A Short Guide to Electric Utility Load Forecasting

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Rand

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PREFACE

This report offers a brief guide to methods used by U.S. electric utilities to forecast the future consumption of electricity. It is written for a general audience. Preparation of the report was supported by a research grant from the Bechtel Power Corporation as part of Rand's Private Sector Sponsors Program.

A companion report, *Projecting the Demand for Electricity: A Survey and Forecast*, R-3312-PSSP, provides a technical survey of major forecasts and analyzes the uncertainty associated with a forecast for the 1985–1994 period.

A SHORT GUIDE TO ELECTRIC UTILITY LOAD FORECASTING

Electric utilities, governmental energy agencies, and some private economic forecasting services make long-term forecasts of electricity sales and peak demand. This report briefly reviews the methods currently used to make such load forecasts, describes sources of variation between forecasts, and discusses the problems that confront electricity forecasters.

WHO NEEDS ELECTRICITY FORECASTS?

- *Utilities* need long-range load forecasts because it takes many years to plan, license, and build new generating plants.
- *Engineering and construction firms* as well as equipment suppliers need load forecasts to anticipate future orders.
- *Policymakers* need load forecasts to understand the implications of proposed regulatory policies and to assess the adequacy and reliability of electricity supply.

WHAT INFORMATION DOES AN ELECTRICITY FORECAST PROVIDE?

Electricity sales forecasts predict total electricity consumption (measured in kilowatt-hours, kWh). Peak demand forecasts predict the maximum rate of electricity consumption (measured in kilowatts, kW). Forecasts are usually made for five to 30 years in the future, for each customer class (residential, commercial, industrial), and separately for summer and winter.

WHY ARE THERE MULTIPLE METHODS OF ELECTRICITY LOAD FORECASTING?

Through the 1960s, most utilities projected electricity needs by simple trend analysis. Because prices and economic growth had followed steady trends, these forecasts were fairly accurate.

In the 1970s, fuel and capital costs, inflation rates, and plant-development lead times increased, whereas economic growth decreased. Figure 1 shows how electricity consumption departed from its past trend after the Arab oil embargo, beginning in 1974. From 1960 to 1973, consumption grew at an average rate of 7.4 percent per year. A forecast that projected continued growth at that rate would have been about 60 percent too high in 1983. Figure 2 shows that the economy's total use of energy per dollar's worth of national product has declined markedly since 1973. Over the same period, electricity use per dollar's worth of gross national product has grown, but only slightly. Trend analysis could not accommodate this unstable situation and new forecasting methods were developed. The new methods take account of behavioral and technological changes that affect electricity use. Trend analysis and the methods that have largely replaced it are discussed below.

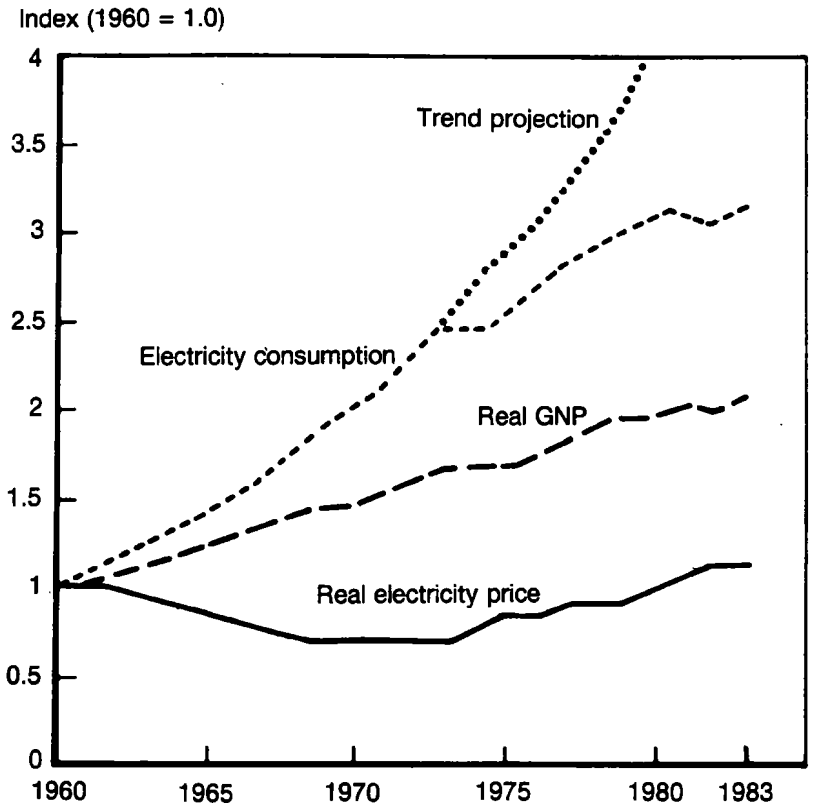
WHAT METHODS OF FORECASTING ARE CURRENTLY USED?

Four methods of forecasting are currently used: *trend analysis, econometric modeling, end-use analysis,* and *combined analyses.* A fifth type, *sum-of-the-utilities,* is not considered a separate method of forecasting, because it merely combines the results derived from other methods.

With the exception of trend analysis, these forecasting methods all predict total electricity sales first by determining what variables affect electricity use. These variables (sometimes called *driving variables*) include price of electricity, the size of the utility's customer population, available equipment that uses electricity, weather conditions, customer income, etc. After determining which key variables determine electricity use, forecasters must *estimate* the relationship between these variables and electricity consumption and then *project* future values of the variables.

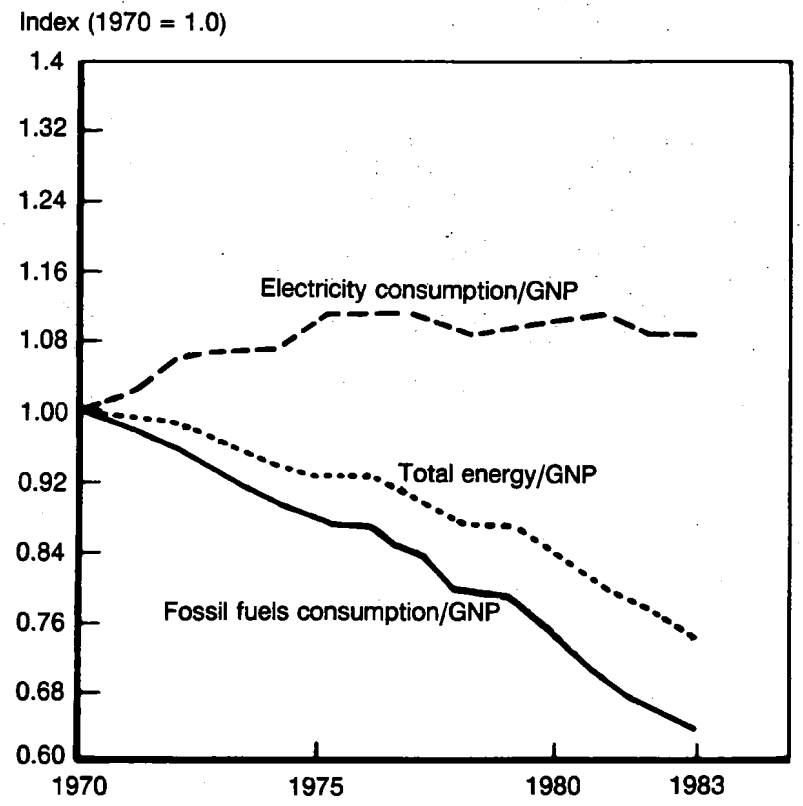
Forecasters do not necessarily agree with one another about the numeric values of these estimates and projections, nor do they necessarily use the same databases when making them. Furthermore, they may not be making forecasts for comparable geographical areas. As a result, there can be substantial differences between forecasts.

Table 1 presents a summary comparison of these forecasting methods. Appendix A contains a more technical discussion of trend analysis, econometric analysis, end-use analysis, and peak demand forecasting.



SOURCE: U.S. Energy Information Administration.

Fig. 1—Trend projection of electricity consumption compared with actual growth, growth of real GNP, and the price of electricity



SOURCES: U.S. Energy Information Administration, U.S. Bureau of Economic Analysis.

Fig. 2—Indices of energy/GNP ratios

Table 1

SUMMARY COMPARISON OF FIVE FORECASTING APPROACHES

Who Uses/When Used	Basic Approach	Advantages	Disadvantages
		TREND ANALYSIS	
Small utilities, especially those that do not generate their own power	Estimate electricity consumption in a base year plus an additional amount for each year after the base year	Inexpensive Easy to understand	Inaccurate when there are sudden, substantial changes in the variables that affect electricity consumption (e.g., price, population, economic growth)
		ECONOMETRIC MODELING	
All types of utilities for all customer classes	For each customer class (e.g., residential, commercial, industrial), estimate the relationship between electricity consumption and the major variables that affect consumption (e.g., price, economic growth, population) Project future values for these variables Solve the equations for future values of consumption	Relatively inexpensive Requires relatively small amount of data Can continuously update forecasts as projections of driving variables change	Estimates of relationships that were accurate in the past may be wrong for the future Influences not in the historical data (e.g., conservation, load management incentives) can be handled only on an *ad hoc* basis Projected values of driving variables may be inaccurate
		END-USE ANALYSIS	
Midsize and large utilities Confined largely to forecasting residential loads; major loads surveyed Some large utilities now extending it to the commercial and industrial sectors	Project the quantity and use of each type of electricity-using equipment and combine them to make a forecast. Adjust these figures to account for anticipated changes in equipment efficiency	Responsive to consumer changes in kinds of equipment customers use Allows analysis of conservation programs based on energy efficiency of appliances or building code modifications Indirectly measures customers' behavioral responses to conservation programs through the equipment usage rate (kWh/unit)	Requires an extremely large data set that is expensive to obtain and to keep current Accurate historical usage rate data almost impossible to obtain Usage rate data measured in one year may not represent use in other years Requires detailed projections of future equipment ownership and usage rates Does not directly measure cusomers' responses to economic (or other) factors that alter equipment purchase and usage rates Difficult to apply to commercial and industrial loads because forecasters lack data and customer equipment and usage rates vary widely

Table 1—continued

Who Uses/When Used	Basic Approach	Advantages	Disadvantages
		COMBINED ANALYSIS	
Large utilities	Combine econometric modeling and end-use analysis to produce a forecast	If both econometric and end-use models are used for the same sector, the results provide a check on reasonableness and consistency of the models End-use methods can be used to account for individual appliance use Econometric methods combined with the end-use framework can be used to account for economic and other factors that shape customer behavior; such an approach, however, is difficult and expensive	Projections of driving variables and estimates of relationships may be inaccurate Estimated relationships between variables and electricity consumption may not be constant Combined models may generate inconsistent forecasts because they are unlikely to use the same sources of data, make the same assumptions, or assign the same values to the common variables for each method
		SUM OF THE UTILITIES	
When forecasts for large geographic areas are needed	Add individual utility forecasts	Total consumption measure is easily obtained Summarizes the collective expectations of the affected utilities	The component forecasts from different utilities are usually based on different and inconsistent projections of major variables (e.g., GNP growth, price level) A range of forecasts cannot be developed because there is not a single set of projected variables that can be changed

WHY DO ELECTRICITY CONSUMPTION FORECASTS DIFFER?

Consumption forecasts differ because

- Different forecasters estimate different relationships between electricity consumption and driving variables, and
- Different forecasters project different future values for those variables.

The differences can be substantial. For example, the companion Rand study[1] compared 17 different national forecasts performed between 1981 and 1984. It found that forecast growth for the period 1982–2000 ranged from 0.8 to 4.5 percent per year. The highest forecast predicted 90 percent more electricity consumption in 2000 than did the lowest forecast.

FORECASTING CONTROVERSIES

Major controversies deal with:

- Price response: the relationship between electricity consumption and electricity price.
- The relationship between electricity consumption and economic growth.
- The effect of switchovers to and from alternative fuels.
- The effect of conservation programs.

Price Response

Price response refers to how consumption responds to changes in price when other factors that could alter consumption are not changing. If a small price increase leads to a large drop in consumption, the relationship is said to be highly elastic; if a large price increase has a minimal effect on consumption, the relationship is said to be highly inelastic.[2]

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[1]Bridger M. Mitchell, Rolla Edward Park, and Francis Labrune, *Projecting the Demand for Electricity: A Survey and Forecast*, The Rand Corporation, R-3312-PSSP, February 1986.

[2]Formally, price elasticity (E_p) is defined as the percentage change in kWh relative to a very small percentage change in price when other variables (such as fuel prices and income) are unchanged; that is

$$E_p = (\mathrm{d}kWh/kWh) / (\mathrm{d}P/P).$$

Price elasticity is always expected to be negative.

How responsive is consumption to changes in electricity price? Until the mid-1970s, most utility forecasts assumed that electricity consumption was unaffected by price. Increased electricity rates in the 1970s and 1980s, however, were accompanied by declines in growth rates and even by declines in actual consumption.

Forecasters now agree that electricity price and consumption are related, but differ in their estimates of that relationship. For example, in 1982, when the Bonneville Power Administration (BPA) made its first Pacific Northwest regional forecast, it estimated the long-run price elasticity to be −1.0. That is, BPA economists believed that each 1 percent increase in electricity prices would result in a 1 percent decrease in consumption within 10 years. Consultants who reviewed the forecast believed that −0.5 was a more accurate estimate of price elasticity. That is, for every 1 percent increase in electricity prices, consumption would drop only 0.5 percent.

Electricity consumers do not usually adjust immediately to a price increase. They can quickly change the way they use their existing stock of equipment, but many will not replace their equipment with more efficient models until the old ones wear out. Thus, the long-run response to a price change will generally be greater than the short-run response. Some forecasters may estimate a short-run price elasticity, some a long-run elasticity, and others something in between, depending on the equations that they estimate and the data that they use to estimate them.

The relationship between consumption and price varies somewhat from utility to utility because of different demographic factors, types of industries, and other factors that cannot be fully accounted for in forecasting models.

Even if all forecasters agreed on the relationship between electricity consumption and electricity price, different forecasts would still result because forecasters use different projections of future electricity prices. For example, in 10 models compared by the Energy Modeling Forum at Stanford University, the projected rates of real electricity price increase used in the base case forecasts ranged from 0.2 to 2.6 percent.

Electricity Consumption and Economic Growth

From 1947 to 1973, increases in electricity consumption substantially outpaced the growth of the national economy. Since 1973, electricity consumption and the economy have grown at approximately the same rate. However, electricity consumption has outpaced the economy in some regions and has lagged in others. What relationship will prevail in the future?

The future relationship of electricity consumption and economic growth—when other factors, including electricity price, are not changing—depends upon the following:

- The mix of national output. Shifts in the balance between industries that consume large amounts of electricity and those that consume lesser amounts may affect the relationship between GNP and electricity consumption.
- Consumers' tastes. Since electricity is a more desirable energy source for many uses, electricity consumption may continue to grow faster than the economy as national income rises.
- The energy balance in international trade. Changes in the relationship of U.S. and world energy prices and the strength of the dollar may affect electricity consumption.

The *income elasticity* of electricity consumption measures how electricity consumption is affected when national income increases while other factors that could alter consumption are not changing. Different assessments lead forecasters to disagree about the income elasticity of electricity consumption.

- Some forecasters assert that electricity consumption growth will parallel economic growth.
- Other forecasters argue that consumption of electricity will grow faster than the economy in the future because electricity is a more desirable energy source. It is, they argue, more flexible, readily available, and less environmentally damaging.
- Still other forecasters believe that the relationship between the two has been severed or "decoupled." This last group contends that conservation efforts and an altered industrial base (more high-technology and service-oriented business, less heavy industry) will permanently change the relationship between electricity use and economic growth. In their view, the economy will grow more rapidly than electricity consumption.

Even if forecasters agreed about the relationship between electricity consumption and economic growth, forecasts could still differ because projections of the economic growth rate differ.

Effect of Switchovers to and from Alternative Fuels

Electricity can be substituted for many other fuels, but customers could switch away from, as well as to, electricity. There are several difficulties in determining how alternative fuels will affect electricity consumption.

For example, when residential builders decide to change from oil heat to electric heat, they consider not only comparative prices for both fuels but also the costs of obtaining and installing new equipment and the chances of an interruption in fuel supplies. Determining the likelihood of such a change requires forecasters to project fuel costs (which are very uncertain), to know how many people actually have oil heat, and to estimate the type of electric heating that could replace it. Because these data are expensive to gather and maintain, many utilities do not have much information about consumers' equipment. As a result, estimates of the effect of alternative fuels on electricity consumption often rely on inadequate data and involve many subjective judgments. Moreover, even if forecasters agreed about the relationship between the price and availability of alternative fuels and electricity use, they could still make different projections of future prices and availability.

Effect of Conservation Programs

Conservation activities may decrease electricity consumption but, because conservation programs are so new, forecasters disagree about how to analyze the savings and use different methods. Conservation programs include utility weatherization programs mandated by public utility commissions, state-mandated energy standards for new buildings and appliances, and utility-originated programs such as energy audits and financing for fuel conversion expenditures. Conservation savings, which can be analyzed with end-use models, include:

- Reduced use resulting from equipment and building efficiency standards.
- Reduced use resulting from utility-sponsored conservation programs like energy audits, weatherizing campaigns, and heat pump conversion programs.

It is difficult to determine how much savings result from conservation programs because they have been accompanied by higher electricity prices which also reduce consumption. Some forecasters believe that the savings uniquely attributable to conservation programs are quite limited. Utilities taking this view may treat conservation savings as a marginal matter with little bearing on consumption. Or they may treat them as a factor reflected in other variables; e.g., as a part of price elasticity insofar as higher prices reduce consumption.

Other forecasters expect conservation programs to reduce consumption by a significantly greater amount than would be attributable to the

price effect alone. In their forecasts, conservation is included as a separate variable directly affecting consumption. For example, Tennessee Valley Authority (TVA) forecasters include a variable based on the cost-effectiveness of specific conservation programs, as well as a price-induced conservation variable.

Similarly, other large utilities in states with strong conservation programs may factor the effects of conservation into their forecasts in more than one way. A Florida utility, for example, (1) calculates conservation from higher prices in the price-elasticity variable of its econometric model, (2) accounts for changes in equipment efficiency in its end-use forecast, and (3) quantifies the effects of its own conservation programs, subtracting that figure from its base forecast.

Because conservation efforts are new, estimates and projections of their effects are based on inadequate data. Voluntary conservation is difficult to determine in the absence of good equipment censuses. Even if forecasters knew and agreed about how current conservation programs alter electricity consumption, they would not know what programs would be in place during the years covered by a long-term forecast nor the effect of those programs.

Beyond the problem of inadequate data, conservation programs are hard to quantify because:

- The conservation savings may be counted more than once (e.g., both in reduced use through price increase and again in conservation program savings).
- The total effect of a customer's participation in several conservation programs is less than the sum of the individual programs (e.g., several conservation programs may be aimed at reducing use of a single kind of electricity-consuming equipment).
- Those who volunteer to participate in conservation programs probably are not "average" customers; estimates for the whole population based upon the volunteer group's behavioral changes will be biased.
- Customers who voluntarily conserve electricity in some ways may increase use in others (e.g., some residential customers may weatherize their homes but then turn up their thermostats).

CONCLUSION

Electric utility load forecasts are needed to plan investments in new generating capacity, to assess public policies that regulate electric utili-

ties and to evaluate the reliability of electricity supply and the effectiveness of conservation programs.

Forecasting methods attempt to estimate how key variables (including the price of electricity, the growth of the economy, the price and availability of alternative sources of energy, and energy conservation programs) affect electricity consumption and to project the future values of those key variables.

Electricity load forecasts are uncertain, because the relationships determining electricity use are imperfectly measured and because future energy and economic conditions are unknown and must be projected.

During the 1970s, load forecasts consistently exceeded actual electricity consumption. More recent forecasts, which incorporate consumer reponses to higher prices and conservation programs, predict lower rates of growth. These forecasts are also uncertain, however, and actual electricity use in 1995 could exceed or fall below current forecasts.

Appendix

FORECASTING METHODS

In the discussion below, the equation used to describe each method is highly simplified and contains only two or three variables.

TREND ANALYSIS

In simplified form, this method calculates electricity consumption as an estimated amount *(a)* in a base year plus an additional amount *(b)* for each year after the base year.

Type of calculation:

$$(class\ kWh)_{year} = a + b \bullet (year - base\ year)$$

ECONOMETRIC MODELING

Forecasting with an econometric model requires three steps:

- Estimate the relationship between electricity consumption and its driving variables.
- Project future values of the driving variables.
- Solve the relationship for future values of consumption.

Forecasters use historical data to *estimate* the relationships. They use macroeconomic models (e.g., forecasters may use government agencies' or private forecasting services' projections), projections of future trends (e.g., the Bureau of Census projections of population growth), and a utility's own records and plans (e.g., rate requests) to *project* driving variable values. An econometric forecast estimates electricity consumption as a function of consumer income, of the price of electricity, of population, and of other variables.

In the following simplified equation, the effect of a small increase in each variable is represented by an estimated exponent *(a, b, c,* or *d)*. To calculate an electricity consumption forecast for some future year using this equation, the forecaster would raise the projected value of each variable to the estimated exponent, then multiply the results together.

Type of calculation:

$$(class\ kWh)_{year} = a \bullet (income\ per\ capita)^{b}_{year} \bullet$$

$$(population)^{c}_{year} \bullet (price)^{d}_{year}$$

Figure A.1 shows the major elements of an econometric model.

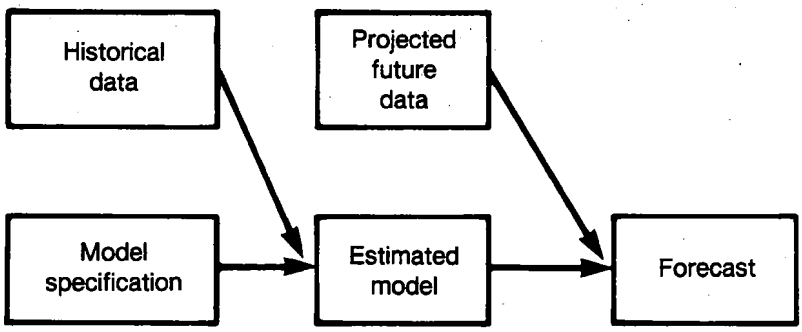


Fig. A.1—An econometric model

END-USE ANALYSIS

End-use analysis is confined largely to forecasting residential loads, although some large utilities are now extending it to the commercial and industrial sectors. This method surveys major electricity-consuming residential equipment. Forecasts are made by projecting equipment quantity, energy efficiency, and use.

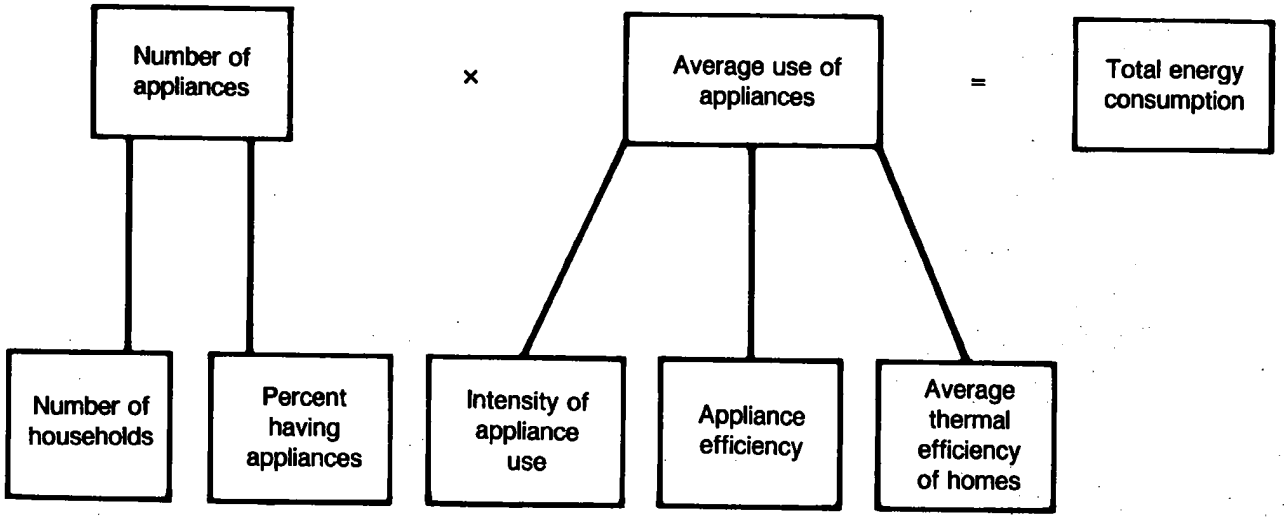
In simplified form, electricity use for a particular type of equipment (e.g., refrigerators) is forecast by multiplying the total number of customers times the estimated fraction of customers with that type of equipment (the "saturation rate") times the estimated average energy use for that equipment (the usage rate).

Type of calculation for equipment type$_i$:

$$(kWh)_i = (customers) \bullet \left(\frac{units\ of\ equipment}{customer}\right) \bullet \left(\frac{kWh}{units\ of\ equipment}\right)$$

$$= N \bullet saturation\ rate \bullet usage\ rate$$

Figure A.2 shows the components of an end-use model.



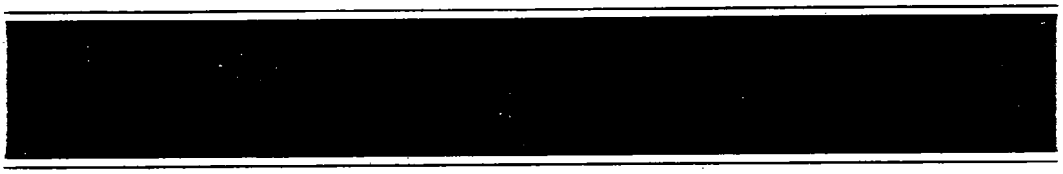
SOURCE: Bonneville Power Administration forecasts of electricity consumption in the Pacific Northwest, 1980–2000, July 1982.

Fig. A.2—Residential end-use forecasting model

PEAK DEMAND FORECASTS

Utilities also forecast peak demand to anticipate the need for additional generation and transmission capacity. Forecasters predict peak demand by combining the total electricity sales with additional analysis. For most utilities, peak loads are affected by extreme weather conditions. Therefore, in estimating the relationship of peak loads to driving variables, forecasters separate base loads and weather-sensitive loads.

Three types of methods are used to make peak demand forecasts:

- Project the system load factor. (The load factor is defined as the average demand divided by peak demand. Average demand is the total kWh sales over a period divided by total hours in that period.) Then calculate peak demand by dividing the forecast kWh sales by the projected load factor.
- Conduct econometric analysis of yearly or seasonal peak demand for the system.
- Conduct end-use analysis of load curves by type of equipment, combined with load forecast projections of equipment ownership.

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