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Electricity Demand Growth and the Energy Crisis

An analysis of electricity demand growth projections suggests overestimates in the long run.

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In one sense the term energy crisis means simply that the supplies of fuels and power are less than we want, or that they might cost much more in the future.

In another sense, an enlargement of the first, it refers to a tangled web of problems concerning the quality of the environment and the availability, marketing, and growing demand for energy resources. Figure 1 is a diagram of these problems. We can see, for example, that our perception of the need for breeder and fusion reactors is influenced by our understanding of the energy crisis. In turn, our view of this possible crisis is affected by our beliefs about the growth of the demand for energy. If energy prices significantly influence this growth, then our energy system has some interesting circuits. Regulation of surface mines, for example, could reduce the need for the development of fusion power through the mechanism of higher costs and prices and reduced growth rates for demand and supply.

However, most observers today believe that the growth of demands for the various types of energy will be autonomous: Demand will grow independently of any changes in the "factors" box at the top of Fig. 1, or these factors will themselves continue to develop according to past patterns. In this article we focus on the demand for electricity; a generalization to overall energy research problems is suggested in the conclusion.

Observers of electricity demand generally believe that it will continue to increase at constant (or nearly so) compound growth rates for the rest of the century. Table 1 shows predictions made by government, industry, and university researchers. The Federal Power Commission (FPC) estimate is based on the work of six regional advisory committees for the 1970 National Power Survey (*1*). The National Petroleum Council (NPC) projection was prepared by the energy demand task group of the Committee on U.S. Energy Outlook (*2*). The energy demand panel of the Cornell–National Science Foundation (C-NSF) Workshop on Energy and the Environment adopted a modification of the NPC projection as the basis for comparing alternative assumptions (*3*).

Note the similarity in projections. In 1980 the range is only 0.4 of a trillion kilowatt hours (Tkwh). The lowest projection is 89 percent of the highest. The "double-ten" assumption, that electricity demand will double nearly every 10 years, seems to be supported by these projections (*4, 5*). By the end of the century, the demand for electricity is expected to have increased at least six times, to more than 10 Tkwh.

We believe that these projections are generally incorrect. However, before we explain the basis for our conclusion and its possible implication for energy research and development, it is appropriate to note that the kind of projection given in Table 1 has been accurate in the past.

Consider a hypothetical analyst working for a regulatory agency or university in early 1965. He has been asked to project the national electricity requirements for 1969 and 1970. Our analyst favors extrapolated compound growth, and employs that method. The total sales grew 7.35 percent per year for the 5 years from 1959 to 1964. So he predicts that total sales will grow 7.35 percent per year for the next 5 years, to 1.28 Tkwh in 1969 and to 1.37 Tkwh in 1970. For good measure he draws the graph in Fig. 2 (omitting, of course, the actual sales for 1969 and 1970).

Six years pass, a time of war and rebellion, inflation and unemployment, increasing affluence and hardening poverty. In early 1971 he recalls his prediction, and decides to compare it to actual sales. The actual sales were 1.31 Tkwh in 1969 and 1.39 in 1970.

A year later, in early 1972, our analyst is curious about the extension of his projection to 1971. His projection would have been 1.47 Tkwh. The actual sales were 1.47 Tkwh. This kind of experience, repeated at the regional and national level, has reinforced confidence in projections made by assuming compound growth or by extrapolation, or both.

Probably the most accurate 10-year prediction was made in 1960 by the Edison Electric Institute. At that time they predicted that the total sales for 1970 would be 1.31 Tkwh. This estimate was, in fact, too low. It was based

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on an extrapolation of the growth of the gross national product and on a predicted population of 208 million (*6*). The total sales did, in fact, double in the 10 years from 1960 to 1970. Thus, there is historical justification for the type of projections reported in Table 1.

Changes in Causal Factors

It is our opinion that many of the factors influencing the demand for electricity are themselves departing from long-established patterns. Figure 3 shows the post–World War II relationship between the average price of electricity and an overall inflation index. Electricity has become an increasingly better buy. This is apparently true when electricity prices in each consumer class are compared with overall price indexes and the cost of labor, capital, gas, fuel oil, and coal. It seems to be equally true when prices of household electrical appliances and industrial machinery are compared to appropriate overall prices (*7*). All of the changes in relative prices since World War II have pointed toward an increased demand for electricity, and this seems to have been true in all regions of the country.

The information available to us at this time strongly suggests that this pattern will not continue for the rest of the century. The increasing costs involved in environmental protection and decreasing fuel supplies will cause costs and prices to increase. Last year, for the first time since 1946, the deflated average electricity price increased. It rose from 1.66 to 1.69 cents per kilowatt hour in 1971 prices. This marks the beginning of a new period in electricity rates. The concern with the environmental problems noted in Fig. 1 will force continued cost increases in the foreseeable future.

The energy demand panel of the C-NSF workshop reviewed likely cost increases in fuels and environmental protection as well as cost savings from technological improvements. The panel observed, "In general, we conclude that in the course of the next several decades electricity prices (in 1968 dollars) will increase by at least 50 percent." The 1970 National Power Survey estimated a more modest average national cost increase of 19 percent between 1968 and 1990 (*1*, p. I-19-10; *3*, pp. 151–153).

Aubrey J. Wagner, chairman of the Tennessee Valley Authority (TVA), has published estimates of minimum and maximum environmental protection costs for strip mine regulation, mine safety, fly ash and sulfur removal, a sulfur tax, waste heat control, licensing delays, and underground transmission. Minimum environmental protection improvement would mean a one-eighth cost increase. To meet all of the nontransmission requirements he discussed, he stated that (*8*) "TVA would be faced with an approximate doubling of its revenue requirements." Placing underground the high-voltage transmission system of TVA would raise its costs to three times its present revenue.

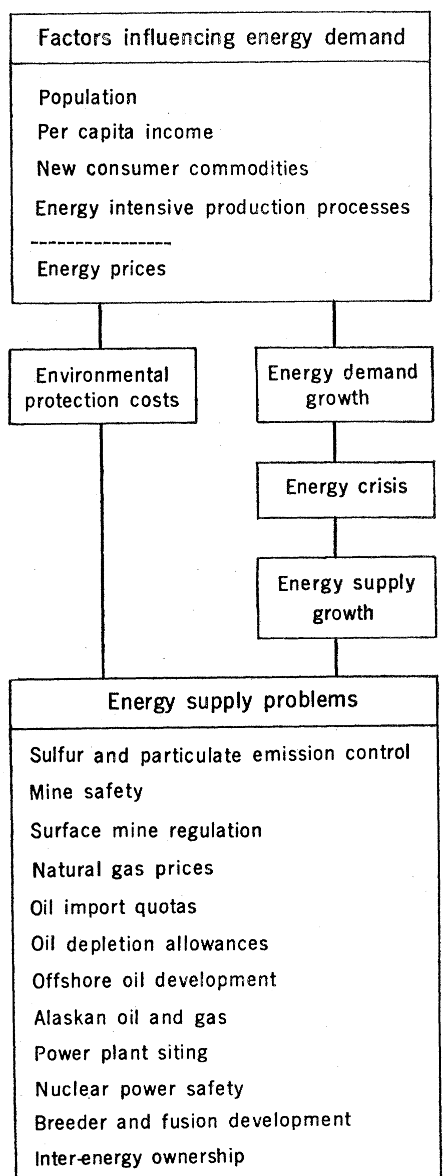

Fig. 1. The energy crisis. Energy supply problems influence energy demand growth through their effect on environmental protection costs. Other demand factors such as population and income influence energy supply problems by their impact on energy requirements.

Analyses of population trends in the studies in Table 1 have lead to the conclusion that past population trends will continue in the foreseeable future. The FPC study groups assumed that the population will continue to grow 1.3 percent per year. In the NPC and C-NSF studies, the Series D projections of the Census Bureau, of 1.1 percent population growth per year, were adopted (*1*, pp. I-3-3, 15; *2*, p. 5; *3*, p. 134). However, there is much uncertainty about future population growth. The recession and new attitudes have combined to drastically lower the fertility rate in the recent past. The birth rate (children born per thousand people) declined for 13 of the 14 months through March of this year. More significantly, the fertility rate (a measure of children born to women of childbearing age) has continued its decline since 1960 and fallen to 2.14 children per woman. The significance of this figure is well known; it is approximately the "zero population growth" fertility rate. At this fertility rate, population growth would slowly decline (except as influenced by immigration and age structure bulges) until stability would be reached in 2035 or 2040 (*9*).

The implication for electricity demand growth is clear. To the extent that past population growth rates continue, the projections in Table 1 are supported. To the extent that the fertility rate declines, the projections will be too high, particularly in the latter part of the century.

Elasticities of Causal Factors

The economic concept of elasticity is useful in describing the magnitude of the influence of causal factors. For particular values of the electricity demand and a causal factor, an elasticity estimate represents the percentage change in the electricity demand associated with a 1 percent change in the causal factor. For example, a commercial price elasticity estimate of −1.5 means that a 1 percent increase in the average price of commercial electricity would, in the long run, cause the demand to be 1.5 percent less than it otherwise would have been.

Wilson (*10*), MacAvoy (*11*), and Halvorsen (*12*) have made quantitative estimates of the influences of causal factors on the demand for electricity. Since each investigator used different definitions of variables and different data bases and statistical techniques, it is difficult to summarize their results (*13*). For illustrative purposes we report eight elasticities from the three studies. Each of those estimates was apparently significant at or beyond the 5 percent level. In these studies residential demand and total demand have price elasticities from −1.1 to −1.3.

Wilson's estimate of a negative income influence of −0.46 is surprising. It may follow from his cross-section study of 77 urban areas in a single year. His explanation is that ". . . federal power projects (and associated low wholesale prices) are concentrated in low-income areas . . . they are totally absent from the high-income northeastern industrial belt from St. Louis to Boston" (*10*, p. 12). Another possible explanation is that one or more omitted factors which are negatively related to demand (such as high fuel oil prices, climate, and appliance prices) are, through geography, positively related to income. In any event, the result is perverse and should be ignored. Halvorsen and MacAvoy examined changes over time as well as geographic differences. Their income elasticity estimates of +0.61 and +0.86, respectively, are likely to be more representative.

MacAvoy reported a population elasticity estimate of +0.91. Since the elasticity demand was defined in terms of consumption per household and per customer by Wilson and Halvorsen, respectively, and since no relationship has been reported between these variables and population, their population elasticity estimate is implicitly +1.00. The elasticity of electricity demand with respect to the price of gas was determined as +0.31 by Wilson and +0.04 by Halvorsen; it was not part of the MacAvoy study.

The major part of our work in the last 2 years has been devoted to numerically evaluating these and other relationships for each consumer class. We are concerned with the stability of these relationships and with the delay or lag in the response of electricity demand to changes in the causal factors. Table 2 shows a summary of the preliminary results of our analysis (*14*).

The small response in the first year (10 or 11 percent) and the length of time necessary for 50 percent of the total response to occur (7 or 8 years) follows from the nature of the processes by which electricity is consumed in residences, commerce, and industry. Electricity is not consumed directly, but through intermediaries such as smelting furnaces, light bulbs, and air conditioning. Changes in preferences for appliances and machinery are reflected in decisions about replacement and new installations, and these decisions in turn affect electricity demand growth.

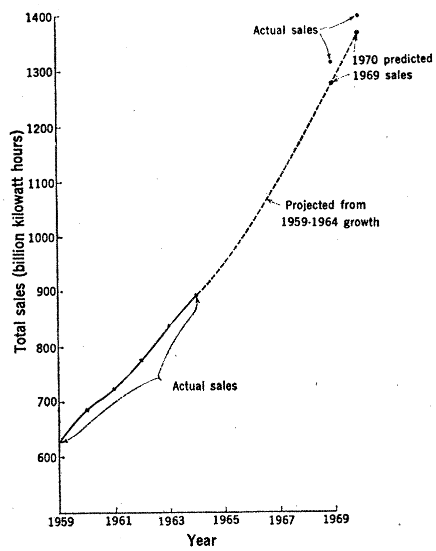

Fig. 2. Projections by 5-year extrapolation of compound growth. The projected sales correspond closely to the actual sales for 1969 and 1970. The extension to 1971 projected sales at 1.47 Tkwh, the actual level for last year.

The estimates in Table 2 suggest a hierarchy of importance of the four factors. The most important factor seems to be the price of electricity, followed by population growth, income, and gas prices in order of decreasing importance. While modification of these estimates is certain, we believe that future amendments will be of small magnitude. The estimates indicate that substantial cost increases (as indicated above) and a reduction in population growth will noticeably lower electricity demand growth in the 1980's and 1990's. Because of the lengthy time period of response, growth reduction in the 1970's might be limited.

Projecting Growth for the Rest of the Century

The growth rate of total electricity demand from 1970 to 1971 was 5.4 percent. This is the lowest rate of growth since 1960, and below the 7.2 percent of the "double-ten" projections. A significant fraction of this growth reduction is probably caused by changes in the causal factors discussed above. The deflated average national price of electricity increased for the first time since World War II: It rose 1.8 percent between 1970 and 1971. The real disposable income per capita increased 3.3 percent per year from 1960 to 1970. The increase from 1970 to the first quarter of this year

Table 1. Selected predictions of electricity demand growth.

Source	Ref.	Electricity demand (Tkwh)					
		1970	1975	1980	1985	1990	2000
Federal Power Commission	(*1*)	1.53		3.07		5.83	
National Petroleum Council	(*2*)	1.59	2.29	3.29	4.54		
Cornell-NSF Workshop	(*3*)	1.57	2.15	2.92	3.96	5.38	10.25

Table 2. Summary of the estimated elasticities of electricity demand associated with electricity prices, income, population, and gas prices. The units of observation are each of the states from 1946 to the present. The average price of electricity is calculated separately for each consumer class. The average price of gas for a particular consumer class, state, and year is calculated by dividing the total revenues of gas utilities for natural gas, mixed gas, manufactured gas, and liquefied petroleum gas by the total sales in therms. Residential electricity and gas prices and per capita personal income are deflated by the Consumer Price Index, and commercial and industrial prices are deflated by the Wholesale Price Index. The percent of response in the first year is equal to 100 $(1-\theta)$ from Eq. 1. The elasticities are derived from coefficients in an equation, which (except for the gas price coefficients) are all significant beyond the 1 percent level. Over 99 percent of the variance of the quantity of electricity is explained by the model for each of the three consumer classes (*14*).

Consumer class	Elasticity				First year response (%)	Years for 50% total response
	Electricity price	Population	Income	Gas price		
Residential	−1.3	+0.9	+0.3	+0.15	10	8
Commercial	−1.5	+1.0	+0.9	+0.15	11	7
Industrial	−1.7	+1.1	+0.5	+0.15	11	7

has been 1.6 percent per year. And, as noted, the fertility rate continues to decline.

It would be incorrect to interpret the statistics for 1971 and early 1972 as defining the quantitative nature of growth for the rest of the century. Rather, these statistics should be seen in a more cautious perspective as indicating that the causal factors influencing electricity growth are changing, and the direction of the change may be toward continued but slower growth.

The methodology of projecting the estimates in Table 1 does not provide quantitative links between population, income, prices, and demand (*15*). (As noted above, this has not been necessary in the past.) In this section we take independent projections of regional and national population, income, and prices and, through the quantitative estimates in Table 2, explicitly relate electricity demand projections to assumptions about causal factors.

One source of estimates of regional populations and per capita income is a study prepared by the Bureau of Economic Analysis (BEA) of the Department of Commerce (*16*). On a national level, population growth is estimated at 1.4 percent per year, gross national product growth at 4 percent per year, and per capita personal income growth at about 2.9 percent per year. Estimates are made for each state and for eight regions. The poorest region, the Southeast, is expected to experience the greatest percentage income increase, but the absolute difference between the poorest region and the richest region (the Midwest) is expected to increase. We may consider an alternative estimate of population growth, that the fertility rates will stay at or below the current level, resulting in a stable population in 2035 or 2040 (*17*).

As discussed above, there is wide variation in analyses of future cost increases. A useful pair of alternatives spans these estimates. Therefore, we use as one assumption the FPC estimate of a 19 percent real cost increase, and as a second assumption a doubling in 30 years. A 13 percent increase in the price of natural gas from 1970 to 1990 is taken from the median projection given in an FPC staff memorandum (*18*).

Thus, we have two alternative cost projections and two alternative population projections. Our assumptions about the growth of gas prices and in-

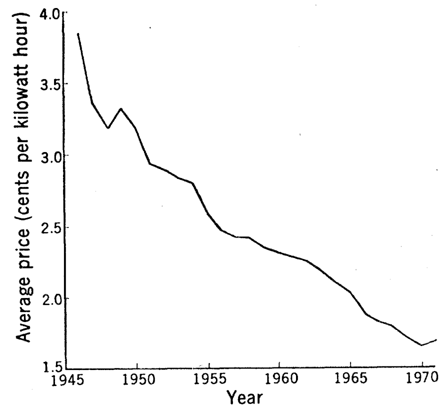

Fig. 3. Ratio of the average electricity price to the gross national product inflation index. The average electricity price (total revenues from utility sales divided by total kilowatt hours sold) declined relative to the implicit price deflator for the gross national product from 1946 to 1970. This real average price inceased in 1971.

come are not varied. For comparability, factor projections terminating in 1990 are extrapolated to 2000. Quantitative estimates of the influences of the various factors are taken from Table 2. Projections can be made with this equation:

$$Q_{ijt} = A_{ij}\,(Q_{ijt-1})^{\theta_i}(PE_{ijt})^{\alpha_i} \times (N_{jt})^{\beta_i}(Y_{jt})^{\gamma_i}(PG_{ijt-1})^{\sigma_i} \quad (1)$$

where i is the consumer class; j is the region; t is the year; Q is the demand for electricity; A is a constant; θ is a time response parameter; PE is the average price of electricity; N is the

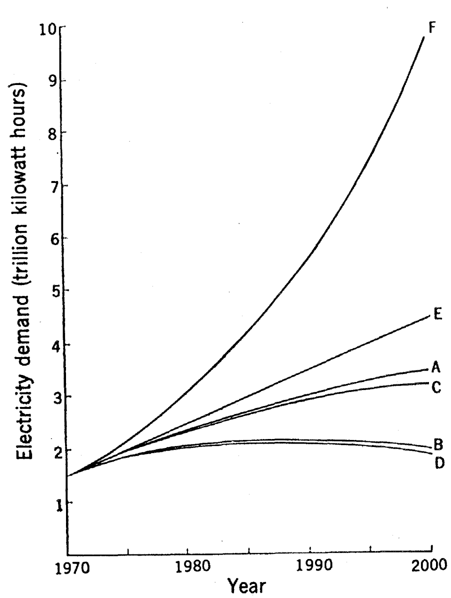

Fig. 4. Electricity demand projections from Table 3. Note the near-term agreement and far-term divergence.

population; Y is the per capita income; PG is the average price of gas; and α, β, γ, and σ are short-run elasticities for electricity price, population, income, and gas price. The units are as described in Table 2.

The results of the four combinations of assumptions are shown in Table 3 and Fig. 4 as cases A to D. For case E (the fifth case) we assume that the real average electricity prices for each consumer class and region do not change from their 1970 levels. The detail for case E shown in Table 4 illustrates the framework used in each projection. For case F we use the FPC demand projections and the BEA population projection, and solve for the appropriate price declines. This shows the price declines that might be necessary to cause the growth from 1970 to 1990 shown in Table 1.

Some conclusions based on this analysis are as follows:

1) The near future, say 1975, is not much affected. All projections show that about 2 Tkwh of electricity will be generated in 1975. Supply problems in the next few years will not be eased by likely rate increases and population trends.

2) The population assumption is unimportant for demand growth in the next 20 or 30 years.

3) The generally accepted projections and the estimates of the influence of causal factors are incompatible. In case F, for example, we use the FPC demand in Table 1, the parameter estimates in Table 2, and the BEA population and income projections. In so doing we must reject the FPC price assumptions and instead postulate continued declining prices as indicated.

4) On balance, it seems likely that the projections of demand growth in Table 1 are too high for the 1980's and thereafter.

Implications for Energy Research and Development

This analysis suggests other aspects of our future energy requirements that should be investigated. The results of our work are preliminary and are limited to electricity. Additional studies of the growth of the demand for other forms of energy are desirable. Perhaps future research can clarify the nature of substitution between energy forms as well as the growth of each form and of total energy use.

Table 3. Electricity demand growth and alternative assumptions. BEA, Bureau of Economic Analysis; FPC, Federal Power Commission; ZPG 2035, zero population growth reached in 2035. In the constant price assumption 1970 prices are maintained in each region. In the "double by 2000" assumption, the average price in each region increases annually by 3.33 percent of its 1970 value for 30 years. In case F, the FPC demand projection in Table 1 and the BEA population projections were used, and Eq. 1 was solved for prices. Electricity demand here includes losses of about 9 percent to make the figures comparable with the generation totals in Table 1. A total of 1.53 Tkwh of electricity was generated in 1970.

Case	Population assumption	Electricity price assumption	Electricity demand (Tkwh)			
			1975	1980	1990	2000
A	BEA	FPC	1.98	2.38	3.01	3.45
B	BEA	Double by 2000	1.88	2.07	2.11	2.01
C	ZPG 2035	FPC	1.98	2.37	2.95	3.29
D	ZPG 2035	Double by 2000	1.88	2.05	2.07	1.91
E	BEA	Constant	2.02	2.54	3.56	4.56
F	BEA	*	2.14	3.05	5.66	9.89

* Average prices decline 24 percent from 1970 to 1980, and 12 percent each 10 years thereafter until 2000.

Most observers other than ourselves believe that electricity use per capita will at least quadruple by the end of the century. Per capita generation was 7500 kwh in 1970, and the C-NSF projection is for 35,900 kwh per capita in 2000. This presumably implies substantial growth in the use of metal products in construction and of electric heating, air conditioning, automobiles, plastics, concrete, packaging, paper, drugs, fertilizers, pesticides, chemicals, and other products connected with an intensive use of electricity. It is desirable to know how material living standards would be affected if growth is less than presently projected, and whether less growth in the future has any significance for the welfare of low-income groups.

Our analysis indicates that if increased environmental protection costs are passed on to consumers in the form of higher prices, then the rate of growth of demand is reduced. Thus, further research into the energy supply problems outlined in Fig. 1 is linked to better predictions of future energy demand growth.

Finally, a question is raised about technological research and development. If energy demand growth in the 1980's and 1990's is less than expected at present, will the relative importance of research on present energy sources

Table 4. Detailed estimates of electricity demand (in million kilowatt hours) for case E. The BEA population projection and constant price assumption are used (see Table 3). Total demand includes other uses, as for subways, street lighting, and so forth. The estimated transmission losses (average about 9 percent) are added to the demand in order to derive the generating requirements.

Area	Electricity demand (Mkwh)						
	1970	1975	1980	1985	1990	1995	2000
			Residential demand				
New England	20,900.0	31,733.7	42,246.4	51,858.4	60,529.6	68,495.2	75,994.9
Mideast	69,146.0	100,351.0	129,657.1	155,928.6	179,365.1	200,764.2	220,864.0
Great Lakes	79,687.0	110,721.4	139,981.8	166,671.1	191,007.4	213,706.6	235,384.2
Plains	35,339.0	49,549.8	62,558.2	74,049.1	84,223.4	93,471.7	102,123.9
Southeast	129,124.0	202,016.5	272,694.1	336,848.4	394,286.7	446,574.9	495,391.5
Southwest	40,127.0	61,098.3	81,273.6	99,686.9	116,378.9	131,778.9	146,326.1
Rocky Mountains	9,652.0	12,842.5	15,795.9	18,572.1	21,249.3	23,866.1	26,454.3
Far West	63,820.0	81,279.3	98,599.3	115,467.0	131,860.8	147,990.2	164,024.0
United States	447,795.0	649,592.4	842,806.1	1,019,081.6	1,178,901.0	1,326,647.0	1,466,544.0
			Commercial demand				
New England	14,643.0	22,546.0	30,840.3	39,148.1	47,410.6	55,799.5	64,453.8
Mideast	57,696.0	79,827.4	103,129.0	126,737.3	150,476.4	174,782.6	199,969.4
Great Lakes	53,911.0	80,329.4	108,139.0	136,017.4	163,702.7	191,792.2	220,749.2
Plains	21,406.0	30,375.9	39,663.0	48,934.9	58,153.1	67,499.6	77,109.3
Southeast	63,556.0	96,842.8	132,157.8	167,914.3	203,815.9	240,472.1	278,392.0
Southwest	33,628.0	47,667.9	62,652.6	78,141.6	94,053.6	110,588.8	127,900.1
Rocky Mountains	10,356.0	14,273.2	18,474.5	22,925.2	27,639.5	32,644.4	37,960.4
Far West	57,554.0	78,612.2	102,300.1	127,479.1	153,682.2	181,191.9	210,218.7
United States	312,750.0	450,474.8	597,356.1	747,297.6	898,933.8	1,054,771.0	1,216,752.0
			Industrial demand				
New England	18,161.0	20,136.2	22,897.8	26,100.4	29,578.1	33,285.7	37,194.1
Mideast	94,108.0	107,519.6	123,566.9	141,013.1	159,293.4	178,356.0	198,167.6
Great Lakes	123,395.0	127,440.1	139,361.6	155,343.8	173,705.3	193,840.3	215,382.5
Plains	30,703.0	38,085.8	45,549.8	52,938.6	60,241.7	67,563.8	74,978.0
Southeast	160,003.0	193,058.1	229,185.7	267,079.3	306,206.7	346,648.6	388,467.9
Southwest	50,853.0	69,864.1	88,833.6	107,463.4	125,841.4	144,249.6	162,912.2
Rocky Mountains	16,642.0	17,973.4	20,065.0	22,706.8	25,779.2	29,180.9	32,849.0
Far West	78,657.0	90,713.8	106,143.1	123,604.7	142,426.2	162,457.5	183,594.9
United States	572,522.0	664,791.1	775,603.4	896,249.8	1,023,071.9	1,155,582.0	1,293,544.0
			Total demand				
New England	55,261.4	76,573.9	98,768.0	120,502.9	141,506.3	162,150.2	182,794.4
Mideast	233,765.1	304,384.5	377,021.4	448,252.3	517,504.7	586,029.1	654,884.1
Great Lakes	267,272.7	331,230.6	402,981.6	476,353.5	549,552.0	622,312.6	698,376.5
Plains	90,421.2	122,023.8	152,795.1	181,903.8	209,507.2	236,305.3	262,854.4
Southeast	365,732.3	510,118.4	657,496.9	800,400.0	937,768.7	1,071,942.0	1,205,254.0
Southwest	129,966.1	186,311.3	242,768.4	297,559.4	350,733.7	403,241.8	455,935.3
Rocky Mountains	38,262.6	47,073.0	56,726.1	67,029.1	77,953.3	89,461.8	101,543.2
Far West	210,632.6	263,887.4	323,315.8	385,978.0	450,651.4	517,696.4	587,403.0
United States	1,391,312.0	1,841,601.0	2,311,872.0	2,777,978.0	3,235,174.0	3,690,136.0	4,149,043.0

compared with new energy sources be changed? We have no answer to this difficult question.

Perhaps the most appropriate conclusion is to observe that energy demand growth is partly a matter of choice. Our decisions about the quality of our natural environment, our material standards of living, and equity will influence our demand for energy and will, in turn, be affected by our use of energy.

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11. P. W. MacAvoy, *Economic Strategy for Developing Nuclear Breeder Reactors* (M.I.T. Press, Cambridge, Mass., 1969).
12. R. Halvorsen, *Sierra Club Conference on Power and Public Policy* (Public Resources, Inc., Burlington, Vt., 1972).
13. Wilson (*10*) worked with the average annual residential consumption per household (in kilowatt hours) for 77 cities in (apparently) 1966. MacAvoy (*11*) studied the total added electrical capacity (in megawatts) for nine regions over three 4-year periods. Halvorsen (*12*) examined the annual residential consumption per customer (in kilowatt hours), by states, in the period from 1961 to 1969.
14. We work with data from 1946 to the present for each state, region, and consumer class. Various functional forms, variables, and dynamic models are compared. Details for our analysis and a more comprehensive review of other studies are discussed elsewhere. T. Mount, D. Chapman, T. J. Tyrrell, in preparation; also papers presented at the meeting of the American Association for the Advancement of Science in Philadelphia, 1971; at (*3*); and at (*12*).
15. In the studies cited in Table 1 various opinions are offered about the competitiveness of electricity prices as a significant influence on electricity demand growth (*1*, p. I-1-14; *2*, vol. 1, p. 8, vol. 2, p. 2; *3*, pp. 134, 155, 156). In *The Economic Impact of Pollution Control* (*5*, p. 97) it was stated that "We assume for purposes of this report that the demand for electricity is relatively inelastic."
16. R. E. Graham, Jr., H. C. Degraff, E. A. Trott, Jr., *Surv. Curr. Bus.* **52** (No. 4), 22 (1972).
17. More precisely, we consider that the fertility rate is low enough so that the sum of births and new immigrants less the number of deaths will be zero by 2035 or 2040.
18. P. Kline, "Projections of electricity consumption in the United States 1970–1990" (unpublished) (Federal Power Commission, Washington, D.C., 1971), p. 14.

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Nutrition and Mental Performance

Prenatal exposure to the Dutch famine of 1944–1945 seems not related to mental performance at age 19.

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Nutrition is one among the complex of factors embraced by social class that may account for the influence of social class on intelligence. Despite the attention given to the influence of malnutrition on mental performance through its effect on the developing brain (*1*), the evidence to establish this causal sequence in humans is lacking. Published studies have suffered from flaws in design or execution; many have not had adequate control groups; and both specifying and assessing nutritional intake in human populations is very difficult (*2*). The circumstances of the *hongerwinter* in the Netherlands in 1944–1945 have enabled us to isolate the experience of famine from other elements of the social environment. Here we relate material starvation during pregnancy to the mental status of the offspring in adult life.

The Dutch famine was remarkable in three respects: (i) Famine has seldom if ever struck where extensive, reliable, and valid data allow the effects to be analyzed within specified conditions of the social environment. (ii) The famine was sharply circumscribed in both time and place. (iii) The type and the degree of nutritional deprivation during the famine were known with a precision unequaled in any large human population before or since.

On 17 September 1944 British paratroops landed at Arnhem in an effort to force a bridgehead across the Rhine. At the same time, in response to a call from the Dutch government-in-exile in London, Dutch rail workers went on strike. The effort to take the bridgehead failed, and the Nazis in reprisal imposed a transport embargo on western Holland. A severe winter froze the barges in the canals, and soon no food was reaching the large cities (*3*).

Several indices attest to the severity of the famine in the cities of western Holland:

1) At their lowest point the official food rations reached 450 calories per day, a quarter of the minimum standard. In cities outside the famine area, rations almost never fell below 1300 calories per day (Table 1). The supply of food gradually declined during the first 6 weeks of the embargo, until in

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