectors; less progress was realized in other sectors of the economy. While delivered energy intensity fell by 27% in the service sector, electrification restrained the reduction in primary energy intensity to 11%.

Norway

The rise of the offshore oil sector in Norway in the 1970s provided a burst of income growth that caused significant changes in the structure of the economy (Schipper et al., 1990b, 1992b). Rising incomes led to explosive growth in the service sector and in passenger transportation. Growth in residential energy services, while significant, lagged GDP by a wide margin. Little growth occurred in total manufacturing value added, but the availability of low-price electricity permitted the continued growth of energy-intensive industries so that energy-using activities in manufacturing grew by 36% while GDP increased by 71%.

Primary energy intensity rose significantly in the residential and service sectors, driven by the increased use of electricity for the provision of space heat. Only in manufacturing did energy intensity fall substantially over time. Nonetheless, the energy/GDP ratio fell by 20% because of the slow growth in energy-using activities relative to GDP.

Denmark

Energy-using activities in the Danish residential and freight sectors grew in step with the economy (Schipper et al., 1992a). Industrial energy services grew less rapidly than GDP, mainly because of a declines in the relative importance of energy-intensive industries. Growth in the passenger transportation sector was limited by high taxes on fuels and vehicles that limited the ownership of automobiles.

Substantial reductions in energy intensity were achieved in the industrial and service sectors. The largest reductions, however, occurred in the residential sector, where primary energy intensity fell by 30% as Danes improved the thermal integrity of their homes and modified their behavior to save energy. Little change occurred in the energy intensity of passenger transportation, while energy intensity increased by 13% in freight transport.

West Germany

In West Germany, the growth in energy-using activities in the residential and service sectors far outstripped the 33% growth in GDP that occurred between 1973 and 1988. The passenger and freight transport sectors also grew somewhat more rapidly than GDP. Manufactuing energy services, on the other hand, grew by only 9% due to restrained growth in total manufacturing value added and shifts away from energy-intensive industries. But while important changes occurred in the structure of the West German economy, these tendencies had offsetting impacts on energy use so that the total growth in energy-using activities closely matched the change in national income.

Substantial energy savings were achieved in all end-use sectors except for passenger transportation, where increases in the size and performance of automobiles and decreased load factors led to a 12% rise in energy intensity.

Japan

Japan experienced a 77% increase in national income between 1973 and 1988 that led to parallel growth in energy-using activities in the residential, service, and passenger transport sectors. The growth in energy-using activities was relatively restrained in freight transport and in manufacturing, where the production of energy-intensive goods fell relative to total industrial production. Production activities continue to dominate energy use in Japan. In 1973, the industrial and freight sectors accounted for 72% of primary energy use. This figure fell to 59% by 1988. Despite the growth in energy services in some sectors, then, the total growth in energy-using activities fell substantially behind the rise in GDP.

A large reduction in manufacturing energy intensity was observed over the period of analysis. A smaller decrease occurred in freight transportation. In the residential sector, primary energy intensity rose by 21% due to increased heating levels and electrification. The primary energy/GDP ratio fell by 28%, while primary energy intensity, averaged across sectors, fell by only half as much. Structural change thus had important implications for the development of energy use in Japan.

CONCLUSIONS

The analysis presented in this paper is purely descriptive in nature. Our aim is to identify key patterns and trends in the structure and intensity of final energy demand, not to discern their causes or model their future development.

That said, the results of our work may be used to construct simple scenarios that illustrate the potential consequences of ongoing energy-use trends. Between 1973 and 1988, total energy-using activities (weighted by 1973 primary energy intensities) grew by 1.9 %/yr in Denmark, 2.1 %/yr in West Germany, 2.4 %/yr in Norway, 2.6 %/yr in the U.S., and 2.9 %/yr in Japan. Primary energy intensities (weighted by 1973 activity levels), fell by 0.2 %/yr in Norway, 1.0 %/yr in Japan, 1.2 %/yr in West Germany, 1.5 %/yr in the U.S., and 1.5 %/yr in Denmark. If these trends continued 30 years into the future (with uniform changes in all activity levels and energy intensities), primary energy use would grow by a total of 13% in Denmark, 29% in West Germany, 38% in the U.S., 75% in Japan, and 95% in Norway.

While policy makers are considering the goal of stabilizing or reducing energy use to alleviate the threat posed by global climate change, the trends are pointing to substantial increases in energy use in the absence of concerted policy action. Indeed, these naive scenarios probably underestimate the rate of energy growth since they assume that energy intensity will fall at its historic 1973-1988 rate. As we have seen, however, progress towards reduced energy intensity slowed considerably as oil prices eased in the mid 1980s.

The future course of final energy demand will depend on a large number of underlying factors. It is tempting but misleading to assume that energy demand is a simple function of energy prices and the level of aggregate economic activity. Energy costs are generally a small share of the total costs of any given activity, and both activity levels and their related energy intensities are driven in large part by changes in lifestyles, technologies, and the structure of the economy.

In the manufacturing sector, for example, the 1973-1988 trend towards improved energy productivity is consistent with long-term trends dating back to the 1950s; the high and uncertain energy prices of the post-oil-shock era did not induce an obvious acceleration of the trend (Howarth, 1991; Howarth and Schipper, 1991). This descriptive finding does not necessarily imply that energy prices had no impact on energy use. But "autonomous" energy intensity reductions of 2-3 %/yr have occurred even during periods of stable energy prices due to the uptake of new process technologies. A second important question is the role of energy-intensive raw materials in the future economy. While the empirical evidence suggests a decline in the relative importance of materials processing relative to aggregate economic activity, the sources of this change — and hence their implications for future energy use — remain uncertain.

Standing in sharp contrast are developments in the consumer-driven energy-demand sectors. Of the nations considered in this analysis, substantial improvements in automobile fuel economy occurred only in the United States in the 1970s and 1980s — a development caused more by U.S. fuel economy standards than by increases in the price of fuel over the period (Schipper et al., in prep., Ch. 4; Greene, 1990). In the residential sector, consumer incentives to improve energy efficiency are often weak; although opportunities exist to achieve energy and financial savings, the total benefits are often too small to motivate homeowners to take action. The development of transportation energy use will depend on trends in automobile ownership, driving behavior, and the characteristics of the vehicle stock. Underlying determinants include lifestyle factors such as the emergence of two-income families and increased recreational travel in addition to the conventional explanatory variables of price and income.

In general terms, our perspective is that models of energy demand should be rooted in an understanding of the conditions of real-world energy use — not purely theoretical structures that are analytically appealing but limited in their realism and explanatory power. Disaggregation by class of activity is a first step towards realistic modeling. Within this framework, one should pay careful attention to the complex of factors that shape both the structure and intensity of energy demand.

Table 1. Impacts of changing activity levels on primary energy use.

	% Change, 1973 - 1988				
	USA	Norway	Denmark	Germany	Japan
RESIDENTIAL SECTOR					
Actual Energy Use	+14%	+69%	-9%	+18%	+89%
Activity	+62%	+33%	+36%	+61%	+77%
Intensity	-25%	+18%	-30%	-23%	+21%
MANUFACTURING SECTOR					
Actual Energy Use	-6%	+9%	-1%	-7%	-2%
Activity	+34%	+36%	+20%	+9%	+40%
Intensity	-27%	-16%	-15%	-14%	-30%
OTHER INDUSTRY					
Actual Energy Use	+5%	+29%	-15%	+3%	+29%
Activity	+3%	+23%	+10%	-2%	-2%
Intensity	-12%	+4%	-23%	+6%	+36%
SERVICE SECTOR					
Actual Energy Use	+36%	+97%	+21%	+20%	+95%
Activity	+54%	+70%	+51%	+58%	+85%
Intensity	-11%	+16%	-20%	-24%	+5%
PASSENGER TRANSPORT					
Actual Energy Use	+11%	+81%	+13%	+56%	+77%
Activity	+36%	+78%	+20%	+39%	+70%
Intensity	-14%	+7%	-4%	+12%	+5%
FREIGHT TRANSPORT					
Actual Energy Use	+40%	+43%	+69%	+19%	+34%
Activity	+38%	+58%	+42%	+43%	+45%
Intensity	-1%	-5%	+13%	-22%	-14%
ALL SECTORS					
Actual Energy Use	+12%	+37%	+2%	+11%	+27%
Activity	+46%	+42%	+33%	+37%	+53%
Intensity	-19%	-3%	-20%	-15%	-14%
GDP	+45%	+71%	+39%	+33%	+77%
ENERGY/GDP	-23%	-20%	-26%	-17%	-28%

Table 2. Impacts of changing activity levels on delivered energy use.

	% Change, 1973 - 1988				
	USA	Norway	Denmark	Germany	Japan
RESIDENTIAL SECTOR					
Actual Energy Use	-2%	+41%	-22%	+6%	+68%
Activity	+65%	+36%	+33%	+59%	+65%
Intensity	-28%	-1%	-41%	-32%	+8%
MANUFACTURING SECTOR					
Actual Energy Use	-13%	+0%	-20%	-20%	-12%
Activity	+32%	+33%	+18%	+5%	+38%
Intensity	-32%	-21%	-30%	-23%	-35%
OTHER INDUSTRY					
Actual Energy Use	-15%	+19%	-19%	-1%	+33%
Activity	+3%	+23%	+10%	-2%	-3%
Intensity	-12%	-3%	-26%	+2%	+40%
SERVICE SECTOR					
Actual Energy Use	+12%	+43%	-6%	+1%	+58%
Activity	+54%	+70%	+51%	+58%	+85%
Intensity	-27%	-16%	-38%	-37%	-15%
PASSENGER TRANSPORT					
Actual Energy Use	+11%	+81%	+13%	+56%	+77%
Activity	+36%	+78%	+19%	+39%	+70%
Intensity	-14%	+7%	-4%	+12%	+5%
FREIGHT TRANSPORT					
Actual Energy Use	+40%	+43%	+69%	+19%	+34%
Activity	+38%	+58%	+41%	+43%	+45%
Intensity	-1%	-5%	+13%	-22%	-14%
ALL SECTORS					
Actual Energy Use	+3%	+24%	-10%	+2%	+16%
Activity	+45%	+44%	+31%	+36%	+50%
Intensity	-23%	-11%	-29%	-22%	-20%
GDP	+45%	+71%	+39%	+33%	+77%
ENERGY/GDP	-29%	-27%	-35%	-24%	-34%

Table 3. Electricity as a fraction of total delivered energy use (%).

	1973	1988
United States	11.5	15.5
Norway	38.0	44.0
Denmark	8.5	17.4
West Germany	11.1	16.1
Japan	13.3	20.5

Primary Energy Use

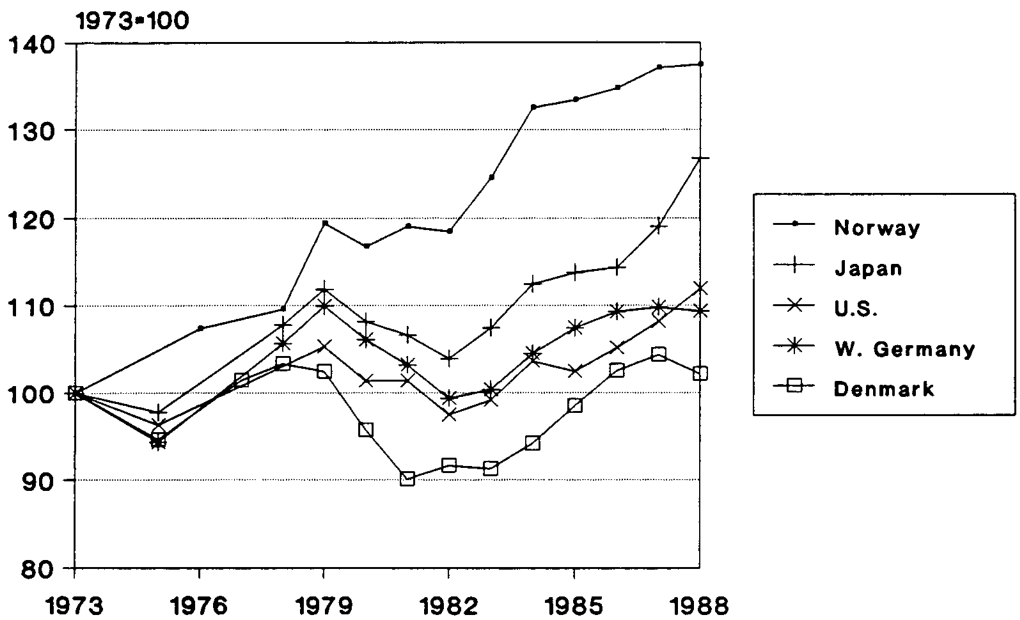

Figure 1

Primary Energy by End-Use Sector: 1973 and 1988

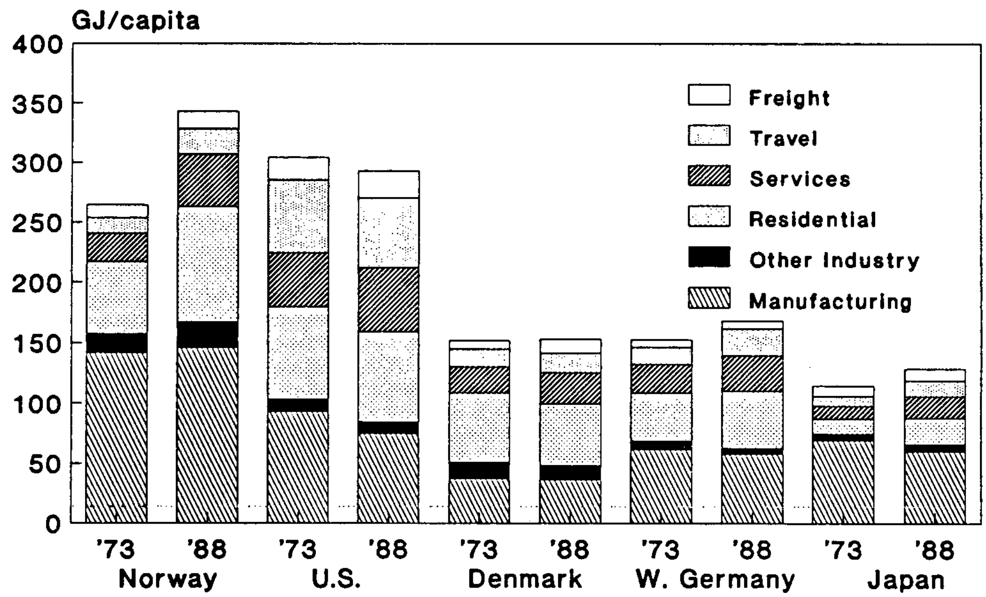

Figure 2

Industrial Electricity Prices

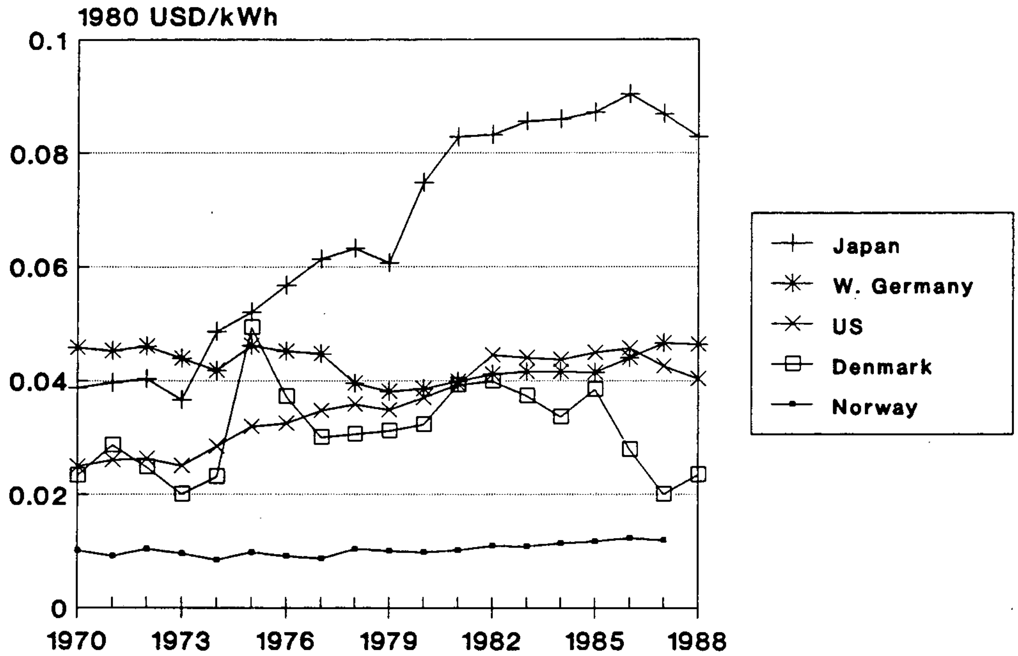

Figure 3

Primary Energy/GDP

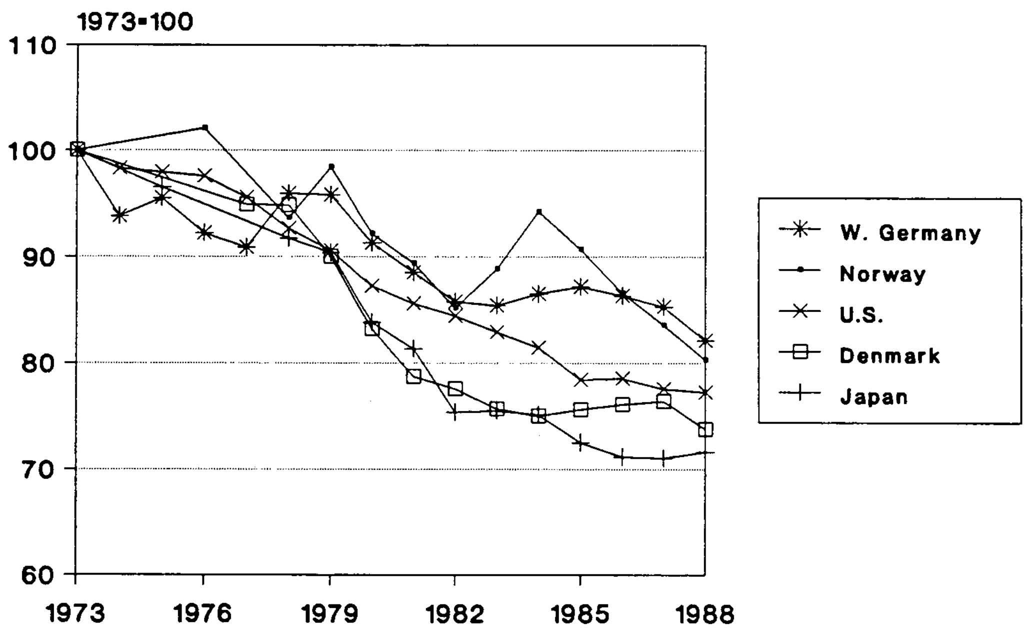

Figure 4

Primary Energy Use: Actual Energy Intensities, 1973 Activity Levels

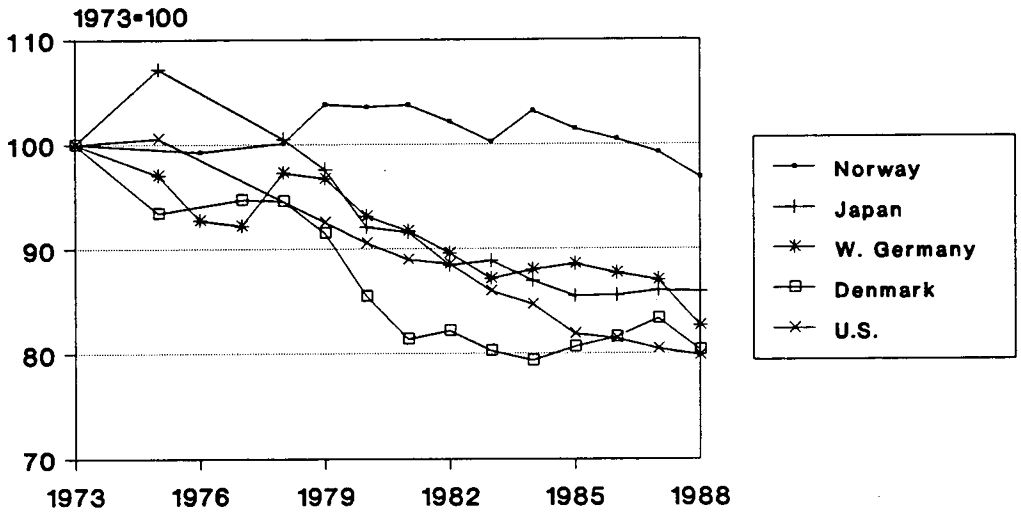

Figure 5

Residential Heating Oil Prices

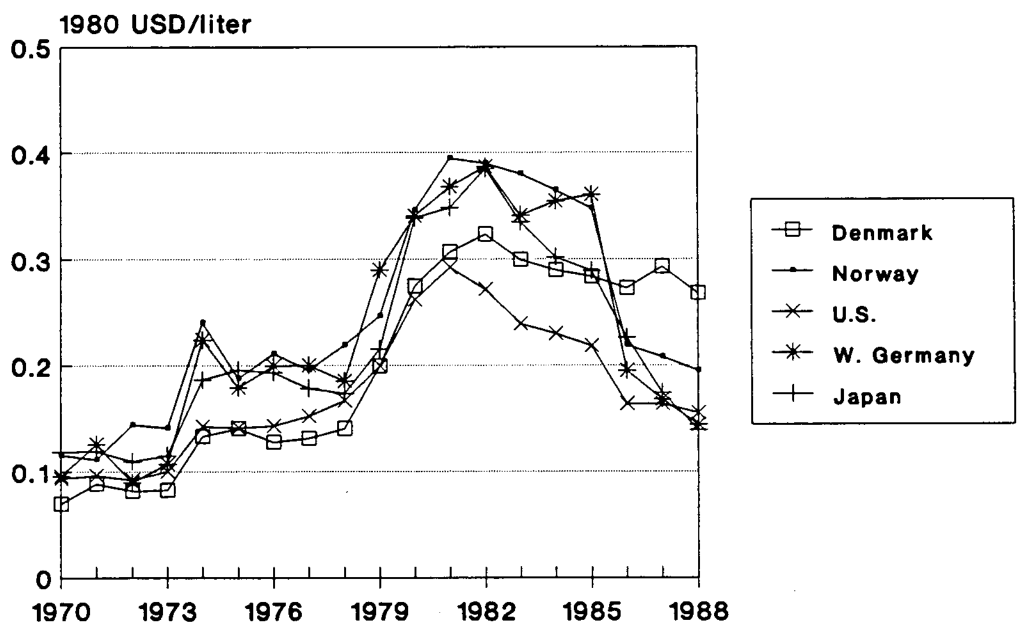

Figure 6

Primary Energy Use: Actual Activity Levels, 1973 Energy Intensities

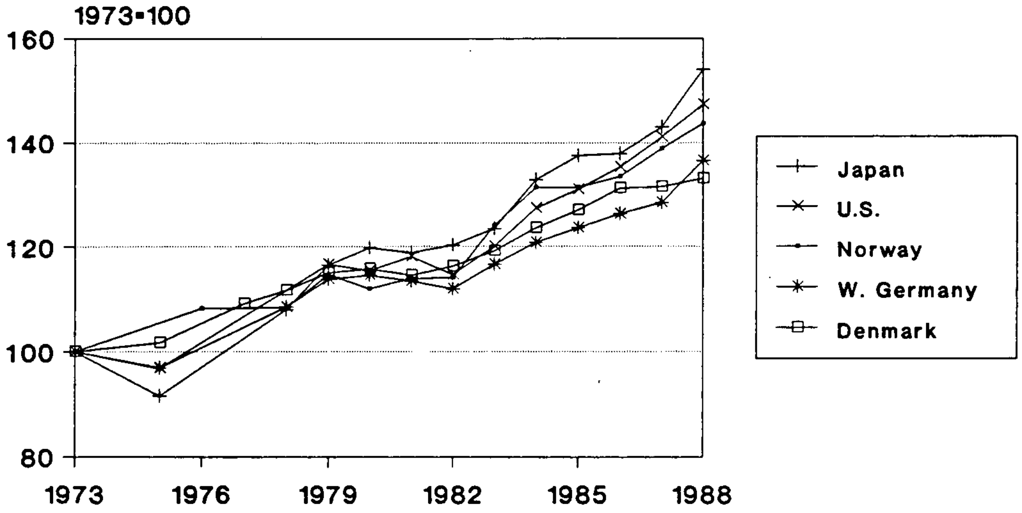

Figure 7

Energy-Using Activities/GDP

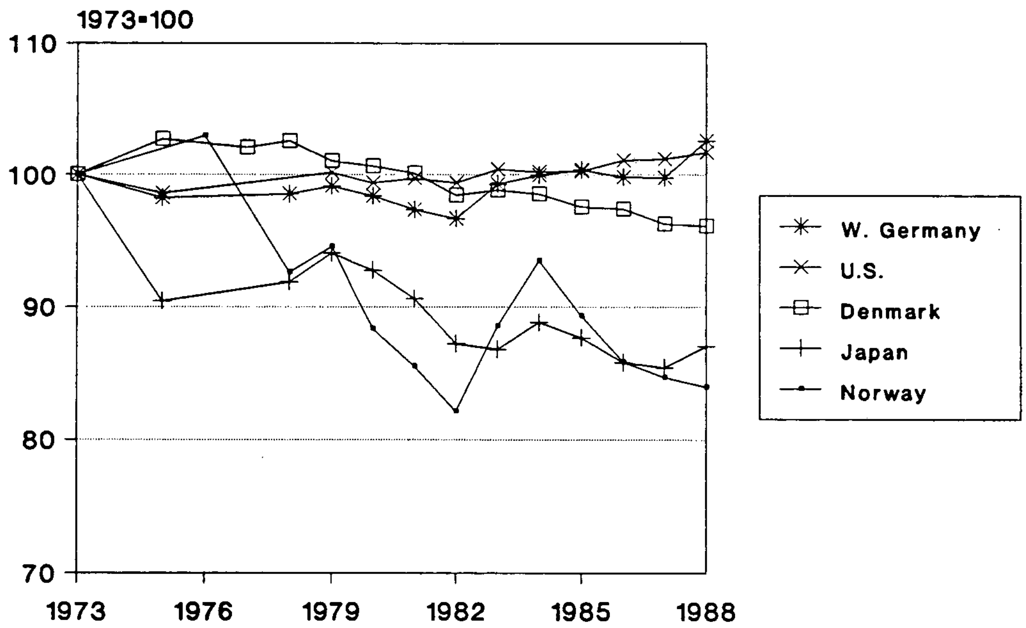

Figure 8

REFERENCES

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

Howarth, R.B. (1991). "Energy Use in U.S. Manufacturing: The Impacts of the Energy Shocks on Sectoral Output, Industry Structure, and Energy Intensity." *Journal of Energy and Development* 14: 175-191.

Howarth, R.B. and B. Andersson (1992). "Market Barriers to Energy Efficiency." Lawrence Berkeley Laboratory, LBL-32541.

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

Howarth, R.B., L. Schipper, P.A. Duerr, and S. Strøm (1991). "Manufacturing Energy Use in Eight OECD Countries." *Energy Economics* 13: 135-142.

Jorgenson, D.W. and P.J. Wilcoxen (1991). "Reducing U.S. Carbon Dioxide Emissions: The Cost of Different Goals." In *Advances in the Economics of Energy and Resources* (J.R. Moroney, ed.). Greenwich, Connecticut: JAI Press.

Manne, A.S. and R.G. Richels (1991). "Global CO_2 Emission Reductions — the Impacts of Rising Energy Costs." *The Energy Journal* 12(1): 87-108.

National Academy of Sciences (1991). *Policy Implications of Greenhouse Warming — Report of the Mitigation Panel.* Washington: National Academy Press.

Ruderman, H., M.D. Levine, and J.E. McMahon (1984). "The Behavior of the Market for Energy Efficiency in Residential Appliances including Heating and Cooling Equipment." *The Energy Journal* 8(1): 108-124.

Schipper, L., S. Bartlett, D. Hawk, and E. Vine (1989). "Linking Life-Styles and Energy Use: A Matter of Time?" *Annual Review of Energy* 14: 273-320.

Schipper, L., R.B. Howarth, and B. Andersson (1992a). "Energy Use in Denmark: An International Perspective." Lawrence Berkeley Laboratory, LBL-32362.

Schipper, L., R.B. Howarth, and E. Carlassare (1992b). "Energy Intensity, Sectoral Activity, and Structural Change in the Norwegian Economy." *Energy — The International Journal* 17: 215-233.

Schipper, L., R.B. Howarth, and H. Geller (1990a). "United States Energy Use from 1973 to 1987: The Impacts of Improved Efficiency." *Annual Review of Energy* 15: 455-504.

Schipper, L., R.B. Howarth, and D. Wilson (1990b). "A Long-Term Perspective on Norwegian

Energy Use." Lawrence Berkeley Laboratory, LBL-27295.

Schipper, L., A. Ketoff, and A. Kahane (1985). "Explaining Residential Energy Use by International Bottom-Up Comparisons." *Annual Review of Energy* 10: 341-406.

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

Schipper, L., S. Meyers, and A. Ketoff (1986). "Energy Use in the Service Sector: An International Perspective." *Energy Policy* 14: 201-218.

Schipper, L., R. Steiner, P. Duerr, F. An, and S. Strøm (1992c). "Energy Use in Passenger Transport in OECD Countries: Changes Since 1970." *Transportation* 19: 25-42.