OECD Household Energy Use Efficiency After the Oil-Price Crash: End of an Era?

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We have analyzed developments in the structure and efficiency of household energy use in OECD (Organization for Economic Cooperation and Development) countries through 1990. We found a slowdown in the improvement rate of space-heating efficiency since the oil-price crash of 1986, but the efficiency of electric appliances appears to be increasing and may accelerate as utility and government programs reinforce market pressures for greater efficiency. Overall, household energy intensities declined 2.5%/year between 1973 and 1985 but only 1.2%/year between 1985 and 1990. Higher energy prices were the most important stimulus, but efficiency programs-thermal standards for new homes and appliance efficiency programs-also played a role.

Efficiency improvements were not the only changes. Larger homes, increased appliance holdings, and smaller households boosted energy use throughout the entire period. These income-driven increases offset gains from efficiency in many countries. But energy services are beginning to saturate, and future increases in incomes will not produce the same percentage increases in household energy use.

Concerns over the environment and the greenhouse effect have focused attention on the evolution of energy use in each major sector. Future household energy use depends on the competition between structural factors increasing energy use and technical and behavioral forces that could either reduce or increase intensities. With present trends, total household energy use will increase unless a combination of higher energy prices (which stimulate energy-saving behavior as well as accelerated take-up of energy-efficient technologies) and efficiency programs rekindle interest in improving efficiency.

Introduction

During the last two decades interest in household energy use (about 20% of final energy use in OECD countries) has shifted throughout a series of perceived energy-related problems (Schipper, Meyers, et al. 1992). In the 1970s, the years after the first oil-price shock, oil use itself was the focus of most energy policies. As prices for all energy forms increased with the second oil shock, pressure mounted to seek other energy sources and improve energy efficiency. In the late 1980s, concern over nuclear power as well as recognition of the potential for improving efficiency shifted the focus of energy policies once again. Now the emerging apprehension over the release of CO_2 and other greenhouse gasses into the atmosphere from fossil fuels has thrust the use of these energy sources into the center of much energy policy.

The course of post-1985 household energy use differed from the trends of the 1970s and early 1980s. Real prices stopped rising or even fell. Did this affect the changes that we have observed? The decline in the share of oil in total energy use slowed, but did not stop or reverse significantly in most countries. Slower growth in electricity use appears to be permanent too. However, there was a distinct slowdown in the rate of decline in household energy use per unit (energy intensity) after 1985, suggesting that a plateau of efficiency is already characterizing the early 1990s. But with stable energy prices and secured sources, stagnated energy use should not be a worry for anyone.

A new concern, carbon dioxide, and measures to restrain its emissions will undoubtedly be a policy goal for many countries. We have already traced sources of CO_2, and our results show how changes in household energy use led to declines in per capita CO_2 emissions. But a change in this pattern of sustained reversal could boost residential CO_2 emissions, thus subjecting energy use to additional strong policy measures. Hence our concern for the evolution of household use after 1985. Although CO_2 is not the primary focus of this paper, we report its calculations as a useful index of the environmental impact of energy use.

The slowdown in improvements in efficiency does not signify the end to improvements in efficiency, even with the fall in energy prices. The slow pace of replacement or renovation of homes, as well as the more rapid replacement of electric appliances, ensures a slow improvement in efficiencies because the newer (or renovated) systems are almost always more efficient than those they replace. Moreover, some countries' policies, particularly those governing the efficiency of household appliances, could spark significant improvements in these devices throughout the 1990s.

A number of national studies suggests a significant potential for improving the thermal properties of existing homes. But without strong policy measures, or significantly higher real energy prices, or both, the improvements in space-heating efficiency may be slow, while those that could affect electric appliances, while significant, may only represent part of the long-term potential for improvement.

Trends in Household Energy Use in OECD Countries

Between 1972-73 and 1990, residential delivered energy use increased by an average annual rate of 0.31% in Europe-4 and 3.3% in Japan, but contracted by 0.25% year in the U.S. by 0.29% in the Scandinavia-3.[1]

Table 1 shows aggregate energy use for households in the nine OECD countries in 1973 and 1990 as well as per capita values of the same consumption. Indicators like per capita energy use or heating energy use per square meter of floor space are called "energy intensities. " In general, the energy intensity of an end use is the inverse of the energy efficiency of the end use. (The per capita values show a considerable variation, which is discussed in Schipper, Meyers, et al. 1992.) Per capita energy use only declined in five countries, but, the efficiencies of most uses in most countries actually improved.

Electricity and district heat require considerably more energy resources in order to be transformed (and distributed) to reach a building's boundary. Including this energy, the resulting primary energy use increased by 0.8%/year in the Europe-4 and 1.7%/year in the Scandinavia-3, by 4.4%/year in Japan, and by 0.8%/year in the U.S. These differences between rates of growth of delivered and primary energy—more than 1.5 percentage points per year in Scandinavia and around 1 point in the U. S.–arose because of the growth in electric heating and appliance ownership. This growth increased the share of

Table 1. Residential Energy Use in Nine OECD Countries in 1973 and 1990

	Delivered[(a)] Energy Use (EJ)		**Energy Use Per Capita (GJ)**	
	1973	**1990**	**1973**	**1990**
United States	11.33	10.86	53.6	43.4
Japan	0.91	1.62	8.1	13.1
Europe-4	6.28	6.62	29.1	29.5
W. Germany	1.98	2.10	31.9	33.3
G.B.	1.80	1.73	38.5	36.1
France	1.58	1.70	29.9	29.6
Italy	0.95	1.14	17.3	19.7
Scandinavia-3	0.74	0.71	43.6	39.5
Sweden	0.38	0.37	47.0	42.2
Norway	0.12	0.17	29.3	40.5
Denmark	0.25	0.17	49.4	33.4

(a) Delivered energy, including wood, counting the thermal content of electricity and district heating provided at the boundary of the home. Correction for annual variations in winter severity are explained in Schipper, Meyers, et al. (1992).

electricity in final energy use and thereby increased primary energy use relative to delivered energy use.

Knowing total primary energy use, we can calculate the resulting CO_2 emissions, which in our calculation include the fuels converted to electricity and district heat. Figure 1 shows that per capita CO_2 emissions were lower in 1990 than in 1973 in all but two countries. The reasons include significant shifts away from coal for direct use (West Germany, U.K.), shifts from oil to gas for heating (in most countries), shifts from fossil fuels for electricity production (Sweden, France) and for space heating (Sweden, Norway), and significant reductions in per capita energy use for space and water heating (Denmark, particularly the U.S.). However, other factors served to increase per capita CO_2 emissions in Italy and Japan (Sheinbaum and Schipper, 1993).

Shifts in fuel mix played an important role in restraining or reducing CO_2 emissions. Table 2 shows the use of oil and electricity, in 1973 and 1990, each measured in per capita terms and as a share of total delivered energy (gas and district heating (in Sweden and Denmark) provided most of the remainder).

The changes in fuel mix laid out in Table 2 were brought about by four important factors:

- Changes in the importance of lighting and appliances, which raised electricity use, all else being equal, and reduced the importance of space-heating fuels such as oil.
- Reductions in the unit consumption of each of the final uses, reductions that may have been led by decreases in the intensity for one fuel (oil in most cases) more than in the intensities of others.
- Switches in the principal fuel used in existing homes for heating space or water or for cooking, which was led by conversions away from oil-based space and water heating, with some gains by electricity.
- Changes in the sources chosen for new homes and equipment, which saw a drastic drop in the importance of oil, in favor of gas, in the U. S., Great Britain, and continental Europe, electricity in Norway and Sweden, and district heating in Sweden and Denmark.

We see that the importance of oil declined dramatically in most countries, which fulfills a major policy goal of OECD countries. Growth in electricity use was substantial, although this growth slowed in the late 1980s (Schipper, Meyers, et al. 1992).

The indicators reviewed above, while implying that great changes in household energy use took place during the last 20 years, are not sufficiently disaggregated to permit further conclusions. Changes in electricity use, changes in CO_2 emissions, and changes in efficiency have many components that are obscured when only total aggregate energy use is studied. Since we have investigated electricity use and CO_2 in other studies (Schipper, Ketoff, Meyers, and Hawk 1987; Sheinbaum and Schipper 1993), we focus the remainder of this paper on efficiency.

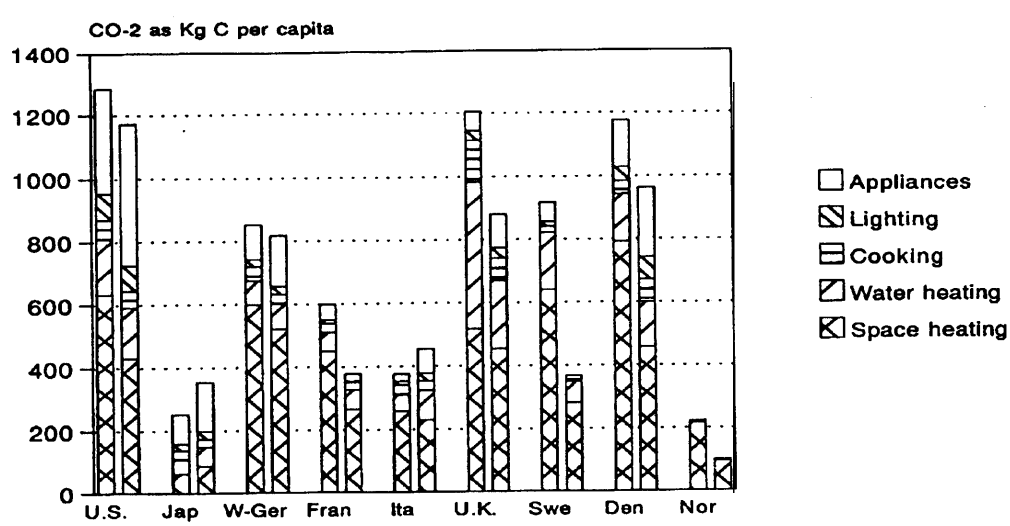

Figure 1. 1973 and 1990 OECD Residential CO_2 Emissions

Table 2. Residential Energy Use in OECD Countries in 1973 and 1990: Shares of Oil and Electricity in Final Demand

	Oil (%)		Electricity (%)	
	1973	**1990**	**1973**	**1990**
United States	28.1	14.7	18.6	31.5
Japan	42.3	34.9	27.9	38.6
Europe-4	47.2	28.3	13.8	18.3
West Germany	61.3	40.6	11.3	18.1
G.B.	16.6	9.2	23.9	16.4
France	53.9	28.8	7.5	21.0
Italy	69.6	35.6	9.3	15.5
Scandinavia-3	65.3	24.3	18.7	43.2
Sweden	70.1	25.0	15.1	39.2
Norway	37.4	11.5	51.8	73.3
Denmark	71.8	34.6	7.6	20.0

A Closer Look at Changes in Household Energy Use

Between 1973 and 1990, per capita final energy use declined by 19% in the U.S. and by 9.4% in Scandinavia-3, but rose by 1.4% in Europe-4 and by 55% in Japan. Growth was slowest, or the decline was greatest, in the 1979-1985 period. In all countries except Japan, growth was strongest, or the decline least, in the 1986-1990 period, which strongly suggests a rebound in energy use following the crash in prices in 1986. By contrast, the growth in Japan was greatest before 1979. To understand how these changes might hide trends in improving efficiency, we must disaggregate the components of change more carefully, which we do below. Figure 2 shows the pattern of final energy use by end use for the four regions.

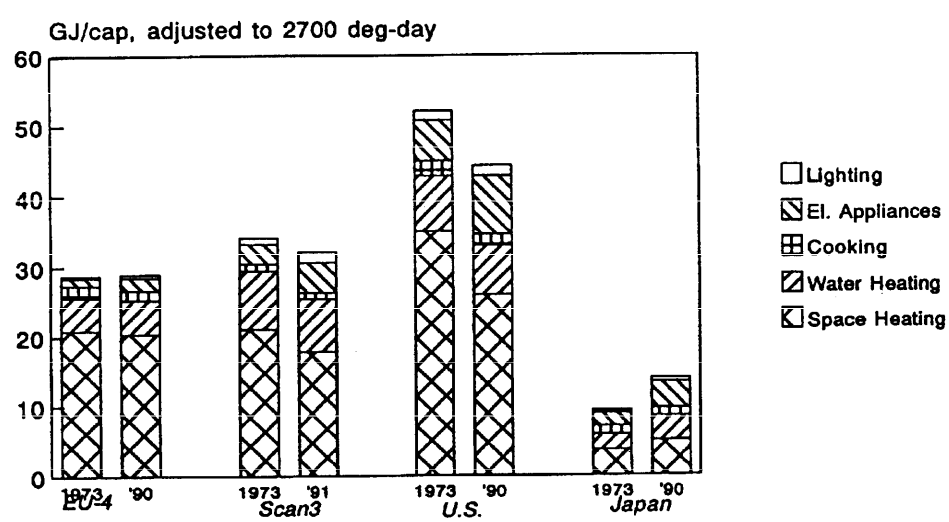

Figure 2. OECD Residential Energy Use (Deliver Energy)

Some of the changes in residential energy use occurred because electricity or district heating, for which there are no combustion losses in the home, substituted directly for fossil fuels, the use of which entails significant losses.[2] To be able to compare fossil fuels with electricity and district heat, we introduce the concept of "useful energy." Useful energy more closely measures the amount of heat and hot water delivered to consumers by subtracting combustion losses (assumed to be 33% of the oil and gas consumed in homes and 45% of the solid fuels). This action sets the use of these fuels on a basis that is easier to compare with electricity and district heat. During the 1973-1990 period, per capita useful energy consumption declined by 15% in the U.S. and 2.3% in Scandinavia-3, but rose by 4.3% in Europe-4 and by a full 69% in Japan. This growth was strongest in the 1985-1990 period, again suggesting a rebound in energy use after the crash in energy prices. [3] We observe the behavior of broad indicators of household energy use changing in the most recent period for which data are available. To see if these increased growth rates spell an end to improvements in efficiency, we must disaggregate our figures further.

We decompose the evolution of household energy use into three components (Schipper, Meyers, et al. 1992; Howarth, Schipper, Andersson 1992):

- Activity, which is measured by population, the ultimate force driving residential energy use.
- Structure, which measures per capita heated home area and equipment ownership for heating, water heating, lighting, cooking, and major electric appliances. (Note that shrinking household size boosts per capita ownership of equipment.)
- Energy intensities, or unit energy consumption, of each of these major end uses.

These changes are combined with 1973 energy-use patterns to show the effect of each change alone on energy use using Laspeyres indices (Howarth, Schipper, and Duerr 1990; Schipper, Steiner, Duerr, An, and Strain 1991).

Structural Factors Influencing Household Energy Use

Structural factors have an important effect on our analysis because they sometimes masquerade as changes in efficiency, sometimes mask real changes in efficiency, and at the same time often offset the impact of improved efficiency on household energy uses:

- Between 1972-73 and 1990, average household size fell from 3.1 to 2.67 persons in the U. S., from 3.77 to 3.17 in Japan, from 2.93 to 2.51 persons in Europe-4, and from 2.57 to 2.2 in Scandinavia-3. All else being equal, per capita energy use rises as household size decreases because energy uses in a homes are shared among fewer people (Schipper, Bartlett, Hawk, and Vine 1989).
- The average size of homes has increased moderately in the OECD countries, which together with the decline in family size, increased total space to be heated between 1973 and 1990, from 45 to 54 m^2 in the U.S., from 21 to 29 m^2 in Japan, from 26.5 to 35 in Europe-4, and from 38 to 49 in Scandinavia-3.
- The share of homes with central heating was already high in the U.S. and Scandinavia-3, but increased significantly from around 40-45% to 70-75% in Europe-4 and remained very low in Japan.[4]
- Ownership of the four largest energy-consuming electric appliances (not including air conditioners)—refrigerators, freezers, clothes washers, and dishwashers—increased more in Western Europe than in the U.S., while ownership of air conditioners, insignificant in Europe, increased to 68% of all households (of which the majority were central) in the U.S. and to about 64% of all homes in Japan (of which the majority were room-type).
- Changes in the utilization, sizes, or features of appliances, which play a major role in determining the average energy consumption of each type of appliance, tended to increase energy use for refrigeration and cooling equipment but lower energy use for washing and drying equipment.

To measure the impact of structural change on household energy use, we hold the energy intensity of each energy use constant at its 1973 value and multiply it by the change in the corresponding structural indicator (e.g., floor area per capita) between 1973 and the year in question. The product gives the change in each energy use caused by structural changes alone.

Using this method, we find that structural changes raised per capita space heating energy use between 1973 and 1990 by 23% in the U.S., 38.5% in Japan, 56% in Europe-4, and 32.4% in Scandinavia-3.5 For electric appliances, growth in ownership of the main appliances alone boosted energy use by 49% in Europe-4, 24% in Scandinavia-3, 27% in Japan, and 10% in the U.S. As with heating, the figure for Japan hides the enormous increase in energy use that occurred there because the size of refrigerators more than doubled during the years of observation.

We can combine the impacts of these changes (and those for water heating, cooking, and lighting) as described in Schipper, Meyers, et al. (1992) on 1973 energy use by multiplying the structural growth index for each end use by the 1973 value of that energy use. Figure 3 shows the year-by-year evolution of this index, with 1973 set to 1,0. With this done, we find that structural changes increased U.S. residential energy use through 1990 by 19%, compared with 1973, and increased energy use in Japan by 24%. The increase for Europe-4 was 45%, that for Scandinavia-3 was 26%. For all regions except Japan, the growth in energy use from structural factors was most rapid in the 1979-1985 period; for Japan, the first period saw the most rapid growth. What is interesting is that these spurts did not take place during the periods of the most rapid growth in income, which generally occurred after 1985. Indeed, the low rate of growth from structural changes, combined with the higher rate of income growth in this period, suggests a certain “saturation” of household equipment growth. By the late 1980s, a 1% increment in income was associated with a far smaller amount of structural growth than in the 1970s or early 1980s.

Energy Intensities and Energy Efficiencies

We now examine energy intensity, or the ratio of energy consumed to service performed, for each important end use. So defined, energy intensity is closely related to the inverse of energy efficiency. Energy intensities are affected primarily by changes in energy prices, but are also affected by efficiency standards and programs as well as by technical progress. In our study we measure changes in the energy intensities of each appliance, space heating, water heating, cooking, and lighting. Here we examine the behavior of heating, appliances, and the aggregate during all three periods.

Space Heating

Per capita energy use for space heating, which accounted for about 60% of energy use in 1990, fell in every region except Japan. Space heating energy intensity—expressed as useful energy per m^2 of area-has declined in all of the OECD countries except Japan and Norway since 1972-73.6 There, higher indoor temperatures and longer heating hours pushed up energy use. The decline in space heating intensity was somewhat greater in the U.S. (43%) than in Europe-4 (24%) and Scandinavia-3 (32%) (see Figure 4). In Japan, this intensity grew (3.3%), because of the increase in indoor temperatures and heating hours.

The above intensity indicator includes the effect of the growth in central heating, which typically led to a doubling of energy use in a home (compared with room heating). In Europe-4 especially, such growth obscures the improvement that took place in technical efficiency and the modest decline in indoor temperatures in homes already fitted with central heating before 1973. Growth in the number and size of heaters in Japan also pushed intensity upward. If not for these changes, we estimate that space heating energy intensity would have declined by 35% in Europe-4 (instead of 15%), and by 1% in Japan (instead of an increase).

The rapid drops in space heating intensities after 1973 were caused principally by changes in behavior, as noted in Schipper, Meyers et al. (1992). By the 1980s, however, retrofit activity, some with support from government programs, was underway in every country, and new homes entering the stock had considerably lower heat losses than

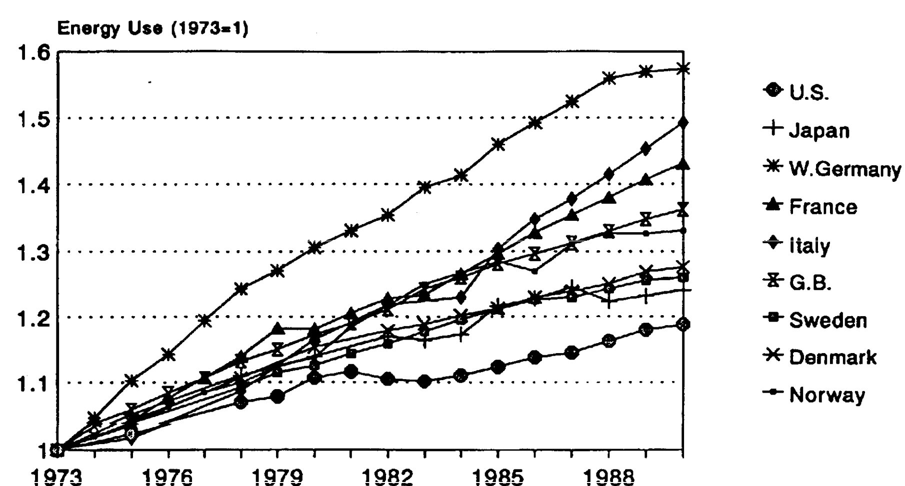

Figure 3. Impact of Structural Changes on Delivered Residential Energy Use

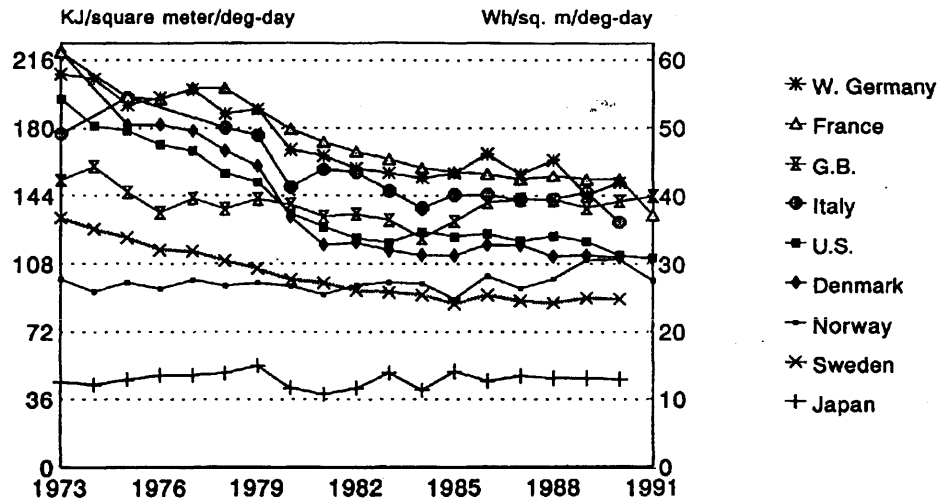

Figure 4. Space Heating Intensity (Useful Energy) of OECD Residential Energy Use

those built before the mid-1970s. Although thermal standards on new homes have been progressively tightened in most countries, the rate of addition of new homes is small, so that by 1990, most of the change in average heating intensity resulted from changes to existing homes.

All of the space heating indicators show a clear plateau, with the rate of decline after 1985 far less than in the previous period or two. Even given uncertainties in the breakdown of energy use into its components and the various ways in which the indicators are constructed, clearly efficiency improvements have slowed, or at least their progress has been masked, in part by increases in indoor temperatures and heating hours, which is the case for the Scandinavia-3.

Electric Appliances

The largest growth in residential energy use in the OECD countries has been for the so-called “electric-specific” end uses: lighting, food preservation (refrigerators and freezers), clothes washing and drying,[7] dish washing, entertainment (television, stereo), air conditioning, and other miscellaneous uses. Between 1972-73 and 1990, per capita appliance electricity use increased by 46% in the U. S., 60.2% in Scandinavia-3, 107% in Europe-4, and 110.5% in Japan. Among the seven major appliances, growth rates for electricity use were higher than overall appliance growth except in Scandinavia, where the major appliances were already widely diffused in 1973. Given the strong impact of increased appliance ownership and size noted previously however, we suspect that this indicator masks important changes in the unit consumption of appliances.

If we hold changes in appliance ownership at their 1973 levels, we can estimate the impact of changes in the energy intensities of appliances in the stock on appliance energy use by 1990. This indicator increased in Europe-4 by 2%, decreased by 26% in Scandinavia-3, fell by 12% in the U. S., and increased by a full 55% in Japan. The reason for the increases in Europe and Japan has been the hidden improvements in the size and features of refrigerators. We know that energy use for refrigerators of a given size in Japan fell dramatically, but the volume of refrigerators more than doubled, with an increasing share of new models having two or even three compartments. For Europe, this effect was smaller but still offset the improvements in models of a given size and characteristics. For the U.S. and Scandinavia, where appliances were relatively large and ownership levels high in 1973, the effects of improved efficiency more than offset the impact of growth in size and features. The declines in this indicator did not occur in the same periods for different regions; significantly, however, only in Europe-4 did the indicator rise in the 1985-1990 period, a consequence of the rapid growth in refrigerator-freezers, which pushed up the average intensity of refrigerators.

Unlike the space heating intensities, appliance intensities fall primarily as new, more efficient appliances enter the stock. While there is some leeway for consumers to reduce their use of washing appliances or reduce water temperatures or quantities, these changes tend to be temporary and minor, although changes in the kinds of clothing washed (fabrics requiring lower wash temperatures) have reduced hot water needs everywhere (Schipper and Hawk 1991), a change that affects both existing and new machines.

The changes in intensities of new appliances, as reviewed in Schipper and Hawk (1991) and Schipper, Meyers, et al. (1992), have slowed only slightly. Since a gap still exists between these intensities and the averages intensities for appliances already in the stock, the average for the stock should continue to drift downward for some time. This means that the rate of decline of intensity depends on how quickly the stock is replaced.

Overall Impact of Energy Intensity Changes

Using our analysis of changes in space heating, appliances, and water heating/cooking (not shown here but discussed in Schipper, Meyers, et al. 1992), we can trace the evolution of energy intensity of household energy use. Figure 5 shows this development, with each country's 1973 intensity set equal to 1.0. Denmark shows the largest savings, followed by a group of countries that includes the United States. Norway and Japan show no overall decline, a result of significant increases in indoor comfort that appear as increases in space heating intensity.

Analysis of Changes in Household Energy Use

Energy intensities of household energy uses fell around 2%/year in Europe-4 and Scandinavia-3, fell by more than 2.5%/year in the U. S., but increased by slightly over 1%/year in Japan. Had we been able to account for increases in the size of refrigerators and space-heating equipment, the Japanese results would likely have shown a small negative result.

Reductions in space heating intensities (confirmed by our calculations using useful energy) led to these savings. Substitution of electricity for the direct use of fuels was one reason for the decline in heating intensity in Scandinavia-3, the U. S., and Japan but played a smaller role than the decline in intensities of individual fuels. Reductions in the energy intensities of household appliances, mainly through the introduction of more efficient new appliances, also lowered household energy use from what it otherwise would have been. For virtually all countries and end uses, the rate of decline in energy intensities slackened after 1985, when the price of energy fell.

The changes we observed certainly reduced oil use and, through improved efficiencies, restrained overall household energy use significantly. Growth in household electricity use slowed markedly in the late 1980s, both because of improved efficiency and because of the rise in popularity of electric space and water heating slowed. As a result of all of these changes, per capita CO_2 emissions fell in almost every country we studied.

Income and Structural Changes: Signs of Saturation?

In the 1970s and early 1980s, structural changes obscured or even offset the impact of more efficient energy use. These changes were driven by increasing incomes, which permitted consumers to own or occupy larger homes and acquire more equipment. Income, measured as per capita personal consumption expenditures, grew nearly 50% in Europe-4 and Japan over the study period, by 28% in Scandinavia-3, and by 25% in the U.S. Figure 6 shows how these structural changes affected household energy use in each of the three periods analyzed.

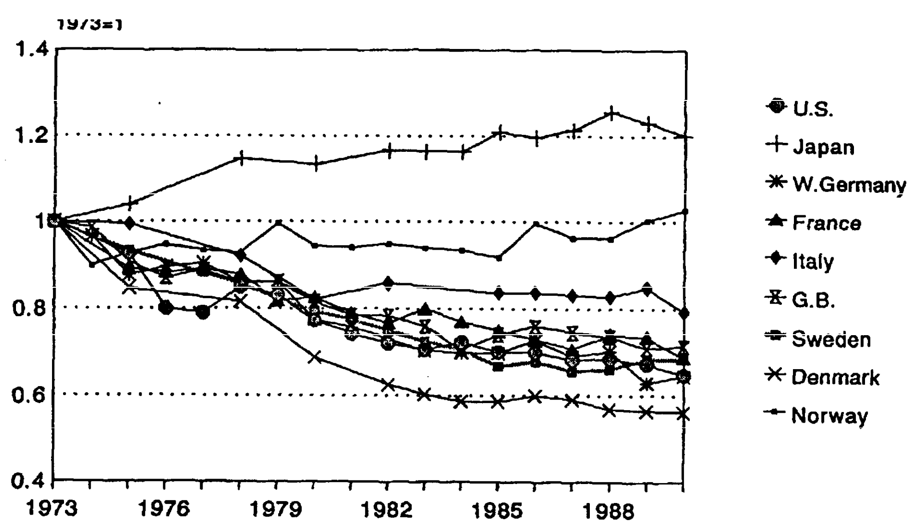

Figure 5. Impact of Intensity Changes on Delivered Residential Energy Uses

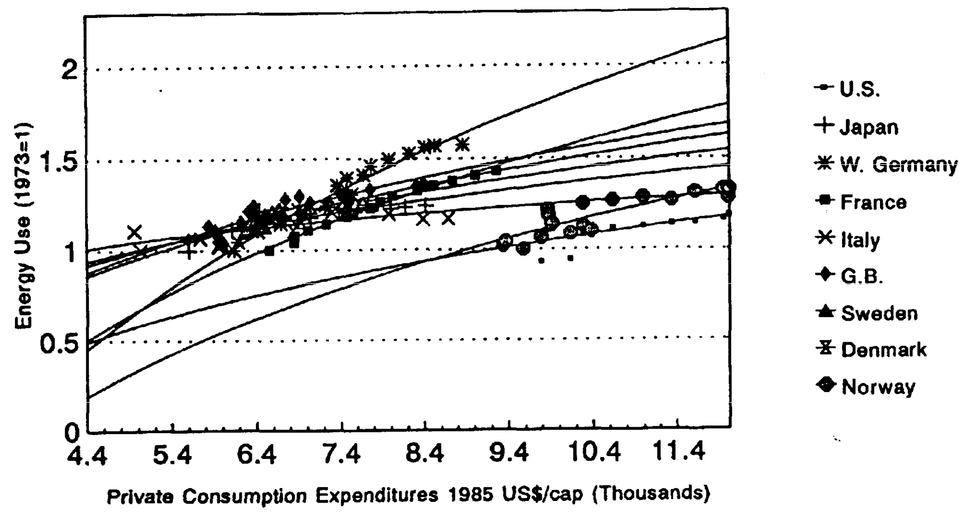

Figure 6. Impact of Structural Changes on Household Energy Use in OECD

The upward impact of structural changes on household energy use slowed toward the end of the 1980s, even in the U.S. and Japan, where personal income growth was the most rapid for each of the three periods. Figure 7 shows log-regression lines drawn for each country (R2 typically 0.6-0.7) that are indicative of equipment saturation, i.e., compared with earlier periods, equal increments of income produced less change in household energy use (measured by our structural change calculation) in the last period. The reason was that central heating penetration and appliance ownership growth were slowing as saturation was approached. Thus the importance of income growth, one factor that drove increases in household energy use in the past, appears to be weakening: the income elasticity of household energy use is declining.

Future income growth will become less important to growth of overall household energy use. The major uses, space and water heating and cooking, are virtually saturated in Europe and the U.S. Higher incomes certainly permit growth in the size of televisions and refrigeration appliances in all countries and air conditioners in the warm ones, factors that will boost energy use; and there remains significant potential for increased ownership of electric or gas clothes dryers. Acquisition of appliances for washing leads to substitution of a small amount of electricity (in motors) for labor. But other uses,

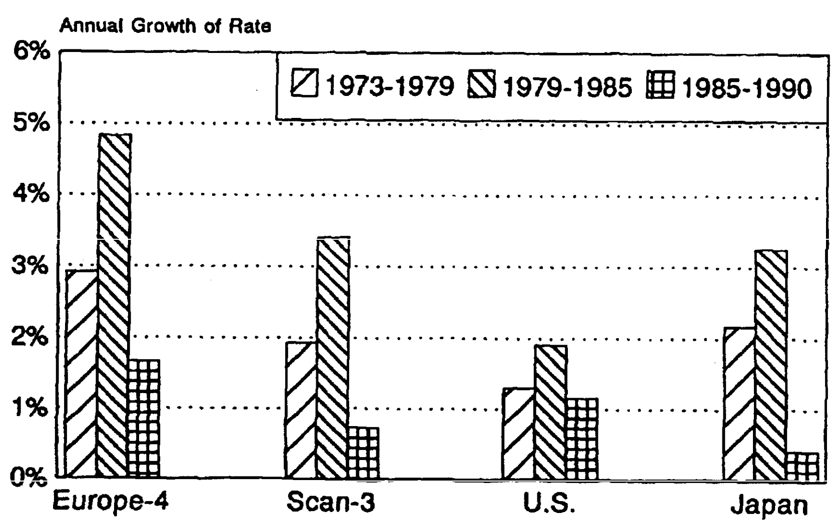

Figure 7. Impact of Structural Changes on Residential Energy Use

particularly communications and electronics uses, are not likely to be significant end uses.

Shrinking household size was the other component of structural change that increased energy use throughout the entire period studied. Its influence is included in the changes shown in Figure 7. But even this important change is slowing. In all regions household size fell less rapidly in the late 1980s than in previous periods. Schipper, Bartlett, Hawk, and Vine (1989) point out, however, that home energy use for retirees is somewhat higher than for active people with the same household size because retirees are home more. The gradual aging of populations in all these countries could boost household energy use as more people retire and spend more time at home. (This change, however, would be offset by reduced energy use for personal services away from home and transportation as well.)

Income growth also stimulates the turnover of equipment and housing renewals. Since new equipment or homes are more efficient than old, turnover reduces average energy intensity. With population growth slowing and family size shrinking, new housing starts will be less important to overall energy use than in the past. Therefore, factors that promote the renewal of the existing stock, whether through replacement or rehabilitation, could be important for ushering in more efficient energy uses.

Income and household energy use also appear to be coupled in the short term. While we have not made a formal analysis of the impact of income on household energy use, studies of individual countries' year-to-year data suggest that the recessions of 1974-75, 1979-82, and 1990-present contributed to the drop in household energy use during those periods, although the impact of higher energy prices in the first two periods was still dominant.

Impacts of Energy Price Changes

Between 1973 and 1981, most OECD countries experienced three major changes in energy prices. [8]The retail price of heating oil rose by about a factor of three (in two stages), but declined thereafter in the U.S. and Japan (remaining high in Western Europe due to taxation until the crash of 1986). In the U. S., the price of natural gas, the most important household fuel, rose less than the price of oil. In contrast to oil, electricity prices remained about the same or declined in most countries in the 1970s. There was a jump in price in some countries in 1980-82, but the general trend since then has been one of decline, with West Germany being an exception. Trends in Western Europe have differed because of taxation policies, but new taxation introduced in the late 1980s and early 1990s had an important upward impact on real prices in Denmark, Sweden, and Italy. In general, U.S. prices were the lowest (except for electricity in Norway and Sweden), Japanese the highest, and Danish energy taxes the highest.

Figure 8 shows the change in all energy prices (coal, heating oil or kerosene, natural gas, and electricity) weighted by actual consumption over all end uses. The decline after 1985 is dramatic in contrast with the increases that occurred during the first two periods. The apparent slow rise is caused by the increasing share of electricity in total final household energy use. Had these indices been computed using constant shares of each fuel, the effect of greater electricity use would disappear and the average would resemble more the changes seen in the prices for each energy carrier.

Energy prices strongly affected household energy intensities, both in reducing energy use in the first two periods and in permitting a slowing of the pace of efficiency after 1985. The rapid reductions in the use of fuel for space heating in the 1974-75 and 1979-81 periods were clearly driven by higher prices. The rebound or slower decline of intensities after 1986 was clearly related to the drop in prices as well. The improvement in new appliances (Schipper and Hawk 1991) has been dramatic and certainly related to higher electricity prices, but other factors, including standards, first in California and then in the U. S., voluntary efficiency targets established in W. Germany and Japan (Wilson et al. 1990), and programs in Scandinavia have added important pressure too.

Energy prices had another far-ranging impact through the mix of fuels offered and consumed. As the price of oil rapidly rose, national and private authorities invested in capacity to supply alternative fuels (gas, district heat for oil). These alternatives worked their way slowly through the marketplace, mostly as fuels used in new homes. Where price differentials were large however, consumers shifted fuels in existing homes. Rapid shifts from oil to wood or electricity in Sweden and Norway or from oil to gas and wood in the U.S. occurred. Where differentials were small the shifts were made more slowly, such as occurred with the move from oil to gas in West Germany or Denmark. And even though in theory the price of coal usually makes it an attractive fuel (i.e., on a $/GJ basis), difficulties, including problems related to air pollution, certainly contributed to its near demise. At the same time, the availability of "free" wood in some countries suggests consumers will use solid fuels if the price is right; conversely, the drop in oil prices after 1985 stopped the rise in wood use, and in the case of Sweden and Norway, even slightly reversed the march from oil to electricity.

These considerations suggest that energy prices have had an important impact on efficiency. We believe price changes remain the single most important stimulus to improved efficiency. Furthermore, even moderate price differentials between fuels can have important impacts on fuel choice, all else being equal. This means that a carbon tax, which would affect oil more than natural gas and raise the cost of coal (now mostly used in electric power and district heat production), could contribute to reducing or restraining CO_2 emissions by encouraging certain fuel substitutions.

The reduction in energy intensities, combined with the drop in energy prices after 1985, means consumers are paying less for energy services in the early 1990s than they have for many years. If we combine the weighted price for energy with our measure of energy intensity (corrected for structure), we find that households in the U.K. and West Germany paid less for a unit of space heat in 1990 than in 1973, those in France and the U.S. paid about the same, while in Denmark, Norway, Sweden, and Italy, households paid considerably more. The higher costs in Norway and Sweden are explained by the considerable rise in the share of electric heating, but the higher costs in Denmark and Italy reflect the very large increases in the prices for heating fuels. From this picture we surmise that consumers in most of the countries see little strong, direct incentive to reduce heating use, which explains in part the plateau of heating intensity. While our studies suggest a significant, further economic potential for energy efficiency improvements, the fact that present energy service costs are not far from their 1973 levels in so many countries, while incomes are higher, argues that consumers are not pressured to make such improvements relative to the situation in the early 1980s. This illustrates an important dilemma for public policy: whether and how to stimulate harvesting the potential for further improvement in household energy efficiency.

Energy Use and Efficiency in the Future: What Matters?

The foregoing discussion does not argue that energy prices are the only factor determining energy intensities and the pace of energy efficiency improvements. But our analyses (see also Schipper 1987, Schipper, Meyers, et al. 1992, and Schipper 1993) suggest that energy prices were the most significant of three factors causing reductions in energy intensities between 1973 and 1990.

Another factor is long-term technological progress, which has always led to more efficient energy-using equipment and better building materials, particularly in Sweden (Schipper, Meyers, and Kelly 1985). This progress arises as competition and research and development spur firms to develop more effective materials, manufacturing methods, and housing-construction methods. For the household sector, this progress appears in many forms: gas-filed, double-paned, multiple-glazed coated windows that reduce glare and heat transfer; new insulation materials, like aerosol gels, which permit greater insulation for a given thickness and thus contribute to lowering fabrication or construction costs; compact fluorescent lights, whose main selling point is longevity, but which also reduce the electricity required to provide a given amount of light by as much as 75%. Certainly these developments were spurred by changes in energy prices and energy-conservation campaigns, but they have continued unabated even after prices fell.

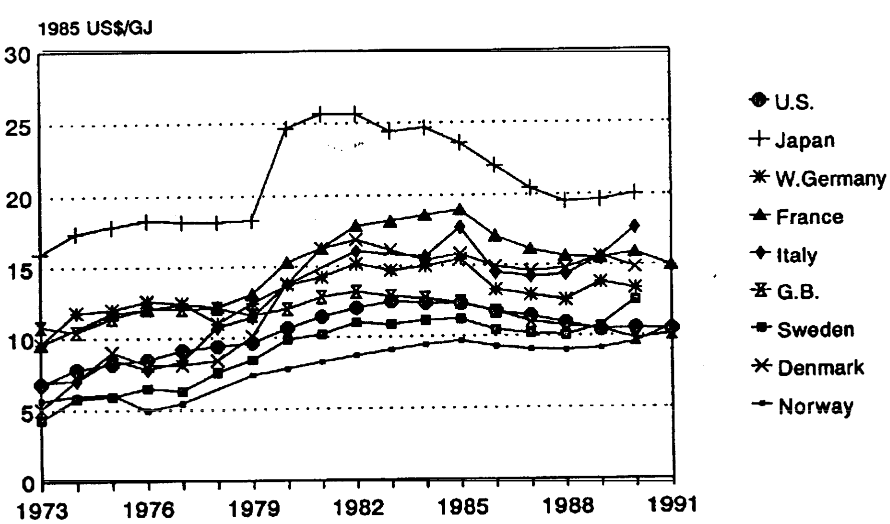

Figure 8. OECD Residential Energy Prices Weighted by Actual Useful Energy

Potential for Further Improvements in the Household Sector

In spite of the slowdown in the pace of efficiency improvements, a variety of studies suggests these improvements need not be ended, even if energy prices do not rise. That is, the economic potential for further improvements remains. Few disagree about the "potential" for savings; the question is rather how rapidly improved (or new) technologies will penetrate the market compared with the rates of growth in energy services.

In our reviews of trends and studies of further potential for improvements (Schipper, Meyers et al. 1992; Schipper and Scheinbaum, 1994), we found a clear pattern:

- Space and water heating requirements in existing homes are likely to fall slowly with housing rehabilitation, heating equipment replacement, and some purposefi.d retrofit. Most studies foresee a 20-35% decline in heating intensity in the U.S. and Europe. Since new homes are typically 35% less heating-intensive than existing ones, overall heating intensity will drift downward, but the speed of the decline is uncertain.

- Electric appliance intensity is also drifting downward because new models use significantly less electricity than existing ones. The current gap is approximately 30% in Europe and as much as 50% in the U.S. Since the size of appliances is not increasing at a significant rate and ownership growth is slowing, we expect electricity use per capita for appliances to barely grow or even decline.

- Per capita electricity use for lighting is increasing slowly, with increased home area per capita, but falling as compact fluorescent bulbs gradually replace incandescent ones.

Of course, further declines are possible: an extensive retrofit program might reduce heating needs by as much as 50%; replacing electric appliances with those of the lowest consumption on today's market could lead to a similar 50% decline in appliance intensity by 2010. Further penetration of compact fluorescent bulbs into homes might also affect a 50% decline in electricity use for lighting. How much more could efficiency improve? This is a question both of technology and of market penetration. Various programs (Golden Carrot (ACEEE 1991), the U.S. Consortium for Energy Efficiency (Frantz 1993), and the Swedish procurement program or Teknik Upphandling (NUTEK 1993a)) have already begun to move new products toward this potential, as have the new U.S. standards (Turiel et al. 1991) and the possibility of EEC-wide standards (MacKenzie 1993), backed by the Nordic countries, three of which are not yet members of the EEC (see, for example, NUTEK (1993 b)) Furthermore, simulations point to deeper cuts in space heating, but whether consumers or housing authorities will take the measures necessary to carry these out remains uncertain. Finally, one can foresee an almost complete penetration of the lighting market by compact fluorescent bulbs. Thus the "potential" for reduced energy intensity in each of the markets we reviewed in no way exhausts energy savings.

Trends, Goals, and Reality

The foregoing should offer convincing evidence of a significant potential for further reductions in household energy intensities. But most of the national authorities whose studies we reviewed back away from expecting the full potential to be realized in any given time. Lower energy prices and doubts about how to deliver retrofits for space heating underlie reduced expectations. Only in appliances and lighting do we see intensity reductions of more than 25%—or even more than 35% —as both possible and likely by 2010.

The likelihood of further increases in energy prices is mixed. As Schipper, Meyers, et al. (1992) note, it is hard to imagine significant increases in local or world energy prices, unless an environmental disaster or a war in the Middle East disrupts energy markets in ways that events like Chernobyl, the Exxon Valdez, or the Persian Gulf war were not able to.

What, then, might accelerate the pace of efficiency improvements? A carbon tax or other measures that boost household energy prices would clearly, help, since such an action would magnify the size of the savings offered by energy efficiency improvements and also increase the incentive to lower temperatures, lessen hot water use, or establish moderate lighting levels. Certainly, demand-side management (DSM) programs may accelerate harvesting the potential for saving electricity, but we have implicitly counted these programs in our own reckoning of the pace of energy and electricity savings (Schipper, Meyers, et al. 1992; Schipper and Meyers 1993). Tightened standards on the thermal properties of new homes are unlikely, only because most countries have continually tightened thermal requirements since the 1970s. More stringent standards on some appliances are likely, but this will probably depend on both the results of the next round of U.S. standards and the success or failure of an EEC-wide effort to impose standards, which is still opposed by German and British authorities (MacKenzie 1993).

When all energy uses are counted, heating and hot water in existing homes will account for most of the consumption even in the year 2010. Developing an effective mechanism for reducing energy needs in these homes is a clear priority for energy-conservation policy. But reduced energy intensity need not arise solely from technical measures. Behavior affects energy needs. Lower temperatures and reduced water heating means lower energy use. But with efficiency slowly improving and no major energy price increases, the cost of energy services will remain roughly constant, certainly not increasing faster than incomes. Under these circumstances, we expect consumers will not change their current energy-using habits.

Two Energy Policy Dilemmas

These observations lead to two dilemmas. First, little doubt exists about the potential for more efficient and more economic household energy uses. But consumers have slowed their efforts to realize this potential. Public policies contribute through efficiency standards on new homes and equipment and through local programs backed by utilities or other authorities that provide incentives for the development and purchase of more efficient equipment. To what extent can these programs be sharpened in response to environmental concerns such as the CO_2 problem?

The dilemma is whether efficiency standards or incentive programs alone can affect significant changes in efficiency. National and local authorities in the U.S. rely on this approach, backing away from addressing the larger issue of energy pricing.[9] By contrast, authorities and utilities in Europe (outside of Scandinavia, Holland, and a few regions in West Germany) have been slow to develop standards or incentive programs beyond those affecting the thermal properties of new buildings. The Swedes and the Danes appear to have tried to strike a middle way, combining high taxes on some or all energy forms with a variety of incentive programs. Our assessments of the development of energy use in these two countries suggest some success (Schipper, Howarth, Andersson, and Price 1992; Schipper, Johnson, et al. 1993), particularly in Denmark. We noted that the high taxes on all forms of energy forced Danes to reduce their demand for household energy services more than the Swedes, for whom electricity (and free wood) remained alternatives to expensive oil.

Here lies the second dilemma: that concerning energy pricing. Improved energy efficiency is only one component of reducing energy use; restraining the growth in energy services is the other. Improving efficiency per se lowers the cost of energy services. While this effect probably only "takes back" part of the effect of energy efficiency as higher demand for energy services, this effect blunts the interest consumers might have in reducing the level of energy services they demand as well as their own willingness to perform maintenance, shut off lights, and implement similar energy-saving practices in their homes. To the extent that present energy prices do not reflect externalities like environmental costs, strategies that rely only on provoking efficiency improvements without proper pricing will fail to capture the reduction in energy services, however large or small, that higher prices would have provoked. This means consumers will use more energy than otherwise, with potentially important environmental consequences.

It is sometimes argued that as long as there are cost-effective efficiency measures at present prices, public policy need not focus on measures to internalize costs and raise prices. This argument is flawed: higher prices motivated by environmental damage raise the cost effectiveness of efficiency investments and restrain the demand for energy services.

Moreover, failure to try to capture differential environmental impacts among fuels, such as the SO_x impacts of using oil, the SO_x and NO_x impacts of power production from coal, or the externalities and hidden costs associated with using nuclear power (like decommissioning or the small but non-zero risk of an accident somewhere in the nuclear fuel cycle) gives energy producers and energy users the wrong price information about the relative costs and benefits of using one fuel over another. And ignoring the carbon tax entirely omits CO_2 from the equation, which means that any advantages renewable or nuclear power have over fossil fuels are eliminated, while uses of fossil fuels necessary for renewable or nuclear power (for fuel harvesting, power plant construction, and so on) are underpriced. While some U.S. states and utility districts have incorporated certain of these externalities into their shadow pricing for determining levels of DSM investment, this strategy still shields the ultimate beneficiary of energy use from paying the fuel cost of what is used.

No one argues that finding correct environmental pricing is easy (Ottinger et al. 1990; Hohmeyer 1989), but no environmental pricing at all is a "statement" itself that is presently giving both energy consumers and energy producers incorrect signals. Correct pricing does not solve all our energy problems, although underpricing energy probably makes the problems worse. And the clear link between the stagnation or drop in energy prices since 1985 and the slackened fall in household energy intensities suggests that this underpricing of energy also hurts energy efficiency efforts. A few countries, notably the Nordic countries (Magnussen and Brandel 1991), have tried to adjust their prices for some of the environmental costs of using energy, but others—notable the U.S.—are far from doing this. Let us hope that leaders and citizens alike will soon agree on the real costs of using energy and act to confront those costs directly.

Acknowledgment

This work was supported by the Office of Environmental Analysis, Office of Policy, Planning and Program Evaluation, U.S. Department of Energy, through Contract No. DE-AC-3-76SF00098. Special acknowledgment is given to the U.S. Environmental Protection Agency (U.S. EPA) for its invaluable support of this work.

Endnotes

1. Over the past 15 years, the International Energy Studies Group at Lawrence Berkeley Laboratory has organized and analyzed data on residential energy use in nine OECD countries. Data and sources are explained in Schipper, Ketoff, and Kahane (1985), Ketoff and Schipper (1990), and Schipper, Meyers, et al. (1992). We discuss trends for the United States, Japan, “Europe-4” (an aggregate of West Germany, France, the United Kingdom, and Italy), and “Scandinavia-3” (an aggregate of Sweden, Norway, and Denmark) which have different patterns of energy use from those in the Europe-4.

2. This change was driven in part by the increased market share of electricity for space heating, water heating, and cooking in new homes.

3. The share of electricity and district heating was highest in the third period. These two energy carriers are counted at 100% of their delivered value in the useful energy calculation. This accounts in part for the diverging growth in useful energy per capita, relative to delivered energy per capita.

4. We have found that domestic central heating heats a larger share of total area for more hours and to higher indoor temperatures, roughly a factor of two increases in heating fuel use, all else being equal. In our calculations of structural change, area heated by central systems counts twice as much as area heated by room stoves, reflecting approximately the actual differences between these two systems in energy use.

5. The Japanese figure probably underestimates the real impact of structural change through increases in the capacity of kerosene room heaters.

6. We include estimated energy use by secondary space heaters under space heating energy use. Increased use of secondary heaters was an important factor in the United States and Scandinavia. We also include estimated use of wood, much of which was used in secondary heaters. Energy-use data for space heating have been normalized for climate within each country over time and among countries.

7. While most clothes dryers in OECD countries use electricity, around 20% in the United States are gas-fired.

8. Prices here include all taxes. They are converted first to real local currency (base 1985) using local consumer price indices. Then they are converted to U.S. dollars using purchasing power parity exchange rates. These rates, in 1985 local currency per 1985 U.S. Dollar, are Japan, 217 z-Y; Denmark 9.05 DKK; France 6.48 FFR; German 2.15 DEM; Italy 1196 LIT; Norway 9.4 NOK; Sweden 7.8 SEK; UK 0.54 GBP. For comparison, exchange rates in the summer of 1993 lay at 105 z-Y, 7 DKK, 6.90 FFR, 1.75 DEM, 1500 LIT, 7.5 NOK, 8.0 SEK, and 0.54 GBP.

9. This can be seen in both the National Energy Strategy (U.S. DOE 1991) and the most important response from an important consortium of environmental groups (Alliance to Save Energy et al. 1991), neither of which treat pricing as a major element of an efficiency strategy. The “Climate Action Plan” also avoids carbon taxes or other price-related measures.

References

Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defence Council, Union of Concerned Scientists. 1991. *America’s Energy Choices: Investing in a Strong Economy and a Clean Environment,* Cambridge, MA: Union of Concerned Scientists.

American Council for an Energy-Efficient Economy (ACEEE). 1991. *The Golden Carrot News.* Washington, D.C.

Frantz, S. 1993. “The Race to Make the Fridge of the Future,” *Home Energy,* 10(1):36-37.

Howarth R., L. J. Schipper, and P. Duerr. 1990. “Manufacturing Oil and Energy Use in Eight OECD Countries: A Review of Recent Trends.” Presented at the Bergen Energy Conference, Bergen Norway, August 23-24, 1990. Also Lawrence Berkeley Laboratory Report No. LBL-27887.

Howarth R., L. J. Schipper, and B. Andersson. 1992. “The Structure and Intensity of Energy Use: Trends in Five OECD Nations.” Lawrence Berkeley Laboratory Report No. LBL-32431 rev.

Hoymeyer, O, 1989. *Social Cost of Energy Consumption,* Berlin, Germany: Springer-Verlag.

Ketoff, A., and L. J. Schipper. 1990. "Looking Beyond the Aggregate Figures: What Really Happened to House Energy Conservation." In: Vine, E. and D. Crawley (Eds.) *State of the Art of Energy Efficiency: Figure Directions,* Washington D.C.: American Council for an Energy-Efficient Economy.

MacKenzie, D. 1993. "Britain's Fridges: Too Hot to Handle." New *Scientist,* 139(1889:14-15.

Magnussen, J., and M. Brandel. 1991. *Energi och Miljoe i Norden.* NORD 1991:23. Copenhagen, Denmark: Nordiska Rådet (the Nordic Council).

NUTEK (Narings- och teknikutvecklingssverket). 1993a. *Utvärdering av Programmed for effectivare energianvandning.* Stockholm, Sweden: NUTEK, 31 August 1993.

NUTEK. 1993b. Normer *ör faximal elör brukning i hushaallsppaaraterm.m. [Standards for maximum electricity consumption in home appliances].* Third Edition. Report R 1992-24. Stockholm, Sweden: NUTEK.

Ottinger, R., N. Robinson, S. Babb, D. Wooley, D. Hodas, S. Buchanan, P. Schernick, E. Caverhill, J. Meltzer, A. Krupnick, W. Barrington, and S. Radin. 1990. *Environmental Externalities Costs from Electric Utility Operations.* Albany, NY: New York State Energy Research and Development Agency, and Washington, D. C.: U.S. Department of Energy. Available from the American Council for an Energy-Efficient Economy, Washington, D.C.

Scheinbaum, C., and L. J. Schipper. 1993. "Residential Sector Carbon Dioxide Emissions in OECD Countries, 1973-1989: A Comparative Analysis." *The Energy Efficiency Challenge for Europe: Proceedings of the 1993 ECEEE Stumer Study.* Vol. II: 255-268. Rungstedgård, Denmark, June 3-5, 1993. Oslo, Norway: European Council for an Energy-Efficient Economy.

Schipper, L. J. 1987. "Energy Conservation Policies in the OECD." *Energy Policy,* 15(10):538-548.

Schipper, L. J. 1993. "Energy Efficiency and Human Activity: Lessons from the Past, Importance for the Future." Report presented at the World Bank Development Conference, May 3-4, 1993, Washington, D.C.

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

Schipper, L. J., and S. Meyers. 1993. "Using Scenarios to Explore Future Energy Demand in Industrialized Countries," *Energy Policy,* 21(3):264-275.

Schipper, L. J., and C. Sheinbaum. 1994. "Recent Trends in Household Energy Use Efficiency in OECD Countries: Stagnation or Improvement?" Lawrence Berkeley Laboratory Report No. LBL-35313.

Schipper, L. J., A. Ketoff, and A. Kahane. 1985. "Explaining Residential Energy Use with International Bottom-Up Comparisons." *Annual Review of Energy* 10:341-405.

Schipper, L. J., S. Meyers, and H. Kelly. 1985. *Coming in from the Cold: Energy-Efficient Homes in Scandinavia,* Report to the General Marshall Fund. Washington, D. C.: Seven Locks Press.

Schipper, L. J., A. Ketoff, S. Meyers, and D. Hawk. 1987. "Residential Electricity Consumption in Industrialized Countries: Changes Since 1973." *Energy-The International Journal* (12)12 1197-1208.

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

Schipper, L. J., R. Steiner, P. Duerr, F. An, and S. Strøm. 1991. "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987." Lawrence Berkeley Laboratory Report No. LBL-29831.

Schipper, L. J., R. Howarth, B. Andersson, and L. Price. 1992. "Energy Use in Denmark: An International Perspective," Lawrence Berkeley Laboratory Report No. LBL-32362.

Schipper, L. J., and S. Meyers, with R. Howarth and R. Steiner. 1992. *Energy Efficiency and Human Activity: Past Trends, Future Prospects.* ISBN No. 0 521 43297 9. Cambridge, UK: Cambridge University Press.

Schipper, L. J., F. Johnson, R. Howarth, B. Andersson, and L. Price. 1993. "Energy Use in Sweden: An International Perspective," Lawrence Berkeley Laboratory Report No. LBL-33819.

Turiel, I., D. Berman, P. Chan, T. Chan, J. Koomey, B. Lebot, M. D. Levine, J. E. McMahon, G. Rosenquist, and S. Stoft. 1991. "U.S. Residential Appliance Energy Efficiency: Present Status and Future Policy Directions." In: Vine, E. and D. Grawley (eds.) *State of the Art of Energy Efficiency: Future Directions,* Washington, D.C.: American Council for an Energy-Efficient Economy.

U.S. DOE (Department of Energy). 1991. *National Energy Strategy: Powerful Ideas for America.* Washington, D. C.: Superintendent of Documents, DOE/S-0082P.

Wilson, D., L. J. Schipper, S. Tyler, S. Bartlett. 1989. "Policies and Programs for Promoting Energy Conservation in the Residential Sector: Lessons from Five OECD Countries. Lawrence Berkeley Laboratory Report No. LBL-27289.