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Efficient Energy Use and Well-Being: The Swedish Example

Swedes use less than two-thirds as much energy per capita as Americans, at the same standard of living.

Lee Schipper and Allan J. Lichtenberg

It is often said that there is a direct relationship between per capita energy use and standard of living as measured by gross national product (GNP) (*1*). However, examination of the energy and GNP statistics for the most industrialized countries indicates a large spread in the ratio of energy use per unit of GNP (see Fig. 1). This article compares energy use in the United States, one of the countries with a high energy/GNP ratio, with that in Sweden, a country which in 1971 used approximately 60 percent as much energy as the United States to generate each dollar of GNP. Sweden was chosen not only because of its low energy/GNP ratio, but also because the GNP per capita is essentially the same in both countries. Moreover, much of the economic activity and many of the demographic features in Sweden are similar to those in the United States. Thus, evaluating the differences in energy utilization between these two countries may illuminate strategies for saving energy (*2*).

Studies of energy conservation in the United States indicate that the more important of these strategies, taken together, could reduce energy consumption 25 to 40 percent (*3–5*), while lowering pollution, reducing capital requirements for energy production, and generally raising employment. But the interrelationships among economic inputs (including energy) within an economy are complex. Thus, examination of an economy that is similar to ours but requires substantially less energy than our own may provide guidance in understanding the total effect of energy conservation.

Interest in energy use and conservation has stimulated a number of international comparisons (*6, 7*), as well as new evaluations of data from single countries (*8, 9*). A preliminary study concerned with a number of countries showed some of the differences reported here, but no conclusions were drawn (*10*). In a study of the United States and West Germany (*11*) comparisons were developed further, and methods for conserving energy in the United States were discussed; the conclusions reached are in qualitative agreement with those in this article. Two other comparisons of U.S. and Swedish energy consumption have been undertaken (*6, 7*), and we have been able to compare our data with theirs. Although there are many small discrepancies in data from different sources, in no cases are these discrepancies large enough to change our general conclusions.

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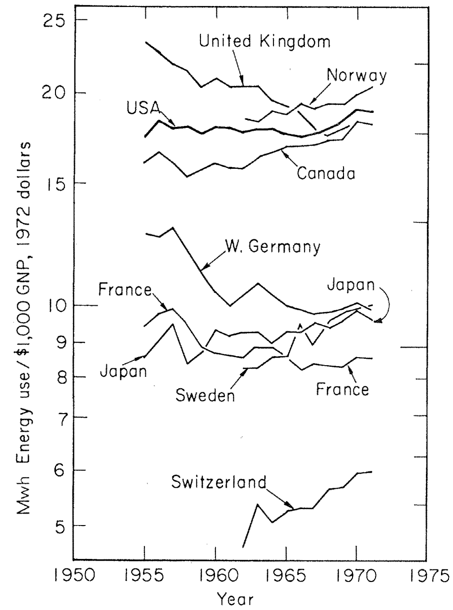
Factors Entering into International Energy-Use Comparisons

Many factors enter into the determination of the energy/GNP ratio. Among these are energy costs relative to other costs, government policies including taxes, subsidies, and regulations, and demographic and cultural variables. One meaningful measure of the effect of energy prices on consumption is the price elasticity of demand, defined as the ratio of the percentage change in demand to the percentage change in price, other factors being held constant. A study of the long-term elasticity for electricity in the United States, for example, gave values of −1.2 for residential use, −1.8 for industrial use, and −1.4 for commercial use (*12*). Recent studies indicate that the long-term elasticity for gasoline may be as great as −0.75 (*13*). The long-run effects of energy prices can be seen qualitatively in Fig. 1. The high energy/GNP countries are those that historically have had cheap energy (relative to other goods and services); the United States, Canada, Great Britain, and Norway are examples. The countries with lower energy/GNP ratios are those that have been relatively fuel-poor, especially since World War II. Although Sweden, for example, has had abundant hydropower, the country has been increasingly dependent on imported petroleum, particularly for nonelectric uses. Consequently, electricity has been inexpensive relative to fuel, with both price and per capita consumption very similar to that in the United States. Motor fuels, on the other hand, have been taxed heavily in Sweden, and per capita consumption of these refined petroleum products has been far below U.S. consumption. Similar taxes have been the rule in other oil-poor countries. Although oil for home heating has been relatively inexpensive in Sweden (comparable to U.S. oil prices) the large amounts demanded for long winter heating seasons acted in place of higher prices to stimulate conservation efforts (*14–18*).

Sweden's energy/GNP ratio was rising during the 1960's, probably because of

Fig. 1. The energy/GNP ratio for several countries over time, with hydroelectric power counted at 3 kwht/kwhe. From Linden (*1*). For a discussion of units, see (*2*).



changes in life-style similar to those which had taken place in the United States a decade or two earlier. These changes include greater living space and gasoline use per capita. The ratio has since stabilized and then fallen in the period of high energy prices after the oil embargo, as has the ratio in most other countries. The United Kingdom and West Germany had a falling energy/GNP ratio during the 1950's and early 1960's, probably due to a shift away from coal, which was their main cheap source of fuel, to more expensive substitutes.

One factor that can be important in determining the energy/GNP relationship is the relative industrialization or type of industry in a country. Certain products are particularly energy-intensive, including steel, aluminum, cement, paper, and plastics. The effect of changing the output mix is most noticeable in comparing Luxembourg, where the steel industry plays a dominant role in the economic structure, with Switzerland, where banking, insurance, timepieces, and other items of high value added per unit of energy expended predominate. Luxembourg has an energy/GNP ratio of 30 kilowatt-hours total per dollar compared to Switzerland's 6 kwht per dollar (*10*). The energy/GNP ratios of Great Britain and New Zealand were found to differ by a factor of 2 (*5*), which may be partly attributable to the degree of wealth based on agriculture in New Zealand. However, effects due to the agricultural sector are usually small among industrialized nations. For the countries in Fig. 1, agricultural sectors comprise between 3 and 5 percent of the total GNP; if any correlation exists, it is between energy use and the size of the services sector, which will be explored further below.

The effects of cultural and life-style differences on energy consumption are very difficult to quantify but are clearly very important. Cultural patterns, although not wholly controlled by the marketplace, may be tempered over long periods of time by prices and fuel availability. Some of the current pattern of intensive energy use in the United States and Canada can be traced to the availability of fuel wood during the 19th century (*19*). In 1850, for example, with a per capita energy consumption of 30.8×10^3 kwht, including wood, the United States used as much energy per capita as Switzerland does today.

We take the years 1970 to 1972 as our comparison period, because complete data are available and energy prices and use trends were relatively stable. Where appropriate, we use data from other years. In 1971, there was a mild recession in Sweden; total energy use was slightly higher in 1970, and our Swedish industry statistics were taken from that year. Because of variations in exchange rates, relative GNP's can change independent of changes in real wealth. Unless otherwise noted we employ the exchange rate of 5.18 Swedish crowns (Skr) per dollar, which applied until late 1971. The rate was as low as 3.9 Skr per dollar in 1973 and has since stabilized at 4.3 Skr per dollar in 1975 and 1976. It is generally believed that the old exchange rate undervalued the Swedish crown relative to the dollar.

In comparing energy/GNP ratios, additional problems arise. Comparing the size and content of the GNP has received considerable attention (*20*). In our study we give indications of the structure of the economy in Sweden and in the United States, highlighting the differences and similarities, comparing various physical standards of well-being. Accounting for differences in climate, geographic factors, population distribution,

Table 1. Basic economic and social indicators for the United States and Sweden (1971). Data for the United States are from (*24*), data for Sweden from (*22, 23*) and fact sheets distributed by the Swedish Institute, New York.

Indicator	United States	Sweden
Physical characteristics		
Population (million)	207	8.1
People per square mile	57	47
Climate-heating [degree-days per year (68°F)]*	5,500	9,200
Economic activity		
GNP (dollars per capita)	5,051	4,438
Energy consumption (kilowatt-hours per capita)	96,000	52,450
Steel (kilograms per capita)	620	680
Cement (kilograms per capita)	342	430
Fertilizer (kilograms per capita)	105	67
Paper (kilograms per capita)	224	540
Food (per day)		
Energy (kilocalorie per capita)	3,300	2,850
Protein (grams per capita)	99	80
Cereals (grams per capita)	176	168
Meat (grams per capita)	310	142
Health and education		
Doctors per 1000 persons	1.5	1.35
Dentists per 1000 persons	0.49	0.72
Hospital beds per 1000 persons	7.8	15
Infant deaths per 1000 births	19	11.1
Teachers per 1000 students	34	60
Newspaper copies per 1000 persons	301	534
Books published per 1000 persons	0.39	0.94
Conveniences		
Telephones per capita	0.59	0.56
Television sets per capita	0.45	0.32
Automobiles per capita	0.45	0.3
Automobile passenger miles per capita (1970)	7,900	5,050
Refrigerators (percent of households)	100	93
Freezers (percent of households)	28	46
Clothes washers (percent of households)	76	41
Vacuum cleaners (percent of households)	88	89

*We use 68°F for the United States and Sweden and have adjusted figures for the United States accordingly (*27*).

and so on, is also important; we have made comments on this problem where applicable. The method of counting the contributions of hydropower and of combined electricity and heat generation can be significant in international comparisons, and is discussed below. We find that no matter how one counts hydropower the difference in energy use between Sweden and the United States is large, especially since the largest contrasts appear in transportation, space heating, and process heat applications. The use of noncommercial sources of energy, usually considered only when discussing less-developed countries, is important to our comparison. The paper industry in Sweden, which accounts for fully 15 percent of the total consumption of energy there, actually generates 60 percent of its fuel internally from waste forest products. Together with other waste products, including urban wastes, these noncommercial fuels account for 9 percent of Sweden's total fuel use in 1971 (*21*) compared to 1 percent for the United States. Finally, a troublesome statistical problem is inconsistency between different information sources. For example, the fuel used by agricultural and construction equipment could be counted in transportation or industry, depending on how figures are kept. Similarly, self-generated electricity, district heating, by-product fuels (such as coke gas), noncommercial fuels, consumption of energy by energy producers, and so forth must be carefully sorted out. We believe we have resolved these various problems to the point that the remaining errors are only a few percent.

Sweden and the United States: Physical and Economic Comparison

In Table 1 we compare physical characteristics, economic activity, and various measures of well-being in the United States and Sweden (*22–24*). Although the populations differ by a factor of 25, the population densities are similar, as is the distribution into densely populated urban centers and sparsely populated rural regions. Movement to the suburbs, fostered by the automobile, started earlier and is more advanced in the United States, although there are signs of such a trend in Sweden (*25, 26*). The natural distances over which goods must move are larger in the United States, although in Sweden much of the lumber, iron ore, and electric power flows from the sparsely populated far north to the more crowded south. The climate in Sweden is more severe; the number of degree-days, weighted by population distribution, is close to 9200 in Sweden, comparable to the value in North Dakota, whereas the weighted U.S. average is approximately 5500 degree-days (*27*).

Table 1 indicates that in 1971 the United States had a GNP per capita 10 percent higher than Sweden's at the then current exchange rates. However, for each dollar of GNP Sweden required

Table 2. Per capita energy consumption in the United States and Sweden in 1971. Data for the United States are from (*28–30*); we included 1,000 kwh per capita in wood wastes (*30a*); the totals in the kwh and kwht columns do not agree because of differences in counting hydropower. The Swedish data are from (*16, 21, 31*), with feedstocks estimated from (*32–34*); we included 4,000 kwh per capita in wood wastes; hydropower was counted at 3,413 Btu/kwhe in the kwh column. All kwht values were calculated by distributing utility losses to end consumers; consumption of electricity within electrical sectors was counted in "Industry." The kwht column for the United States includes hydropower at 10,460 Btu/kwhe; that for Sweden counts all electricity at 10,400 Btu/kwhe. The actual "heat rate" for thermal and back-pressure plants in Sweden is 8,870 Btu/kwhe, including distribution losses; the rate for production only is 7,780 Btu/kwhe. Cogenerated electricity in the paper industry is excluded from the kwht columns.

Consumption	United States			Sweden		
	kwh	kwhe	kwht	kwh	kwhe	kwht
Transportation	24,025	25	24,075	7,350	200	7,775
Commercial	9,600	2,150	14,250	7,375	1,500	10,625
Residential	13,500	2,300	18,450	11,125	1,400	14,150
Industry	28,900	3,300	36,000	20,400	4,200	29,450
Feedstocks	5,600		5,600	2,500		2,500
Utility losses (actual)*	14,200			3,700		
Actual consumption†	95,825	7,775	98,375	52,450	7,300	64,500
Energy embodied in foreign trade‡	1,800§		1,800	−4,600‖		−4,600
Net consumption¶	97,625	7,775	100,175	48,150	7,300	59,900

*Hydropower was counted at 3,413 Btu/kwhe. Other losses are according to actual consumption. †Actual consumption refers to fuels and electricity, including petroleum refining losses and other captive fuels. ‡Embodied energy includes the process energy of refined fuels but not the energy available when the fuel is burned. §The import-export energy balance for the United States is from (*35*). ‖The import-export energy balance for Sweden is from (*16*). ¶Exports of coal, crude oil, or refined products are excluded from this balance.

Table 3. Passenger transportation data for the United States (*36–38*) and Sweden (*33, 40, 41*). Division of modes into urban (within areas of population 30,000) and intercity [from (*41*)] does not exactly correspond to our classification by local and intercity; PM, passenger mile.

Passenger mode	United States (1972)			Sweden (1970)		
	D_J' (PM per capita)	E_J' (kwh/PM)	T_J (kwh per capita)	D_J' (PM per capita)	E_J' (kwh/PM)	T_J (kwh per capita)
Automobile*						
< 30 miles	4,850	1.72	8,330	1,825		
> 30 miles	4,200	1.02	4,300	3,225		
Totals	9,050	1.41	12,630	5,050	0.74	3,760
(Totals for 1970)	(7,900)	(1.41)	(11,200)			
Bus†						
Local (< 30 miles)	112	0.50	56	460	0.41	200
Intercity (> 30 miles)	122	0.30	42	25		
Rail‡						
Local (< 30 miles)	64	0.21 (0.63)§	13.7	85	0.16 (0.48)§	15
Intercity (> 30 miles)	21.3	0.87	18.6	356	0.25 (0.75)§	90
Total land	9,370	1.36	12,760	5,975	0.68	4,065
Air domestic	490	3	1,500	46	1.12(?)	275(?)
Air international‖	243(?)	1.38(?)	335	200		
Other passenger and military			1,500		?	200
Total passenger	10,103		16,095	6,221		4,540

*Hirst (*36*) gives 1969 load factors that imply an overall load factor (ratio of passenger miles to vehicle miles) for automobiles of 1.7, which seems unreasonably low. A load factor of 2.2 is implied in (*37, 38*), and a load factor of 1.9, which we adopt, is assumed in (*42*). There was a similar discrepancy in the Swedish data, most references giving an implied overall load factor of 2, with one giving 1.7. We adopt 2, since the driving in Sweden is dominated by family driving to a greater degree than that in the United States. †The U.S. bus fleet is 75 percent diesel; the Swedish bus fleet is 10 percent electric, the remainder either diesel or gasoline. ‡The U.S. local rail service is electric; intercity rail service is 75 percent diesel, the rest electric. In Sweden 90 percent of rail service is electric, the rest diesel. §Electricity figures are net values, and the E_J's in parentheses reflect a theoretical 3 kwht/kwhe. ‖The figures for international fuel and passenger miles are uncertain.

only 68 percent as much energy as the United States. Correcting for the energy embodied in foreign trade (see below) reduces the 1971 Swedish figure to 61 percent. Despite the difference in energy use, the total per capita production of basic industrial commodities is comparable in Sweden and the United States.

Basic well-being is difficult to compare quantitatively. As seen in Table 1, food intake is similar, with Americans eating considerably more meat (about twice the Swedish per capita consumption), which, per gram of protein, is more energy-intensive than most other foods. In health and education, Sweden leads the United States in almost all categories. When the comprehensive health and social security system in Sweden is examined this difference is even more striking.

The large number of automobiles and TV's in the United States is accounted for mainly by multi-unit ownership by families. Transportation convenience is, in fact, comparable, because public transportation is more readily available in Sweden, and domestic distances are generally smaller (*25, 26*). Swedes have more second homes (500,000 in all) per capita than Americans, and most of the population enjoys 4 weeks of paid vacation each year. Thus we conclude that the living standards are comparable quantitatively in Sweden and the United States, but the mix is substantially different, with somewhat less energy-intensive economic activities and life-styles in Sweden.

Table 4. Automobile data for the United States and Sweden (1970). (Conversions used: 1 U.S. gallon = 33.75 kwh; 1 mile = 1.6 km.)

Parameter	United States	References	Sweden	References
Persons per vehicle	2.25	(*42*)	3.4	(*16*)
Licensed drivers per capita	0.5	(*38*)	0.4	(*16*)
Passenger miles per capita	7,900	(*42*)	5,050	(*40*)
Vehicle miles per capita	4,160	(*37*)	2,560	(*46*)
Miles per vehicle*	9,360	(*37*)	8,900	(*46*)
Load factor	1.9	(*42*)	2.0	(*40*)
Average weight (kg)	1,700	(*43*)	1,100	(*44*)
Miles per gallon†				
Actual	13.7	(*37, 43*)	24	(*43–45*)
Theoretical	12.5		20	
Kilowatt-hours per passenger mile	1.4		0.73	
Kilowatt-hours per capita	11,200		3,710	

*The surprising similarity between the U.S. and Swedish values suggests that in Sweden second cars are replaced by mass transit, and a significant number of families have no car at all. †The U.S. theoretical value is estimated from the weight-fuel economic statistics of the Environmental Protection Agency (*43*); the actual value is determined by dividing actual miles driven by fuel consumed. The Swedish theoretical value from Ullén (*44b*) matches the actual value for Sweden.

Table 5. Goods transportation data for the United States and Sweden. The U.S. data are from (*30, 30b, 39*). Swedish data are from (*16, 40*), with the breakdown for truck by distance based on the 1973 distribution.

Transport	United States (1972)			Sweden (1970)		
	D_J (ton-mile per capita)	E_J (kwh per ton-mile)	T_J (kwh per capita)	D_J (ton-mile per capita)	E_J (kwh per ton-mile)	T_J (kwh per capita)
Truck						
Local (0 to 30 miles)	360	1.95	700	339	0.58	200
Intercity (>30 miles)	2069	0.63	1430	1284	0.86	1100
Total truck	2429	0.88	2130	1623	0.8	1300
Rail	4132	0.19	800	1350	0.06 (0.18)*	80
Domestic air	20	7.5	150			
Water						
Domestic			420	704	0.3	190
International†			480			1600
Total goods	6585		3980	3670		3170
Nonrevenue goods transport (agriculture, forestry, construction, and so forth)			1850			470
Pipeline			200‡			
Other			120‡			930
Totals	6585		6150			4570

*The value in parentheses reflects a conversion factor of 3 kwht/kwhe. †Excluded from totals in Table 2. ‡These are 1971 data.

Comparison of Energy Use

In Table 2 we compare energy use in the United States and Sweden (*16, 21, 28–35*). Sweden uses less energy per capita in all sectors, the largest difference being in the transportation sector. There are considerable differences in basic materials processing in the industrial sector and electricity use in the residential and commercial sectors.

A useful formula that summarizes the uses of energy (T_J's) is: energy use = $\Sigma_J E_J D_J = \Sigma_J E'_J D'_J = \Sigma T_J$, where the D_J's are the dollar demands for goods and services and the E_J's are the energy intensities of those demands; or, in physical terms, the D'_J's are the quantities of goods and services and the E'_J's the energy intensities associated with those quantities.

When data are disaggregated in this way, both the relative mix of modes (D_J or D'_J) and the efficiency of those modes $(E_J)^{-1}$ or $(E'_J)^{-1}$ can be compared among countries. Energy use in the economy can be lowered by shifting economic activity to less energy-intensive sectors (D_J) or by increasing the efficiency (lower E_J) of production of a given D_J. We use this formalism in the specific comparison of U.S.-Swedish energy use. The differences in E_J's between countries indicate possibilities for energy conservation through technical change, without requiring changes in life-style.

Transportation. Table 3 shows basic passenger transportation data for Sweden and the United States (*33, 36–42*). Major differences exist in all modes. In addition to the striking differences in automobile D', E', and T, we note that Swedish passenger transportation is more heavily concentrated in rail (including subway) and bus modes, at the expense of the automobile and the airplane. All Swedish E'_J's are lower than the corresponding U.S. values. This is due in part to higher load factors and the extensive use of air and bus charters.

In Table 4 we consider the automobile in more detail (*37, 38, 40, 42–46*). We see that the Swedish D' is only 62 percent of the U.S. figure, and E' is only 60 percent of the U.S. figure. The biggest contributor to efficiency is the lower weight of Swedish cars (1100 compared to 1700 kilograms). The weight distributions are given in Fig. 2 (*43–45*). Interpolation of Environmental Protection Agency (EPA) measurements of fuel consumption as a function of inertial weight suggests that weight alone accounts for a 30 percent difference in energy consumption per mile (*43*). The lack of power extras, automatic transmissions, and air conditioners in Swedish cars reduces fuel demand further, as does the lower ratio of engine displacement to car weight.

In addition to these technical differences there are differences in automobile utilization that have significant consequences. For trips of 10 kilometers or less, for which automobile fuel consumption per mile is nearly double average fuel consumption (*47*), the Swedes use private cars and public transit in the ratio 55/45 (percentage of trips) (*45*). In the United States, by contrast, the ratio is 90/10 (*38*). This traffic accounts for 65 percent of all automobile trips in the United States, resulting in lower average driving cycle efficiencies. Thus it becomes apparent why actual miles per gallon in Sweden are higher than predicted by interpolation of EPA measurements (*43*); the driving cycle demands less energy. Surprisingly, load factors in both countries average approximately 2. This is probably because the smaller size of families in Sweden compensates for that country's higher ratio of family to commuter use.

Speed limits further reduce Swedish automobile energy use. The Swedish speed limit during our period of comparison was as high as 110 km/hour (68 mile/hour) on only about 10 percent of the largest highways. In the United States highway speed limits were commonly 65 mile/hour or more in 1971.

It has been noted (*25, 26*) that the use of alternatives to the automobile in Sweden has gradually eroded. Nevertheless, the automobile's share of all passenger miles has stabilized at 82 percent in Sweden (*33*); the U.S. figure is 92 percent (*38*). The availability and use of mass transportation in local and long-distance travel is an important factor in the optimization of the use of the auto discussed above (*25, 26*). In Stockholm, Gothenburg, and Malmö, where more than 25 percent of Sweden's population resides, mass transit, motor bikes, and pedal bikes account for 75 percent of all commuting (*41*). The figure for the entire country is 46 percent. Mass transit provides half of this, mostly in the cities named above. Most of the cities of more than 50,000 people in Sweden have bus systems and economic incentives, including subsidies, to encourage their use by riders going into the city center. In Gothenburg, for example, one can obtain a round-trip ticket for the price of a single fare by using the streetcars and buses at off-peak daytime hours; in Stockholm and other cities a 70-Skr pass allows unlimited transportation on all rail and bus lines. Buses are often as close as 4 minutes apart during peak hours, and rapid rail and buses provide direct service to places as much as 40 km from the city centers. Thus, to the city or suburban dweller in Sweden, mass transit presents a viable and economic alternative to the use of an automobile, and development of suburbs and new towns around rail and bus stations reflects the popularity of mass transportation. For longer trips, alternatives to automobile transport in Sweden are also available. Intercity buses, semicharter buses, and trains carry 20 percent of the passenger miles in trips over 50 km. Swedish Railways offers hourly departures between Malmö, Gothenburg, and Stockholm during day and early evening hours, traveling at average speeds of 80 to 100 km/hour.

The tax system has strongly affected use of the automobile in Sweden. In 1971, the gasoline tax of 50 cents per gallon raised the price by 250 percent to 70 cents per gallon (*23, 48*). Automobile excise taxes and yearly fees rise in proportion to vehicle weight according to the formula shown in Fig. 3. These fuel and weight taxes influence owners to purchase light cars, as the small proportion of cars heavier than 1700 kg (the U.S. average) shows (Fig. 2). In addition, the excise taxes raise the cost of a new car in Sweden (compared to the United States), providing an incentive to keep an older car in running condition.

Table 6. Per capita residential and commercial energy use in the United States (*3, 30b, 49, 49a*) and Sweden (*16, 41, 53, 54*) in 1972.

Use	United States	Sweden
Residential		
Direct fuel (kwh)		
Heating	9,660	8,200
Water heating	1,950	3,300
Gas appliances	630	125
Second homes		300
Electricity (kwhe)		
Refrigerator and stove	610	530
Lighting	335	105
Air conditioning	300	
Other appliances	590	475
Heating	280	400*
Water heating	500	
District heating saving		−1,300†
Total net use (kwh)	14,855	12,135
Electric conversion loss at U.S. rate‡	5,230	3,020
Total gross use (kwht) (with actual losses)‡	20,085	15,135 (12,820)
Commercial		
Floor space (m²)	10	13§
Direct fuel (kwh)		
Space heat	5,625	4,800
Water heat	790	
Air conditioning	200	
Electricity (kwhe)		
Air conditioning	205	
Lighting	1,250	625
Electric heat and other	310	1,075
Total net use (kwh)	8,380	6,500
Electric conversion loss‡	3,530	3,200
Total gross use (kwh) (with actual losses)‡		(7,280)

*Includes hot water in all-electric homes, and second homes. †Assigned to residential sector for convenience. ‡Losses are counted at the U.S. rate of 2 kwht/kwhe for uniform comparison, as in Table 2. Actual Swedish losses (0.46 kwht/kwhe) are reflected in the totals in parentheses. §This value is obtained from the volume of commercial office space by assuming a 4-m room height.

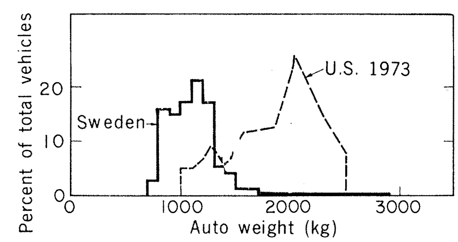


Fig. 2. Distribution of automobiles by weight. 1974. Swedish data are for 1974 and are from (*44*); U.S. data are for 1973 and were estimated from (*43a*).

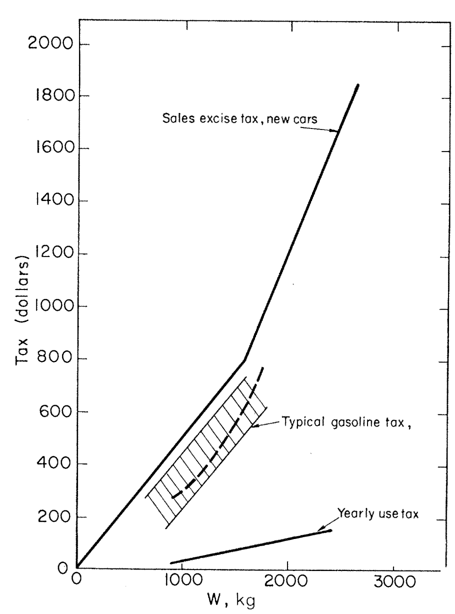


Fig. 3. Taxes on automobiles and gasoline in Sweden in 1974 (based on the old exchange rate of 5.18 Skr/$). Sales excise tax was computed from $45 per 100 kg to 1600 kg and $58 per 50-kg additional weight. The shaded area and dashed line give an estimate of gasoline tax as a function of weight, using 14¢/liter for a typical 20,000 km/year. The yearly use tax was computed from $32 + $8.40 [weight (kg)-900]/100. Data are from (*23, 44a, 48*).

The average car in Sweden has a lifetime of about 14 years compared to a U.S. average of less than 10 years.

Nontax disincentives have also been employed to discourage use of automobile transit in Sweden. In Stockholm there is no 24-hour free street parking in the greater downtown area, and parking fines begin at $12.50. Both Stockholm and Gothenburg have set up systems of barriers, one-way streets, mass transit–only lanes or passageways, and pedestrian-only streets that further discourage use of cars.

For freight transport, as shown in Table 5, the largest difference in per capita energy use is associated with distances through which goods are moved (*16, 30, 30b, 39, 40*). A lesser, though still important, factor is the energy intensity of freight movement. Although a complete study of efficiency is yet to be made, some important factors can be identified. Long-haul trucks are more energy-intensive in Sweden than in the United States, but short-haul freight is much less energy-intensive. Small station wagons and four-cylinder microbuses or diesel minitrucks are used extensively for short hauls in Sweden, in contrast to the heavier pickup or panel trucks used in the United States, so that mode and vehicle are more closely matched to the demands of the task. Much of the difference in freight miles would be accounted for by shipments of Swedish exports of raw materials through other countries, exports that far outweigh (literally) imports. However, these freight miles are not distinguished in our study. Also, coal and other fuels are transported over much greater distances in the United States than in Sweden.

Energy used in foreign passenger travel, particularly in European countries, where this constitutes a significant fraction of what corresponds to domestic travel in the United States, may distort comparative energy use analysis. This is particularly true of air travel. Nearly every passenger flight connecting Sweden with anywhere stops in Copenhagen, where most of the fuel for the trip is put aboard. Thus, Danish fuel intensity per air passenger mile is abnormally high (*8*), while that for Sweden is low (*16*). It is also difficult to credit passenger miles when foreign visitors travel to or within a country. Because of these uncertainties, we have refrained from drawing conclusions from the great differences in E' for air passenger travel in Table 3.

Residential and commercial energy use. A comparison of energy use in the residential and commercial sectors is given in Table 6 (*3, 16, 30b, 41, 49–51b*). Although the per capita consumption is significantly lower in most categories, a full appreciation of the differences is only obtained by examining the D'_j's and E'_j's separately.

Table 7. Residential space energy consumption (fossil fuels only). Data for the United States are from (*14, 15, 24, 51*); values are for single-family dwellings, except the kwh per capita value, which includes all dwellings. Swedish data are from (*16, 17*); MFD = multiple-family dwelling, SFD = single-family dwelling.

Parameter	United States	Sweden		
		MFD	SFD	Average
Persons per housing unit	3.3	2.1	3	
Rooms per housing unit	5.1	3.2	4.5	
Persons per room	0.66			0.66
Average area (m^2)	115	70	110	
Degree-days (68°F)	5,500			9,200
Kilowatt-hours per housing unit	34,000	16,350	28,750	
Kilowatt-hours per square meter	300	235	260	
Kilowatt-hours per degree-day	6.2	1.77	3.10	
Kilowatt-hours per square meter per degree-day	0.054	0.025	0.028	
Kilowatt-hours per capita	9,150			8,200

Table 8. Heating intensities by climatic regions for the United States (*14, 15*) and Sweden (*17*). In the Swedish data (*17*), curves for electrically heated homes were adjusted upward to reflect oil furnace efficiencies and construction.

Parameter	United States			Sweden		
	California	Pennsylvania	Minnesota	Malmö	Stockholm	Norrbotten
Degree-days (68°F)	1,900	5,500	8,500	7,700	9,200	13,000
Kilowatt-hours per square meter per degree-day	0.11	0.063	0.049	0.028	0.027	0.026

Space heating, consuming more than one-half of the total residential energy (Table 7), shows very large differences in efficiency when account is taken of the differing climates and the actual energy use per unit area of residential or commercial space. The larger number of degree-days in Sweden is compensated for by considerably lower heating intensity (kilowatt-hours per square meter per degree-day). A study of insulation in Swedish homes and apartments showed that heat loss through walls declined steadily to a typical U value of 0.06 British thermal unit per hour per square foot per degree Fahrenheit (*16*). One can almost guess the year of construction of a residence in Sweden by the U values, the scatter from the average value for any year of building being very low (*16*). This indicates that factors such as building codes have acted to permit only energy-efficient (and economic) construction in housing (*52*). In contrast, U values in the United States have been set mainly by a weak Federal Housing Administration (FHA) minimum property standard, which before 1971 was 0.12 Btu $hour^{-1}$ ft^{-2} $°F^{-1}$ for ceilings and 0.19 for walls (*50*). The factor of 2 difference between U.S. and Swedish U values is nearly equal to the average ratio of heating intensities. Swedish houses also have correspondingly less infiltration and heat loss through glass because of the use of double glazing (*17*).

Although the lower heat loss in Swedish houses is in part a response to the more severe climate, this is not the primary reason, as seen by comparing heating intensities in terms of degree-days in various regions in the United States and Sweden (Table 8). Although there is little overlap between the U.S. and Swedish degree-day values, the plots of intensity (kilowatt-hours per square meter per degree-day) against degree-days would clearly lie on different curves for Sweden and the United States. Also, the Swedish values are nearly independent of degree-days, reflecting the use of similar standards in their four climate zones (*52*).

In Sweden, the mix of single-family dwellings and apartments (multiple-family dwellings), 42 and 58 percent, respectively, is considerably different from that in the United States, where in 1970 the corresponding figures were 71 and 29 percent. However, this does not account for much of the difference in heating efficiency, as the kilowatt-hours per square meter was only slightly lower in Swedish apartments than in single-family dwellings, and the kilowatt-hours per capita was also very similar, because of the higher number of people per house in single-family dwellings. In apartments, common metering of all units in a building removed the incentive to conserve, raising both space heat and hot water use (*41*).

Use of electric resistance heating in Sweden was increasing rapidly (*53*), as was U.S. use (*49*), until the embargo of 1973 caused a reevaluation of the overall effectiveness of such systems. In 1972, 7 percent of Swedish homes (15 percent of single-family dwellings) were heated electrically, similar to the 8 percent in the United States, but much less than the approximately 20 percent in Norway, where hydroelectricity is the largest single contributor to the total energy supply. The average heat losses in Swedish all-electric homes are two-thirds of those in oil-heated homes (*17*).

In the commercial sector, overall energy use per square meter of space may be as much as 30 percent lower in Sweden than in the United States (*16*), even before the difference in heating degree-days is considered. The heating intensity, when measured in kilowatt-hours per square meter per degree-day, is approximately 2.5 times lower in Sweden. We attribute this mainly to the same differences in insulation, ventilation, and construction standards that applied to the residential sector, but the energy consumed in the commercial sector is reduced further by more realistic lighting standards, which also lower the need for cooling. (Unlike many large buildings in the United States, Swedish office buildings do not generally require air conditioning in winter to remove the heat produced by high lighting levels.)

In Table 6 the important residential and commercial uses of electricity are compared. Higher U.S. energy use arises primarily from a combination of factors: significantly more use of large appliances like dryers and large "frost-free" refrigerators, excess lighting, and more small appliances (*53, 54*). Air conditioning is conspicuously absent from Swedish electricity use, but accounts in the United States for only 12 percent of electricity used in the residential and the commercial sectors and only 3 percent of total energy use. The per capita total energy use for space cooling in the United States is roughly equal to the total consumption for space heating of factories in Sweden, a factor unimportant in the United States (*30a, 54*).

Water heating, another major energy user, requires typically 6,200 kwht per household in apartments (central water heating) and 10,500 kwht per household for single-family dwellings in Sweden, while the corresponding U.S. figures are 9,600 and 11,500 kwht. Much of the hot water in Sweden is prepared in centralized systems, eliminating some of the losses typical of American single-unit water heaters. On the other hand, the larger systems are not easily metered individually; in studies of energy use in apartments in Sweden (*16, 41*) it was noted that occupants paying individually for heat, hot water, and electricity use at least 15 percent less than those paying indirectly by sharing the cost in the rent.

An important mechanism for supplying space heat in Sweden is district heating, in which central stations either produce heat alone, or cogenerate heat and electricity. District heating supplies 19 percent of the total residential heat needs in Sweden (*16*). The energy balance for Swedish thermal power plants shows that 24 percent of the kilowatt-hour input appears as warm water or steam, primarily for heating of homes and buildings, and 29 percent as electricity (*21, 55a*). Figure 4 illustrates the combined electricity-heat balance for the United States and Sweden for 1971. In Malmö, a city of 250,000, combined electricity-heat stations provide heat for more than 50 percent of the homes (*55b*). The overall effect of these systems, after the slightly lowered production of electricity is taken into account, is a net saving of fuel of 1300 kwh per capita, which is 2 percent of the total energy consumption in Sweden. These savings are somewhat offset by the high demand for heat and hot water in unmetered

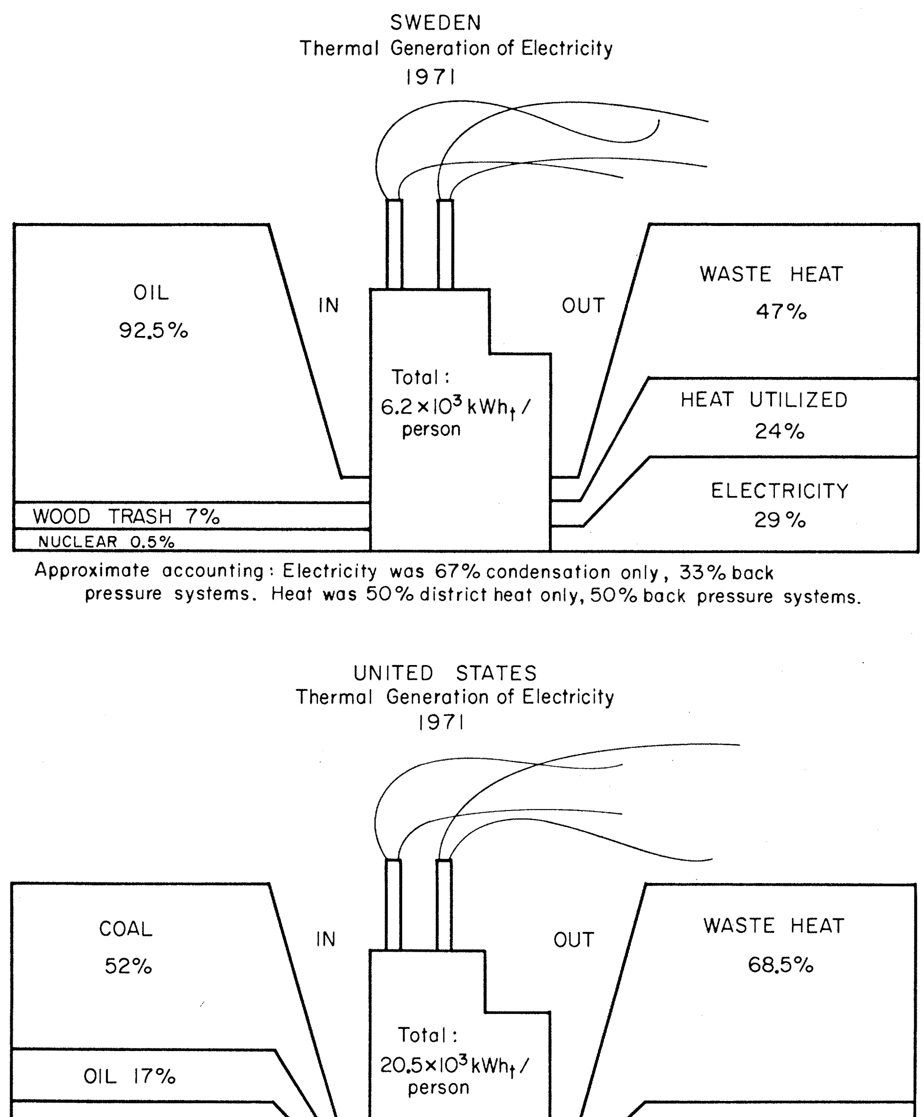


Fig. 4. Use of fuel to produce electricity in Sweden and the United States in 1971. The Swedish data exclude some process heat supplied to paper and mining industries (500 kwh per capita). The U.S. data exclude a small amount of co- and self-generation in industry. Data are from (*16, 21, 29, 55a*).

apartments in Sweden compared to single-family dwellings.

Industrial energy use. In both Sweden and the United States the largest use of energy in industry is for basic materials processing. In Sweden this energy use is highly concentrated, five sectors accounting for 85 percent of the net use (*16, 21, 30–35, 56–64*).

In Table 9 we see that larger fractions of Sweden's manufacturing value added and energy use are concentrated in the five energy-intensive sectors. Additionally, the energy use in each sector and the value added are more concentrated toward materials processing—organic chemicals versus drugs, paper mills versus paper products, and so forth. Thus the mix of output in Swedish industry is more energy-intensive than in U.S. industry. This is reflected in the E_J for the total of the energy-intensive industries, which is slightly higher in Sweden than in the United States, as is the aggregate E_J for all manufacturing. While some energy-intensive products, such as plastics, chemicals, and aluminum, are made in greater per capita quantities in the United States, steel, cement, paper, and pulp are made in greater per capita amounts in Sweden. Much of Sweden's energy-intensive raw output is exported.

However, these measures of intensity can be misleading. As Table 10 shows, the process energy intensity (E') is significantly lower in Sweden for virtually every product, usually because of reduced process heat requirements. We note that similar differences in process energy intensities were found in the study of West Germany (*11*). These findings suggest that Sweden's industry is more energy-efficient than our own. More important, though, these findings stress the inaccuracy of measuring energy use, or efficiency, by aggregate ratios of energy use to value added or GNP, as done in (*1*).

Swedish industries use more electricity as a fraction of industrial energy consumption, or as a fraction of all electricity used in the whole economy, than their American counterparts. This effect can be understood by noting that historically nearly all of Sweden's electricity has been generated from hydropower, the predominant domestic energy resource; industries could be expected to utilize this resource, which has been less costly than steam-based electricity. Since electricity prices are similar, we attribute the higher electric intensity of Swedish industry to the lower ratio of the price of electricity to the price of fuels, as compared to that in the United States, where most electricity is steam-based. These costs and the quantities used are summarized in Table 11.

Other factors in Sweden tend to reduce specific industrial energy consumption compared to that in the United States. Sixty percent of all fuel used in the paper industry (which consumed 15 percent of all energy in Sweden) is provided internally by barks and liquors, as opposed to 35 percent in the United States (*21*); but a third of the electricity used by that industry (and smaller frac-

Table 9. Energy use in industry—an economic overview. Data for the United States are from (*30, 56, 57*), data for Sweden from (*16, 33–35*). Values of kwh include kwhe. The E_J and T_J values are net; for gross kwht, multiply by [(2 kwhe/kwh) + 1], where the kwh and kwhe are from T_J. The U.S. figures for kwhe include self-generation, but these are not included in the E_J's. The U.S. E_J's are for 1971; value added from (*56*) was inflated to 1971 dollars.

Industrial sectors	D_J Value added ($/capita)		E_J (kwh/$)		T_J			
					U.S. (1971)		Sweden (1970)	
	U.S.	Sweden	U.S. (1971)	Sweden (1970)	kwh	kwhe	kwh	kwhe
Manufacturing								
Paper*	62	101	44	75	3,200	290	7,625	1,300
Market pulp	2	34			125	25	3,680	500
Paper mills	24	60			2,500	230	3,895	800
Percent of sector†	40%	84%			82%	88%	99%	100%
Chemicals	156	62	25	18	3,930	575	1,135	540
Organic	16	7			1,575	110	80	250
Inorganic		9			1,220	250	110	100
Plastics and fibers	24	18			630	80	305	80
Agricultural	8	7			115	15	120	55
Percent of sector	31%	49%			90%	79%	54%	90%
(Feedstocks consumed)‡					(4,600)		(1,600)	
Petroleum products	30	11.5	142.9	81.7	4,000	145	940	30
Refining§	25	8	152.0	112.5	3,800	135	900	23
Stone, glass, and clay	51	50	36.3	32.5	1,850	120	1,625	150
Primary metals	110	103	51.8	37.7	5,700	710	3,880	910
Basic steel	46	74			4,390	190	3,065	500
Alloys	10	3			80	35	280	160
Nonferrous	8	6			640	300	370	225
Percent of sector	57%	81%			90%	74%	96%	97%
Total energy-intensive‖	421	328	44.4	46.4	18,680	1,840	15,205	2,930
Other manufacturing	1,320	808	3.4	2.0	4,525	1,050	1,600	710
Total manufacturing	1,741	1,137	13.3	14.8	23,205	2,750	16,805	3,640
Energy harvest (excluding refining and electrical utilities)					2,500	230	500	280
Mining					570	100	570	180
Agriculture and forestry					1,825	55	510	200
Construction (excluding vehicles)					900	16	650	85
Total industry (excluding feed stocks)					29,020	3,290	19,035	4,385

*Includes wood wastes. †The value added is given for groups that are more energy-intensive than the average. Percent of sector gives the percentage of the sector contained therein. It can be seen that Sweden's value added is more concentrated in these sectors. ‡Feedstocks for Sweden are estimated from (*31–33*). These are excluded from totals. §Includes captive consumption not counted in most Swedish studies, but found in (*31, 32*). Feedstocks are subtracted from refining losses in (*31*). Here 500 kwh per capita of nonfuel petroleum (lubricants and so forth) is omitted, but it is counted in Table 2. The Swedish refining T could be as low as 700. ‖Excludes self-generation for electricity totals, except 400 kwh of self-generation in paper and pulp industries in Sweden.

tions elsewhere) is cogenerated with steam production (*16, 21, 55a*), thus reducing fuel needs. Cogeneration has also achieved considerable energy savings in Germany (*11*), and is considered to be economic for the United States (*65*), where half of the electricity consumed in the paper industry is self-generated, but only a small amount is cogenerated.

Like process industries, assembly industries in Sweden tend to show a lower use of fuel per unit of product (or value added) than those in the United States. This is in spite of greater space heating requirements in Sweden, which in some cases surpass requirements for electric drive and lights. A total of 20 percent of Sweden's industrial energy use is for space heating. In the entire Volvo concern, encompassing several large assembly plants, 1974 energy use was estimated at 0.6×10^9 kwh for space heat and hot water, a similar amount for process heat, and an equal amount for electricity, of which one-third went for lighting and office use. [Volvo was able to cut its total energy use 25 percent after the oil embargo through "leak plugging" (*62a*).] If Swedish industrial fuel use were adjusted to take into account the difference in climate, it would be 10 percent lower.

The relatively more modern equipment in Swedish industry—Sweden's capital stock has grown significantly faster than ours as the Swedish GNP approached ours—certainly contributes to the higher efficiency. Both U.S. and Swedish industry have improved energy efficiency through technological change since World War II, in spite of generally falling energy prices (*56*). A comparison of data collected by Meyers *et al.* (*56*) with Swedish data (kilowatt-hours per ton or per dollar) suggests that the energy intensity of Swedish industry today would lie 10 to 15 years hence on the projected curves of Meyers *et al.* for U.S. industry. Significantly absent from Swedish industrial energy use were (and are) "interruptable" gas at bargain prices and cheap coal, two fuels that have been important to many U.S. industries and whose low price and availability fostered higher energy use in the past. The importance of relatively higher prices for energy in Sweden as a major factor in its relative energy efficiency was emphasized in a series of studies by Carlsson (*61*); see also (*16*), vol. 2, appendix 3.

Both official Swedish government forecasts (*16*) and the views of individuals in industry (*61–63*) reflect the belief that

Table 10. Materials and energy consumption data for the United States and Sweden. Data are for 1970 and 1971; U.S. data are from (*5, 7, 11, 24, 30a, 56, 59*), Swedish data from (*7, 16, 23, 32, 33, 60*). Electricity was included (net) in E_J. The T_J value for Sweden reflects 3 kwht/kwhe.

Material	D_J' (kg/capita)		E_J' (kwh/kg)		E_J' (kwhe/kg)		T_J (kwh/capita)		T_J* (kwht/capita)	
	United States	Sweden	United States	Sweden	United States	Sweden	United States	Sweden	United States	Sweden
Basic steel*	580	650	7	4.8	0.5	1.0	4000	3100	4640	4420
Aluminum†	17	9	17.7	17.7	17.0	17.0	300	160	880	465
Oil refined‡	2900	1400	1.4	0.7	0.05	0.05	4060	900	4350	940
Market pulp‡	~ 1	550	9	6.7	1	1		3685		4900
Paper, including pulping§	260	550	9.5	6.6	1.5	1.5	2470	3630	2860	4730
Cement	342	460	2.0	1.6	0.1	0.1	685	735	755	830
Organic chemicals‖	234	89	6.7	4.0			1575	355	1800	855
Inorganic chemicals‖	100	87	12.2	4.4			1220	390	1720	600
Plastics and fibers‖	51	43	12.3	5.0			630	215	790	375
Fertilizer‖	105	67	1.0	1.8			115	115	145	230
Feedstocks (energy)‖	480	215	11.63	11.63			5600	2500		

*We did not include the energy content of scrap, estimated at an average of 500 kwh/ton for the United States and 1000 kwh/ton for Sweden, averaged over all steel. †Counts only the smelting of Al_2O_3 to Al. Refining of bauxite takes place in the United States but not in Sweden. ‡The U.S. oil refining E_J is from (*56, 59*). Swedish losses are estimated from (*31*) and (*33*). The last source gives a very low figure of 0.65 kwh/kg, but estimates based on the known flow of oil through refineries indicate 1.0 kwh/kg. We do not account for differences in refinery output mix. §Pulp and paper values include the energy in wood wastes and liquors. This amounts to 1000 kwh per capita for the United States (*30a, 59*), and about 4000 kwh per capita for Sweden (*16, 21*). Sweden uses more wood waste for fuel per ton of output, and uses fewer external fuels as well. Swedish electricity was one-third cogenerated, and U.S. electricity about half that. ‖Values of E for chemicals are difficult to obtain and to compare. Feedstocks used, including road oils, were converted to kilograms by using the approximate relation 1 kg (oil equivalent) = 11.63 kwh. Energy consumed by uranium enrichment in the United States is counted in industrial chemicals (*57*).

Table 11. Energy intensities and costs in industry. The U.S. data (for 1971) are from (*56, 57, 60*), Swedish data (for 1970) from (*16*). Price figures are for purchased fuels only. Electricity data are for purchased electricity, except for the Swedish paper industry. Subscripts e and f mean electricity and fuel.

Industry	T_J (kwh/capita)		E (kwh/$)		P (¢/kwh)		P_e/P_f	
	United States	Sweden	United States	Sweden	United States	Sweden	United States	Sweden
Five energy-intensive industries (excluding feedstocks)*								
Fuel	16,840	12,275	40	37.4	0.15	0.20	5.4	3.75
Electricity	1,840	2,930	4.4	8.9	0.81	0.75		
Other manufacturing†								
Fuel	3,475	900	2.6	1.1	0.19	0.36	6.3	3.1
Electricity	1,050	710	0.8	0.9	1.2	1.1		
Total manufacturing								
Fuel	20,315	13,175	11.7	11.6	0.16	0.22	6.25	3.7
Electricity	2,890	3,640	1.7	3.2	1.0	0.82		

*Energy-intensive industries include paper [Standard Industrial Classification (SIC) 26, Svensk Näringsgrenindelning (SNI) 341], chemicals (SIC 29, SNI 353 and 354), stone glass and clay (SIC 32, SNI 36), and primary metals (SIC 33, SNI 37). †"Other" industries include SIC 20 to 25, 27, 30, 31, and 34 to 39, and SNI 31 to 33, 342, 355, 356, 38, and 39.

optimization to counter ever-increasing fuel prices will further reduce specific energy requirements of Swedish industry toward the end of the century, as many have also predicted for the United States (*3, 4, 56*). Since Sweden traditionally has paid a high industrial wage, the saving of energy has come about not by direct substitution of labor for energy, but through the substitution of energy management (*62*) and capital [Carlsson in (*16*), vol. 2, appendix 3] for energy.

Other factors in resource use in Sweden contribute to both lower demand per product and lower demand for energy-intensive products themselves. It was noted above that Swedish cars outlast American cars, weigh less, and use materials that themselves require less energy than their American counterparts. Furthermore, Swedish consumers have maintained the widespread use of returnable bottles. Other utilization patterns (relative sizes of D_J) are interesting; in the late 1960's plastic bags became popular, only to be replaced by paper again as the cost of plastic, made from imported petroleum, rose compared to the cost of paper, made largely from domestic sources. We can generally conclude that cultural and institutional factors combine with economic and technical factors to effect energy savings in the industrial sector in Sweden relative to the United States. This is mainly done by increasing efficiency (lowering the E_J's); but changing the mix of products (mix of D_J's) actually consumed in Sweden toward lower energy intensity is also significant in some areas.

Imports and exports of goods. Since imports and exports comprise an important part of economic activity it is important to evaluate the energy embodied in nonenergy trade, as well as the process energy embodied in refined fuels, such as gasoline. We consider direct energy to be that applied by the producer of a good or service, and indirect energy that required to produce the materials and services used by the producer. For the United States, Herendeen and Bullard (*35*) found that while nonenergy imports and exports contained equal amounts of energy, the imports of refined oil embodied more energy than exports of coal and refined oil products (excluding the heat of combustion of these fuels). A similar balance for Sweden was evaluated by the Energi Prognos Kommitéen (*16*). The results, summarized in Table 2, show that Sweden's energy use per capita is overestimated due to an export surplus of embodied energy; the United States has a small import surplus. In contrast, Denmark's per capita energy use is considerably underestimated, as shown by Elbaek (*8b*), who found that the energy balance of trade amounted to an import of 20 percent of the energy consumed in Denmark. By contrast, West Germany has a large export surplus (*11*). Note that in every case the energy embodied in import of fuel is much larger than any of these figures. We conclude that an accounting of the energy embodied in foreign trade widens the difference in energy use between Sweden and the United States.

Electricity production and district heating. Sweden is rich in hydropower, an energy source that accounted for approximately 14 percent of all energy and 75 percent of all electricity produced in 1972. In Swedish statistics the electricity is counted at 85 percent First Law efficiency. Since most of Sweden's hydroelectric resources are in the far north, transmission line losses are greater than in the United States, per net kilowatt-hour sold.

About 35 percent of Sweden's fuel-based electricity came from combined heat-electricity systems, which produce more useful kilowatt-hours per kilowatt-hour total consumed than do purely electrical-thermal plants (*16, 55a*). In 1971 Sweden consumed fuel amounting to about 4.11 Mwh per capita to produce 1.77 Mwh per capita of electricity, for a "heat" rate of 2.32 kwht/kwhe. This is illustrated in Fig. 4, in which 0.8 Mwh per capita heat-only production is included. If the heat and electricity had been generated separately, about 1.3 Mwh per capita additional fuel would have been required if the heat was then produced in central plants, and about 1.5 Mwh per capita more if it was produced in smaller boilers. Only the half of the combined heat-electricity and heat-only systems that are in or near cities, to supply residential and commercial heat, are included in Fig. 4. The other half, located in industries, primarily paper, doubles the energy savings given above. Central heat-only plants provide heat for 600,000 dwellings, at 85 percent fuel to home (First Law) efficiency, compared to 65 percent for boilers in apartments. This

Table 12. Typical energy prices in the United States and Sweden. The exchange rate used is $1 = 5.18 Skr (1960 to 1970) and 4.30 Skr (1974). The U.S. data are from (*15, 24, 57*); Chern (*58*) gives the following prices (¢/kwh) for U.S. industry as a whole in 1971; gas, 0.13; coal, 0.12; oil, 0.23; electricity, 0.98; and other, 0.25. Compare with Swedish prices. The Swedish data are from (*16, 23, 48*) and a 1975 press release from the Swedish embassy.

Energy type	United States				Sweden			
	1960	1970	1974	1970 (¢/kwh)	1960	1970	1974	(1970) (¢/kwh)
Oil products (¢/gallon)								
Gasoline*	30	35	45	1.04	53	61	116	1.82
Diesel	23	28	35	0.83	42	48.8	90	1.45
Heating oil								
Small customers	15	18	35	0.50	13.3	13.2	40.6	0.37
Large customers	10.5	12	25	0.33				
Heavy oil	7	8	23	0.23	7	8.5	22.5	0.24
Gas (¢/MM Btu)								
Residential	82	87	113	0.29		550	680†	1.9
Industrial								
Firm Service	51	50		0.17				
Interruptable service	33	34		0.11				
Coal, industrial ($/ton)‡	10	13	25	0.14		18		0.2
Electricity (¢/kwh)								
Base	2.75	2.75		2.75	3.14‖	2.12‖	2.3§‖	
Base and space heating	1.75	2.0		1.5		~1.5	2.0§	
Industrial	1	1	1.5	0.4–2.1		0.93	1.8§	0.6–2.2

*Swedish gasoline taxes: 42¢ per gallon in 1970, about 68¢ per gallon in 1974. The U.S. prices include a tax of 10 to 13¢ per gallon. †Data for 1973. ‡Coal price excludes captive and utility coal. §Data for 1975. ‖Swedish figures are based on 1700 kwh/year (1960), 3000 kwh/year (1970), and 2000 kwh/year (1974).

saves 5100 kwh per dwelling or 375 kwh per capita. Another 25 kwh per capita is saved by district heating of buildings, for a total savings of about 400 kwh per capita from heat centrals. These savings must be added to those obtained by use of district heat from combined generation. The use of back pressure and heat-only centrals, in Sweden, leads to a heat rate of about 2.3 kwht/kwhe. Applying this thermal heat rate to hydropower in Sweden leads to a value of kwht which is 12 percent greater than the net kwh. This is in contrast to the 20 percent increase in Table 2 that was obtained by applying the U.S. heat rate to Swedish hydropower.

An additional factor that should be taken into account when comparing electricity use is that, stimulated by the low ratio of the price of electricity to the price of fuel, Swedish industry tended to use electricity for a wider range of tasks. Had electricity been 85 percent thermally generated, as in the United States, it would have been more expensive, and therefore used more sparingly (*66*).

Analysis of Differences in Energy Use; Conclusions

In Table 12 we show explicitly some important energy prices for Sweden and the United States. The largest price differences occur in road fuels, even before the higher taxes on automobiles in Sweden are considered. Electricity, on the other hand, has been relatively inexpensive (compared to fuel) in Sweden, because in the past a large share of electricity has been hydropower (*66*). In 1971 electricity use in Sweden (7400 kwh per capita) was close to that in the United States (7700 kwh per capita), but more of this total was used in the industrial sector in Sweden and more in the residential and commercial sector in the United States. Other fuels in Sweden lie between these two extremes, being slightly more expensive in Sweden (before 1973) and used more efficiently there as well. Since the price of oil used for home heating in Sweden was comparable to U.S. values (until 1973), the length of the heating season, as well as institutional factors mentioned above, must account for the efficient use of that fuel for space comfort. Significantly, Sweden had no natural gas or domestic coal, two fuels whose low prices certainly encouraged intensive use in the United States.

Higher energy prices alone, however, do not account for the more efficient energy use in Sweden. In this article and elsewhere (*4*) it has been stressed that, while a particular set of energy prices determines a mix of energy and other economic factors that allows production for the least cost, institutional and social factors determine how close individual consumers, firms, and society as a whole come to this most economic energy use. In the United States, for example, mortgage policies and market considerations constrain developers to minimize first costs, rather than life-cycle costs, constraints that do not appear to be applicable to construction in Sweden. Also, building codes have imposed energy-conserving construction more uniformly in Sweden, and the Swedish government has given priority to energy conservation in housing loans (*52*). Energy conservation in passenger transport in Sweden has also been strongly influenced by government policy, in this case mainly through the market mechanism, by various taxes and incentives. These factors also have important synergistic effects. Good intracity transport, and high costs of operating an automobile, tend to keep the population more concentrated. In addition to maintaining the viability of the public transport system itself, this situation also affects housing and living patterns in energy-saving ways. With increased population densities apartment living is more common, potentially effecting energy savings through fewer external walls, better insulation, and more efficient heating systems. Shopping also becomes easier, with more neighborhood stores; trips are shorter, often on foot; and smaller storage facilities are

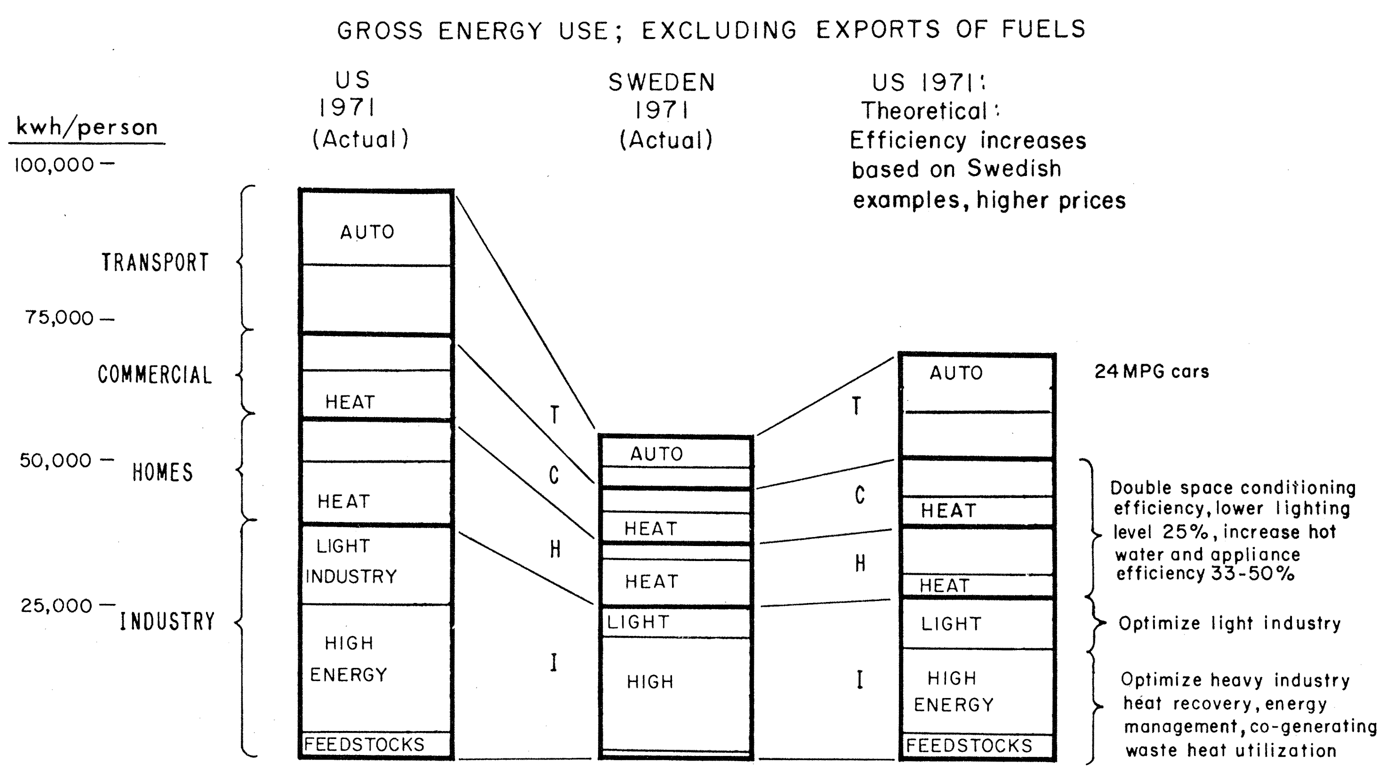


Fig. 5. Summary of U.S. and Swedish energy use in 1971, and theoretical U.S. energy use based on Swedish intensities in industry, space conditioning, and automobiles (miles per gallon). For theoretical U.S. use it is also assumed that appliance use and lighting levels decrease by 33 percent. Freight, airlines, and energy extraction are ignored, but higher air-conditioning and lighting efficiency are factored in. Life-style factors (such as numbers of appliances and passenger miles) were not considered. Values in the column at the left are kwh per capita. Compare with (*3*—*5*).

required, resulting in smaller refrigerators with consequent electricity savings.

In a recent study of energy use in the United States, Hannon (*67*) suggested that lowering the energy requirement for an economy by changing life-styles and the mix of consumer goods (the D_J's) would be difficult, because consumer expenditures would generate energy requirements no matter how they were directed. We have shown here that in Sweden the D_J's are shifted toward less energy-intensive activities, and the E_J's toward higher efficiency. For both effects, dollars saved by saving energy in one activity and respent on another do not, on the average, generate as much energy use as expenditures for a more energy-intensive mix of D_J's, or activities with less efficient E_J's, would have done. All energy intensities are reduced through higher efficiencies (conservation), and shifts from more to less energy-intensive activities are made at the same dollar level. Sweden, like other European countries, developed these energy economies to offset its higher energy prices and balance of payments problem resulting from importing energy. This resulted in a higher standard of living for a particular level of energy consumption. This suggests the answer to the dilemma posed by Hannon: in the face of energy scarcity and consequent rising energy prices, consumers in the United States would seek to maintain their standard of living by optimizing energy use both through increased energy efficiency and through shifting to less energy-intensive activity.

Future work should further elucidate both the underlying causes of and the mechanisms for achieving higher energy use efficiency in Sweden. At this point we offer some tentative conclusions about energy use based on our comparison of Sweden and the United States.

1) For a particular GNP, the efficiency of energy use, demographic factors, and the mix of goods and services share in determining the energy requirements of an economy.

2) Some of the main factors that have accounted for the reduced energy use in Sweden are smaller automobiles, more use of mass transit, more insulation and tighter construction, more efficient industrial processes, and the use of cogeneration and district heating.

3) Higher efficiency (lower E values) accounts for the largest portion of the lower energy use in Sweden arising from these factors.

4) Counting hydropower at 3 kwht/kwhe, as is done in U.S. accounting, results in a ratio of Swedish to U.S. energy consumption of 0.6, while using a one-to-one accounting results in a ratio of 0.5. The difference, although significant, does not account for the dramatically lower Swedish energy use.

5) The most important variable affecting energy use and energy efficiency is the relative price of energy with respect to other resources. However, institutional and social factors are also important.

6) It is necessary to consider individual energy intensities (E_J's) as well as levels of activity (D_J's) in order to understand energy uses and needs. Consideration of only total energy use (ΣT_J) or the energy/GNP ratio (*1, 28, 68*) obscures dramatic differences in intensity (or efficiency) and economic structure. Similarly, forecasts of energy "needs" in which the aggregated quantities are used also overlook vital details and trends in the components of E and D, components that may be more or less sensitive to changes in energy prices.

Although we have seen that energy use in Sweden is generally more efficient than that in the United States, both countries can improve energy use effectiveness by optimizing to the higher energy prices that have developed since the period we examined. Our comparison indicates that many energy conservation measures are available to the United States, as energy prices continue to rise. The Swedish economy performs well as a (relatively) energy-efficient economy, suggesting that more efficient energy use will not interfere with the function of the American economy. While we hesitate to give an exact figure, we suggest that Swedish methods of energy conservation, including smaller cars, better structures, and more efficient use of process heat, would result in a savings of 30 percent of the total energy used in the United States (Fig. 5). Thus, international energy use comparisons, far from suggesting an inevitable coupling between level of economic activity and energy use, actually suggest ways in which more well-being can be wrought from every Btu of fuel and kilowatt-hour of electricity consumed in a given country (*69*).

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Life Events, Stress, and Illness

Judith G. Rabkin and Elmer L. Struening

Studies relating social factors and life events to illness appear with remarkable regularity in the major psychological, psychiatric, psychosomatic, and sociological journals, and to a lesser extent in those of clinical medicine and epidemiology. While some of these publications derive from the cumulative efforts of investigators who have worked in this field for many years, concern has been expressed that many recent studies repeat both the findings and the flaws of earlier ones, delaying a hierarchical growth and development of knowledge in the field. Accordingly, there is a need for critical evaluation of this literature, taking in issues of method as well as content. In this article our goals are (i) to review selectively the research literature on the relations of life events, stress, and the onset of illness; (ii) to delineate trends in its development; (iii) to evaluate the conceptual and methodological approaches employed; (iv) to identify major variables mediating the impact of stressful events on individuals and groups; and (v) to recommend more comprehensive approaches to substantive issues.

Despite historical recognition of the predisposing role of social factors in the onset of illness, it is only during the last 40 years that scientists have attempted to study these phenomena systematically. In 1936 Hans Selye articulated his concept of stress as the "general adaptation syndrome," a set of nonspecific physiological reactions to various noxious environmental agents (*1*). This formulation was largely responsible for popularizing the concept of stress in the scientific

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