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The International Decline in Household Oil Use

Lee Schipper and Andrea N. Ketoff

The oil price shocks of 1973 and 1979 caused many difficulties in households in Europe and Japan, as well as in parts of the United States and Canada, where oil products dominated home energy use. Most of the industrialized nations of the Organization for Economic Cooperation and Development (OECD) (*1*) adopted pricing and policy strategies to lower the dependency of indoor comfort on oil. Conservation programs were launched in most countries, and large sums of public and private funds were spent to help reduce home oil use. These strategies and expenditures raise important policy questions:

1) By how much has home oil use been reduced, and how?

2) How much of the reduction might be reversed if oil prices decline?

3) Will oil continue to lose its share of the residential market?

4) Given the change in oil use that did occur, how much was caused by higher prices or lower incomes, and how much by conservation programs or new technologies?

We study here the use of oil products in the residential market of the largest OECD countries. International comparisons of changes lead to conclusions that may apply to countries outside the study, while allowing assessment of future trends in world oil use. The aggregate energy use in the countries studied makes up a substantial share of world oil demand.

The study examines the evolution of the structure of the oil-heated dwelling stocks, their type (single or multiple-family), heating system (central or non-central), and the presence of hot water based on oil. We combine these observations with information on energy intensity provided by oil suppliers and national surveys that follow oil consumption per household. We then decompose changes in oil use into those caused by changes in the number and characteristics of oil-using households ("structure") and those caused by changes in the amount of oil used per household ("intensity"). Reduced intensity is most often associated with conservation.

Switching from oil to other fuels and conservation are two complementary responses to higher oil prices that must be addressed separately. Changes in intensity can be brought about rapidly by occupants in response to higher prices, aided, in many countries, by subsidies for insulation or other oil-saving techniques. Fuel switching, on the other hand, depends on the price distribution of alternative fuels as well as on the expansion of large-scale networks of natural gas and district heating (a centralized system supplying heat to several buildings). With few exceptions, fuel switching involves long-run changes, while conservation involves both short-run and long-run changes in the dwelling stock. Because our analysis examines the rate of change in both structure and intensity, we can estimate the components of change that may be long-run (and virtually permanent) or short-run and therefore easily reversible if, for example, the decline in world oil prices were to continue.

To understand the changes in household oil use, we must analyze the components of oil use at a very disaggregated level. Data problems have hindered previous quantification of changes in residential energy use. Few countries counted residential consumption (or even deliveries) of oil products separately from the "other" or "residential-commercial" sector, a residual left over when industrial and transportation uses were accounted for in national energy balances. We therefore developed a database on residential energy use in the major OECD countries, built from a variety of official and private sources (*2–10*). In this article we include important new data on oil use.

The key difference between this study and previous ones, then, is one of detail. Previous international studies of the residential sector, as well as statistical estimation of the factors influencing residen-

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tial energy use, used the aggregate "other" sector (*10, 11*), while many studies of individual countries focused on more measurable natural gas or electricity use (*12*). In our earlier statistical work (*10*), we found price and income elasticities for total household energy use consistent with those reported in the literature (*13*). While data, particularly those from 1973 and before, still limit the application of formal statistical tests to oil use, actual changes in oil use since 1973, as well as the important differences among countries, are much greater than the intrinsic uncertainties in the data. Thus, important questions now being asked by policy-makers and analysts who seek to quantify changes that have occurred (*14*) can be answered with the material we present, even before formal tests are applied. Our results may allow readers to perform their own analysis of the permanent and reversible components of changes in oil use.

The Aggregate Picture

In 1982 the residential sector (*15*) in the OECD accounted for approximately 20 percent of total final energy use and 20 percent of oil use (including kerosene and liquefied petroleum gas); in addition, oil accounted for about 25 percent of the energy consumed in the residential sector. These fractions varied substantially among countries (*2*). Figure 1 shows the share of oil, 95 to 98 percent of which was for space and water heating, in residential energy use in seven of these countries (*16*). Although oil use dominated residential energy use in almost every one of these in 1972–73 [total, 6100 petajoules (PJ) (1 PJ = 1×10^{15} J)], there was a clear break in the pre-1973 trends. But changes in the share of oil occurred at different rates, and the levels attained varied significantly. We will explore the reasons why below.

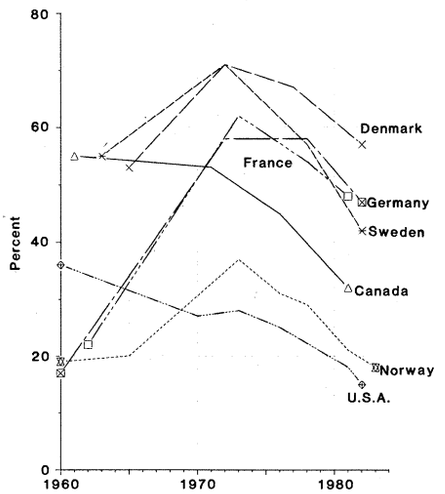

Fig. 1. Share of heating oil, kerosene, and liquefied petroleum gas in residential energy use in the seven OECD countries.

Summary. In this article estimates are made of the permanent and reversible components of changes in heating oil use in major countries of the Organization for Economic Cooperation and Development. The components of the increase in oil use through the mid-1970's, and of the subsequent decline, are revealed. For seven countries, residential oil use decreased by 40 percent between 1972 and 1983, for a savings of about 1.2 million barrels per day (59 million metric tons of oil equivalent per year). One-third of this resulted from reductions in the number of homes heated with oil, the rest from reductions in oil use per oil-heated home. During that time, however, the size of these homes and the penetration of central heating increased significantly, so these figures underestimate the actual conservation achieved. Of the total oil savings, at least 46 percent are of a permanent nature, while the rest could be reversed with a continued slide in oil prices, although it seems likely that most of the savings will be maintained and may even increase.

Evolution of the Determinants

To identify and evaluate the forces underlying these changes in residential oil use, we will analyze the patterns of the different determinants, isolating their contrasting effects on overall oil demand. We break these changes into two principal components:

1) Changes in the number of dwellings using oil as the principal heating fuel, which we call structural changes. Substructural change occurs as dwelling size changes, as the relative numbers of single-family dwellings (SFD's) and multi-family dwellings (MFD's) with central heating or noncentral heating change, and as the presence of oil-based water heating varies. Substructural change is measured by a substructural index, constructed by weighting the shares of oil-heated SFD's and MFD's with and without central heating using weights 1.0 (SFD's with central heat), 0.5 (SFD's without central heat, MFD's with central heat), and 0.33 (MFD's without central heat) (*2*).

2) Changes in oil consumption per dwelling or per square meter, which we describe as changes in intensity or unit consumption. These occur when occupants make "behavioral" changes in the way they heat, like changes in indoor temperatures or in the area heated; when they change the thermal characteristics of their homes or their heating equipment (technical change); and when they use a second or third fuel to provide backup heating (supplementary fuels). Reductions in intensity are called conservation.

Structure of Oil Use

The distribution of heating fuels is shown in Table 1. The high share of homes using oil as the principal heating fuel exemplifies the dominant role played by oil in space heating in most countries. Until 1973 the share of oil-heated homes increased, except in North America, where gas was readily available. The number of oil-heated homes continued its increase after the oil price shock, until fuel switching, brought on by the sharp rise in prices in 1979, began to reduce the share and absolute number of homes using oil. By 1983 the number of oil-heated homes was lower than in 1972 in every country but Germany. Table 1 shows how solid fuels yielded to oil through 1973, and how oil gradually or suddenly yielded to other fuels after that time.

Substructure, measured by the index in Table 2, differs among countries, and has changed over time, mostly toward greater intensity, as the penetration of central heating and the share of SFD's increased. In addition, the living area of oil-heated dwellings and the penetration of hot-water systems fired by oil (not captured by the index because of data problems) all increased at various rates. Finally, a reduction in the number of homes heated with oil after 1979 affected MFD's more than SFD's in most countries. As a result of all these substructural changes, the stock of oil-heated homes was more energy-intensive in 1983 than in 1973. This is clear from the change in the index in Table 2. This increase reduced the apparent impact of important efforts at energy conservation.

Building vintage is an important determinant of consumption. By the late 1970's, the stocks of oil-heated homes in Canada, Sweden, and the United States were on average considerably older than other homes, giving the oil-heated homes the poorest thermal characteristics in the

stock. Equipment in these homes was old. Conversely, oil-heated homes in Germany, France, and Denmark were younger on average than those in the first group of countries, generally having been built in the 1960's. Occupants of the older, leakier homes had greater incentives to reduce oil use or switch fuels than those in the newer homes. This is one reason why there were so few conversions away from oil in the second group of countries. There are few data on the age distribution of residential heating equipment, although its lifetime is considerably shorter than that of structures. This means that much oil-using equipment in Germany, France, and Denmark will need replacement by the late 1980's or early 1990's, which could accelerate fuel switching there.

Fuel choices in new homes (*2*) have changed markedly. Before 1973, oil was the most frequent choice, except in North America. The oil price shock of 1973 and 1974 reduced the frequency of oil heating for new homes everywhere. In North America gas and electricity quickly increased their shares at the expense of oil, while in Sweden and Norway electricity and wood provided immediate alternatives. Elsewhere oil persisted, holding about 40 percent of the new stock in Germany as late as 1981 and 20 percent of new Danish construction as late as 1982. In France, oil heating declined slowly until 1978, then fell rapidly to almost nothing by 1984. In these three countries, gas, district heating, and electricity gained market shares at the expense of oil, although the relative prices of electricity or gas were not so low as to render a rapid shift to these fuels attractive. Some delay was also caused by the lead time needed for extending the gas and district-heating networks to areas where oil was previously popular, particularly because over 60 percent of new construction in all countries between 1979 and 1982 involved SFD's, which tend to lie far from gas or district heating. Electric heating which is independent of the gas or district heating system, is popular in France, but remains expensive in Germany and Denmark, leaving oil as a frequent choice in those two countries. Although new oil-heated homes in every country are considerably less energy-intensive than old ones (*2, 3*), their numbers are large enough to have an impact on average consumption per unit only in Germany and Denmark.

In all, the share of homes with oil heat increased through 1972, continued to increase in some countries, and then decreased everywhere after 1979. The substructural index of the stock increased continually through the early 1980's. The share of oil in new homes fell everywhere. If the share of oil-heated dwellings had remained constant through the 1970's and early 1980's, total oil use in 1983 would have been considerably higher than it was in 1972. But the two oil price shocks changed the oil market radically, and the absolute number of oil-heated homes fell 12 percent. In the following sections we show what happened to the households that continued to use oil.

Table 1. Use of primary space-heating fuels (*2*). For all countries, the principal fuel used is indicated. For Canada, France, and the United States, the values reflect occupied dwellings; for other countries, all dwellings. Arrows indicate that the value is small and is contained in the value to which the arrow points. LPG, liquefied petroleum gas.

Year	Number of dwellings ($\times 10^6$)	Percentage of dwellings heated with						
		Oil	LPG	Piped gas	Electricity	District heat	Coal and coke	Wood and other
				Canada				
1961	4.50	58	←	18	0.5	0	11	12
1973	6.40	57	←	33	7	0	0.6	2
1978	7.54	44	←	37	16	0	0.3	2
1983	8.66	31	←	42	23	0	→	4
				Denmark				
1965	1.60	46	←	1	0	19	33	←
1972	1.86	62	←	2	1	30	6	←
1977	2.02	59	←	2	3	32	3	←
1983	2.20	53	←	2	6	36	2	1
				France				
1962	14.6	12	3	6	10	0.7	68	←
1973	17.3	50	3	12	4	1.6	26	3
1978	18.6	45	3	18	10	3	18	3
1983	19.9	36	4	25	17	3	7	8
				Germany				
1960	15.4	14	→	1	0	1	84	←
1972	21.4	48	→	11	4	5	32	←
1978	23.4	53	1	15	7	5	19	1
1983	24.7	50	1	24	7	8	9	1
				Norway				
1960	1.08	13	0	0	16	0	3	68
1967	1.22	29	0	0	29	0	1	41
1973	1.37	47	0	0	31	0	1	21
1983	1.56	25	0	0	49	0	1	25
				Sweden				
1963	2.8	56	0	1	0.5	4	15	24
1972	3.3	69	0	1	6	17	1	6
1978	3.6	57	0	0.8	15	24	0.2	3
1983	3.7	38	0	0.3	24	32	0.2	5
				United States				
1960	53.0	32	5	45	2	0	12	4
1973	69.3	25	6	55	11	0	1	2
1978	77.2	21	5	55	16	0	1	2
1982*	84.4	15	5	57	16	0	1	6

Intensity of Oil Use

The intensity of oil use gives the most direct measure of the consumer's short- and long-term responses to changing oil prices. Because SFD's with central heating have come to dominate total residential oil consumption, we will examine the intensity of their use of oil for space heating (Fig. 2) (*17*). There were great differences in intensity among the seven countries before 1973, with Sweden showing the lowest intensity. Intensity dropped in every country in 1974–75, rebounded in most countries after 1975, and then fell rapidly after the 1979 price shock to less than two-thirds of its pre-1973 value in almost every country. The differences among countries shrunk. Significantly, intensity in Sweden fell slowly but steadily, and is still the lowest among the countries.

Oil intensity in MFD's also fell between 1972 and 1982 (*2*). Sweden had the lowest intensity throughout the study period, and this indicator moved slowly downward to a point about 20 percent lower in 1982 than in 1972. Intensities in France, Germany, and Denmark fell 34, 35, and 45 percent, respectively, between 1972 and 1982. In those three countries many apartments have direct metering of heat used. This caused greater fluctuations of use with energy prices than in Sweden (*18*).

The intensity data show that oil con-

sumers reduced use significantly, by 25 to 45 percent, over a 10-year period. If they had not, residential oil use in the seven countries would have been 33 to 80 percent higher than it actually was, given the number of homes that used oil in 1982–83.

Secondary Heating Fuels: A New Component

One reason that the intensity of oil use may decrease is that consumers use supplementary heating fuels. They do this because such fuels are cheaper than oil or because they can be used in individual rooms, allowing the central heating unit to be turned off. But if secondary fuels are now providing heat formerly provided by oil, then the drop in oil use does not necessarily represent a drop in energy use; there may or not remain a potential for more efficient oil use. Use of secondary fuels may decrease or even cease if oil prices drop. Hence it is necessary to consider their use separately.

Use of secondary fuels to supplement oil heating grew in importance after 1978 (*2*). The impact of these fuels on unit consumption is not well known in France, Germany, and Denmark, although we believe it to be very small compared to the savings of oil in SFD's (*2*). On the other hand, Canadian surveys (*19*) indicate high ownership of wood- and electricity-using secondary heating equipment but do not report quantities consumed. Swedish (*20*), Norwegian (*21*), and U.S. (*22*) surveys show that the impact of wood (and electricity) use in reducing oil intensity in SFD's is appreciable; in Sweden, for example, 45 percent of oil-heated SFD's also used electricity or wood or both in 1983, up from only 15 percent in 1972. Oil consumption in these dual fuel users was near 78 gigajoules (GJ) (1 GJ = 1 × 10^9 J) per dwelling versus 123 GJ in those using only oil. Secondary fuels—mostly gathered wood (12 PJ), but 3 PJ of electricity as well—displaced an average of 45 GJ of oil per dwelling in dual fuel users.

In Norway and Japan, use of two heating fuels is the rule. In Japan, where central heat is found in only about 4 percent of all homes—primarily those in the far north—85 to 90 percent of all households used small kerosene heaters as principal or secondary heat sources through the 1970's, in combination with small electric heaters (*3, 4, 7*). Norway represents the European equivalent in style; while almost half of all homes there used oil or kerosene in 1973, the combination of wood, oil, and electricity characterized most SFD's and even many MFD's (*21*). Significantly, fuel substitution, not energy conservation, dominated changes in residential energy use in both these countries between 1973 and 1983.

We estimate that secondary fuel use was responsible for half of the decline in oil intensity through 1982 in SFD's in Norway, 20 percent of the decline in Sweden, and 15 percent in Canada and the United States, but had far less impact in Denmark, France, and Germany, and was unimportant in MFD's in any country. Thus use of secondary fuels, while of some significance, contributes only slightly to overall oil savings except in Norway.

Changes in Oil Use: Role of Structure and Intensity

The changes in oil consumption in Germany between 1960 and 1983 are shown in Fig. 3, which displays growth in total oil use, growth in number of homes, and changes in intensity, all indexed to their 1960 values. Growth in the energy intensity of the substructure (shares of SFD's and central heat, and penetration of oil-based hot water) is also portrayed. The increase in the gap between oil use and number of homes was caused by greater central heating and hot water penetration and larger floor areas. The narrowing of the gap after 1973, and even more so after 1979,

Table 2. Indicators of oil heating: substructure, intensity, and total use. For Canada, France (up to 1978), and the United States (before 1970), we assume that half of the dwellings labeled "noncentral systems" by our sources are SFD's and half MFD's. The sum of columns eight and nine gives the total penetration of oil-based hot-water systems among oil-heated dwellings. Where the "split" is not known, the aggregate penetration of oil-based hot water is shown midway between these two columns. Oil consumption per dwelling and total consumption are corrected to average climate conditions (*2*). For Japan, oil use was 466 PJ (393 PJ for heating and hot water) in 1973, 624 PJ (554 PJ) in 1979, 582 PJ (510 PJ) in 1981, and 630 PJ (558 PJ) in 1983. Oil heaters were used in 31.9 million dwellings in that country in 1978, 35.4 million in 1979, and 37.4 million in 1983 (*3*).

Year	Dwellings with oil ($\times 10^6$)	Type (%)				Substructural index	Oil-based hot water (%)		Oil use	
		SFD's		MFD's			SFD's	MFD's	Per dwelling (GJ)	Total (PJ)
		Central	Noncentral	Central	Noncentral					
					Canada					
1961	2.66	70	30	←	←	~0.70			145	387
1973	3.66	57	11	26	6	0.78	13	12	162	593
1978	3.43	59	11	26	4	0.79	13	12	142	489
1983	2.68	65*	4*	31*	←	~0.79	14*	12*	109	291
					Denmark					
1965	0.75	43	9	33	15	0.69	32	26	125	93
1972	1.16	58	5	29	9	0.78	55	27	153	177
1977	1.19	62	3	30	5	0.80	61	30	131	156
1983	1.16	65	2	30	3	0.82	65	30	85	98
					France					
1962	2.14	10	27	36	27	0.51	7		50	107
1973	9.05	26	19	35	19	0.59	14	18	87	785
1978	9.09	34	14	38	14	0.64	20	21	79	722
1983	7.88	42	14	38	7	0.70	26	20	69	542
					Germany					
1960	2.08	21	26	27	26	0.56	7		77	160
1972	10.35	35	19	31	14	0.64	30	15	100	1031
1978	12.40	44	13	33	10	0.70	34	18	96	1193
1983–84	12.45	46	12	34	8	0.72	57		72	900
					Norway					
1960	0.14	21	40	26	13	0.57	18†	25†	94	14
1967	0.36	18	64	11	8	0.58	17†	9†	64	23
1973	0.59	14	65	14	7	0.60	14†	13†	70	41
1983	0.39	18	56	21	5	0.57	13†	18†	56	21
					Sweden					
1963	1.56	27	5	64	4	0.63	22	58	92	144
1972	2.23	41	1	56	2	0.70	40	56	116	250
1978	2.06	44	0.3	55	0.2	0.72	44	55	96	198
1983	1.49	41	0.2	59	0.2	0.70	40	59	81	118
					United States					
1960	19.6						37		145	2813
1973	21.5	63	10	24	4	0.81	37		150	3223
1978	20.0	64	10	23	4	0.82	34		140	2790
1982	16.9	65*	10*	22*	4*	~0.82	~35		99	1677

*Substructure value for 1981. †Value interpolated.

represents a drop in overall energy intensity compared with the peak in 1972 (Table 2). By 1981, average intensity had fallen to below its 1960 value, in spite of the enormous increase in living standards represented by the substructural components.

Rising incomes and the falling real price of oil through the early 1970's stimulated the swing to oil in homes with solid fuels in all noncentral heating systems, as well as the choice of oil in new centrally heated homes in Germany between 1960 and 1972 (*2, 3, 10*). At the same time, the data on SFD's and MFD's with central heating in Germany show a slight decrease in consumption per square meter between 1965 and 1973 (*23*), suggesting that real increases in comfort were obtained without additional oil use through improvements in building shells and equipment. The increase in oil heating continued, albeit at a lower rate, through the early 1980's.

This pattern is typical for the European countries (and Canada) represented in Table 2, although the underlying components and overall rates of growth vary in importance. During the period up to 1973, increases in the number of oil-heating dwellings—more than threefold in France, Germany, and Norway—and increases in the intensity of the substructure accounted for most of the increase in total oil use. In Denmark, Sweden, and Canada the changes after 1960 were less dramatic because the share of oil was already high in 1960, while in the United States it was declining.

Between the first oil price shock and 1978, total oil use declined most in Sweden, where consumption per unit and the number of oil-heated homes fell the most. In Denmark, consumption per unit fell as much as in Sweden, but the number of homes increased slightly; in other countries total use fell 15 percent at most, and in Germany it actually increased because oil remained popular in new homes and the penetration of central heating increased. As real oil prices stabilized and even fell slightly between 1976 and 1978, intensities in all countries (except Sweden) increased (Fig. 2). Thus the first oil price shock appears to have had only a minor effect on oil use in most countries. But prices shot up again between 1979 and 1981. After this, both intensity and the number of oil-heated dwellings decreased markedly. By 1982 the share of oil use in total residential energy consumption in all countries was heading back toward or below its share in the early 1960's (Fig. 1 and Table 2).

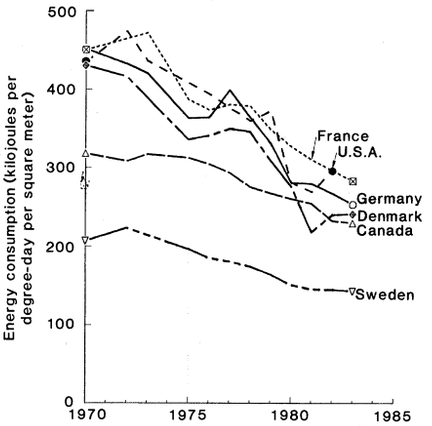

Fig. 2. Oil heating intensity in SFD's with central heat. Heated area was estimated from 1981–82 values and used for every year.

Savings in Oil, 1972 to 1982

Figure 4 shows the impact of changing structure and intensity on total oil use in Germany in 1960, 1972, and 1982 (Table 2 gives data for all the countries studied). The vertical axis represents the number of oil-heated dwellings, S, while the horizontal axis represents the consumption of oil per dwelling, I. The area under each rectangle thus gives total oil consumption for each year represented. S increased almost fivefold from 1960 to 1972; I, about 1.3-fold. By contrast, the increase in S from 1972 to 1982 was more than offset by the decrease in I: total oil use decreased 13 percent. That I fell by only about 30 percent is a reflection of the increase in the substructural index during this period; consumption per unit in homes with central heating fell by over 45 percent (*2*), but the share of central heating and the share of SFD's increased enough to cut this decline to only 30 percent. The effect of substructure is thus important because it can obscure the magnitude of conservation in homes having central heating before 1972, that is, in the cohort of oil users that survived the entire post-1973 period.

The appreciable magnitude of the oil savings is shown in Table 3 for each country. The relative importance of the components in the total change varies significantly among countries. In Sweden and Canada the absolute number of oil-heated dwellings dropped 27 and 35 percent, respectively, so that close to half of the change in oil use arose from structural changes. In the United States, intensity dropped considerably more than the number of dwellings. In Norway, the number of homes using oil as the principal fuel decreased greatly, but many homes still use oil as a secondary fuel, making assessment of the changes in intensity uncertain. Nevertheless, in these countries both structure and intensity contributed to lower oil use.

In the other countries the situation is quite different. In Denmark, structure has barely changed, but intensity dropped more than in any other country. In France the number of oil-heated dwellings reversed after 1978, and the overall drop in unit consumption was moderate, 21 percent, although falling by more than 30 percent in SFD's with central heating. In Germany there was an even greater decrease in intensity in all dwellings with central heating (~35 percent), but the number of homes with oil was 20 percent higher in 1983 than in 1972. Thus in these three countries the reduction in oil use has been caused mostly by a rapid decrease in intensity, both in new and in older homes. In

Table 3. Oil savings, 1972 to 1983. The structure change gives the change in the number of dwellings using oil. The index change gives the change in the substructural index. The intensity change gives the change in oil use per oil-heated dwelling. The structural component is the intensity for 1972 or 1973 multiplied by the change in structure; the intensity component is the structure for 1982 or 1983 multiplied by the change in intensity.

Period	Structure change (%)	Index change (%)	Intensity change (%)	Structural component (PJ)	Intensity component (PJ)	Total oil savings	
						PJ	Percentage of use in 1972–73
			Canada				
1973 to 1983	−27	1	−33	−160	−143	−302	−51
			Denmark				
1972 to 1983	0	5	−44	0	−78	−78	−44
			France				
1973 to 1983	−13	19	−21	−102	−141	−243	−31
			Germany				
1972 to 1983	20	12	−27	204	−338	−135	−13
			Norway				
1973 to 1983	−36	−5	−20	−14	−5	−19	−47
			Sweden				
1972 to 1983	−35	2	−30	−92	−49	−141	−55
			United States				
1973 to 1982	−21	3	−34	−690	−856	−1546	−48
Total	−12		−33	−854	−1611	−2465	−40

France and Germany the substructural index increased 12 and 19 percent, respectively, over the period from 1972 to 1983; this had an appreciable upward impact on aggregate intensity.

In all, the reductions in total oil use in Scandinavia and North America are significantly greater than those in Germany and France. We attribute this both to the greater availability of less costly substitutes (in Norway, Sweden, Canada, and the United States) and to the higher standards of heating and hot water use (in Denmark, Sweden, Canada, and the United States) prevalent before 1973, which yielded to great savings after that year (*24*). By the early 1980's, however, oil use was falling rapidly in all countries because of structure or intensity or both.

Japan presents an important exception to this pattern. There, use of oil for heating was 40 percent higher in 1983 than in 1973, having dropped briefly in 1973–74 and 1980–81 (*25*). Most of this growth arose because the number of oil-using homes increased steadily. Fuel substitution accounted for the two dips in oil use, while overall, consumption per unit grew throughout the 1970's.

Causes of Conservation

The factors that may have contributed most to the changes in oil use are higher prices, stagnant incomes, and government-instituted conservation programs.

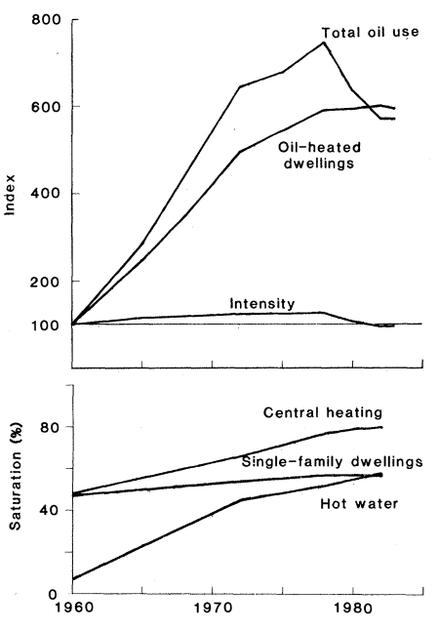

Fig. 3. Factorial analysis of the evolution of total oil use in West Germany. The values for total oil use, total number of oil-heated dwellings, and oil use per dwelling (intensity) are compared with 1960 values (=100). In the lower panel, the share of SFD's and the saturation of central heat and oil-based hot water in oil-heated homes are shown.

While a full analysis awaits even better data, we will review these factors briefly.

Prices. Higher oil prices (*2, 5, 10*) played a key role in the back out of oil from the residential market. The decline in energy intensity that followed the price increases in 1973–74 and 1979–80 and the increase in some countries when prices fell after 1976 suggest that higher prices are the principal cause of the decreased intensities over the short run. Over all countries, the relative increases in oil prices between 1972 and 1982 vary by almost a factor of 2. However, there is no monotonic inverse relation between price and quantity changes in the countries studied, suggesting that other factors are also important.

The changes in oil prices relative to other fuels is one such factor. The cost and availability of substitutes for oil vary widely among the seven countries. In Sweden and Norway after 1981, electricity became far less expensive than oil for heating purposes, stimulating a rush to electricity. In France, most of the conversions were made to gas, while electricity dominated the market in new construction; electricity still being 60 percent more expensive than oil, incentives to install electric heat there probably stimulated a swing to electricity in new homes. In Canada and the United States, gas and wood were substituted for oil. In Denmark there were few conversions to electricity because of its cost, while gas entered the market only in 1983. Instead, district heating, itself becoming less dependent on oil, took over for oil in apartments. In Germany, gas took up most of the conversions from oil as well as gaining a share in new homes from oil, electricity, and district heat. Finally, oil in Japan remains the least expensive heating fuel, explaining why the share of oil in residential use increased through 1979.

Not surprisingly, we find that a large price differential is needed to cause defections from oil to substitute fuels, but a small price differential is all that is necessary for the share of the substitute to increase in new homes. The greatest price differentials were in Sweden and Norway between oil and electricity and in North America between oil and gas; in these countries we also observed the greatest speed of conversion. Thus, higher oil prices appear to be the dominant cause of savings in oil from changes in structure as well as from intensity changes.

Incomes. Total residential end-use energy grew as fast as or faster than incomes before 1973 (*2*). Income growth and falling oil prices fueled the move to oil-fired central heating and hot water systems. Chern *et al.* (*10*) found that the long-term income elasticity of total energy use was less than one, if home size and central heating penetration, which are colinear with income, are included as explanatory variables along with prices and incomes. Thus energy use per dwelling need not increase once the major energy uses are satisfied. In Japan, residential energy use was low in 1973, and heating use per degree-day extremely low by OECD standards (*3, 7*). Not surprisingly, then, continued income growth spurred greater demand for space and water heating and greater oil use during most of the 1970's.

But when incomes fall, does energy use in existing equipment and houses fall? We believe the effect to be minor. First, the drop in oil intensity is much greater than the reduction in incomes. Second, the drop or stagnation in income is small compared to the relative increase in oil prices. These two effects suggest that income stagnation accounted for only a small part of the drop in oil use. Furthermore, recession may actually retard fuel conversion and conservation, which requires capital that is scarce in hard times. Similarly, new housing and equipment replace old more rapidly in good times. Because of these opposing effects, we conclude that the overall impact of slowed economic growth on oil use was slight. A return to faster eco-

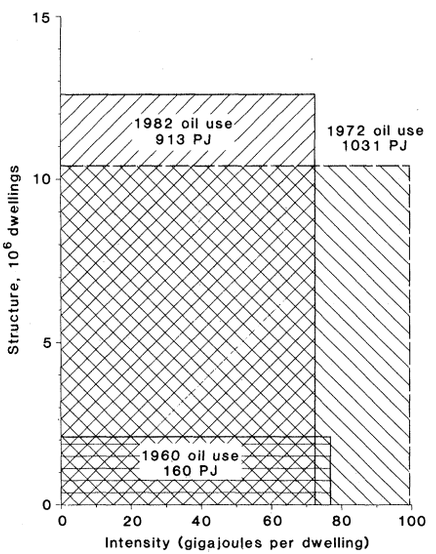

Fig. 4. Total oil use and its structural and intensity components in Germany in 1960, 1972, and 1982. The vertical axis gives the relative number of dwellings (with the actual numbers shown for reference) in the 3 years; the horizontal axis shows the intensity of oil use; and the area under each year's rectangle is proportional to total oil use. The upper left rectangle portion corresponds to the effect of changing structure on oil use; the lower right rectangle is the effect of changing intensity.

Table 4. Permanent and reversible components of residential oil savings in seven OECD countries. The components were derived from the structural and intensity components listed in Table 3.

Period	Permanent		Reversible (PJ)	Total savings (PJ)
	PJ	Percent		
		Canada		
1971 to 1983	−196	65	−107	−302
		Denmark		
1972 to 1983	−20	25	−59	−78
		France		
1973 to 1983	−137	57	−106	−243
		Germany		
1972 to 1983	119	*	−254	−135
		Norway†		
1972 to 1983	−13	65	7	−19
		Sweden		
1972 to 1983	−110	78	−31	−141
		United States		
1972 to 1982	−766	50	−780	−1546
		Total		
1972–73 to 1982–83	−1122	46	−1344	−2465
(percent of 1972–73 use)	(18%)		(22%)	(40%)

*Because of the great increase in the number of oil-heated dwellings, the permanent reduction in oil use from reduction in intensity is far less than the increase from structure. †Values for Norway are uncertain because of a domination of mixed systems, the changes in which are probably significant.

nomic growth will not cause a major increase in oil use.

Energy conservation programs. A variety of energy-saving programs have been instituted by governments to reduce oil and energy use by subsidizing consumers' and builders' investments in energy savings. More specific goals of reducing oil dependence mark each country's program as well (*14, 26–30*). While higher prices appear to be the most important cause of savings, there is a consensus that programs have accelerated savings somewhat or even caused some savings that would not have occurred otherwise. The interaction of higher prices and programs is significant, too.

Our analysis was not aimed at separating effects of programs from prices and incomes. Indeed, we believe it difficult, if not impossible, to separate the impact of a program from that of changes in prices and incomes without very detailed survey data currently available only for the United States (*22*) and France (*31*). However, data given herein and other data that should be available in the next few years should make it possible to estimate the incremental effect of conservation programs, particularly where energy intensities continue downward even as prices stabilize or fall, as was the case in Sweden and France in 1983 and 1984.

Oil Back Out: Permanent or Reversible?

To see whether the oil savings noted in Table 3 will persist, we estimate the permanent and reversible components of the changes in each country. Conversions away from oil usually involve substantial investment with a long payback time, so we classify these as permanent. However, 20 to 25 percent of the homes that abandoned oil as a principal fuel in Norway (*21*), Sweden (*20*), and the United State (*22*) still have their oil-heating equipment (or have dual-fired systems) as a secondary system. This means that certain homes could rapidly revert to oil. Let us estimate therefore that 80 percent of the conversions to oil in these countries are permanent; the rest are potentially reversible.

To evaluate changes in unit consumption, we classify modifications to the building stock (and heating equipment), through investments that increase efficiency, as virtually permanent. It is unlikely that falling oil prices would lead to reversals in these measures, particularly those with long lifetimes. We classify behavioral changes—setting thermostats lower, using less hot water—as reversible if prices fall. Similarly, improved maintenance of systems might be abandoned if oil prices decrease.

It is difficult to evaluate exactly the components of the decline in consumption per unit. However, several facts allow rough estimates of the nature of changes in oil use. In Sweden the decline in unit consumption has been slow but steady, and indoor temperatures are the highest among the countries studied (*3, 5*), yet oil intensities are still the lowest. The share of homes that underwent substantial retrofits is among the highest of the countries studied. On the basis of these characteristics, we estimate that 75 percent of the drop in intensity there is permanent. The rest is caused by lower temperatures or reduced hot water use, and by use of secondary fuels, which we deem reversible.

In France, Germany, and Denmark there were precipitous drops in 1973 and 1974 (reversed somewhat by 1976) and 1979 to 1981, which began to flatten out in 1982. In Norway, the United States, and Canada, the changes were also rapid, especially after 1979. The rapidity of this decline leads to the conjecture that most of the drop was caused by changes in behavior. Technical modifications to dwellings were not insignificant, particularly improvements in boiler maintenance (reversible) or purchases of better equipment, according to surveys in each country (*32*), but it is difficult to conceive of retrofitting all oil-heated dwellings in such a short time as to cause the drop in intensity that occurred between 1979 and 1982. In our judgment, 75 percent of the drop in unit consumption in these countries through 1983 was caused by changes in behavior or very simple measures to improve boiler efficiency through better maintenance; this part of the drop in intensity is reversible if prices fall. This is consistent with estimates made by authorities for France (*33*). However, it is possible that technical improvements will supplement or replace some of the behavioral changes in the 1980's (*34*).

We can now transform the structural and intensity changes into permanent and reversible components. Our results (Table 4) indicate that only in Sweden are the oil savings overwhelmingly permanent (78 percent). In the United States, Norway, France, and Canada, one-half to two-thirds of the savings are permanent. In the other countries, reversible savings dominate, and in Japan (not shown in Table 3 or 4) reductions in oil use in 1974–75 and 1980–81 were indeed reversed. Overall, we estimate that 46 percent of the change in oil use through 1983 (excluding Japan) is permanent.

Our figure for permanent savings is a lower limit: in early 1985, the experts who provided data for this study all indicated that through 1984 the permanent part of the reduced oil intensities in Denmark, France, and Germany was at least 50 percent, if not greater, or significantly larger than in 1982. Therefore, we judge that by 1984 the overall share increased to at least 60 percent of total oil savings.

Falling oil prices could reverse the remainder of the change. However, the number of oil-heated dwellings continued to decrease through 1984 in all countries, as substitutes became more attrac-

tive. This downward momentum kept oil use from rising in 1983. It appears that residential oil use will probably slide downward for several years to come, as more homes convert from oil and as more of those homes remaining with oil are retrofitted.

Conclusion

Figure 1 suggests that the heating oil era is on its way out. Our detailed examination of the nature of the decline after 1979 confirms this suggestion. Consumers in the seven OECD countries reduced home oil use 40 percent between 1972–73 and 1982–83; consumption per unit dropped over 30 percent on average, and the number of oil-heated homes fell 12 percent. While the conditions for each country studied differed significantly in 1973, the back out from oil is continuing. Only in Japan has oil use grown steadily between 1973 and 1983.

Can anything "bring back" oil? We do not think so. Heating oil will probably remain limited to smaller markets, such as homes far removed from gas or district-heating networks, while losing SFD's in countries with cheap electricity or wood. While economic recovery will allow somewhat greater energy use in homes in the short term, an upturn will also hasten the replacement of old, inefficient houses, appliances, hot-water heaters, and heating systems and will encourage greater renovation and retrofitting of structures—as well as conversion away from oil—by making more capital available.

If oil prices fell considerably for many years and economic growth were strong, however, conversions away from oil would probably stop, more homes might convert to oil, conservation investment would slow, and the share of oil in newer homes would increase again. We will not judge the likelihood of these preconditions, but we assert that both must occur in order to bring back oil. Even if all of the reversible part of the oil savings were to disappear, current trends in the number of oil-heated homes point to greatly decreased oil use during the coming years. We believe that the main uncertainties facing the OECD residential oil market are how far use will drop and how fast.

We noted at the outset that reduced dependence on oil was a goal in every country's energy policy (*14*). By 1983 this was achieved in every country in the study. Household oil savings contributed to this change. Overall, then, governments have met a very important energy policy goal. But, to the extent that public policies are concerned with the economics of comfort and not simply oil savings, the differences in the reactions of consumers in the countries analyzed are extremely important. In particular, the rapid decreases in intensity between 1979 and 1981 in Denmark, Germany, and the United States suggest that, while consumers saved oil, they may not have been comfortable. Indeed, people in oil-heated homes in many of these countries have yet to make the major investments required if they wish both comfort and lower heating costs through conservation. Bringing these two natural goals together remains an energy policy challenge of the 1980's.

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16. The countries are Denmark, Canada, France, West Germany, Norway, Sweden, and the United States. Oil use was very small in the Netherlands and the United Kingdom, so these are omitted from the analysis. While oil use has been significant in Italy (511 PJ in 1980) and Japan (630 PJ in 1983), data problems forced us to limit our treatment of these countries.
17. By dividing by degree-days and square meters, we account for the gross differences in climate and dwelling area. Figure 2 underestimates slightly the reduction in intensity because we use the floor areas for 1982–83, which were greater than those in 1972–73, for the entire period.
18. Consumption per square meter is higher in apartments than in SFD's in Sweden and in the United States. In these two countries, submetering of heat in oil-heated MFD's is almost unknown. In the other countries, where some recording devices are present in many apartments, MFD's do indeed have lower intensity.
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35. We gratefully acknowledge the contributions of S. Meyers, D. Hawk, P. Goering, A. Kahane, and those who provided data throughout North America and Europe, particularly those in the energy industries. F. Abel and M. Rothkopf provided critical comments. Energy, housing, and statistics officials in every country provided much assistance. We also thank Shell, Exxon (Esso), British Petroleum, and Olje Konsumenterna (OK) for information. Finally, special thanks are due to K. F. Holm whose early assistance provided information that served as a model for our work. Supported by the Department of Energy under contract DE-AC03-76SF00098.