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Michigan State University PH.D. 1983

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THE RELATION BETWEEN ORGANIZATIONAL SIZE AND TECHNICAL EFFICIENCY IN EIGHT MICHIGAN ELECTRIC UTILITIES

by

Gary Claude Chilson

A DISSERTATION

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Department of Resource Development

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ABSTRACT

THE RELATION BETWEEN ORGANIZATIONAL SIZE AND TECHNICAL EFFICIENCY IN EIGHT MICHIGAN ELECTRIC UTILITIES

by

Gary Claude Chilson

The notion of an optimal size exists for every organization. Economic analyses, however, which do not separate technical and pecuniary contributions to economies of scale, have failed to find empirical evidence of an optimum firm scale. Focusing on technical efficiency, this examination of eight Michigan electric utilities found evidence of an optimum organizational size.

Defining technical efficiency to mean the organization's energy utilization efficiency allowed the use of an energy analysis technique to measure the effect of firm size on technical efficiency. Data for each firm's energy inputs and outputs were collected from published documents, personal interviews, and a questionnaire completed by a representative of the utility. Direct (fuel) energy costs are converted to British thermal units (Btu's). Indirect (goods and services) energy costs are converted from their dollar expense to Btu's using an input-output energy analysis technique. These energy costs are averaged over the five year time frame of the study and divided by the organization's average kilowatt-hours sold for a measure of technical efficiency in Btu's per kilowatt-hour delivered.

Due to the small and non-random nature of the sample selected, the results may not be generalized to the population of electric

utilities as a whole. For the sample examined, however, a U-shaped energy efficiency curve best described the observed data for overall technical efficiency. The organization's operations energy efficiency was also found to be significantly related to organizational size and is best described by an ascending logarithmic curve. Distribution efficiency, however, was not dependent on organizational size; it is related to the organization's distribution density, or customers per mile of line, and is best described by a descending asymptotic curve. Neither power plant size or age were significantly related to power plant efficiency.

It is concluded that, for the utilities examined, an optimal size exists for technical efficiency. This conclusion reinforces the need to explore the implications of an optimum technical size for economic organizations in general.

ACKNOWLEGMENTS

Numerous persons including utility representatives, faculty, department staff and students contributed to the successful completion of this dissertation. I am particularly indebted to Mr. Ron Bulthius, Director of Regulatory and Data Research, Consumers Power Company, for his assistance in designing the questionnaire used to collect the necessary data. Dr. Peter Kakela, my major professor, and the members of my graduate committee also deserve special thanks for their encouragement, advice, and helpful comments. It is to my wife and family, however, that I owe my heartfelt thanks. Their support of both my body and mind enabled me to accomplish this achievement.

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CHAPTER ONE

INTRODUCTION

A Notion

In today's industrial society we are conditioned to equate big with better. The general assumption is that large-scale undertakings are inherently more efficient than smaller ones. In fact, the claim of efficiency is commonly used to justify bigness.

Yet in the history of ideas the notion of an optimal size is both ancient and recurrant. Aristotle(1) may have begun the recorded debate by claiming that:

> To the size of states there is a limit, as there is to other things, plants, animals, implements, for none of these retain their natural power when they are too large or too small.

In Human Scale, Kirkpatrick Sale summarized two thousand years of thought on the subject of an optimal size, drawing on such diverse and often disparate disciplines as philosophy, political and other social sciences as well as the natural sciences such as physics, biology and mathematics.(2) Sale's major focus was on the human perception of size and the side-effects of large-scaled structures and institutions. Some of the adverse impacts he cites include alienation, apathy, absenteeism, reduced productivity, innovation and creativity as well as other psychological aberations. Sale(3) concludes that:

> For every animal, object, institution or system, there is an optimal limit beyond which it ought

not to grow.

> Beyond this optimal size, all other elements of an animal, object, institution or system, will be affected adversely.

Goal and Objectives

The purpose of this dissertation was to construct a test of the idea that organizations can grow too big and thus become energy inefficient in the supply of goods and services. Several electric utilities in Michigan were selected as the organizations to examine because: 1) they represent a broad range in organizational size; 2) their public nature allows access to the necessary data; 3) electric utilities are presumed to benefit from economies of scale; and, 4) time and funding constraints plus the need for personal interviews to collect some of the data limited the geographical distribution of the organizations to be examined.

Four objectives must be met to achieve the goal of this dissertation. The first is to graphically represent the overall energy efficiency of electric utilities over a range of sizes broad enough to capture a description of the proposed relationship. The second objective is to ascertain the relationship, if any, between the size of the organization and the associated energy costs of operation (excluding production and distribution energy costs). The third and fourth objectives seek to determine the relationships, if any, between utility size and the energy costs of the conversion and distribution of electric power respectively.

The remaining chapters are organized to: clarify the advantages of an energy-based measure of an organization's technical efficiency (Chapter II); explain the selection of the electric utility industry as the focus of this test case (Chapter III); conceptually define organizational size and technical efficiency (Chapter IV); describe the method used to assess technical efficiency (Chapter V); present the results obtained (Chapter VI); finally, to summarize the conclusions drawn and make recommendations on subsequent avenues of research (Chapter VII).

CHAPTER ONE NOTES

(1) Aristotle, Politics, Book VII, Chapter 4.

(2) Kirkpatrick Sale, Human Scale, (New York: Coward, McCann and Geoghegan, 1980).

(3) Sale, op. cit. p. 59.

CHAPTER TWO

AN ALTERNATIVE PERSPECTIVE

ECONOMIES OF SCALE

Even if Sale's litany of adverse philosophical, psychological and social effects of size are granted, it may still be to our economic or social advantage to suffer these effects for a greater total return on our limited resources. In short, the advantage gained from economies of scale may outweigh the perceived ill effects that result.

Economies of Plant Scale

Economic analysis is generally considered to be the most powerful measure of optimal size. Here, Aristotle's "natural power," when associated with a best or optimum size, is analogous to the low point on an economist's long-run average cost curve for a production unit.

The long-run average cost curve is an envelope curve that contains the minimum average cost of a series of short-run average cost curves (see Figure 1). In the short-run, the fixed factors cannot be changed and diminishing marginal returns to fixed factors generate the familar "U-shaped" curve for the short-run average cost curve. Over time, however, the fixed factors can be changed (e.g., enlarging plant capacity). This creates a series of short-run average cost curves.(1)

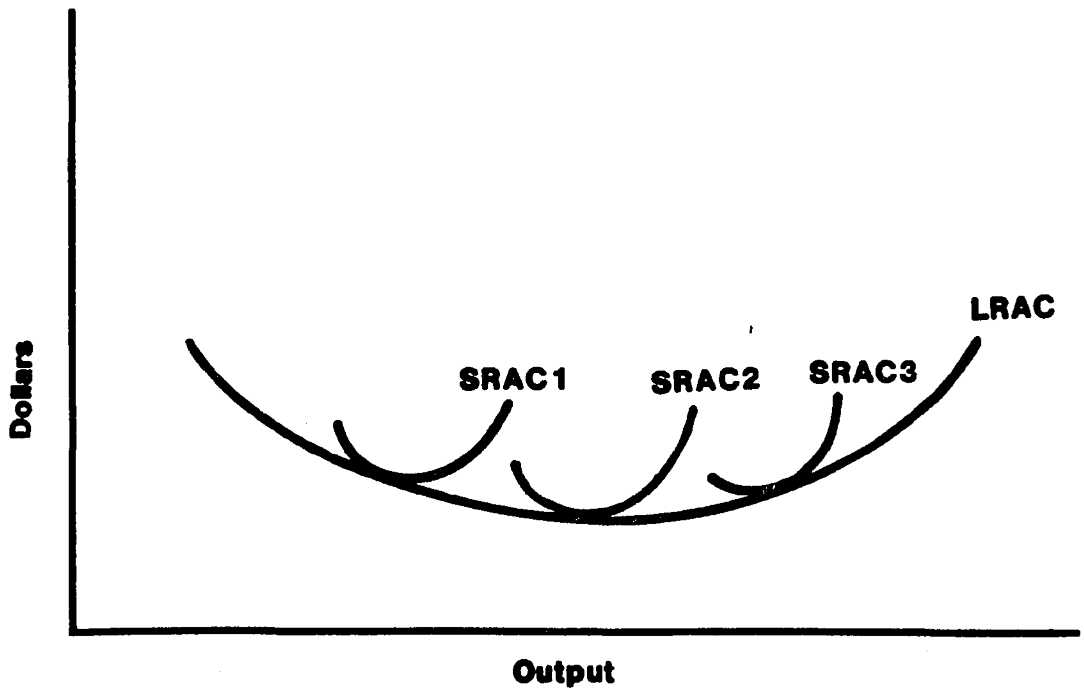

Figure 1. The long-run average cost curve as an envelope curve containing the minimum points of successive short-run average cost curves. (Redrawn from Robert H. Haveman and Kenyon A. Knopf, op. cit. p. 202).

A number of factors tend to decrease the successive average cost curves as the scale of production increases. For example, some factors of production are "lumpier" than others (a machine may not come in small gradations of output), costs per unit of input may be less expensive when purchased in larger amounts, and efficiency may be gained by increased specialization in the division of labor.(2) There is also the fact that the volume of physical objects like containers, buildings and vehicles increase with the third power of length or radius and, thus, faster than the external surface area. Consider, as an illustration, that the external surface area of a cube is six times the square of its length and its volume is the length cubed. As the length is increased, the volume increases at a faster rate than does the external surface area. Since the cost associated with the materials and construction of a facility tend to be related to the external surface area, larger production units have a greater volume or capacity per unit cost.

Eventually, however, a minimum is reached in the scale of a production unit beyond which successive expansion leads to increased average costs. These increased costs due to scale are called diseconomies and are generally believed to stem from the increased costs of managing the larger facility. In fact, as the empirical evidence suggests, the point of maximum efficiency or lowest per unit cost in a single plant always appears before monopolistic control of the industry occurs.(3)

Economies of Firm Scale

The discussion of economies of scale and individual plants reviewed the economic theory and empirical evidence that supports the notion of an optimal size for profit maximization. But scale considerations at the firm level take on a very different aspect because the firm, which may operate several plants, is the smallest organized system of production legitimately viewed as an independent decision-making unit. Considering firm scale then, Stein(4) says:

> [T]here is said to be no problem of diseconomies due to plant size because even assuming that diseconomies of plant scale exist above some point, greater output than that point permits merely requires replication of that efficient unit as often as necessary. The issue thus reduces itself to diseconomies of firm scale when, for example, several such optimum plants are managed by a single enterprise.

Economies of large-scale organizations stem from a number of factors. Some of these are: 1) the ability to make the most of scarce managerial skills; 2) the ability to recruit, train and promote staff internally; 3) the ability to spread risk by diversifying its products; 4) increased market power through advertising; and, 5) a large-scaled organization can frequently obtain lower finance costs for capital. Nonetheless, according to Blaug, economic theory maintains that even at the level of the firm there is an optimal size.(5)

As in diseconomies of plant scale, the diseconomies of firm scale are thought to arise from problems associated with the management of large, complex systems.(6) Townsend(7) illustrates this by suggesting that:

> [L]arge organizations may seem characterized by inflexibility, unimaginativeness, uniformity, complexity, routine, stratification, delay, dispersion, timidity, unresponsiveness, officiousness, mediocrity and stagnation.

As firm scale increases, a number of problems may become apparent including: 1) warehousing and inventory control problems could escallate; 2) labor problems such as specialized labor costs, absenteeism, strikes, grievences and alienation become major factors; 3) locked-in machine processes could make innovation, flexibility and responsiveness to changing market conditions more difficult; 4) distribution costs might increase disproportionately; and, 5) the rate of return should fall as a consequence.

Yet the empirical evidence is lacking to support or reject the notion of an optimal firm size. Bain was unable to find evidence of significant <u>economies</u> of scale for multiplant firms and Blaug was unable to cite any evidence of <u>diseconomies</u> of firm size.(8,9) Summarizing the empirical evidence, Caves[10] claims that:

> To the best of our knowledge, no problems of large-scale inefficiencies exist. Sometimes the largest firm in an industry seems to have higher costs than some of the medium-sized ones. But we can never tell whether these higher costs are an inevitable result of large size, or whether the large firm is just plain inefficient, having let its costs get above the minimum level attainable at that scale.

Normally, we assume that firms seek to maximize their returns as a basis for an economic analysis of efficiency. But this may not be a valid assumption because, as Galbraith suggests, managers of large-scale corporations will continue to seek growth even if it is at the expense of a higher rate of return.[11] Instead of maximizing their return on investment, these managers seek only a satisfactory or target rate of return (shareholder's expectations must be satisfied). Maximizing the rate of return frequently incurs a higher level of risk than the risk found with only a satisfactory rate of return. Corporate managers might even seek to minimize risk within the constraint of a satisfactory rate of return by expending effort on obtaining political and economic power -- an advantage of larger size.

It is therefore conceivable that, beyond a certain scale, gains made to production efficiency may begin to slow, stablilize and then decrease as the firm enlarges. The increased size, however, continues to increase the firm's economic power and these gains may mask the loss in production efficiency. The growth process becomes cyclic: expending some portion of the firm's economic power to capture political advantage increases the firm's economic power and further masks the decline in production efficiency.

Technical and Pecuniary Contributions

Stein[12] distinguishes the two sources that contribute to economies of scale:

> Note that it is possible to regard scale efficiencies as composed of two different sorts: pecuniary and technical. Pecuniary economies (e.g. cost of capital may be less for large sized borrowers) are here regarded as artifacts of the economic system and thus related not to the ability to supply goods and services more effectively, given identical opportunity and factor costs, but to absolute size and the benefits gained from it.

While some pecuniary economies of scale may be legitimate forms of economic power, such as lower finance and input costs, other pecuniary economies may be derived from political advantage and result in the erection of barriers to entry. Examples of the latter would include the ability of a large organization to acquire self-serving regulations, subsidies, tariffs and tax breaks. They also have the power to successfully block the establishment of such political advantages for their competitors.

Consequently, even if production or technical efficiency decreases beyond the optimum size, pecuniary economies of scale may continue to increase. Economic analysis measures both the technical and pecuniary contributions together and cannot distinguish between them. The result is the inability to find an optimum size from an economic analysis (see Figure 2).

In other words, be they technical or pecuniary in nature, economic analysis treats all the factors of production equally. While this aggregation in an economic analysis leads to important information, it does not address the specific problem of an optimum technical size.

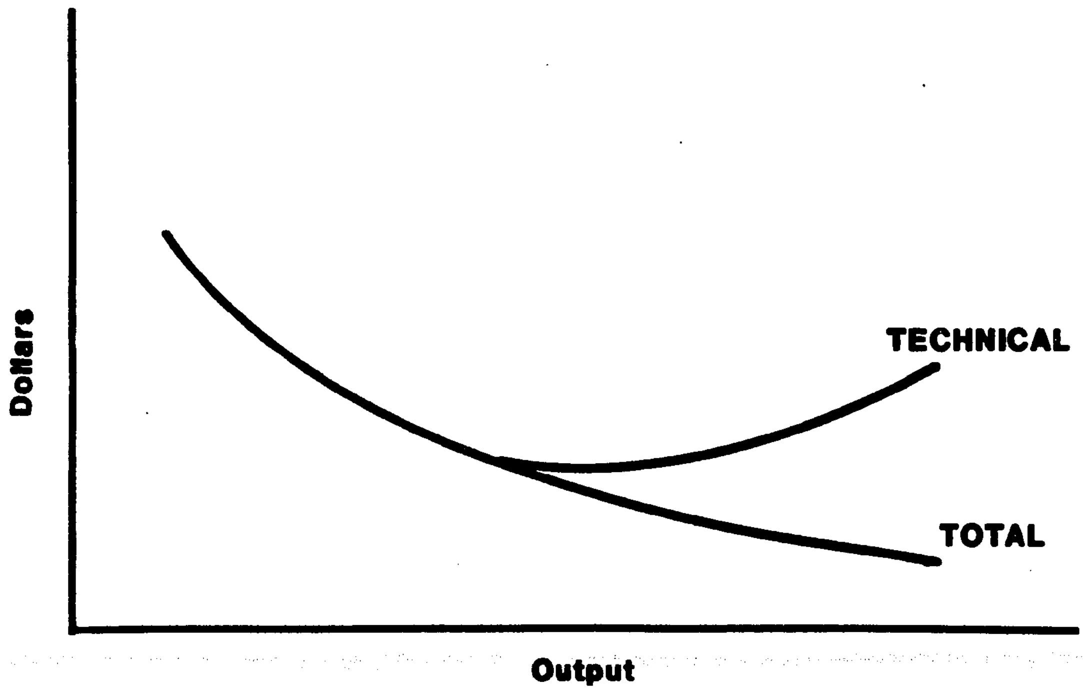

Figure 2. A hypothetical long run average cost curve with technical and pecuniary contributions separated.

An Alternative Perspective

Stein defined technical efficiency in production as "the ability to supply goods and services more effectively...." Traditionally, effectiveness is measured by an economic analysis in terms of cost per unit produced. But, as discussed, an economic analysis cannot separate peauniary and technical contributions to economies/diseconomies of scale. Redefining effectiveness to mean efficiency in energy utilization transforms the definition of technical efficiency into a physical measure of the conversion, distribution and operation process of an organization. Thus, the energy efficiency of converting inputs into the supply of goods or services is one measure of technical efficiency. The advantage gained from a focus on energy efficiency is the ability to separate, explicitly, the technical and pecuniary contributions to the long-run average costs of the industry.

Only one previous attempt has been made to compare firm scale and energy efficiency (and then only in passing). In analyzing the energy costs in the beverage industry, Hannon(13) states that:

> It is interesting to compare the bottling energy of the major urban bottler with the smaller local bottler. The ratio of sales was about 10 to 1. No 'energy economy of scale' is noted as the major bottler uses about 6.3 percent more resource energy per gallon of beverage. This is due entirely to the fact that the major bottler has six buildings compared to the local bottler's one and space heating and lighting account for a major share of bottling energy.

Energy Economies of Scale

Given this perspective, a "U-shaped" long-run average energy cost curve is proposed (see Figure 3). Decreasing energy costs per unit produced are the result of technical or thermodynamic efficiencies gained by increasing scale up to the optimum. Thereafter, energy diseconomies of scale occur as the result of disproportionately increasing energy costs per unit produced.

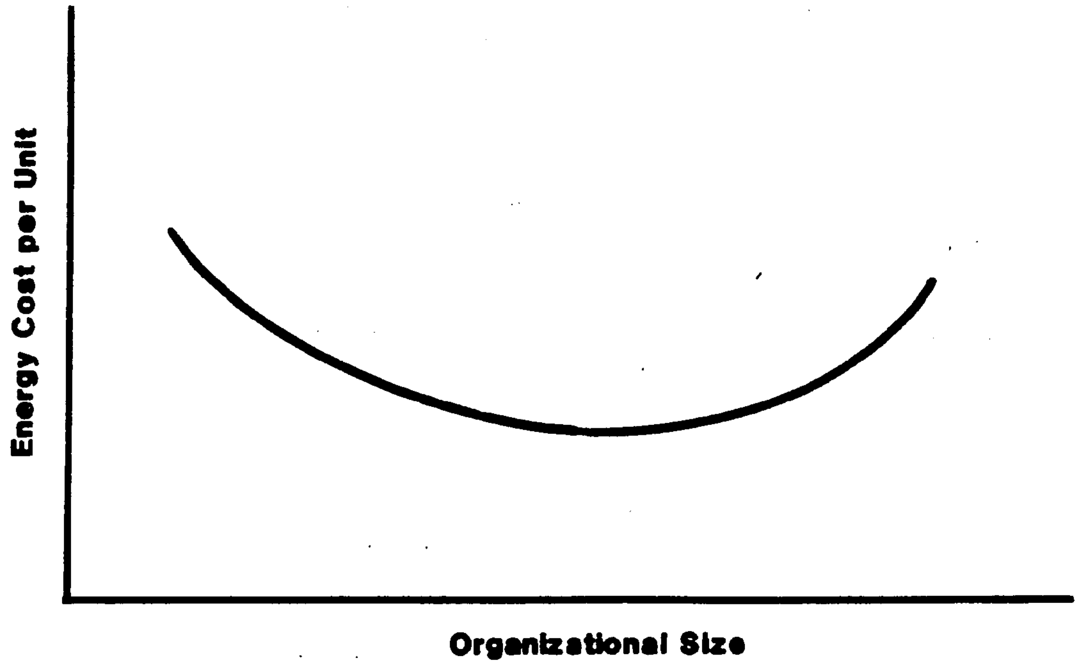

Figure 3. The shape of the proposed energy economy of scale curve.

A Caveat

This examination of the possible relationship between firm size and energy efficiency uses energy as a measureable indicator of a firm's technical efficiency. This does not mean that an energy standard of value is proposed or that a measurement of energy costs is superior to an economic valuation. As Georgescu-Roegen(14) correctly insists:

> The economic process is entropic in all its fibers, yet it cannot be reduced to a vast thermodynamic system. Economic valuation proceeds over a web of anthropomorphic, not physiochemical, categories -- utility, disutility, and distribution. No one, it must be emphasized, has been able to prove the existance of a general quantitative relationship between these human attributes and the energy consumed or spent in their production.

Unlike an energy analysis, an economic analysis captures the benefits and costs of production that are essentially invisible in a physical sense. For example, increased recycling of iron and steel scrap is energetically but not economically feasible.[15] This is partly the result of government policies that encourage the ore to steel process over the recycling process through discriminatory freight rates and tax incentives, as well as biased federal research, labeling requirements, and procurement practices.[16]

These policies encourage the ore-to-steel process over the scrap-to-steel by imposing economic incentives on the one and disincentives on the other. An economic analysis, which includes these important economic effects, correctly identifies the economically superior process but, at the same time, masks the energy impacts of these policies from view. An energy analysis, however, does not measure the influence of these economic policies because they do not contribute to the energy requirements of the two different processes. Consequently, energy analysis is a partial analysis which may be used to clarify the energy impacts of alternative economic policies.

CHAPTER TWO NOTES

(1) Robert H. Haveman and Kenyon A. Knopf, The Market System, Third Edition, (New York: John Wiley and Sons, 1978) p. 202.

(2) Haveman and Knopf, op. cit. p. 233.

(3) See, for example, Richard Caves, American Industry: Structure, Conduct, Performance, 5th edition, (Englewood Cliffs; Prentic-Hall, Inc., 1982) pp. 23-24; Robert H. Haveman and Kenyon A. Knopf, op. cit. pp. 202-204; or Henry R. Seager and Charles A. Gulick, Trust and Corporation Problems, (New York: Harper and Brothers Publishers, 1929) p. 76.

(4) Barry Stein, Size, Efficiency and Community Enterprise, (Cambridge: Center for Community Economic Development, 1974) p. 5.

(5) Mark Blaug, Economic Theory in Retrospect, Revised Edition, (Homewood: Richard D. Irwin, Inc., 1968) p. 463 and also p. 498.

(6) Stein, op. cit. p. 5.

(7) Harry Townsend, Scale, Innovation, Merger and Monopoly (London: Pergamon Press, 1968) p. 21.

(8) Joe S. Bain, "Economies of Scale, Concentration and the Condition of Entry in Twenty Manufacturing Industries," AER 44(1):15-39, March 1954.

(9) Blaug, op. cit. p. 466.

(10) Caves, op. cit. p. 72.

(11) John K. Galbraith, Economics and the Public Purpose, (New York: Houghton Mifflin Co. 1973) pp. 77-85.

(12) Stein, op. cit. p. 95.

(13) Bruce Hannon, "System Energy and Recycling: A Study of the Beverage Industry," CAC Document No. 23, (Urbana: Center for Advanced Computation, University of Illinois, 1972) p. 24.

(14) Nicholas Georgescu-Roegen, "Myths About Energy and Matter," Growth and Change 10(1):16-22, January 1979. p. 16.

(15) Bruce Hannon and J. Brodrick, "Steel Recycling and Energy Conservation," Science 216:485-491, April 1982.

(16) Peter J. Kakela, "Railroading Scrap," Environment 17(2):27-33, March, 1975.

CHAPTER THREE

THE PROBLEM

Focus

The electric power industry was selected to test the notion of an optimal firm size because electric utilities are presumed to benefit from economies of scale. Indeed, the production and distribution of electric power is commonly believed to be a good example of a natural monopoly. Natural monopoly industries enjoy increasing returns to scale up to outputs relatively large in comparison to market demand.(1) This is due to a decreasing long-run average cost curve over such a long range of output that diseconomies of scale, if they exist, do not appear -- at least over the range of scale the industry currently exhibits.

Whenever a firm experiences a continuously decreasing long-run average cost curve the marginal costs will always be less than the average costs of production. Operating on the basis of profit maximization, the firm would set marginal revenue equal to marginal cost and produce a quantity of output less that desired at a price that exceeds average cost (X_1, P_1 in Figure 4).

Consequently, natural monopolies are publicly regulated (as in investor-owned utilities) or publicly owned (as in federal, state and municipal utilities). The goal of public involvement is to equate average cost and the demand for electricity, thereby increasing output and lowering the price (X_2, P_2 in Figure 4).

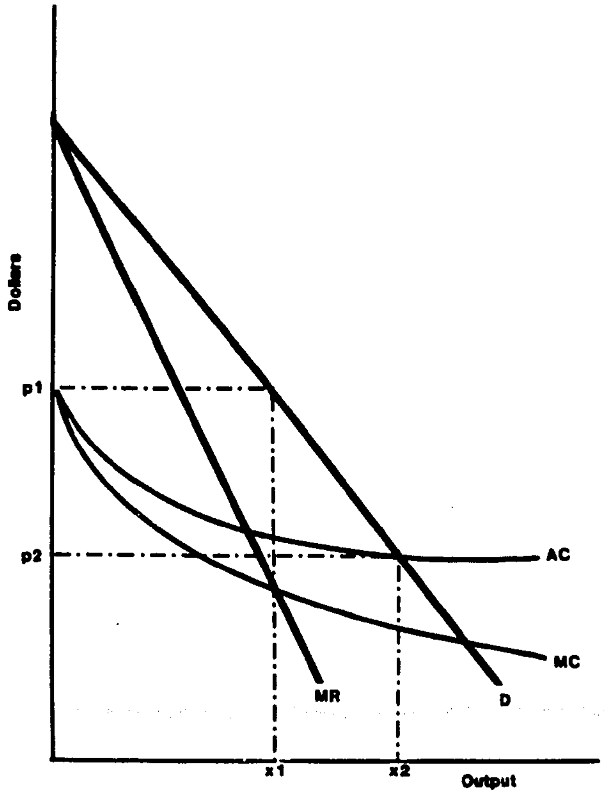

Figure 4. The pricing problem in an increasing-returns-to-scale industry. (Redrawn from Robin W. Boadway, op. cit. p. 155).

Public regulation or ownership allows access to the data necessary to determine average costs, and, by extension, the data necessary to make an energy analysis of technical efficiency. In most cases, proprietary interests would prohibit an independent evaluation of the dollar or energy costs of production. But the public utility nature of the electric power industry eliminates this potential barrier to a preliminary evaluation of an energy economy of scale.

Historical Perspective

The history of expansion and agglomeration in the electric power industry also suggests that some firms may be beyond the optimal size. In the four decades following the first Edison electric company in 1882, the number of electric companies rapidly increased to about 6,500 in the early 1920s. By the beginning of World War II, however, because of advances in technology and a shift in the industry's focus, the number of independent electric companies had dropped to only 3,600.[2] Following the war the trend continued until only 1000 electric generating companies remain today with nearly 80 percent of total power produced from a mere 250 investor-owned utilities.[3]

In the early years many small, independent electric utilities located in densely populated areas. Nearly every sizable town had a private electric company of their own. This was due primarily to the grossly inefficient generating and transmission technology available at that time. These inefficient systems forced the industry to focus on both electric and steam production for distribution in a localized area because neither product could be delivered over any great distance without prohibitive energy transmission losses. Significant improvements in electric transmission and generating technology, however, allowed centralization to capture economies of scale. In addition, the federal government launched the rural electrification program and established the Tennessee Valley Authority as a benchmark performance standard for private electric companies. These changes in technology and the increase in public oversight encouraged the change in the industry's focus to the production of electricity alone.

In addition to the enabling technology and institutional incentives, the growth in electric power demand also encouraged the rapid construction of new facilities which could take advantage of the new conditions. During the first three decades since 1947, sales of electric power doubled every ten years for an average growth rate of seven percent annually. In other words, total electric power consumed rose from 255 billion kilowatt-hours in 1949 to approximately 2000 billion kilowatt-hours in 1979.[4] A major result of this rapid growth was that the mix of power plant sizes and number changed from predominently small and numerous to increasingly large and few. As an illustration, the total number of power plants in the U.S. reached its peak in 1930 with 4,043 plants in operation. By 1970, this number was reduced to 3,519 plants.[5]

This brief historical review indicates this industry's change in market structure from its highly decentralized infancy to its relatively centralized condition today. As a result, some firms are very large and therefore it is possible that they may have grown beyond some optimum size for this industry.

Economic Perspective

To test the notion that some firms may have exceeded the optimum size, Iulo examined the electric industry using linear regression analysis.[6] His goal was to determine if size, as measured by total assets, total electric property, total utility property, kilowatt-hours sold or generating capacity, could be correlated to unit electric costs measured in dollars. Iulo concluded that, "Each of the measures used to reflect directly the size of an individual utility was found to be not significant."[7]

Iulo[8] went on to say, however, that:

> [T]he relationship between the size of steam-electric producing units and unit electric costs is the underlying cause of a substantial portion of any economies that might exist. Consequently, once this relationship is allowed

> for, the remaining relationship (perhaps attributable to such factors as the ability to achieve financing, supervisory and managerial economies) is too intangiable to result in a significant relationship between overall utility size and unit electric costs.

In other words, Iulo found that economies of plant scale exist but was unable to support or refute the notion of an optimum firm size. Nevertheless, the qualifyers to his conclusion presented several leads to this investigation.

Iulo's first qualifyer was that the utilities he examined were predominently large utilities -- small companies and all public utilities were excluded from the analysis.[9] The range in firm size was thus limited to a narrow band within a large sized catagory.

Second, the relationship between size and unit electric costs may not be the simple linear relationship that Iulo assumed in his analysis. "That is," as Iulo said, "the relationship between utility size and unit electric costs may be such that, after some strategic level of utility size is reached, unit electric costs would have a tendency to decrease more slowly or remain fairly constant, or even to increase."[10]

Finally, and most intriguing, Iulo[11] states that:

> The net regression coefficient (which indicates the change in unit electric costs associated with a change in the independent variable while holding the other independent variables statistically constant) was positive in each total size catagory - indicating increasing costs with increasing size though not statistically significant using linear regression.

Increasing costs with increasing size implies diseconomies of firm scale. At the very least, Iulo claims that, "the common presumption that larger utilities are per se able to produce electric power at lower unit costs does not seem to be borne out by even the gross relationship between size and unit electric costs."(12)

Iulo leaves the question of an optimal firm size unanswered due to his assumption of linearity and the distortions imposed by including pecuniary and technical factors. All that can be discerned is that the long-run average cost curve, over the narrow scale of production analyzed, does not continue to decline at a constant rate. The inverse relationship between size and unit electric costs may slow, stablize or even reverse itself and begin to increase. An energy analysis focuses only upon technical efficiency and is capable of clarifying some of these factors.

Significance of Study

Given the current significance of liquid fossil fuels in the U.S. economy (nearly 56 percent of end-use energy consumption)(12) and our dependence on imports, temporary disruptions in supply such as occured during the Arab oil embargo of 1973-1974 have immediate and lasting effects on the economy. But more disturbing in the long run is the prospect of dwindling liquid fossil fuel reserves. A change in the energy basis of the economy seems inevitable.

An alternative energy basis for society is electricity. Electricity may be a highly favored alternative to liquid fossil fuels because of: 1) electricity's versatility; 2) concentration or quality; 3) transportability; 4) convenience; and, 5) its relatively low cost considering its high social value. However, the majority of the electricity produced in the U.S. is a form of energy that depends on a relatively inefficient conversion process from other energy sources.

Fortunately, the fuels to produce electricity come in a variety of abundant forms. Putting economic and institutional considerations aside, nuclear power source materials from breeder reactors may last for as much as 4,000 years at a constant world consumption rate of 275 quads (10^{15} Btu) per year.(14) An indefinite life-expectancy may be possible if fusion reactors become feasible. But among the truely "inexhaustable" energy sources for electricity are the direct or closely associated solar alternatives such as photovoltaics, hydro, wind-power, and biomass conversion. Finally, the most probable transition fuel toward these "inexhaustables" is coal, which Hubbert(15) predicts will not reach its peak of domestic production until well into the 22nd century if the present rate of consumption is not greatly increased.

Following Cottrell's thesis, "that the amount and kinds of energy employed condition man's way of life materially and set somewhat predictable limits on what he can do and on how society will be organized,"(16) a shift toward a dependence on electricity will have a significant impact on the United States' socioeconomic system. Historically, the growth rate of electric power demand has already made an impact. This is reflected in the percentage share of energy consumed by the electric utilities to the total energy consumed in the UnitedStates. In 1949, for example, electric power production required 15 percent of the total energy consumed. In 1979, electric power production consumed 31 percent of the total.(17)

Yet the production of electricity, perhaps even more significantly than its consumption, will also effect the structure and function of society in the future. For example, many have questioned the advisability of promoting the production of electricity from nuclear power in its various forms.(18) Weinberg, a nuclear proponent, set the stage by calling for a "priesthood of responsible technocrats."(19) In a "Faustian Bargain," Weinberg's nuclear priesthood offers unlimited electric power in return for control over the resulting plutonium economy.

Given the potential importance of electricity's role in any future social transformation process, insights into the structure of the industry that produces this significant commodity also becomes significant. This is especially true given this industry's limited flexibility in a rapidly changing environment.

A Changing Environment

Until about the mid-1960s, the electric utility industry existed within a highly favorable environment. Production and distribution costs steadily declined, consumption and revenues steadily rose, earnings tended to increase every year and investors readily provided the additional capital for expansion. Regulation of these organizations was minimal in an atmosphere of friendly cooperation -- Public Utility Commissions occasionally met to hear an appeal for lower rates. On top of all this, planning problems were few -- demand grew at a steady and predictable rate; siting decisions were uncomplicated; rights of way for transmission lines were available with little oppositon; inflation rates were low; and construction or licensing delays were short.

By 1975, however, these aspects of the social, economic and institutional environment changed. First, due to technical design problems and increased public concern for safety, there were a growing number of delays in planning, construction, and securing approval for new nuclear facilities. Increasing intervention by regulatory agencies for the installation of environmental control systems on coal-fired plants came quickly thereafter. These difficulties led to cost increases which, because of increased citizen participation in rate cases, were aggravated by delays in rate adjustments. Imppecise demand projections, which led to lower than expected sales and a consequent decline in revenues, plus increased fuel costs resulted in reduced earnings. Eroded earnings diminished investor confidence and this, together with high interest rates and inflation, exacerbated the problems of capital financing.[20]

These developments created an unprecedented situation for the electric power industry. The steady and predictable growth rate in electric power demand fell to less than half its previous rate. This led to significant regional impacts on power producers. For example, some producers now find themselves carrying 35 to 56 percent excess capacity while still being committed to expensive nuclear power development programs.[21] The growing number of such problems around the country led Daniel Yergin to conclude that the electric industry is an "industry in trouble."[22]

Adaptive Strategies

One major problem facing the electric industry is how to minimize the cost of providing the energy needed by consumers in this rapidly changing environment. Yet the adaptive strategies available to electric producers are limited. Strategies that are essentially functional in nature are virtually exhausted.

Functional changes are defined here to mean technical efficiency adjustments in the production, distribution or operation process that do not, by themselves, require structural (i.e. size) changes. The functional strategies open to the electric industry include the straightforward energy and economic conservation tactics available to virtually all organizations. For example, engines not in use may be turned off, superfluous lighting and heating/cooling of offices may be eliminated and tighter management controls on costs in general may be implemented to directly improve technical efficiences. But functional improvements also include advances in technology which may lead to, but do not require, structual changes.

The last half century has been marked by significant improvements in the thermal efficiency of the industry's production systems. As Schurr explains, "In the 1960s, it took less than half as much coal to generate a kilowatt-hour of electric power as it had taken in 1925."(23) Such improvements in materials and technology allowed utilities to achieve higher conversion efficiencies using conventional Rankine steam cycle equipment (39 percent in 1965 compared to only 17 percent in 1920).(24) But even higher efficiencies would now require, "...exotic, expensive materials and/or risk imposition of unacceptable reliability penalties," according to Bauer and Hirshberg.(25) Consequently, they conclude that, "...contemporary, reliable generating technology now appears to have reached a plateau...."(26)

While the improvements in conversion efficiency could be applied to larger power plants, enabling utilities to capture economies of scale, the improvements were essentially functional because of their applicability to any scale. The same is true for the improvement in materials and technology found in the utility's distribution systems. The use of high voltage transmission lines, however, with their associated reduction in transmission line losses prior to distribution, promoted an increase in the spatial area served by a single utility and a resultant increase in both the number of customers served and the organization's power demand.

The limited functional strategies left open to electric utilities suggest that the next major changes that will occur in this industry may be structural if, that is, there are any energy efficiency gains to be made by such changes in organizational size or the number and size of individual power plants. This study focuses upon this question.

CHAPTER THREE NOTES

(1) Robin W. Broadway, Public Sector Economics, (Cambridge: Winthrop Publishers, Inc., 1979) p. 151.

(2) Marc Messing, H. Paul Friesema and David Morell, Centralized Power, (Washington D.C.: Environmental Policy Institute, 1979) pp. 14-45.

(3) Douglas Bauer and Allan S. Hirshberg, "Improving the Efficiency of Electrical Generation and Usage," in John C. Sawhill's (editor) Energy, Conservation and Public Policy, (Englewood Cliffs: Prentice-Hall Inc., 1979) p. 144.

(4) U.S. Department of Energy, "Table 14: Sales of Electricity by End-Use Sector, 1949-1979," EIA Annual Report to Congress, October, 1980.

(5) Mike Walsh, Office of Energy Information Services, Energy Information Administration, U.S. Department of Energy, Washington, D.C. Personal communication, August 11, 1981.

(6) William Iulo, Electric Utilities - Costs and Performance, (Washington State University Press, 1961).

(7) Iulo, op. cit. p. 92. (emphasis added)

(8) Iulo, op. cit. p. 92.

(9) Iulo, op. cit. p. 92.

(10) Iulo, op. cit. p. 93.

(11) Iulo, op. cit. p. 94.

(12) Iulo, op. cit. p. 167.

(13) U.S. Department of Energy, The Annual Report to Congress, op. cit. "Table 6: U.S. Energy Supply/Demand Balance: History and Projections for Three Base Scenarios, 1965-1995", p. 13.

(14) Samual H. Schurr, Energy in America's Future: The Choices Before Us, (Baltimore: John Hopkins Press, 1979) p. 247.

(15) M. King Hubbert, "Energy Resources" in Resources and Man, Committee on Resources and Man, National Academy of Sciences (ed.) (San Francisco: W. H. Freeman and Co., 1969).

(16) Frederick Cottrell, Energy and Society: The Relation Between Energy, Social Change and Economic Development, (Westport: Greenwood Press, 1955) p. vii.

(17) U.S. Department of Energy, Annual Report to Congress, op. cit. "Table 2: Consumption of Energy by End Use Sector," p. 5.

(18) See for example: Amory Lovins, The Energy Controversy, Hugh Nash (editor), (San Francisco: Friends of the Earth Publications, 1979); Kirkpatrick Sale, op. cit.; and, Langdon Winner, "Do Artifacts Have Politics?," Daedalus 109(1):121-135, 1980.

(19) Alvin M. Weinberg, "Technology and Ecology: Is There a Need for Confrontation?," BioScience 23(1):41-46, 1973, p. 43.

(20) Historical review drawn from Robert J. Kalter and William A. Vogely, Energy Supply and Government Policy, (Ithaca: Cornell University Press, 1976) p. 216.

(21) See the Michigan Gongyer, August 4, 1981 for Michigan examples.

(22) Quoted in: Philip Sheron, "Many Electric Utilities Suffer as Conservation Holds Down Demand, Wall Street Journal, October 9, 1980 pg. 1.

(23) Schurr, op. cit p. 89.

(24) Bauer and Hirshberg, op. cit. p. 154.

(25) Bauer and Hirshberg, op. cit. p. 154.

(26) Bauer and Hirshberg, op. cit. p. 154.

CHAPTER FOUR

CONCEPTUAL DEFINITIONS

Organizational Size

Size can be defined as " a physical magnitude, extent or bulk: relative or proportionate dimensions...."[(1)] This description of size uses a physical measure, and this researcher has sought to apply such a measure to organizations.

Monetary measures of an organization's size are rejected because dollars are a means of exchange and not a measure of size. What costs a lot may be very small, like a diamond, while something that costs very little may be very large, like an acre-foot of water. Iulo stated that, "... the absense from physical measures of distortions introduced into monetary measures argues strongly for the use of physical measures as a more reliable indicator of relative utility size."[(2)] But apart from the possible distortions introduced by monetary measures of size, a physical measure of technical efficiency (such as Btu's per kilowatt-hour delivered) is best compared to another physical measure.

Ideally, a physical measure of size would quantify the total amount of energy contained within the structures owned by the organization. A power plant contains tons of steel, concrete, glass and a host of other materials in varying amounts. Each of these materials required energy for their fabrication and direct fuel inputs were required to assemble them together into a power plant. The sum of the energy required to produce a power plant is the embodied energy of the power plant. The embodied energy of an organization would then be the sum of the direct (fuel) and indirect (goods and services) energy inputs required to fabricate and erect the physical structures owned by the organization. The physical magnitude of an organization would include the embodied energy contained in the organization's power plants, substations, service roads, transmission and distribution lines, office and service buildings, typewriters, vehicles, etc.

Unfortunately, Noguchi demonstrated the lack of available data to calculate the embodied energy contained in even a single power plant, let alone the embodied energy of an entire organization.[(3)] Consequently, an alternative physical measure of size must be used that corresponds to the embodied energy of the organization. This alternative approach must meet four essential criteria: 1) it must vary directly with the embodied energy of an organization; 2) it must be applicable to all organizations in the study; 3) it must be measurable in physical units; and, 4) it must be constructed from readily available and reliable data.

A fundamental assumption made here is that form follows function; that is, an organization's physical structure is dependant upon the organization's function. As defined here, the functional definition of an electric utility is to generate and distribute electric power to customers. Three structural characteristics of electric utilities associated with these functional tasks can be readily identified and measured: 1) power generation and purchase; 2) power distribution; and, 3) service to customers. Power generation and purchase can be measured in terms of peak power demand, power distribution can be computed in terms of miles of line, and customers served is directly available.

One of these three characteristics, peak power demand, is directly related to the embodied energy within the organizations. Peak power demand requires both installed power capacity (associated with the construction of power plants, service roads, fuel facilities, etc.) and the transmission/distribution system (representing tons of steel, copper, concrete and other material inputs) necessary to handle the demand. The greater the peak power demand, the greater the embodied energy.

While proportionate to the organization's total embodied energy, peak power demand does not capture all of the various structures embodying energy in the organization. But it is reasonable to assume that an organization with greater peak power demand must own proportionately larger or more numerous service and office facilities as well.

The units of measure for the three variables follow from the definition of the variables: peak power demand is measured in Megawatts (electric); power distribution is measured in miles; and customers served is the number of customers billed. Operational defintions of size for the organizations as well as additional independent variables to be studied are developed in Chapter VI.

Technical Efficiency

As previously discussed, technical efficiency is defined as the energy efficiency of the production, distribution and operation process (see Chapter II). As such, technical efficiency is a modified thermal efficiency concept. Thermal efficiency is generally taken to mean the direct fuel inputs compared to the output of a production process, reported as a ratio of output to input. Thermal efficiency is a narrow perspective in that the process is complete at the point where the output leaves the production process.

The modifications used here for technical efficiency are a significant departure from a classical definition of thermal efficiency. First, technical efficiency broadens the perspective to include all the energy inputs required to deliver the output to the consumer. This means that technical efficiency includes the energy required in distribution and operations as well as that used in production alone. More importantly, it includes the indirect energy of goods and services required in the overall process. Second, technical efficiency is reported in the ratio of inputs to outputs, the inverse of a thermal efficiency ratio. This convention is used in order to report technical efficiency in terms of the energy inputs required to deliver a unit of electricity to the consumer and is analogous to dollars per unit. Technical efficiency, however, is reported in terms of British thermal units (Btu's) per kilowatt-hour delivered.

The technical efficiency of an electric utility is divided into several components. Overall technical efficiency is the sum of the total power efficiency, distribution efficiency and operations efficiency. Total power efficiency considers the direct fuel energy consumed in the utility's power plants plus the direct and indirect energy embodied in any purchased electricity. Distribution efficiency considers the electric line losses incurred in both transmission and distribution.

Operations efficiency is the sum of the direct energy inputs, such as electricity and natural gas used to power, light and heat offices and service facilities, plus the indirect energy inputs of materials and services required in the operation of the power plants, transmission/distribution network, and the administration of the organization. Operations efficiency does <u>not</u> include the electricity consumed at the power plants to excite generators or to power and light the plants. This cost is subsumed under total power efficiency as net available power for distribution. Operations efficiency does include the embodied energy of operation, maintenance, repairs, depreciation and administrative activities such as rents, insurance, billing, advertising and the like. Operational definitions of these dependent variables follow in Chapter VI.

CHAPTER FOUR NOTES

(1) *Webster's New Collegiate Dictionary*, (G. and C. Merriam Co., 1981) p. 1078.

(2) Iulo, *op. cit*. p. 42.

(3) Tetsushi Noguchi, *Energy Requirement of a 1000 Mw(e) Pressurized Water Reactor Power Station*, Resource Analysis Group Research Paper E-42 (Chicago: University of Chicago, 1978).

CHAPTER FIVE

METHODS

Selection of Analytic Technique

In theory, the purpose of an energy analysis should determine the system boundaries to be used.[(1)] In practice, however, the system boundaries and the choice of analytic methods to employ are constrained by the kind and availability of data.

For example, the production and distribution of electricity requires significant impacts on the natural environment's contribution to useful work done in the region.[(2)] Large power plants and long transmission lines together require thousands of acres of land which might otherwise be devoted to biological processes necessary to the region's overall productive capacity. This definition of the system's boundaries, while ideal theoretically, is unacceptable because the data necessary for its quantification is unavailable or derived from gross estimates of ecosystem processes. For this reason, ecoenergetics, the method used in an analysis of the total man-nature system is impractical at this time.

System Boundaries

By stepping back from the all-inclusive man-nature boundaries, one begins to focus on the more tightly defined processes involved in the system defined by the electric utility's production and distribution of electricity. For the purpose of this examination, therefore, the system's boundaries are defined by the legal description of the electric service division of a public utility.

This description of the system's boundaries eliminates the other possible functions of the utility such as water and sewerage services or natural gas distribution. In multi-service utilities, only the electric power division's inputs of fuels, materials and services are considered. Furthermore, despite the closely associated nature of cogeneration or district-heating steam production and distribution, the boundaries chosen also eliminates the steam services provided. This decision is made reluctantly because of the potential significance of cogeneration and district-heating on overall technical efficiency.(3)

In the extreme case, eliminating steam output from consideration significantly impacts the system's overall efficiency. If steam demand is the controlling factor in determining the system's outputs of steam and electricity, then the electric power production efficiency is greatly reduced. Fortunately, the utilities to be examined do not approach the extreme.(4)

The system boundaries selected also exclude the energy value of human labor. This is a generally accepted practice in energy analysis.(5) By extension, the costs associated with wages, salaries and benefits are excluded wherever possible. Though these dollar costs impact an economic analysis they do not contribute to or diminish the energy requirements of the process. Similar reasoning also excludes such pecuniary effects as taxes or payments made in lieu of taxes. Additionally, finance charges paid for borrowed capital and the dollar cost of purchased fuels and electricity are excluded.

The boundaries selected attempt to create a static picture of the process for the time frame under examination. Thus, the direct energy inputs to the process are included as well as the indirect (material and service) inputs necessary to operate, manage, maintain, and repair the system. An important subset of maintenance and repair expenses under the static conditions imposed are depreciation expenses incurred due to the depreciation of existing structures. Depreciation expense is assumed to represent the replacement value of facility deterioration. Consequently, construction of new facilities, not brought on-line during the time frame, are not considered.

The definition of the system boundaries presented includes the energy cost associated with the electric utility's delivery of the electric power. The output boundary extends up to and includes the electric meter at the end of the utiliity's responsibility for the electric power. But the input boundary is more complex. To avoid locational advantage in the comparison of technical efficiencies, the energy cost of capturing and delivering the direct energy inputs to the utility's gate are not considered. Likewise, the energy cost of delivering the materials and services required are not considered. Only the heat content of the direct (fuels) energy and the embodied energy of the indirect (purchased electricity, materials and services) energy inputs are considered. These values represent the producer's energy cost. Thus, the energy cost of fuels, materials and services are not increased by transportation and "middleman" expenses.

Survey Instrument Design

The system boundaries selected allow the use of either process or input-output analysis techniques.[6] Again, the kind and availability of data constrain the final choice of method to be employed.

With the assistance of Mr. R. H. Bulthuis, (Director of Regulatory and Data Research, Consumers Power Company) and members of his staff, a questionnaire was developed to capture the inputs and outputs of the system defined (see Appendix). Two key features in the instrument's design are: 1) the majority of the information required is available from published documents;[7] and, 2) the availability of data allowed the use of a five year time frame to average the annual figures. The second feature in the instrument's design is deemed necessary to smooth unusual expenses incurred as a result of unforeseen system failures and to reduce the variability in the year to year data.

The kind of data solicited in this manner determined the method of analysis to be a modified input-output technique. Direct inputs, such as coal, natural gas, etc. are reported in either total Btu's or other physical units such as tons, mcf, etc. consumed (see Table 1 for conversion factors employed). Indirect inputs such as operating, maintenance, depreciation and administration costs are reported in current dollars. Of the analytic techniques available, only an input-output energy analysis method can convert the dollar expenses into their equivalent energy costs.

Input-Output Analysis

This analytic technique, developed by members of the Energy Research Group at the Center for Advanced Computation, University of Illinois at Urbana - Champaign, is based on the economic input-output model used to describe the flow of goods and services in the U.S.

Table 1. Conversion factors employed.

Electricity (per kilowatt-hour)	
direct (heat equivalent)	3,412 Btu's/Kwh
*Total	13,056 Btu's/Kwh
Coal (in tons)	
direct	25,000,000 Btu's/ton
Natural Gas (in mcf)	
direct	1,012,000 Btu's/mcf
Fuel Oil (in Bbls)	
direct	5,882,898 Btu's/Bbl
Blast Furnace Gas (in mcf)	
direct	9,500 Btu's/mcf
Nuclear Fuel (in GMs)	
direct	104,958,843 Btu's/GM
Steam (in lbs)	
direct	1,000 Btu's/lb

*used for purchased power

Source: for electricity, natural gas, blast furnace gas and steam: Peter Kakela, "Table A-1, Energy Conversion Factors Employed," in "Pelletized vs. Natural Iron Ore Technology: Energy, Labor and Capital Changes," CAC Document No. 251 (Urbana: CAC of Unversity of Illinois) December, 1977. p. 62; for coal and fuel oil: calculated average based on data supplied by participating utilities; for nuclear fuel: from company data based on a coal equivalent.

economy.[8] Every industry is placed into a sector defined by a common characteristic, such as professional services, maintenance and repair construction, financial services, electrical apparatus manufacturing, etc. The economic activity in each sector is represented by a linear equation that corresponds to each of the input sectors required to produce a dollar's worth of the given commodity. By tracing each of these inputs back to the contribution made by the direct energy sectors, such as petroleum, coal, electricity, etc., an energy intensity can be determined. It is then possible to calculate the direct and indirect energy embodied in a dollar's worth of goods and services purchased from any sector of the economy.

Selection of Sectors

A first stage approximation of total indirect energy costs can be made by simply multiplying the total dollars spent by the total Btu's consumed in the U.S. economy that year and dividing by the number of dollars in the gross national product (GNP). This ratio is often used to estimate energy costs when the nature of the dollar costs cannot be stated more explicitly.[9] The questionnaire used in this analysis, however, separated the total operation costs into 10 Bureau of Economic Analysis (BEA) industrial classification sectors based on the Michigan Public Service Commission's (MPSC) Uniform System of Accounts for Class A and B Electric Utilities and verified by Mr. Bulthuis as the greatest extent the data may be disaggregated into consistent catagories.

Despite this level of refinement, the data collected represents a high degree of aggregation. The MPSC system of accounts lists 130 separate account numbers that conform to the system boundaries as defined. But municipal utilities are not required to report to the MPSC and each firm, therefore, uses its own, individually designed system of records. Apart form this problem, there is also the reluctance on the part of utility executives to participate in voluntary research efforts. According to Mr. Bulthuis, collecting the data on all 130 accounts for a five-year time frame is an unreasonable request to make. The resulting level of aggregation eliminated this latter objection and allowed for individuality in accounting systems.

Table 2 shows the 10 sectors selected and the corresponding input-output model's energy content values. In 1972, the total energy consumed in the U.S. economy was 71.63 quadrillion Btu's(10) and GNP was 1.1075 trillion dollars.(11) Thus the average Btu's per dollar was 64,677 in 1972. None of the industrial sectors chosen surpass this average value and, indeed, several sectors fall considerably below the average. While highly aggregated, the level of aggregation chosen represents a second stage approximation.

Energy Content Corrections

The latest economic data available to calculate the input-output energy values are based on 1972 data. Consequently, the embodied energy per dollar expended must be corrected not only for inflation but also for the conservation strategies employed since that date. This introduces an unknown degree of error into the corrected values.(12)

The Herendeen-Bullard approximation used to update the energy content values is a two step process.(13) First, the changing energy to GNP ratio is used to adjust the energy content values for economy-wide conservation strategies. Second, the changing price index is used to

Table 2. Selected Bureau of Economic Analysis sectors and their corresponding energy content values per 1972 dollar.

Description	Btu's/$ (1972)	BEA Sector
New construction, public utilities	64027	1103
Maintenance and repair	62551	1202
Office supplies	61778	8200
Regulatory services	52075	7903
Credit and financiel accounting	43784	7002
Educational services/public relations	40294	7704
Advertising	39717	7302
Miscellaneous business services	22211	7301
Insurance	15099	7004
Rentals and real estate	12110	7102

Source: Bureau of Economic Analysis sectors and their descriptions from Clark W. Bullard, Peter S. Penner and David A. Pilati, Energy Analysis Handbook, CAC Document No. 214 (Urbana: CAC of University of Illinois, 1976) pp. 32-35; and energy content values from Bruce Hannon, Energy Cost of Goods and Services, 1972, Energy Research Group Document No. 307 (University of Illinois at Urbana - Champaign, 1981).

adjust the values for inflation. Table 3 presents the energy conservation deflators and Table 4 shows the price deflators employed. The energy content value, or energy intensity, for a given industrial sector in a given year is therefore calculated by a series of multiplications. For example, $100 spent on office supplies in 1977 is equivalent to 3,885,639 Btu's (see Table 5).

Table 3. Total energy consumed, gross national product and the energy deflator calculated to correct energy content values for conservation strategies employed since 1972.

Year	Energy Consumed (in Quadrillion Btu's)	Gross National Product (in Trillion 1972 $)	Btu's/$(1972) (x1000)	Energy Deflator
1972	71.63	1.1075	64.68	1.0000
1977	76.33	1.3697	55.73	0.8616
1978	78.18	1.4386	54.34	0.8402
1979	78.91	1.4794	53.34	0.8247
1980	75.91	1.4740	51.50	0.7963
1981	73.91	1.5026	49.19	0.7605

Source: Total energy consumed from the Energy Information Administration, 1981 Annual Report to Congress, Vol. II, Energy Statistics, USDOE, May 1982; Gross National Product from the U.S. Department of Commerce, "Table 1.2: GNP in Constant Dollars," Survey of Current Business 62(7):23 July 1982: Energy Deflator equals Btu's(y)/Btu's(1972) X GNP(1972)/GNP(y) from Robert A. Herendeen and Clark W. Bullard, Energy Cost of Goods and Services, 1963 and 1976, CAC Document No. 140 (Urbana: CAC of University of Illinois, 1974) p. 16.

Table 4. Price deflators used to correct current expenditures for inflation since 1972. Index year, 1972 = 1.000.

Industrial Classification (BEA Sectors)	Year 1977	1978	1979	1980	1981
Services (7301;7302;7704)	0.701	0.655	0.605	0.552	0.508
Finance (7102;7002;7004)	0.752	0.686	0.640	0.587	0.544
Construction (1103;1202)	0.635	0.575	0.503	0.440	0.409
Government (7903)	0.702	0.659	0.618	0.570	0.521
Manufacturing (8200)	0.730	0.689	0.652	0.604	0.558

Source: U.S. Department of Commerce, "Table 7.22: Implicit Price Deflators for Gross National Product by Industry," Survey of Current Business 62(7):115 July 1982.

Table 5. Example of inflation and energy conservation correction employed.

start with $100 in office supply expense in 1977	$100.00	(1977 $)
times inflation deflator	(X) 0.730	
	$ 73.00	(1972 $)
times energy content per 1972 $	(X) 61,778	Btu's/(1972 $)
	4,509,794	Btu's's
times energy deflator	(X) 0.8616	
office supply energy expense	3,885,639	Btu's's

Selection of Subjects

A random sample from the population of 1000 electric generating companies in the United States, though ideal for a statistical analysis, is rejected as being both impractical and inappropriate at this time due to unavoidable constraints and the need for data consistancy. For example, time and funding constraints required a selection of utilities from the state of Michigan. In most cases, personal interviews were required to introduce the purpose of the research project and to describe the nature of involvement required by the participating company executives. This personal contact also insured a consistent definition of the data required. Thus the population to be sampled is reduced to the 47 generating companies in Michigan.

Of these 47 companies, significant differences in their level of self-sufficiency in generating power to meet their power demand required further winnowing. The goal in this process was to look only at companies that produced at least the majority of their total power demand. Companies that operate primarily as distributors of electric power do not conform to the definition of an electric generating and distributing company as defined in Chapter IV. An allowance was made, however, for those companies that, for accounting purposes, consider power obtained from facilities that they own in whole or part as purchased power. This requirement reduced the total number of electric companies to 10 in Michigan that conform to the definition.

This winnowing process left only those companies in Michigan that differed from each other on the basis of size and technology. In order to compare companies only on the basis of size, the kind of generating units and their age had to be comparable as well. The weighted average date a company's production system was brought on line is calculated by weighting the date each unit within a power plant is brought on line by the unit's rated capacity. For multiplant companies, the weighted average date for all power plants is calculated by weighting the weighted average date of each power plant by the net kilowatt-hours produced by the plant. None of the 10 remaining companies in Michigan were eliminated from the sample using this technique because the companies did not differ by more than 10 years from each other.

Finally, to insure that the kind of generators employed by each company was comparable, fossil-fueled power plants are required to make up the majority of total installed capacity. This eliminates those companies that are largely dependent on nuclear or hydro-power, assuming that these facilities are technically incompariable with conventional fossil-fuel technologies. This requirement eliminated only one company which used hydro-power aq its ppedominant energy source. Table 6 presents the eight participating electric companies examined in this analysis. While 9 companies qualified under the constraints imposed, one company refused to participate.

Statistical Analysis

Both linear and polynomial regression analyses (with appropriate data transformations) are used to test the strength of any correlation between the variables presented in Chapter VI.[14,15] In each case, the

Table 6. Qualifying statistics of the participating electric utilities.

Company	Self-Sufficiency (%) Power produced to total power sales	Average Date Production system was on-line	Fossil-fueled Capacity (%) Total installed capacity
A	86.98	1966	95.13
B	76.00	1965	71.30
C	99.93	1964	99.10
D	31.18*	1960	84.20
E	93.56	1962	100.00
F	89.49	1969	93.46
G	93.55	1959	99.53
H	70.46*	1968	94.29

* These companies "purchase" power from facilities they own in whole or part for accounting purposes and qualify at the 70 percent level if this purchased power is considered in-house generated.

Source: statistics calculated from data in the Energy Information Administration, "Table 6: Electric Generation Units by State, Company, Plant and County," Inventory of Power Plants in the U.S., USDOE June 1981 pp. 125 - 137; and the Electric World Directory of Electric Utilities, 89th edition, (New York: McGraw Hill, Inc., 1980) pp. 381 - 399.

null hypothesis states that no relationship exists. The alternative hypotheses are tested against the observed data and a relationship is concluded to exist if the probability of incorrectly rejecting the null hypothesis (a Type I error) is less than five chances out of a hundred (P = 0.05). When more than one alternative hypothesis may be accepted, then the alternative that best describes the data and satisfies theoretical and/or empirical constraints is selected.

Limitations

The primary limitation in this analysis stems from the small and highly structured nature of the sample. Conclusions may be drawn but only on the data collected.

Beyond the limitations of any preliminary research effort, however, are the inherent limitations associated with the nature of the data itself. For example, coal is a highly heterogenous energy source with a great deal of variability in its Btu content. One pound of coal will differ from the next pound due to the variability in the geological processes that created it and the moisture absorbed in the coal piles just prior to combustion. Yet an average heat content value was used to asssess this significant energy source.

Finally, there are the limitations imposed by the methods employed. Converting current dollars expended in various industrial sectors back to 1972 dollars to obtain their embodied energy incurs both inflation and energy conservation uncertainties. Beyond these problems there are also the general limitations of an input-output analysis. For example, classifying expenses into a given sector may introduce an error due to the level of aggregation in that sector. The actual purchases within the sector may be made of goods or services that are not typical to that sector. Further, there are uncertainties in the computed energy cost per dollar for the 357-sector model that stem from disaggregating the 90-sector model.

CHAPTER FIVE NOTES

(1) David E. Gushee (editor), Energy Accounting as a Policy Analysis Tool, Congressional Research Service, (Washington D.C.: U.S. Government Printing Office, June 1976) p. 5

(2) Howard T. Odum, et. al., "Energy Cost-Benefit Analysis Applied to Power Plants Near Cyrstal River, Florida" in Charles A. S. Hall and John W. Day (editors), Ecosystem Modeling in Theory and Pracatice, Chapter 21, (New York: John Wiley and Sons, 1977) pp. 507-545.

(3) For example, the Michigan State University district-heating system was examined as a part of the survey instrument's design and development. Tentative findings indicated that inclusion of the steam output raised overall efficiency to approximately 52 percent.

(4) Four of the eight utilities examined provide steam services but only one attains a steam output (in Btu's) that approach 8.5 percent of total output (in Btu's). In contrast, steam output of the MSU system is approximately 85 percent of the total.

(5) P. F. Chapman, "Energy Costs: A Review of Methods," Energy Policy, June 1974, p. 93.

(6) See, for example, Gushee, op. cit.

(7) Each electric utility files either an Annual Report to the Economic Regulatory Administration (form ERA-412) or an Annual Report to the Michigan Public Service Commission (MPSC form P-521).

(8) Clark W. Bullard, Peter S. Penner and David A. Pilati, Energy Analysis Handbook, CAC Document No. 214, (University of Illinois at Urbana-Champaign, 1976).

(9) Bullard, et. al., op. cit. p. 20.

(10) Energy Information Administration, 1981 Annual Report to Congress, Vol. II, Energy Statistics,(Washington, D.C.: U.S. Department of Energy, May 1982).

(11) U.S. Department of Commerce, Business Statistics, 1975 edition, May 1976.

(12) Robert A. Herendeen and Clark W. Bullard, Energy Cost of Goods and Services, 1963 and 1967, CAC Document No. 140 (University of Illinois at Urbana-Champaign, 1974) p. 16.

(13) Herendeen and Bullard, op. cit. p. 16.

(14) Kenneth Dimoff, Statistical Plotting On-Line Command System User's Guide, MSU Pest Management Technical Report No. 13, Department of Entomology, Michigan State University, 1977 (periodically updated).

(15) Tektronix, Inc., Operations Manual and the Plot 50: Statistics, Volume 3 (Beaverton: Tektronix, Inc., 1976).

CHAPTER SIX

RESULTS AND ANALYSIS

The Independent Variables

Organizational Size

The primary independent variable in this analysis is organizational size. As the single best indicator of the physical size of an electric utility, Iulo recommends using peak power demand. As Iulo explains, peak power demand "recognizes both the capacity that must be built into the distribution system and the capacity that must be provided by the production system in order to meet the maximum demand placed upon the utility."(1) Iulo, however, was unable to use peak power demand in his analysis because his data sources did not consistently report peak power demand. But one of the advantages of the small sample selected and the personal contact it permits with utility executives is the ability to obtain a consistant measure of the utility's peak power demand. Consequently, this analysis follows Iulo's recommendation and uses peak power demand as the measure of utility size.

Each company's five year average value for peak power demand and the other utility-based independent variables are reported in Table 7. The average peak power demand is calculated by averaging the five annual peak power demand figures reported by the company.

Table 7. The Utility-Based Independent Variables

Company	Utility Size Peak Power Demand (Mw)	Distribution System (in Mi)	Customers Served	Distribution Density (Customers per Mile)	Production System Age (Average Date On-Line)
A	7083	41,073	1,735,235	42.2	1966
B	4731	54,368	1,293,221	23.8	1965
C	371	1,280	77,613	209.3	1964
D	140	3,076	58,588	19.0	1960
E	61	208	13,707	65.7	1962
F	43	244	13,481	55.2	1969
G	33	110	8,375	76.1	1959
H	28	79	6,711	85.0	1968

Note: All values except System Age values are averages based on the five year time frame.

Distribution Density

The companies' energy costs in distributing electric power may be dependent upon the density of customers within their service area. As the figures in Table 7 show, the participating companies differ in their five year average miles of line and customers served. These differences are made more distinct in the distribution density column of Table 7. Distribution density is calculated from the five year averages for customers served and distribution miles and equals customers served per mile of line.

System Plant Age

The level of technology employed in the system's power plants may also effect the energy efficiency of the companies. Older plants may be less efficient than more modern plants. The process of selecting the participating companies in this examination attempted to minimize this potentially confounding variable. As Table 5 showed, the weighted average date on-line for the power plants in operation do not differ by more than 10 years. Nonetheless, this factor may still play a part in contributing to the system's energy efficiency.

The calculation for determining the system plant age shown in Table 7 was described previously. To reiterate, the system plant age is a weighted average based on the installed capacity of the individual units within a power plant and the date the units were brought on-line within the plant. Thus larger units within the plant have a larger influence on the calculated overall age of the plant. For multi-plant utilities, the system plant age is calculated by weighting the weighted average age of each plant by the net kilowatt-hours produced by the plant. Thus the larger units within the plant and the larger plants have a proportionately greater influence on the age of the system. This procedure for determining the system's average age is used because the majority of the power produced is base-load power and this power is produced primarily by the larger plants and units within the plants.

Plant Size and Age

It is possible that power plant energy efficiencies are dependent upon the size of the power plant and/or the level of technology employed in the plant. Thus, in order to more carefully perceive the impact of power plant size and age on the system's overall energy efficiency, operating statistics on eight power plants were obtained from the participating companies. Changes in rated capacity over the time frame, from retirement or addition to plant capacity, generated data for essentially 11 different plants based on size. Plant size is based on installed capacity. The plant's age is the weighted average age of the individual units within the plant as described previously. Table 8 presents the plant sizes and ages examined.

The Dependent Variables

Total Power Efficiency

As defined in Chapter IV, total power efficiency combines the heat content of the direct energy consumed in the production process with the direct and indirect heat content of the electricity purchased from other electric producers. The direct heat content of the electricity purchased is multiplied by its energy intensity (from Table

Table 8. Specific Plant-Based Independent Variables

Plant No.	Size (Mw(e) capacity)	Average Date On-Line
1	3280	1973
1a	3014	1973
2	1905	1960
2a	1775	1960
3	1369	1974
3a	650	1965
4	510	1954
5	386	1964
6	70	1958
7	34	1970
8	17	1968

Source: Size based on installed capacity from collected data; average date on-line is a weighted average based on data from the Energy Information Administration, "Table 6: Electric Generating Units by State, Company, Plant and County," op. cit. pp. 125-137.

1) to calculate both the direct and indirect energy embodied in the power made available to the distributing company.

Total Btu's consumed in the direct conversion of fuels and in the purchase of electricity are totaled over the five year study period for an average value. This average is then divided by the five year average of the company's total kilowatt-hour sales to calculate the average energy cost per kilowatt-hour sold. The dependent variables are reported in Table 9.

Distribution Efficiency

Line losses incurred as the inevitable result of transmitting and distributing the electric power produced and purchased are measured in kilowatt-hours and converted to Btu's via the straight conversion of electricity into heat (see Table 1). The five year average heat content of these line losses are divided by the average kilowatt-hours sold for the distribution energy costs per kilowatt-hour delivered (Table 9).

Operations Efficiency

Dollar costs of operating the system's power plants (excluding the cost of fuels), transmission/distribution system and the company's administrative functions are converted to Btu's using the input-output energy analysis technique previously described. Once converted to Btu's, the annual operations energy costs were summed for a five year average and divided by the average kilowatt-hours sold (Table 9).

Table 9. System energy costs: the dependent variables.

Company	Megawatt-hour sales (Mwh)	Production (Btu's/Kwh)	Total* Power (Btu's/Kwh)	Operations (Btu's/Kwh)	Distribution (Btu's/Kwh)	Overall** (Btu's/Kwh)
A	35,782,121	12,623.0	12,799.5	276.4	248.1	13,324.0
B	26,608,582	11,651.0	12,250.7	235.7	295.5	12,781.9
C	2,209,191	11,542.9	11,541.2	242.1	140.1	11,923.4
D	758,499	11,891.1	13,573.1	256.0	306.4	14,135.5
E	255,078	15,414.6	15,312.4	215.7	266.5	15,794.6
F	201,591	13,665.4	13,614.0	224.7	174.7	14,013.4
G	156,539	14,763.8	14,760.0	193.7	134.6	15,088.3
H	137,754	11,641.4	12,256.2	205.5	179.6	12,641.3

*Total power energy costs per kilowatt-hour delivered is the sum of production and purchased electric energy costs per kilowatt-hour delivered.

**Overall energy costs per kilowatt hour delivered is the sum of Total Power, Operations and Distribution energy costs per kilowatt-hour delivered.

Overall Efficiency

A company's average overall energy costs per kilowatt-hour delivered is the sum of the company's average energy costs per kilowatt-hour delivered for the catagories: 1) total power; 2) distribution; and, 3) operations. Alternatively, the average cost per kilowatt-hour delivered may be computed by summing total annual energy costs for a five year average and dividing by the average kilowatt-hours sold (Table 9).

Production Efficiency

Production efficiency is the energy cost of the fuels consumed in the company's production system and excludes all other energy costs including purchased electricity. The five year average energy consumed in converting fuels to electricity is divided by the average kilowatt-hours sold (Table 9).

Power Plant Overall Efficiency

Unlike the output of the electric company itself, where kilowatt-hours delivered forms the denominator of the energy costs per unit measure of efficiency, the output of the power plant is measured at the plant's gate just prior to distribution. The power plant's gross electric power production, minus plant-use, equals the net power produced. The plant's average net power produced is then calculated.

The numerator for power plant overall efficiency is the sum of the direct energy consumed in conversion plus the indirect energy of operating costs (excluding the dollar cost of fuels). The operating costs were reported in dollars and are converted to Btu's using the input-output energy analysis technique. The average energy cost is then calculated and divided by the average net power produced. This produces the power plant overall energy cost per net kilowatt-hour produced (see Table 10).

Power Plant Production Efficiency

Power plant overall efficiency is the sum of the power plant production efficiency and the power plant operations efficiency. Power plant production efficiency is the average direct (fuel) energy consumed divided by the average net kilowatt-hours produced (Table 10).

Power Plant Operations Efficiency

Power plant operations efficiency, the last component in power plant overall efficiency, is the energy cost of the goods and services required to operate the plant. These indirect energy costs, reported in dollars, are converted to Btu's using the input-output energy analysis technique. The average operations energy cost is divided by the average net power produced (Table 10).

Table 10. Plant energy costs: the dependent variables.

Plant No.	Net Power Produced (Mwh)	Production (Btu's/Kwh)	Operations (Btu's/Kwh)	Overall (Btu's/Kwh)
1	15,591,794	9864.6	90.8	9955.4
1a	17,467,673	9688.2	79.1	9767.3
2	7,160,991	10468.4	122.6	10591.0
2a	6,142,878	10575.9	144.6	10720.5
3	7,690,944	9410.0	87.3	9497.3
3a	3,546,307	9497.7	100.4	9598.1
4	2,784,377	10809.6	113.5	10923.1
5	1,183,854	11651.8	122.9	11774.7
6	257,337	14162.7	120.8	14283.5
7	169,055	14202.3	129.5	14331.8
8	125,380	11261.0	140.5	11401.5

Analysis and Discussion of Results

Overall Efficiency

The results of the statistical analysis (Table 11) confirm the null hypothesis, so that at the 5.0 percent level of significance, one may conclude that no relationship exists between utility size and overall efficiency. But an entirely different conclusion is reached if only the most efficient utilities are examined.

This division of the data assumes that the four most efficient utilities, which range from the largest to the smallest (companies A,B,C, and H respectively), are operating closer to the optimum efficiency obtainable at their scale than are the remaining four utilities. Figure 5 illustrates an economic model that underlies this assumption.

The LRAC curve in Figure 5 is the theoretical envelope curve composed of the minimum points obtainable from successive SRAC curves. But empirical data is solely obtained from organizations operating somewhere along a SRAC curve. Two organizations may produce the same quantity of output yet be on different SRAC curves. The assumption being made here is that the most efficient utilities are operating closer to the minimum cost point on their respective SRAC curves and therefore, represent a closer approximation of the maximum efficiency obtainable at their scale on the LRAC curve.

Table 11. Overall efficiency statistics.

(x = peak power demand, y = overall energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	Constants B	Constants C	Coefficients R	Coefficients R^2	Two-Tailed P (Type I)
$a + bx$	13940	-0.143	-	-0.303	0.092	0.4660
$a + b/x$	13270	30690	-	0.332	0.110	0.4224
$a + b(\log x)$	15110	-600.0	-	-0.442	0.196	0.2726
$a + bx + cx^2$	14057	-0.851	0.0001	-0.419	0.175	> 0.30
$a + b(\log x) + c(\log x)^2$	17294	-2485	354.2	-0.468	0.217	> 0.20

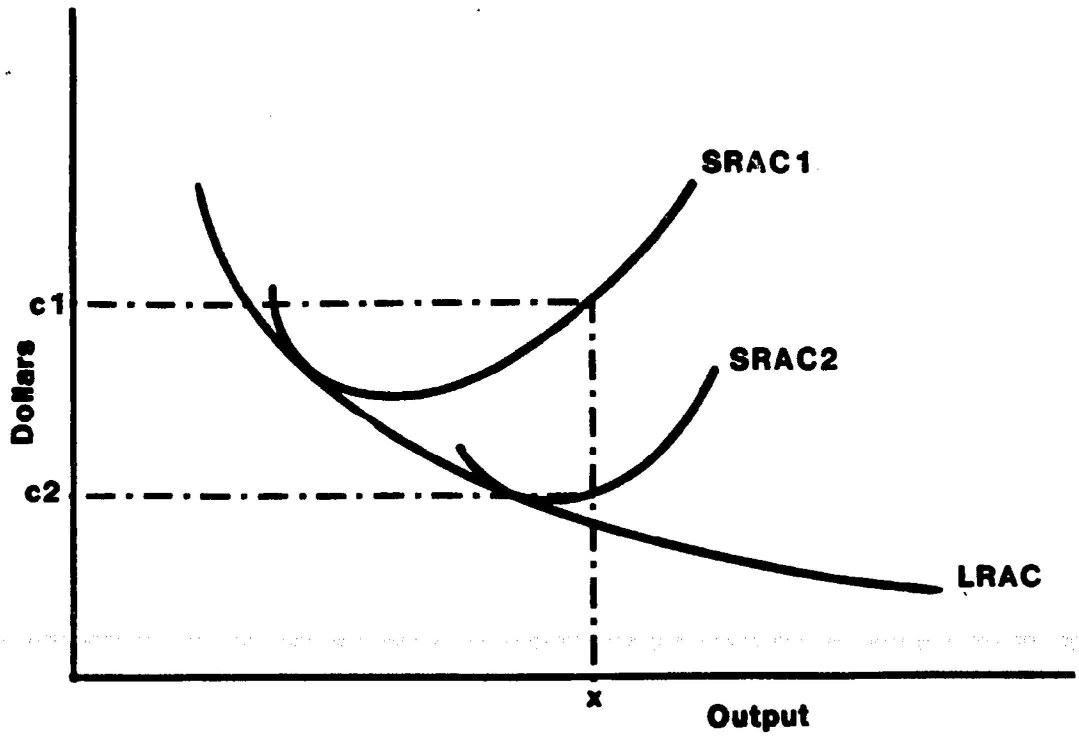

Figure 5. An economic model of how two different companies on different short-run average cost curves, yet producing at the same output level, will have different average costs.

Making this assumption is bolstered by precedent. Messing, et. al. chose to look only at the most efficient power plants in operation.(2) This examination also looks at the energy efficiency of the most efficient utilities. But using the data from only the four most efficient utilities increases the difficulty of finding a statistically significant result. When the complete data set of eight utilities is tested, the degrees of freedom associated with the student's t distribution is six; whereas the smaller data set allows only two degrees of freedom. Nonetheless, based on the four most efficient utilities, a U-shaped relationship between utility size and overall efficiency exists (see Table 12 and Figure 6).

Table 12. Overall efficiency statistics based on the four most efficient utilities examined

(x = peak power demand, y = overall energy costs)

Hypothetical Relationship	Constants			Coefficients		Two-Tailed
(Y = General Form)	A	B	C	R	R^2	P (Type I)
a + bx	12240	0.139	-	0.826	0.683	0.1737
a + b/x	12700	-3120.	-	-0.094	0.009	0.9060
a + b(logx)	11900	267.7	-	0.517	0.267	0.4831
a + bx + cx^2	12310	-0.05	2.8E-5	0.862	0.743	> 0.10
a + b(logx) + c(logx)^2	16292	-3553.	715.8	0.987	0.974	< 0.02

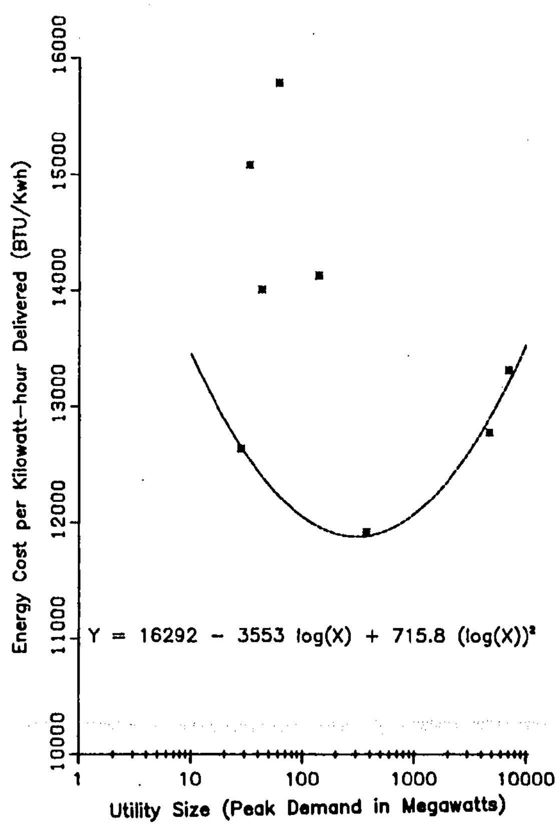

Figure 6. Overall efficiency and best fitting polynomial equation.

This relationship, however tentative, demonstrates the existance of the proposed energy economy of scale curve (Figure 3). As such, it represents the first empirical evidence of a relationship between technical efficiency and organizational size. In terms of overall efficiency, based on the most efficient utilities examined, the optimum size of an electric utility is approximately 300 Megawatts of peak power demand (Figure 6). Overall efficiency, however, is the result of the combined effects of several factors.

Total Power Efficiency

As expected, the energy cost of making electric power available to consumers closely parallels the utilities' overall energy costs. In fact, the energy cost of production and purchase equals 96.7 percent of overall energy costs. Thus, the data used to generate Table 13 are approximately 3.30 percent lower than the data points used in the overall efficiency calculation.

The statistical analysis of the complete data set again showed no relationship between utility size and the utility's total power efficiency (Table 13). Examining only the four most efficient utilities, however, suggests that the utilities' total power efficiency is dependent upon utility size (Table 14). The alternative hypothesis selected is essentially the same as the U-shaped curve selected for the utilities' overall efficiency relationship (Figure 7).

As shown in Figure 7, the optimum size (based on the total power efficiency of the most efficient utilities examined) is 350 Megawatts of peak demand or 50 Megawatts greater than that observed for overall efficiency. Because total power energy costs represent the energy costs of making electric power available to the system but not the costs of distribution or operations, the 50 Megawatts difference in optimum size may be the result of distribution and operations energy costs.

Nevertheless, total power efficiency appears to be the major factor in determining the observed shape of the electric utilities' overall efficiency curve. Total power energy costs include the fuels consumed in the companies' power plants and the energy cost of purchased electric power. When these costs are divided by the electric power actually sold by the utility, the total power efficiency curve becomes a measure of the utility's load management efficiency. The relationship between size and the ability to coordinate power supply with power demand (load management efficiency) is clarified by the results obtained for production efficiency.

Table 13. Total power efficiency statistics.

(x = peak power demand, y = total power energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	C	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	13510	-0.16	-	-0.339	0.115	0.4121
a + b/x	12760	34990.	-	0.378	0.143	0.3564
a + b(logx)	14790	-657	-	-0.483	0.233	0.2253
$a + bx + cx^2$	13638	-0.89	1.1E-4	0.452	0.204	> 0.20
$a + b(\log x) + c(\log x)^2$	17158	-2700	384	0.508	0.258	> 0.10

Table 14. Total power efficiency statistics based on the four most efficient utilities examined.

(x = peak power demand, y = total power energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	C	Coefficients R	R^2	Two-Tailed P (Type I)
$a + bx$	11860	0.116	-	0.771	0.594	0.2293
$a + b/x$	12210	-148.	-	-0.450	0.250	0.9950
$a + b(\log x)$	11630	200.	-	0.433	0.187	0.5674
$a + bx + cx^2$	11939	-0.103	3.2E-5	0.835	0.697	> 0.10
$a + b(\log x) + c(\log x)^2$	15734	-3363.	667.6	0.978	0.956	< 0.05

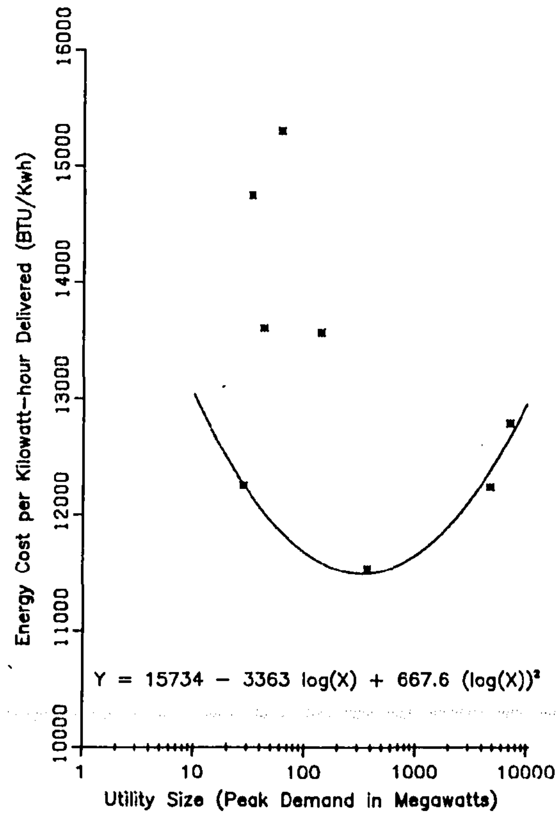

Figure 7. Total power efficiency and best fitting polynomial equation.

Production Efficiency

A significant and U-shaped relationship also exists between utility size and production efficiency based on the four most efficient utilities (Table 15). But unlike the relationship found for overall and total power efficiency, the best alternative here is the simple polynomial: $y = a - bx + cx^2$. Figure 8 illustrates the relationship found.

Based only on the energy costs of electric power production, the curve in Figure 8 suggests that the optimum size of an electric utility is 2500 Megawatts of peak demand. The large difference between the optimum size indicated by production (at 2500 Megawatts) and total power efficiency (at 350 Megawatts) suggests that the energy costs of coordinating purchased power inputs and in-house power to meet the

Table 15. Production efficiency statistics.

(x = peak power demand, y = production energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	C	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	1.3E+4	-0.16	-	-0.280	0.078	0.5015
a + b/x	1.2E+4	4.3E+4	-	0.394	0.155	0.3340
a + b(logx)	1.5E+4	-707.	-	-0.442	0.195	0.2733
a + bx + cx^2	1.3E+4	-1.10	1.5E-4	0.431	0.186	> 0.20
a + b(logx) + $c(\log x)^2$	1.9E+4	-4270.	670.8	0.498	0.248	> 0.20
*a + bx	1.2E+4	0.12	-	0.809	0.655	0.1908
*a + b/x	1.2E+4	-96734.	-	0.331	0.110	0.6688
*a + b(logx)	1.1E+4	264.8	-	0.581	0.337	0.4193
*a + bx + cx^2	1.2E+4	-0.274	5.8E-5	0.999	0.999	< 0.001
*a + b(logx) + $c(\log x)^2$	1.3E+4	-1699.	368.1	0.760	0.578	> 0.20

*Based on the four most efficient utilities.

company's power demand is the major factor in determining the optimum size of an electric utility. In short, if the utility produced 100 percent of its power demand then the optimum size indicated by this analysis would be approximately 2500 Megawatts of peak demand. As the proportion of total power made up by purchased power inputs is increased, problems of effective power coordination appear and reduce the observed optimum size.

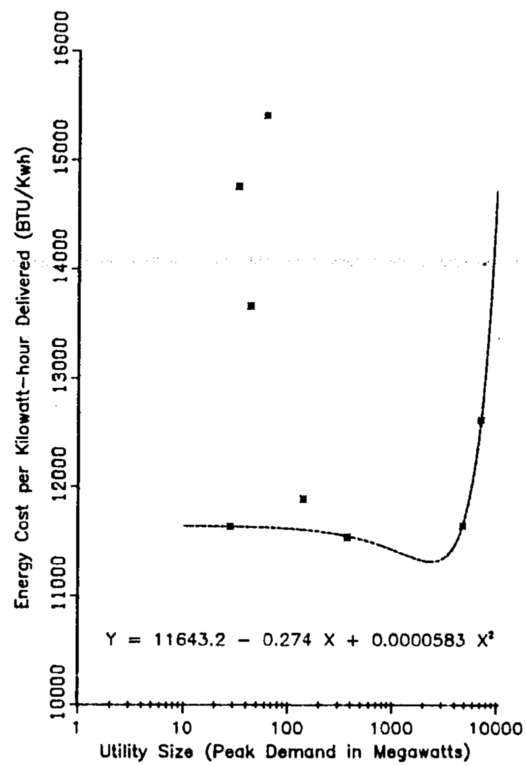

Figure 8. Production efficiency and best fitting polynomial equation.

One of the problems of effective power coordination may be the untimely addition of purchased power to the system while the company's power plants are still on-line. This may occur as the result of contractual arrangements that automatically dump power into the system irrespective of the power demand at the time. For example, demand might increase sufficiently over the production system's capacity to meet the demand. This triggers the purchase of power from an outside source. But the contractual arrangement is for bulk power which may be in excess of the incremental amount of additional power actually needed. As a result, the power produced from some or all of the power plants on-line becomes superfluous. This analysis, however, did not collect the data necessary to fully explore the significance of production versus total power efficiency. Nevertheless, the very high correlation coefficient (0.999) and very low probability of a Type I error (0.001) observed for the polynomial relationship in production efficiency suggests that the proportion of total power produced in-house is a significant variable in determining the overall optimum size for this industry.

Distribution Efficiency

With 96.70 percent of the overall energy costs contained within the production and purchase of electric power, the remaining 3.30 percent is divided between the utilities' distribution and operations energy costs. The energy cost of distributing electric power was initially thought to be second in importance to the energy cost of total power but this is not the case. Distribution energy costs averaged 13 Btu's per kilowatt-hour delivered less than operations energy costs. The difference is not significant and it appears that distribution and operations energy costs divide the remaining 3.30 percent almost equally. Figure 9 plots distribution energy costs against utility size.

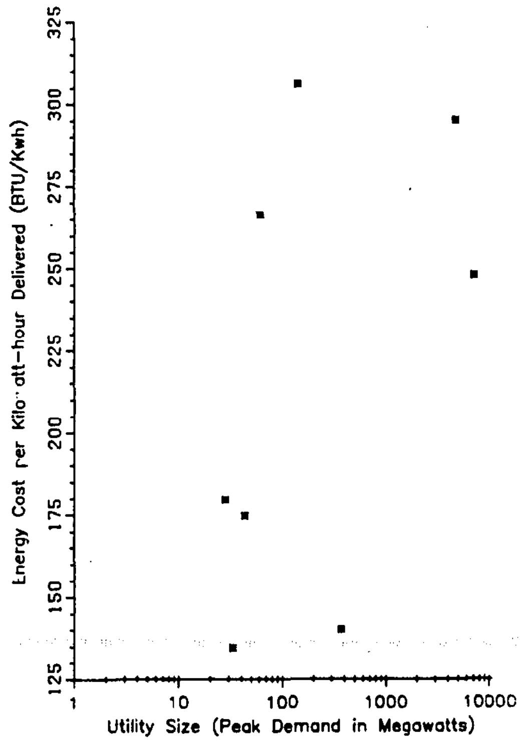

Figure 9. Distribution efficiency against utility size.

The plotted data appear to divide into two separate groups. With two distinct groups, both covering almost the entire range of utility sizes in the study, the plotted data suggest that either samples from two separate populations are being examined or that utility size is not the distinguishing variable. In this instance, utility size was suspected as being irrelevant and distribution density was used as the independent variable (see Table 16).

The asymptotic equation (y = a + b/x) consistently surpasses the level of significance required and is chosen as best representing the relationship between distribution density and distribution energy costs despite the fact that the log equation explains the observed data slightly better (Table 16). This choice seems reasonable because some thermodynamic limit to distribution efficiency might be expected. The asymptotic equation selected descends to a limit of 138.3 Btu's per kilowatt-hour delivered. Of course, determination of the actual limit requires a larger sample size. Figure 10 illustrates the asymptotic equation selected for this relationship.

Table 16. Distribution efficiency statistics.

(x = customers per mile of line, y = distribution energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	276.2	-0.805	-0.701	0.492	0.05262
a + b/x	138.3	3524.0	0.835	0.698	0.00985
a + b(logx)	525.2	-175.8	-0.836	0.699	0.00970
* a + bx	283.3	-0.749	-0.902	0.813	0.09840
* a + b/x	130.0	4173.0	0.980	0.961	0.01969
* a + b(logx)	520.4	-168.0	-0.986	0.972	0.01432

*Based on the four most efficient utilities.

Because distribution efficiency is related to distribution density, but not to utility size, its impact on overall efficiency cannot be directly observed. Moreover, an organization at any scale may benefit from a high distribution density. Consequently, and in light of its very small contribution to overall energy costs, distribution efficiency may be ignored in subsequent investigations of the optimal size of electric utilities.

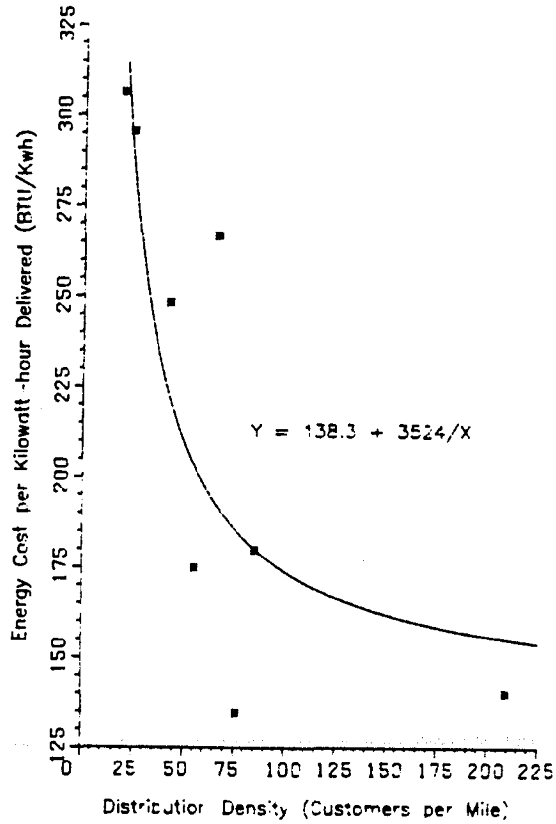

Figure 10. Distribution efficiency and the selected asymptotic equation.

Operations Efficiency

The remaining component of overall efficiency is the energy cost of operating the utility. A relationship clearly exists between utility size and the energy cost of operations (Table 17).

While the asymptotic equation ($y = a - b/x$) is superior to the logarithmic equation, at least for the observed data in this examination, theoretical considerations argue for caution in accepting the asymptotic equation. An asymptotic equation suggests a thermodynamic limit to the amount of energy an organization can expend in operations yet no limit to the size of the organization. The logarithmic equation follows essentially the same pattern as the asymptotic equation and also qualifies at the level of significance chosen, yet does not imply a limit to the amount of energy an organization can spend on operations. Thus the logarithmic equation y = a + b(log x) best describes the observed relationship between operations efficiency and utility size (see Figure 11).

Table 17. Operations efficiency statistics.

(x = peak power demand, y = operations energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	221.1	0.007	0.660	0.436	0.0748
a + b/x	254.8	-1625.	-0.843	0.710	0.0086
a + b(logx)	180.9	21.6	0.764	0.583	0.0275
* a + bx	219.4	0.007	0.795	0.632	0.2053
* a + b/x	252.9	-1344.	-0.804	0.646	0.1964
* a + b(logx)	177.4	21.67	0.830	0.689	0.1700

*Based on the four most efficient utilities.

This observed relationship is significant despite its small contribution to an electric utility's overall energy costs. Of the variables examined in this analysis, only operations efficiency may be applied to organizations in general. The other variables examined are specific to the electric utility industry. But all organizations face similar operation expenses such as facility maintenance, repair, depreciation, day to day operation inputs of goods and services and the energy costs of managing the organization. Consequently, the best fitting logarithmic equation (Figure 11) for operations efficiency suggests that the energy penalty for growth in organizational size becomes less as the organization becomes larger.

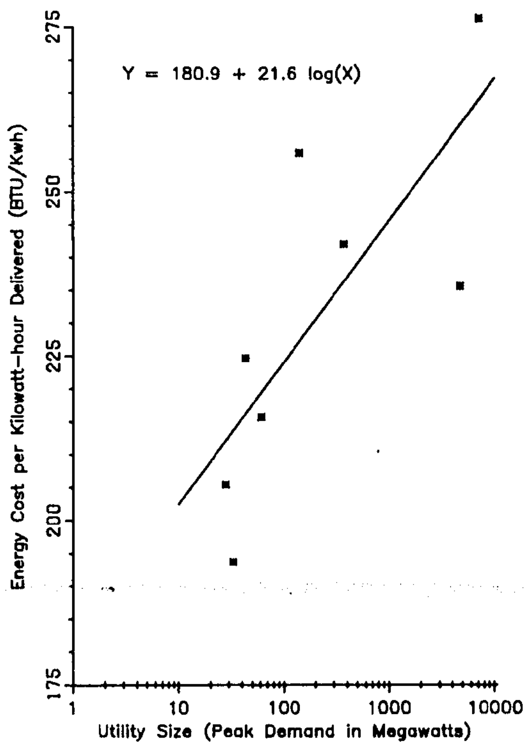

Figure 11. Operations efficiency and best fitting logarithmic equation.

This result implies that if the energy economy of scale curve holds for organizations in general, it is more the result of production or total power efficiency declining beyond the optimum size rather than the influence of operations efficiency. In short, service organizations that do not have a production or total power component may not exhibit a technical optimum size.

System Plant Age

The last utility-based variable to examine is the potential contribution made by the system's level of technology, as measured by the weighted average date on-line of the plants in the production system. No relationship exists between these variables (Table 18 and

Figure 12).

Table 18. System plant-age statistics.

(x = weighted average data on-line, y = production energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	300000	-146.6	-0.344	0.119	0.4035
a + b/x	-280000	5.7E+8	0.345	0.119	0.4028
* a + bx	- 80130	46.80	0.157	0.025	0.8427
* a + b/x	100000	-1.8E+8	-0.158	0.025	0.8422

*Based on the four most efficient utilities.

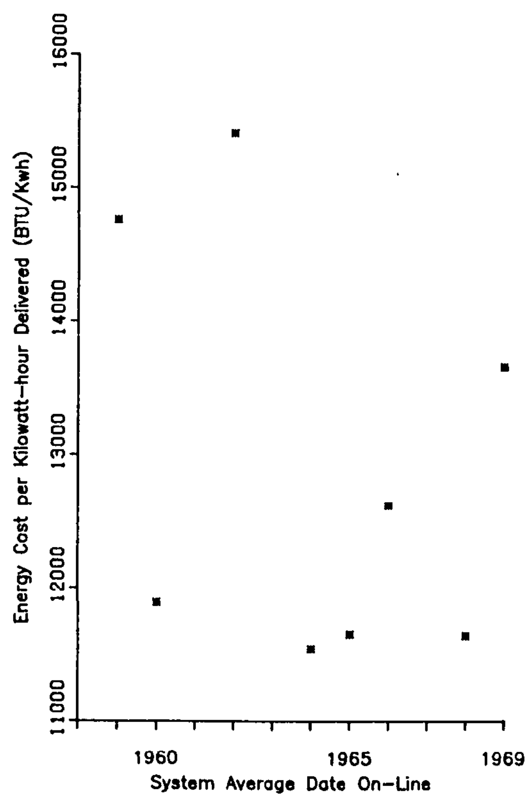

Figure 12. No relationship between system plant age and production efficiency

A major factor in the selection of the utilities to be examined was the attempt to control the possible influence of technology on efficiency. The average age of the production systems in the utilities accepted for analysis differed by no more than ten years of each other. The statistical results shown in Table 18 and illustrated in Figure 12 demonstrate the lack of any significant difference in the level of technology employed.

Power Plant Overall Efficiency

In order to better understand the contributing factors to the total power efficiency relationship, this examination includes an analysis of the possible relationships between energy efficiency and the power production system. Beginning with an analysis of plant size and power plant overall efficiency, strong support was found for the existance of a relationship between these two variables (Table 19).

The logarithmic equation $y = a - b(\log x)$ is clearly superior to the linear equation though both succeed in explaining the observed data at better than the level of significance chosen. Moreover, the logarithm suggests a rapidly declining curve which flattens out as the scale increases. This mirrors the economic model of economies of scale for power plants. Figure 13 illustrates the best fitting logarithmic equation.

Table 19. Power plant - overall efficiency statistics.

(x = installed capacity, y = power plant-overall energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	Constants B	Coefficients R	Coefficients R^2	Two-Tailed P (Type I)
a + bx	12270	-0.929	-0.640	0.409	0.0341
a + b/x	10730	43070.	0.465	0.216	0.1500
a + b(logx)	15500	-1623.	-0.755	0.570	0.0072
* a + bx	11040	-0.395	-0.564	0.318	0.1137
* a + b/x	10330	19150.	0.452	0.205	0.2215
* a + b(logx)	12510	-705.	-0.609	0.371	0.0818

*Based on the four most efficient utilities.

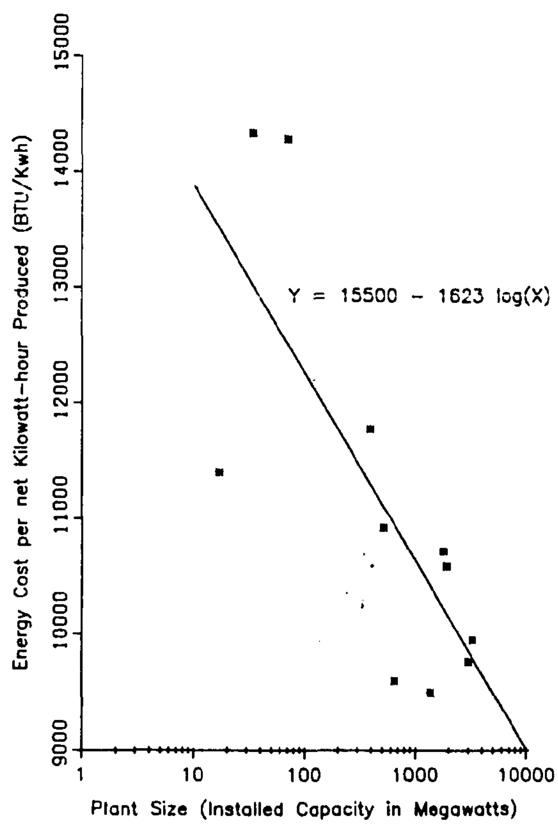

Figure 13. Power plant overall efficiency and best fitting logarithmic equation.

Four concerns make the relationship shown in Figure 13 suspect: 1) the observed relationship does not hold when only the power plants operated by the most efficient utilities are examined; 2) previous research by Messing, et. al.[3] indicates that no relationship exists between plant size and thermal efficiency; 3) a theoretical limit exists for conversion efficiency which the observed relationship does not suggest; and, 4) the very low coefficient of determination (0.570) observed suggests that very little of the variability in the data is explained by this relationship. Nonetheless, based on the small sample observed, the results show a correlation between power plant size and power plant overall efficiency.

Power Plant Production Efficiency

As expected from the results obtained in the analysis of the system's total power efficiency, the direct conversion of fuels constitute the major factor in the power plant's overall efficiency. Once again, the logarithmic equation is clearly superior to the linear alternative (Table 20).

Despite these observed results, the concerns expressed for accepting the similar relationship found for power plant overall efficiency may also be applied to the observed relationship shown in Figure 14.

Table 20. Power plant-production efficiency statistics.

(x = installed capacity, y = power plant-production energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	12140	-0.918	-0.637	0.405	0.0352
a + b/x	10630	424500.	0.461	0.213	0.1535
a + b(logx)	15340	-1607.	-0.753	0.567	0.0075
* a + bx	10910	-0.384	-0.561	0.315	0.1162
* a + b/x	10220	18550.	0.448	0.201	0.2260
* a + b(logx)	12340	-686.6	-0.606	0.368	0.0834

*Based on the four most efficient utilities.

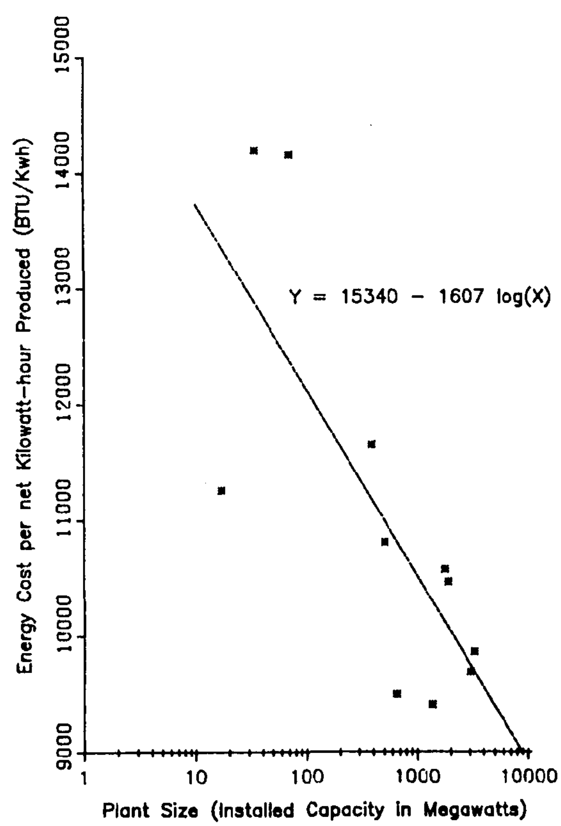

Figure 14. Power plant production efficiency and best fitting logarithmic equation.

Power Plant Operations Efficiency

The remaining energy costs in the power plant's overall efficiency stem from the operating energy costs. The complete data set suggests that no relationship between power plant size and operations efficiency exists (Table 21).

Table 21. Power plant-operations efficiency statistics.

(x = installed capacity, y = power plant operations energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	Constants B	Coefficients R	Coefficients R^2	Two-Tailed P (Type I)
a + bx	126.5	-0.011	-0.580	0.336	0.0615
a + b/x	107.6	618.6	0.526	0.277	0.0965
a + b(logx)	156.3	-15.92	-0.584	0.341	0.0591
* a + bx	126.9	-0.011	-0.540	0.291	0.1337
* a + b/x	107.0	580.9	0.478	0.229	0.1927
* a + b(logx)	164.4	-18.38	-0.553	0.306	0.1225

*Based on the four most efficient utilities.

This may be due to two anomalous data points originating from a single power plant at two different capacity levels (plant number 2 and 2a). By excluding the anomalous data a different conclusion is drawn. The results now strongly support the existance of a relationship and consistantly indicate the logarithmic alternative, $y = a - b(\log x)$, as the best model (Table 22). Unlike the theoretical objections expressed about the possibility of a relationship between plant size and production efficiency, no known objections exist for a logarithmic relationship between plant size and operations efficiency. Indeed, approximately 87 percent of the observed variability in the data is explained by the best fitting logarithmic equation illustrated in Figure 15.

Table 22. Power-plant operations efficiency statistics excluding anomalous data points

(x = installed capacity, y = power plant-operations energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R2	Two-Tailed P (Type I)
a + bx	123.9	-0.014	-0.841	0.707	0.00455
a + b/x	99.57	805.90	0.767	0.588	0.01591
a + b(logx)	169.2	-23.57	-0.931	0.866	0.00027
* a + bx	122.6	-0.013	-0.809	0.654	0.02773
* a + b/x	97.87	745.9	0.744	0.554	0.05510
* a + b(logx)	177.6	-26.12	-0.927	0.860	0.00264

*Based on the four most efficient utilities.

Power Plant Age

The last analysis of power plant efficiency attempts to determine if a relationship exists between the weighted average date on-line for the plants examined, as a measure of the plant's level of technology, and the plant's overall efficiency. From the observed data, (Table 23 and Figure 16), the only conclusion to be drawn is that no relationship exists between the date on-line and the plant's overall efficiency. This conclusion reinforces the observed results for system average date on-line and production efficiency.

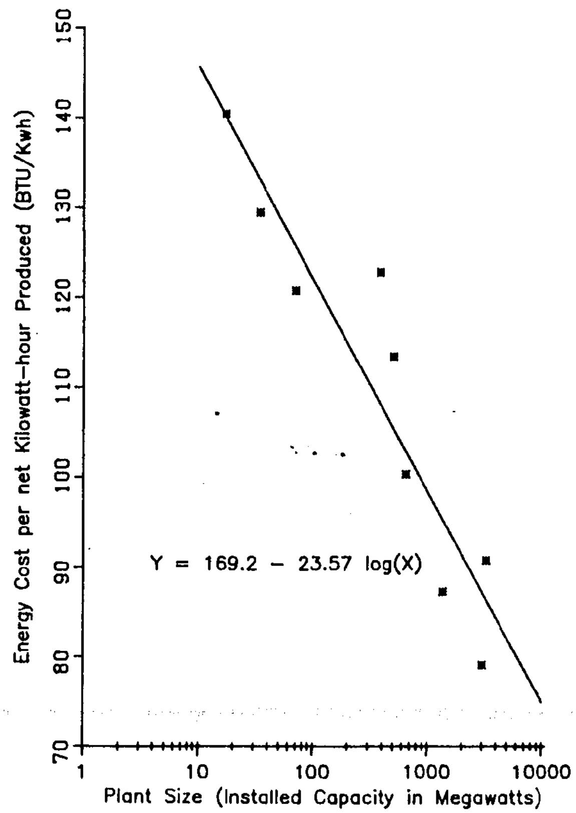

Figure 15. Power plant operations efficiency and best fitting logarithmic equation.

Table 23. Power plant-age statistics.

(x = average date on-line, y = power plant-overall energy costs)

Hypothetical Relationship (Y = General Form)	Constants A	B	Coefficients R	R^2	Two-Tailed P (Type I)
a + bx	155700	-73.55	-0.292	0.085	0.3842
a + b/x	-133000	2.8E+8	0.291	0.085	0.3852
* a + bx	131900	-61.77	-0.526	0.277	0.1455
* a + b/x	-110600	2.4E+8	0.525	0.276	0.1464

*Based on the four most efficient utilities.

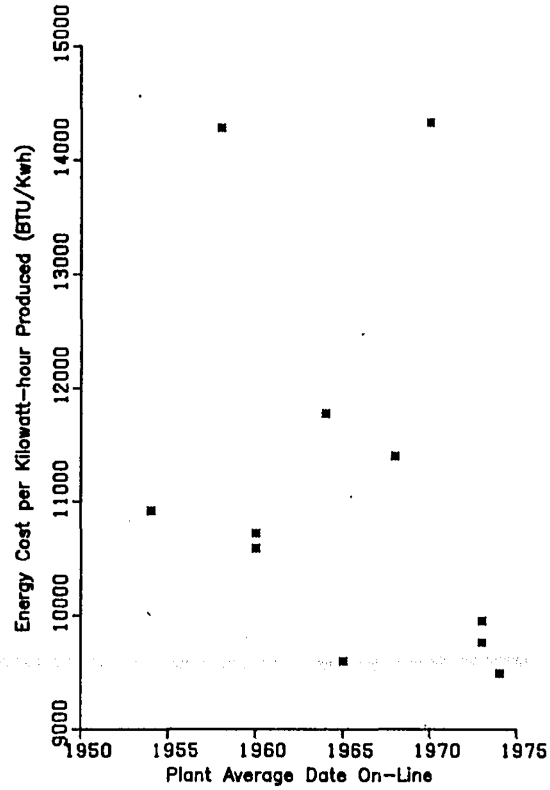

Figure 16. No relationship between power plant age and power plant overall efficiency.

CHAPTER SIX NOTES

(1) Iulo, op. cit. p. 43.

(2) Messing, et. al., Centralized Power, op. cit. p. 9.

(3) Messing, et. al., op. cit. p. 9.

CHAPTER SEVEN

SUMMARY AND RECOMMENDATIONS

Summary of Problem

In this dissertation, the relationship between the physical size of economic organizations and their technical efficiency in supplying goods and services with the hopes of discovering an optimal organizational size was examined.

Economies of scale for individual plant size exist and are well documented for a variety of production technologies. But empirical studies fail to indicate an optimal firm or organizational size. One reason for this lack of empirical evidence may be that economic analyses fail to distinguish between the two sources contributing to economies of scale calculations: technical and pecuniary economies.

As the scale of a firm approaches its optimum size, both technical and pecuniary economies may be expected to contribute to the declining long run average cost curve. Beyond the optimum, pecuniary economies could continue to decrease average costs through the firm's use of market and political power. But the technical contribution to decreased average costs may slow, stabilize, or even reverse itself. As the firm's scale continues to increase, technical diseconomies may be balanced or outweighed by the pecuniary contributions to economies of scale which would continue to decrease the average costs. As a result, it would not be possible to discern a technically optimum firm size with an economic analysis.

Transforming the measure of technical effectiveness or efficiency from a monetary measure into a physical measure of efficiency allows the two contributing sources to be disassociated. One such physical measure of efficiency is the firm's energy utilization efficiency in converting inputs into outputs. If an optimum technical efficiency relationship exists it should produce a U-shaped curve analogous to the economist's U-shaped long run average cost curve. The vertical axis, however, would be measured in energy costs per unit produced instead of dollar costs per unit produced.

The Michigan electric power industry was selected to test this notion because the industry includes firms of various sizes from the very small municipal to the very large investor-owned, but publicly regulated, utilities. Apart from the range of size, the public utility nature of the industry also meant that the data necessary to the analysis was available and not subject to proprietary interests. Another advantage is the existance of a widely cited economic analysis of economies of scale in the electric industry. Iulo's results, as discussed in Chapter III, could neither support nor refute the notion of an optimum scale.

The examination of size and technical efficiency in the production and distribution of electric power required four main objectives. First is an assessment of the participating companies' total energy cost in delivering electric power to its consumers. This total cost, however, is composed of three separate contributing factors. There is the energy cost of fuels consumed in generation and, indirectly, the energy costs of purchased electric power. Then there are the inevitable energy costs of transmitting and distributing the power available to the system. On top of these costs are the energy costs of operating the system such as heating, lighting, administrative functions, and the goods and services required in maintenance, repair, depreciation and everyday operation.

In addition to the main objectives in this study, data was also collected on the potential impact that the size and age of a firm's production system might have on the energy efficiency of producing electricity. In short, energy economies of plant scale and the level of technology employed in the plant might be the controlling factors in determining the firm's overall energy efficiency.

Statistical analyses performed on the collected data determined the nature and strength of the relationships between the various technical efficiency components and the size of the electric utility. Both linear and polynomial regression techniques were used, with appropriate data transformations, to test whether several alternative hypothetical equations fit the data better than the null hypothesis. Acceptance of an alternative hypothesis required the probability of incorrectly rejecting the null hypothesis (a Type I error) to be less than 5.0 percent on a two-tailed student's t distribution. In those instances where more than one alternative hypothesis could be accepted, the coefficient of determination (the percentage of variability in the data explained by the least-squares regression line) was used to distinguish the best fitting alternative. Beyond this distinguishing statistic, theoretical and/or empirical constraints were also required to be satisfied by the alternative hypothesis selected. A summary of the statistical results is presented in Table 24.

Table 24. Summary of statistical results.

Dependent Variable (Y)	Independent Variable (X)	Relationship (Y =)
Overall	Peak demand in Megawatts	$16292 - 3553 \log(x) + 715.8 (\log(x))^2$
Total Power	Peak demand in Megawatts	$15734 - 3363 \log(x) + 667.6 (\log(x))^2$
Production	Peak demand in Megawatts	$11643 - 0.274(x) + 0.0000583(x)^2$
Production	System age	NONE
Distribution	Peak demand in Megawatts	NONE
Distribution	Customers per mile	$138.3 + 3524/(x)$
Operations	Peak demand in Megawatts	$180.9 + 21.6 \log(x)$
Plant-overall	Plant capacity in Megawatts	$15500 - 1623 \log(x)$
Plant-overall	Plant age	NONE
Plant-production	Plant capacity in Megawatts	$15340 - 1607 \log(x)$
Plant-operations	Plant capacity in Megawatts	$169.2 - 23.57 \log(x)$

Summary of Conclusions

Several relationships were observed to exist between the variables examined. However, the small and highly structured sample of eight electric companies in Michigan does not allow these conclusions to be generalized to the electric power industry as a whole. The entire population of electric generating utilities in the United States number approximately 1000 separate firms. Consequently, the sample selected is insufficient both in size and randomness to statistically represent the population. Conclusions may be drawn, however, for the nature of the relationships found for the participating utilities. Most important is the fact that these results form the first body of empirical evidence that, however tentative, support the existance of a relationship between technical efficiency and organizational size.

The most important contributing factor in the U-shaped relationship found between overall efficiency and utility size was determined to be the energy costs associated with the coordination of power supply to the utilities' constantly changing power demand. Approximately 97 percent of overall energy costs were contained in the total power variable which measures the utility's load management effectiveness. The observed results found for production efficiency, a partial measure of load management effectiveness, suggest an optimum organizational size of 2500 Megawatts of peak demand. This is in contrast to the 350 Megawatts of peak demand indicated by total power efficiency. It was concluded, therefore, that the coordination of power supply to power demand is the controlling factor in determining the shape of the overall efficiency relationship.

The other factors examined, though significant in themselves, were deemed insignificant in determining the shape of the overall efficiency relationship. In combination, distribution and operations energy costs accounted for only 3.3 percent of total energy costs. Moreover, distribution efficiency was found to be related to distribution density and not to utility size. The observed results for operations efficiency, while correlated to utility size in an increasing logarithmic relationship, indicate a decreasing energy penalty for increased organizational size. This decreasing penalty may be partly the result of increased operations efficiency in larger power plants.

Recommendations

The results of this examination demonstrate the need to continue investigating the relationship between organizational size and technical efficiency. Three possible research avenues are suggested in the hopes of promoting future efforts.

1) Repeat this examination of electric utilities with an increased sample size. The knowledge gained from this exploratory effort indicates that system power coordination may be the controlling factor in the U-shaped technical efficiency curve for electric utilities. Because operations energy expenses are the most difficult data to obtain and to convert from dollars to Btu's, future research into the technical efficiency of electric utilities might focus on total power, production and distribution efficiency to verify and refine the equations found in this analysis.

The majority of the data necessary for such an examination is available through federal and state regulatory agencies. The remaining information required, such as fuels consumed and peak power demand, must be obtained from the participating companies to insure data consistancy. A random sample from the 1000 generating companies cannot be recommended, however, because of technology differences and the differing degree of generating self-sufficiency;

2) <u>Examine the relationship between organizational size and technical efficiency in a production-oriented industry</u>. An examination of a production-oriented industry, such as the American iron and steel industry, could clarify the importance of the production efficiency relationship for other energy-intensive manufacturing organizations. Dependent upon its existance or significance to overall efficiency, the organization's distribution of its product may be ignored and the research effort could concentrate on production and operations efficiency.

Organizational size may best be measured in terms of raw steel capacity. The dependent variables would be production efficiency, measured in Btu's per ton of raw steel produced, and operations efficiency, also measured in Btu's per ton of raw steel produced. It would be necessary to delineate the energy inputs required in the actual production process from the associated energy costs of operation. For example, the energy costs to operate the production plants include all of the direct and indirect energy inputs except wages, salaries, benefits, taxes, etc., and the production fuels themselves.

Given the potential contraction in this industry and its energy-intensity, such an examination may offer insights into the future structure of this and other energy-intensive industries. This insight may be enhanced if the research effort includes, but keeps separate, an examination of the scrap-to-steel industry. The variables to examine would be the same in both industries but, because the underlying technology is different, the two industries cannot be examined together. In either case, however, overall efficiency should mirror the production efficiency relationship and could be expected to resemble a U-shaped curve; and,

3) Examine the relationship between organizational size and technical efficiency in a service-oriented industry. Because service-oriented organizations do not have a physical commodity to produce, it may be difficult to distinguish the energy inputs required for the actual production of the service from the energy inputs required for the organization's operation. Additionally, the production component may be relatively insignificant even if it exists. Nonetheless, the organization's use of direct (fuel) energy may be analyzed separately from its operations energy costs.

Higher education institutions may be a likely candidate for the examination of organizational size and technical efficiency in a service-oriented industry. As in public utilities, many colleges and universities are public institutions and may, therefore, permit an investigation into their energy costs. Moreover, demographics suggest that the end of the babyboom will continue to force a contraction in this industry. Future increases in the price of energy can only exacerbate this process. Consequently, the results of this examination may contribute to the planning process by indicating the technical optimum size of our public institutions of higher education. Optimum size determined by an energy analysis is, of course, only one estimate of an optimum size. Trade-offs must be made between technical efficiency, economic efficiency, and many other, non-quantifiable determinants of optimality in providing quality education.

Organizational size may be measured in terms of floor space or seating capacity while the dependent variable, overall efficiency, might best be measured in terms of Btu's per degree granted. A distinction must be made, however, between the different types of higher education institutions. Residential and commuter colleges provide a different set of services in conjunction with the degree granted. This is especially true between the services provided by junior and senior colleges.

A Final Word

While the results of this examination should be accepted with caution, they do suggest an exciting new arena for productive investigations. The concept of a optimum organizational size, based on energy utilization efficiency, may become a significant perspective and planning tool as the supply of useable energy becomes scarce and, therefore, more expensive. While one form of energy may be substituted for another, there is no substitute for energy in general. Future energy prices may thus result in a movement toward the technical optimum size as pecuniary contributions to economies of scale lose their relative importance. Prior knowledge of what that optimum size is for a given industry could prove to be an invaluable planning advantage in a transition to a less energy intensive society.

LIST OF REFERENCES

REFERENCES CITED

Aristotle, Politics, Book VII, Chapter 4.

Joe S. Bain, "Economies of Scale, Concentration and the Condition of Entry in Twenty Manufacturing Industries," AER 44(1) March 1954.

Douglas Bauer and Allen S. Hirshberg, "Improving the Efficiency of Electrical Generation and Usage," in John C. Sawhill, (editor), Energy, Conservation and Public Policy, (Englewood Cliffs: Prentice Hall, Inc., 1979).

Mark Blaug, Economic Theory in Retrospect, revised edition, (Homewood: Richard D. Irwin, Inc., 1968).

Robin W. Broadway, Public Sector Economics, (Cambridge: Winthrop Publishers, Inc., 1979).

Clark W. Bullard, Peter S. Penner and David A. Pilati, Energy Analysis Handbook, CAC Document No. 214, (University of Illinois at Urbana-Champaign, 1976).

Richard Caves, American Industry: Structure, Conduct, Performance, 5th edition, (Englewood Cliffs: Prentice Hall, Inc., 1982).

P. F. Chapman, "Energy Costs: A Review of Methods," Energy Policy, June 1974.

Fredrick Cottrell, Energy and Society: The Relation Between Energy, Social Change and Economic Development, (Westport: Greenwood Press, 1955).

Kenneth Dimoff, Statistical Plotting On-Line Command System User's Guide, MSU Pest Manangement Technical Report No. 13, Department of Entomology, Michigan State University, 1977.

Electric World Publishers, Electric World Directory of Electric Utilities, 89th edition, (New York: McGraw Hill, Inc., 1980).

Energy Information Administration, 1980 Annual Report to Congress, (Washington, D. C.: U. S. Department of Energy, October 1980).

________________, Inventory of Power Plants in the U. S., (Washington, D. C.: U. S. Department of Energy, 1981).

________________, 1981 Annual Report to Congress, Vol. II, Energy Statistics, (Washington, D. C.: U. S. Department of Energy, May 1982).

John K. Galbraith, Economics and the Public Purpose, (New York: Houghton Mifflin Co., 1973).

Nicholas Georgescu-Roegen, "Myths About Energy and Matter," Growth and

Change 10(1) January 1979.

David E. Gushee, (editor), Energy Accounting as a Policy Analysis Tool, Congressional Research Service (Washington, D. C.: U. S. Government Printing Office, June 1976).

Bruce Hannon, System Energy and Recycling: A Study of the Beverage Industry, CAC Document No. 23, (University of Illinois at Urbana-Champaign, 1972).

______________, Energy Cost of Goods and Services, 1972, Energy Research Group Document No. 307, (University of Illinois at Urbana-Champaign, 1981).

______________ and J. Brodrick, "Steel Recycling and Energy Conservation," Science 216 April 1982.

Robert H. Haveman and Kenyon A. Knopf, The Market System, 3rd edition, (New York: John Wiley and Sons, 1978).

Robert A. Herendeen and Clark W. Bullard, Energy Cost of Goods and Services, 1963 and 1967, CAC Document No. 140, (University of Illinois at Urbana-Champaign, 1974).

M. King Hubbert, "Energy Resources," in the National Academy of Science, Committee on Resources and Man, editors, Resources and Man, (San Francisco: W. H. Freeman and Co., 1969).

William Iulo, Electric Utilities: Costs and Performance, (Washington State University Press, 1961).

Peter J. Kakela, "Railroading Scrap," Environment 17(2) March 1975.

______________, "Pelletized vs. Natural Iron Ore Technology: Energy, Labor and Capital Changes," CAC Document No. 251 (Urbana: CAC of University of Illinois, 1977).

Robert J. Kalter and William A. Vogely, Energy Supply and Government Policy, (Cornell University Press, 1976).

Marc Messing, H. Paul Friesema and David Morell, Centralized Power, (Washington, D. C.: Environmental Policy Institute, 1979).

Michigan Gongyer Newsletter, August 4, 1981.

Hugh Nash, (editor), The Energy Controversy, (San Francisco: Friends of the Earth Publications, 1979).

Tetsushi Noguchi, Energy Requirement of a 1000Mw(e) Pressurized Water Reactor Power Station, Resource Analysis Group Research Paper E-42, (University of Chicago Press, 1978).

Howard T. Odum, et. al., "Energy Cost-Benefit Analysis Applied to Power Plants Near Crystal River, Florida," Chapter 21 in Charles A. S.

Hall and John W. Day, (editors), Ecosystem Modeling in Theory and Practice, (New York: John Wiley and Sons, 1977).

Samual H. Schurr, Energy in America's Future: The Choices Before Us, (Baltimore: John Hopkins Press, 1979).

Henry R. Seager and Charles A Gulick, Trust and Corporate Problems, (New York: Harper and Brothers Publishers, 1929).

Philip Sheron, "Many Electric Utilities Suffer as Conservation Holds Down Demand," Wall Street Journal, October 9, 1980.

Barry Stein, Size, Efficiency and Community Enterprise, (Cambridge: Center for Community Economic Development, 1974).

Tektronix, Inc., Operations Manual, (Beaverton: Tektronix, Inc., 1976).

______________, Plot 50: Statistics, Vol. 3, (Beaverton: Tektronix, Inc., 1976).

Harry Townsend, Scale, Innovation, Merger and Monopoly, (London: Pergamon Press, 1968).

U. S. Department of Commerce, Survey of Current Business, 62(7) July 1982.

Mike Walsh, Office of Energy Information Services, Energy Information Administration, U. S. Department of Energy, Washington, D. C.. Personal communication, August 11, 1981.

Alvin M. Weinberg, "Technology and Ecology: Is There a Need for Confrontation?," BioScience, 23(1) 1973.

Langdon Winner, "Do Artifacts Have Politics?," Daedalus, 109(1) 1980.

APPENDIX

APPENDIX

ENERGY ANALYSIS QUESTIONNAIRE

The following questions formed the basis of the survey instrument used in this examination. The form of the questionnaire submitted to individual electric utilities differs from that presented only in the addition of space for the answers following each of the years 1977 through 1981.

Part 1: General Information

1) Total installed power capacity in Megawatts (name-plate rating).

2) Total net output from all generating facilities in kilowatt-hours.

3) Total electric power consumed by electric utility in kilowatt-hours (excluding electric power requirements of generating plants).

4) Total electric transmission and distribution line losses in kilowatt-hours (including unaccounted for losses if any).

5) Total electric power purchased plus net delivered interchange power in kilowatt-hours.

6) Total electric power sold in kilowatt-hours.

7) Total pole milage (overhead and underground transmission and distribution power lines).

8) Annual average number of electric customers.

9) Peak demand for total system in Megawatts (60 minute reading).

10) Total fuels consumed at generating facilities in British thermal units (by type of fuel).

11) Total salaries and wages paid (electric division only).

12) Total number of employees (electric division only).

Part II: Specific Plant Information

The following questions refer specifically to the (name of plant) power plant.

1) Total net output in kilowatt-hours.

2) Total installed capacity in Megawatts (name-plate rating).

3) Total fuels consumed at plant in British thermal units (by type of fuel).

4) Total operation expense.

5) Total fuel expense (cost of fuels burned excluding fuel handling expenses).

6) Total rent expense (if any).

7) Total maintenance expense.

8) Total depreciation expense.

Part III: General Production Expenses

1) Total operation expense.

2) Total fuel expense (cost of fuels burned excluding fuel handling expenses).

3) Total rent expense.

4) Total maintenance expense.

5) Total depreciation expense charged to production plant (steam, nuclear, conventional hydraulic, pumped storage and other production plant).

Part IV: General Transmission/Distribution Expenses

1) Total transmission and distribution operation expense.

2) Total transmission and distribution rent expense (if any).

3) Total transmission and distribution maintenance expense.

4) Total depreciation expense charged to transmission and distribution plant.

Part V: Customer Accounts/Service and Sales Expenses

The following questions refer to the electric division only.

1) Total supervision expense.

2) Total meter reading expense.

3) Total customer records and collection expense (excluding bad debts).

4) Total miscellaneous customer accounts expense.

5) Total customer service and informational expense.

6) Total sales expense (if any).

Part VI: Administrative and General Expenses

The following questions refer to the electric division only.

1) Total office supplies expense.

2) Total outside services employed expense.

3) Total property insurance, injuries and damages paid.

4) Total regulatory expense.

5) Total miscellaneous general expense.

6) Total rent expense (if any).

7) Total maintenance of general plant expense.

8) Total depreciation expense charged to general and common plant.