APPLICATION OF SECTOR AND LOCATION SPECIFIC MODELS OF THE "WORTH" OF RENEWABLE ENERGY TECHNOLOGIES

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Abstract

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Renewable energy sources such as solar and wind hold the potential for providing a significant portion of the U.S. energy requirements in the decades ahead. Unlike other energy sources their availability is determined by nonrandom events beyond the control of the consumer. In addition, macro-, meso-, and microclimatic conditions play a major role in determining the worth of such renewable energy sources to their owners. The worth of these new technologies will be a function of owner, location, and application as well as the traditional capital and operating cost, i.e., their worth to an owner in the southwest will be different form that to an owner in the northeast or the southeast.

Dealing with energy sources, with geographic and sectorally specific energy values and with energy technologies with which we have little or no experience in the marketplace has created a set of challenges in analysis and modeling of these new technologies in competition with traditional energy technologies and with other emerging technologies. This paper will look at one simulation methodology for estimating the worth of renewable energy systems providing electricity, such as wind or solar photovoltaic power systems, and will discuss the interaction between such systems and traditional electric utilities with which they may or may not be integrated, be owned or be co-located. The paper concludes with a discussion of the issues associated with the incorporation of econometric techniques into such a simulation modeling structure.

Application of Sector and Location Specific Models of the "Worth" of Renewable Energy Technologies

Introduction

Renewable energy sources such as solar and wind hold the potential for providing a significant contribution to total U.S. energy supplies in the decades ahead if the technology development effort currently under way aimed at price reduction is successful or if the price of alternative sources increases dramatically. Unlike many of the other sources of energy, however, solar and wind power are not available at all times and their availability, while nonrandom, is not totally predictable by the consumer. In addition, relatively microlevel climatic and geographic factors play a major role in determining the worth of these systems to their owner.(2) The worth is a function of the location and the application as well as a function of the owner in terms of his cost of capital and ability to internalize both site-specific costs and variable costs in operations and maintenance.

A second set of attributes of such technologies has made them more difficult to analyze; they represent technologies which produce a good the demand for which is derived rather than direct, i.e., these technologies produce electricity or heat, both of which are consumed through other means, either "comfort" or through the dishwasher or toaster. With the exception of the electric utility industry in which electricity is the final product, or of specific industrial environments within which process heat of a specific nature is required within the production process, the demand for the product, be it photovoltaic power equipment, a wind turbine, or a concentrating thermal collector, is derived through its application rather than demanded directly. Given this environment, the use of traditional behavioral models or more traditional marketing models in the analysis of the decisions of the consumer becomes more difficult if not impossible. One cannot approach the analysis of a potential energy production source such as photovoltaics using the same tools available for analysis of even the decision between electric and oil heat and certainly cannot the tools available for analyzing consumer response to new soap products.(3)

Given the caveats associated with the problems of modeling potential consumer response to these new technologies and measuring and modeling the performance of these technologies, it is necessary to approach the problem from a basically different direction, that of process modeling or detailed simulation modeling. The paper which follows will introduce a modeling structure which has been applied to analyses of applications for photovoltaic power systems in the residential, commercial and industrial, and central power sectors of the United States energy economy. The paper will present a set of results of the analyses to date to highlight the usefulness of such techniques and will then discuss work currently in the developmental stages which will attempt to bridge the gap between the techniques available in more behavioral modeling and those of the worth or simulation modeling presented herein.

Worth Analysis Structure

The examples discussed in this paper will come from research work undertaken for the Department of Energy on photovoltaic development.*

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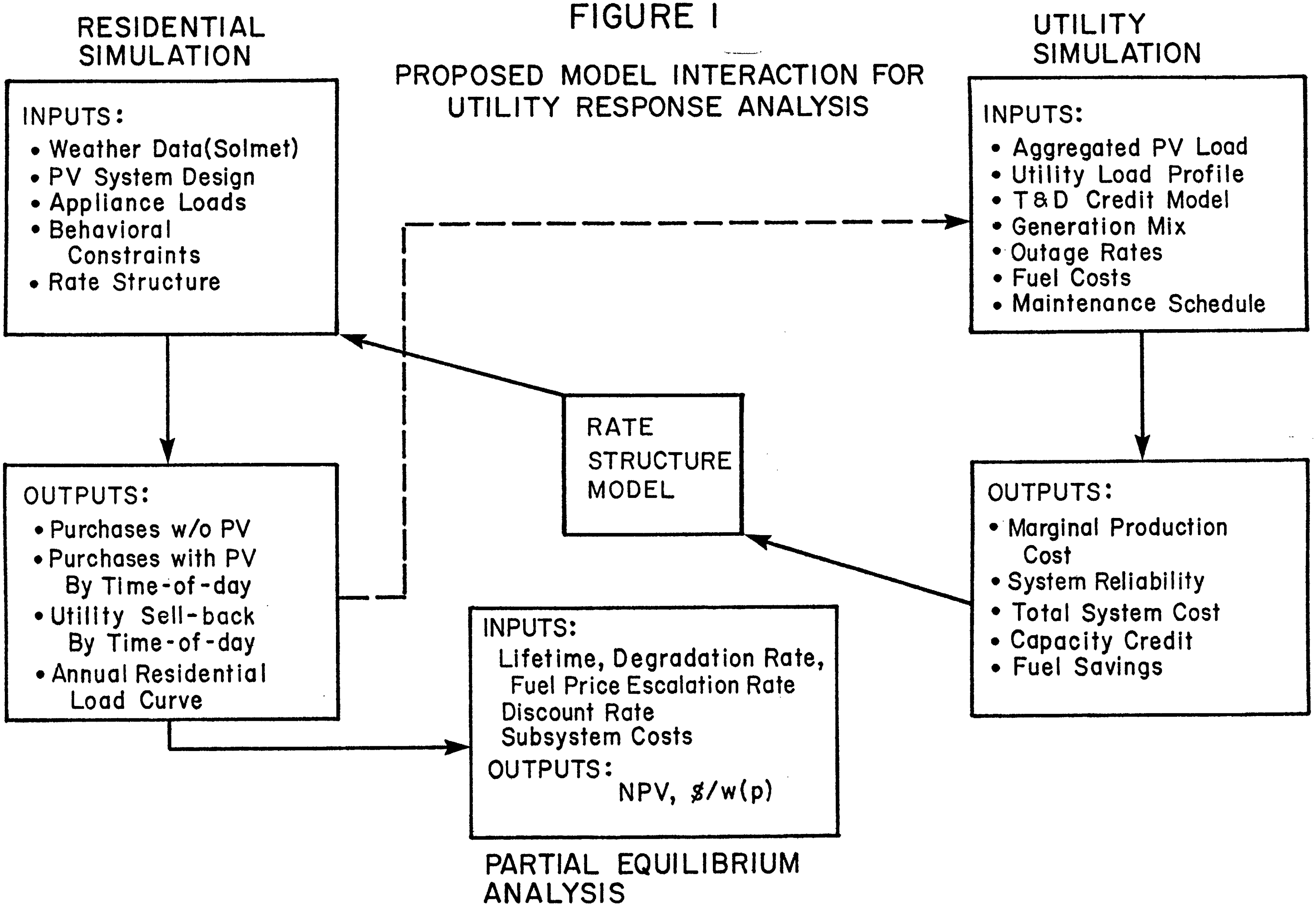
*The discussion which follows is based upon work completed or under way within the Photovoltaics Project, Utility Systems Program, MIT Energy Laboratory under contract EX-76-A-01-2295 Task Order 37A from the U.S.D.O.E. No effort will be made in the length of this paper to describe in detail the technology development efforts in photovoltaics nor the basic physical properties by which sunlight is converted to electrical energy. For additional information see Chalmers (1).

The photovoltaic technology converts sunlight directly into electrical power. It is a modular technology which gains little from economy of scale in use but does gain, in all likelihood, from economy of scale in production. As a result, the photovoltaic technology is equally applicable to residential and smaller scale application as it is to either utility or industrial scale applications. As will be discussed in the paragraphs which follow the relative economics of the specific applications of technology are determined by the availability and cost of capital and operations and maintenance cost differences between applications.

Within the analyses undertaken all applications have been assumed to exist within the United States energy economy and all have access to electric power provided by a utility through their standard grid system. As a result, all of the applications are either grid interconnected or, in the case of central power, are fully utility integrated. Figure 1 presents a schematic diagram of the modeling system as it has been developed and as it is being applied to photovoltaic power systems. As can be seen, the measurement of the economic value of the system within a particular application is made relative to the cost of purchased electric power from the electric power system. The fact that photovoltaic power systems provide power at different levels, and at different times during the day is significant in that the cost of utility generation also differs during the day as a function of level of demand. Thus the value of photovoltaic generated electric power is a function of both when and where it is being provided within the system. The analysis has recognized this difference in that the simulation models developed match the simulated output of the photovoltaic power system on an hour by hour

FIGURE I

PROPOSED MODEL INTERACTION FOR UTILITY RESPONSE ANALYSIS



basis (for 8760 hours per year) with the hourly operating costs of the electric utility for the same time period as shown in their rates. In so doing the worth of electric power from the photovoltaic power system can be measured in terms of the cost to the consumer of buying that power (also theoretically the cost to the utility of producing power) during each time period throughout the year.

Given the above description one can see that the value to the owner of having a photovoltaic power system is not independent of the overall operating environment of the electric utility. Indeed, if one posits a relatively high level of penetration of photovoltaic power systems within any given utility, the value of the photovoltaic system to the owner is not independent of the number and performance of other photovoltaic power systems as well.

Under the circumstances discussed above the modeling requirements are iterative and highly specific in nature. For an accurate evaluation of the cost effectiveness of a photovoltaic power system within a given application, such as a residence, it is necessary to know or estimate the operating characteristics of the utility within which the system is being installed and to know the present--and if possible future--level of penentration of photovoltaic power within the utility system. In addition it is necessary to match carefully the operating characteristics and timing of the photovoltaic power system with those of the utility within which it is operating. The results of such analyses as shown in Figure 1 is a highly deterministic structure in which the application passes information to the utility concerning the load which the utility may expect. Clearly with increased penetration of photovoltaics within the system the utility would see less load from the residential sector and indeed might even see negative load if the residential sector were to generate excess power which could be incorporated back into the utility grid. In turn the utility provides information to the residential customer with a photovoltaic power system concerning the prices during any given period of time. Handled iteratively one can estimate the value of photovoltaic power systems to an individual owner given a specific utility, a specific level of photovoltaic power system penetration into that utility and given a relatively microgeographic, climatological environment within which the photovoltaic power system would operate.

To complete such an analysis requires detailed information on the performance of such a system and detailed information on the performance of such a system and detailed information on the economic and financial environment within which the potential owner would be operating. As an example within the residential sector, would the potential owner of the system be the homeowner and if so would an investment such as a photovoltaic power system be accepted within the mortgage structure of a new home? If so the tax structure of the United States and the long-term-loan nature of a mortgage would make the application of photovoltaics within such an environment more attractive than would be the case in the industrial sector, for instance, where anticipated return on capital investments is higher and where current energy expenditures are tax-deductible, not the case in the residential sector.

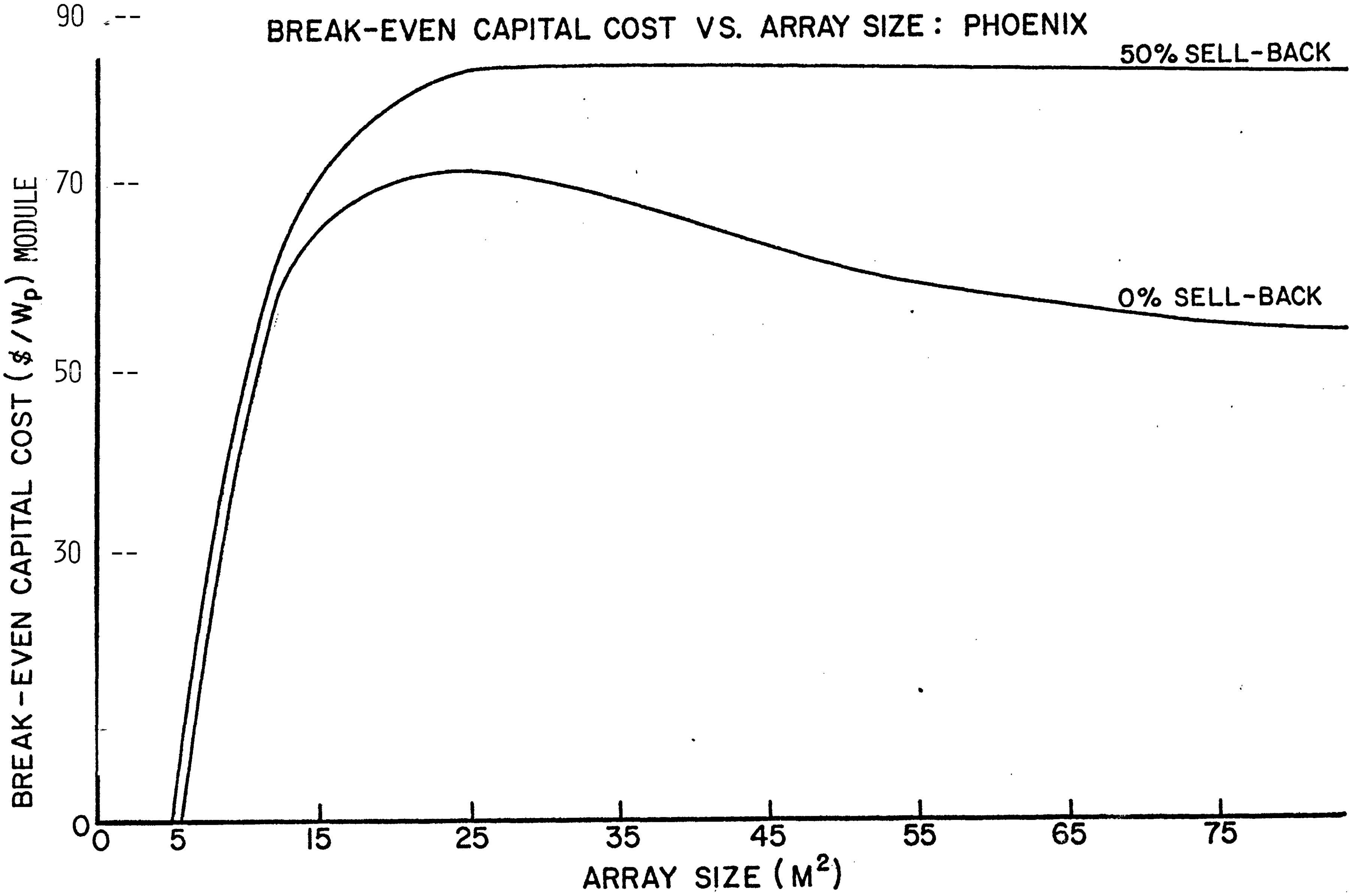
In summary the modeling structure requires the accurate simulation of specific sectoral or individual behavior in order to evaluate the economic worth to the owner of a capital-intensive energy producing technology such as a photovoltaic power system. The assumptions required in such an analysis are many. Probably the most significant is that the owner of such a system be an economic man, i.e., it is assumed that the life cycle breakeven capital cost is the critical variable influencing the decision to purchase or not to purchase the technology. This assumption is called into question most strongly in that it implies than an owner would or could make the decision on the basis of life cycle cost effectiveness. In addition, given that there is little or no practical experience on the performance of photovoltaic systems, assumptions concerning their lifetime and likely performance characteristics over time are open to question as are imputed values for both discount rates and the price of alternative sources of electrical energy. Given these caveats, however, it is nonetheless possible to derive considerable quantities of policy relevant information from the analyses and to begin the process of bridging from models which are totally deterministic in their assumptions to modeling structures which will allow for the inclusion of both deterministic and behavioral attributes within their structure.

The Applications, A Discussion of the Results

The discussion which follows presents the results of worth analyses carried out for the residential sector, for the commercial sector and industrial sector and for the central power sector. While the economic environments and the modeling structures required differ between the application areas, it is significant to analyze briefly the range of conclusions which can be drawn from this work.

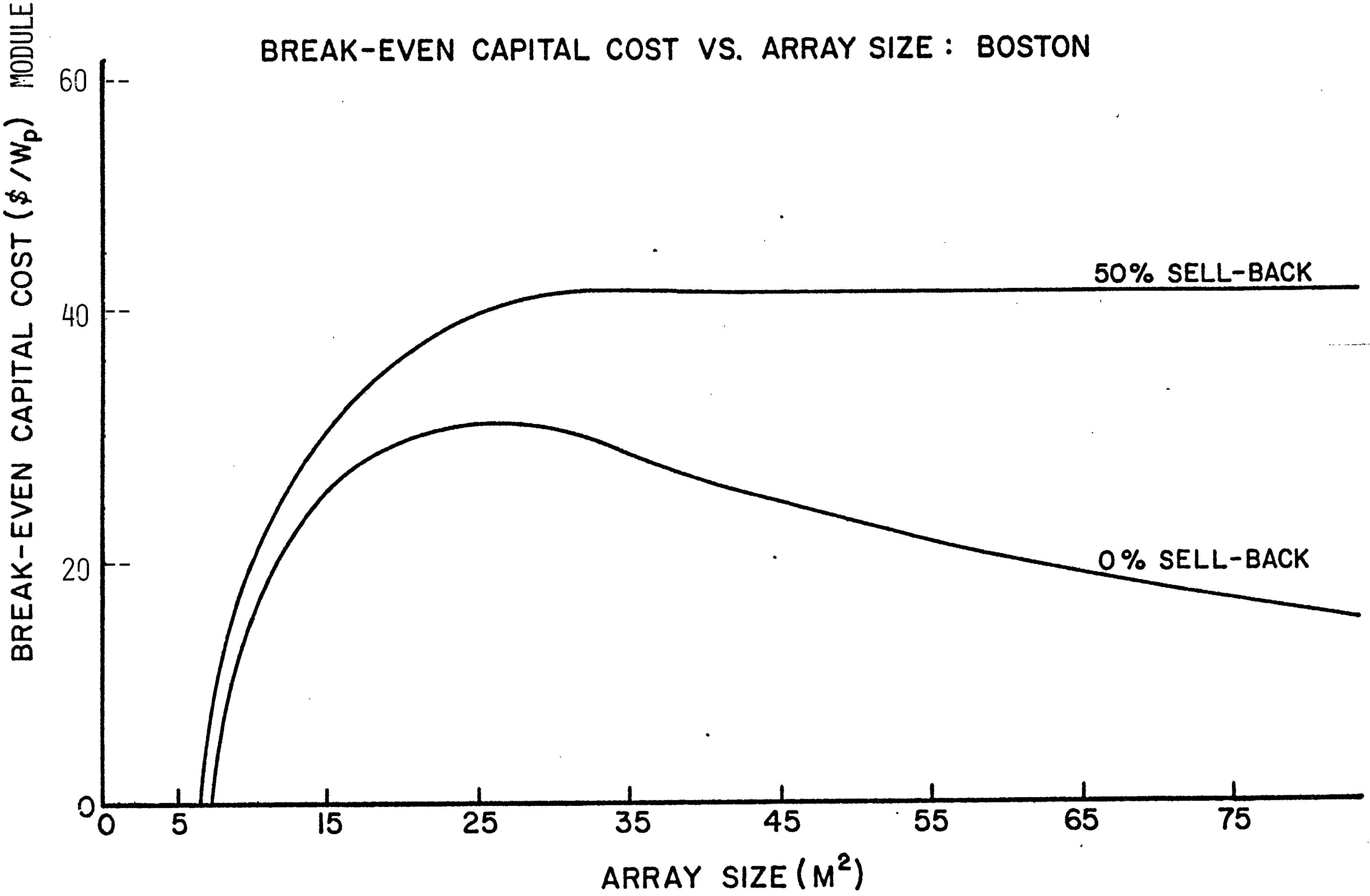
Beginning with analyses carried out for the residential sector, Figures 2, 3, and 4 present the result of analyses carried out for

FIGURE 2



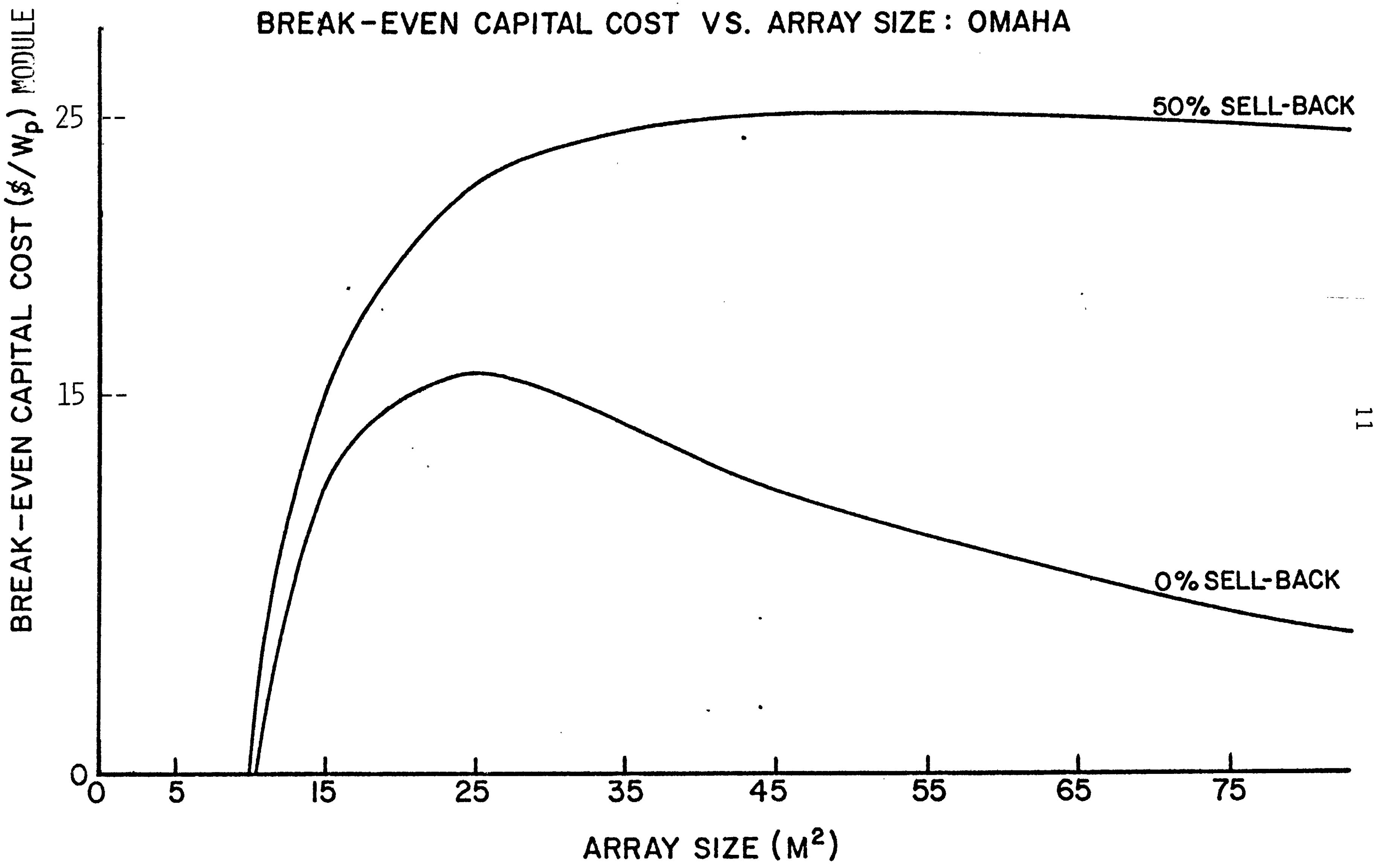
BREAK-EVEN CAPITAL COST VS. ARRAY SIZE: PHOENIX

FIGURE 3



BREAK-EVEN CAPITAL COST VS. ARRAY SIZE : BOSTON

FIGURE 4


BREAK-EVEN CAPITAL COST VS. ARRAY SIZE: OMAHA
BREAK-EVEN CAPITAL COST ($/W$_p$) MODULE
25
15
0
0
5
15
25
35
45
55
65
75
ARRAY SIZE (M^2)
50% SELL-BACK
0% SELL-BACK

Boston, for Phoenix and for Omaha.* In each case the utility rate structure was either that in use or an experimental time of day structure under consideration for use in the region. The results then show the amount that an owner could pay for the photovoltaic hardware measures in 1975 in $/peak watt of installed capacity net of all operating expenses and all nonphotovoltaic capital expenses. It should be noted that these values compare favorably with the DOE program goals of hardware being available at $.50 per peak watt in 1986 and lower values by 1990. Present costs for photovoltaic power systems are in the range of $9 to $11 per peak watt but have shown rapid declines in recent years which would support the achievement of the DOE goals.**

The results of the analysis show maximum values for photovoltaic systems of $.89 in Phoenix, $.42 in Boston and $.24 in Omaha at the point of maximum value, between 25 and 35 square meters of cell area. This reflects a combination of factors in the analysis. Most significant is the cost of alternative power and the availability of solar insolation. The systems analyzed provided between 40 and 45% of the electrical power of the given residence and in each case they provided power for sale back to the utility. Critical uncertainties within the analysis are in four areas, the price for components other than the photovoltaic cells (referred to as balance of systems costs) such as power conditioning equipment, wiring and support systems; economic parameters, particularly

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*The results on residential applications of photovoltaic power systems are taken from Carpenter and Taylor (4). Additional discussion may be found in GE (5) and Westinghouse (6).

**For additional information concerning DOE photovoltaic goals and the progress toward achieving those goals the reader should refer to Photovoltaics Multi Year Program Plan. (7)

the discount rate; the future price of oil and therefore the cost of alternative energy; and the rate at which the utility is willing to buy power from the photovoltaic generator. The analyses presented have assumed values of $.41 per peak watt of balance of systems costs, a 3% discount rate, a 3% rate of increase in real fuel costs and a 50% buyback rate. Sensitivity analyses undertaken showed the most sensitivity to the choice of the discount rate and buy back rate with fuel escalation also having a significant impact on the final estimate of breakeven capital cost. The balance of system cost impact was differentially significant to the locations as it is a fixed dollar amount rather than a proportion of the total value. (4)

The residential analysis has pointed to a significant potential market area and a potential early market for photovoltaic power systems in the United States. It has also identified those areas in both economics and technology development which must be developed further before any firm predictions of market potential can be developed. In addition it identified the critical role which will be played by the electric utilities in encouraging or discouraging the acceptance of the technology within the system and therefore the necessary role of the PUCs in regulating the correct rate for power buyback.

Figures 5, 6 and 7 present similar preliminary results to those above but for three commercial/industrial establishments in Phoenix. In this instance the load data used in the analysis were received from the cooperating utility rather than being generated from a simulation model as was the case in the residential analysis reported above. There are both advantages and disadvantages to use of actual rather than simulated load data.

FIGURE 5

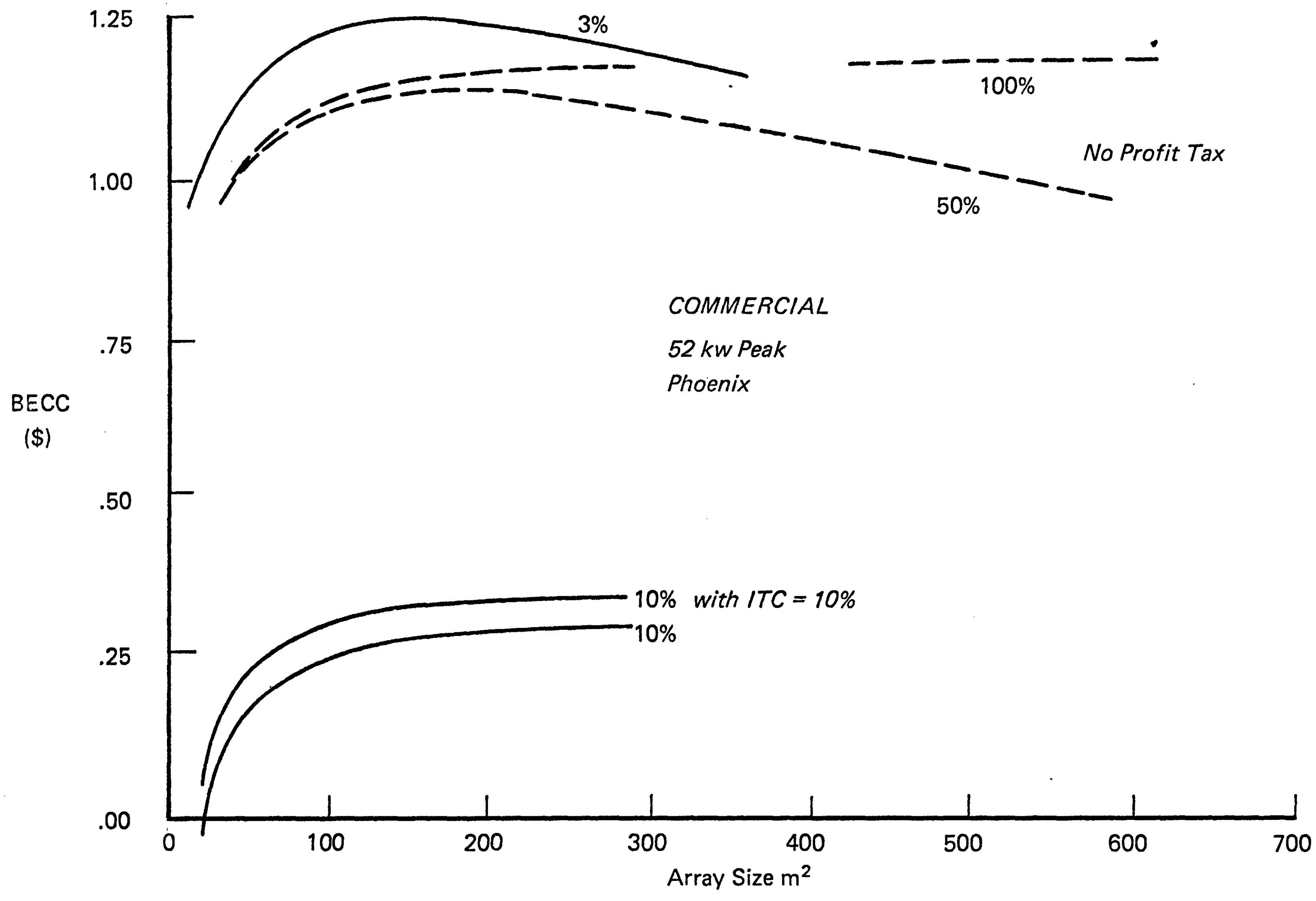

1.25
1.00
.75
.50
.25
.00
BECC
($)
0
100
200
300
400
500
600
700
Array Size m^2
3%
100%
No Profit Tax
50%
COMMERCIAL
52 kw Peak
Phoenix
10% with ITC = 10%
10%

FIGURE 6

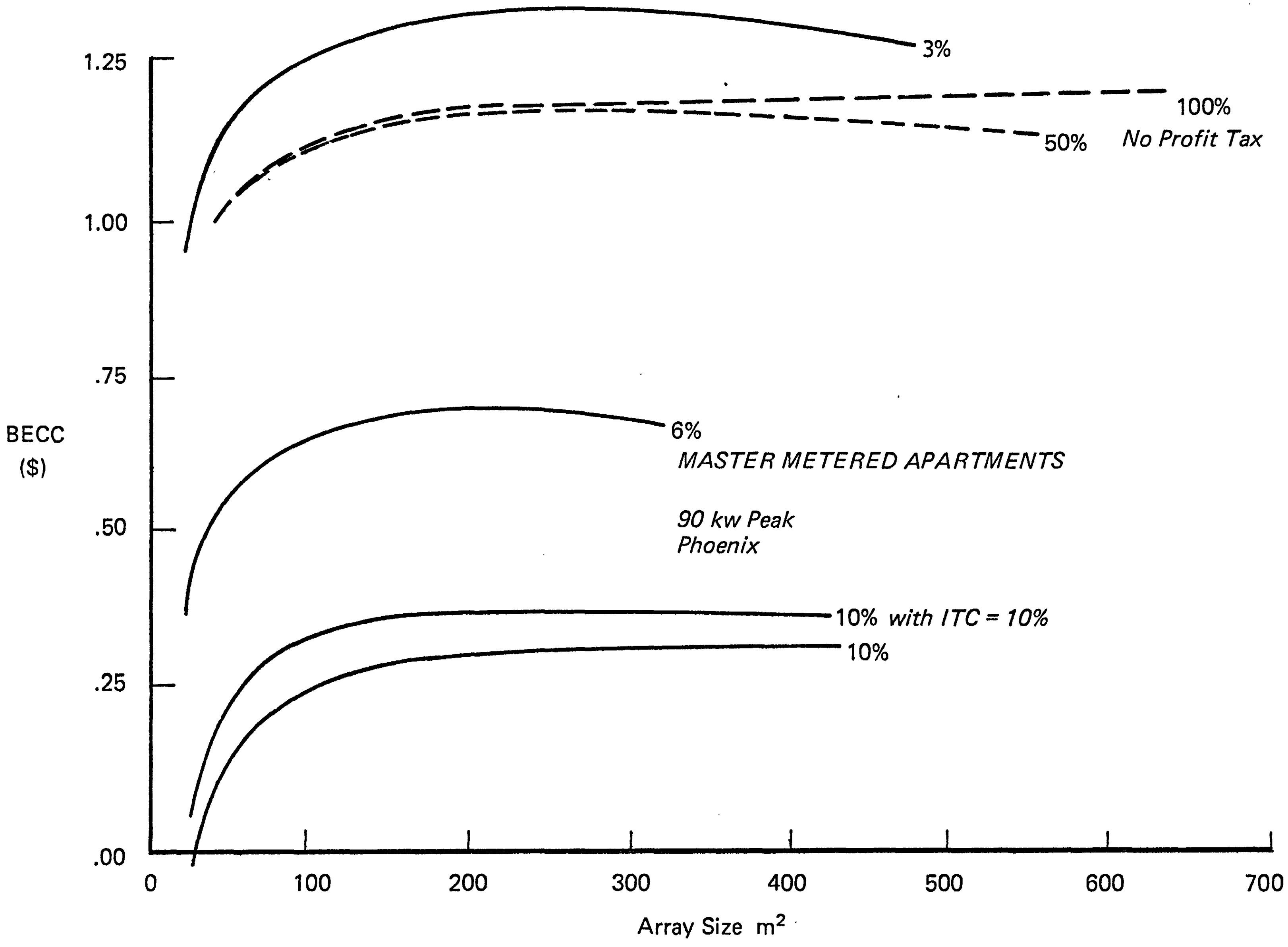
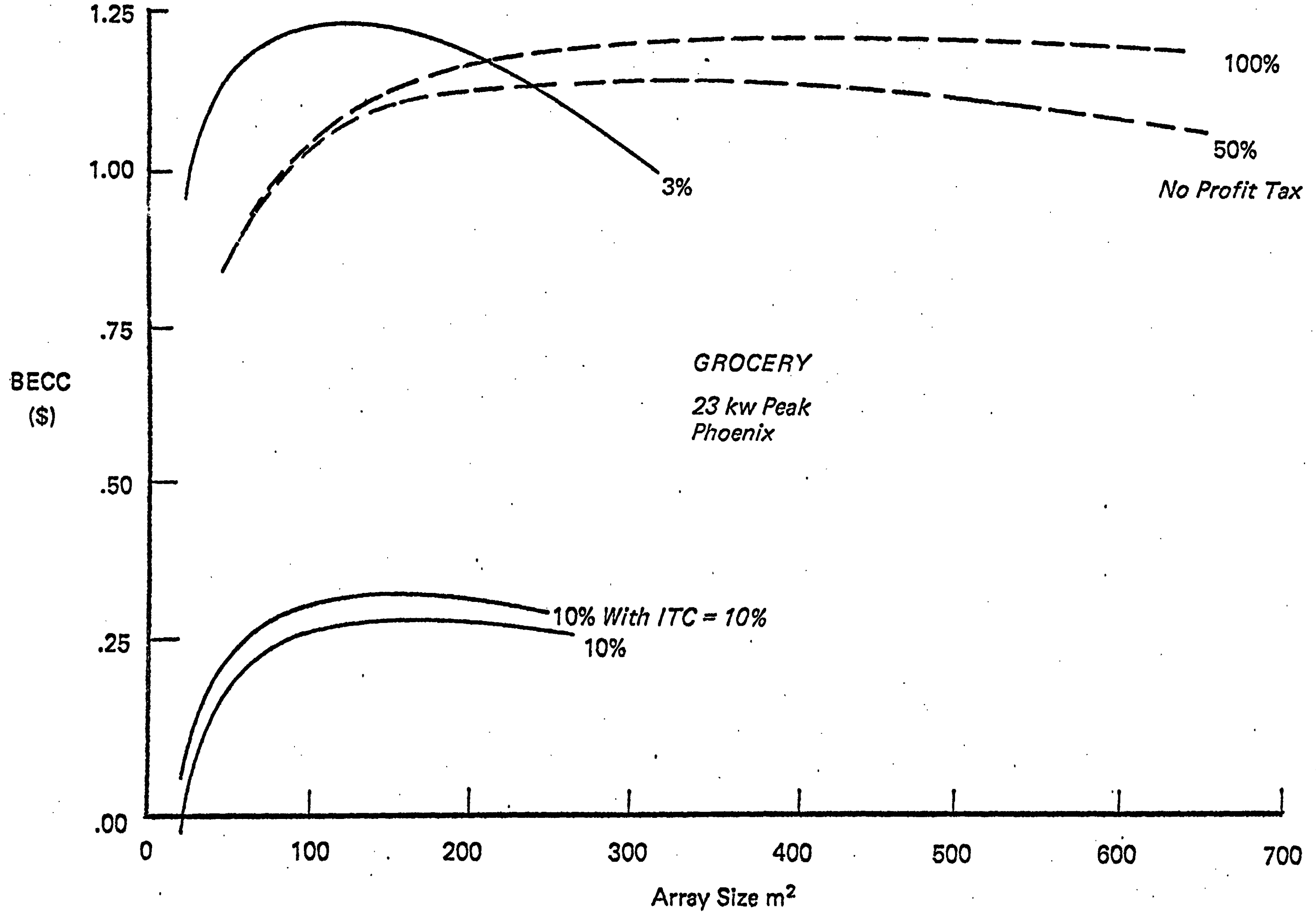

3%
100%
No Profit Tax
50%
6%
MASTER METERED APARTMENTS
90 kw Peak
Phoenix
10% with ITC = 10%
10%
BECC
($)
1.25
1.00
.75
.50
.25
.00
0
100
200
300
400
500
600
700
Array Size m^2

FIGURE 7


1.25
1.00
.75
.50
.25
.00
BECC
($)
0
100
200
300
400
500
600
700
Array Size m^2
100%
50%
No Profit Tax
3%
GROCERY
23 kw Peak
Phoenix
10% With ITC = 10%
10%

The most significant advantage is one of ease of use and availability of the data. many individual firms and commercial establishments as well as individual utilities are now maintaining records of consumption on 15-minute or one-hour time periods. With large and complex energy consumers there are dramatic differences in analytic costs when comparing simulation runs which create load data with the use of load information collected at the source. An additional advantage is that it is possible to match the individual load data with the processes involved within the industry or the individual HVAC system in use in the commercial building. There are, however, disadvantages in the use of fixed load data relative to simulation modeling of the loads. The most significant is the inability to impute any type of behavioral change in energy consumption with respect to alteration in the price of electricity. While this feature was used only sparingly in the analysis of the residential systems, it did allow the researchers to separate the effects of time of day rates alone in modifying the behavior of the owner from changes that could be attributed to the availability of "free" electrical power directly from the photovoltaic system.

Figures 5, 6, and 7 present the results of analyses which assume varying internal rates of return to the establishments for capital investments. The lowest rates, 3% would correspond to the level of rate of return required of a household as discussed in the previous section. Such levels are not acceptable in commercial or industrial establishments where a traditional rate of return of 10% is more likely. As can be seen in the figures the worth of the photovoltaic system declines rapidly as the required rate of return increases. In addition it can be seen that at a 10% rate of return the addition of a 10% investment tax credit (ITC) adds little to the worth of the photovoltaic system. As was the case with the residential sector the worth of the system is sensitive to the buyback rate--shown as 50 or 100% with a 3% rate of return.

The value of photovoltaic power systems to the user is less in the case of the industrial and commercial users than was the case in the residential sector. This is largely brought about by the difference in the financial structures of the two sectors. In addition, it appears that the industrial and commercial sectors are more sensitive to the "goodness of fit" between solar availability and current load than is the case in the residential system. The results gained to date on the commercial and industrial analyses are preliminary but their overall conclusions are that the modeling structure is capable of being used for analysis of the value of such systems to their owners. An improvement in overall reliability nd sensitivity in analysis will be gained if it is possible to develop a set of generic process models which can be sensitive to price elasticities or if it is possible to gain access to load data disaggregated to the production line level in order to posit behavioral changes which could results from shifts in price.

Probably one of the most interesting of the analyses carried out to date utilizing the modeling structure discussed above has been in the area of utilization of the photovoltaics as a generation source owned by the utility. Much of the early work in analysis of the potential for photovoltaic power systems made the assumption that if it generated electricity it would of necessity be a central rather than a dispersed technology in its application. (8) As the above discussions of residential and commercial applications tend to indicate, this is not the case. In addition, it was assumed in early analyses that photovoltaics used in central power applications needed to be coupled with of dedicated storage if they were to operate effectively within a utility system. This has also been shown not to be the case. The analysis of photovoltaics when used in a central power mode requires, therefore, a modeling structure in which the photovoltaic power system (or wind system) can be dispatched when available within the system as a whole and requires a reoptimization of overall system capacity decisions based upon the availability of power with a high capital and low to zero operating cost component. As a result the analyses carried out for the value of photovoltaic power systems integrated in a central power system reflect a simulation approach for the entire utility operating system. (9,10,11) The results of this analysis are shown in Figure 9 for four regional utilities. The results indicate the value of photovoltaics at different levels of penentration within the utility system and produce a generally downward sloping curve which indicates that the higher the level of penetration of photovoltaics into the system the lower is the value of the marginal unit of photovoltaic generation. These results are highly predictable given the fact that photovoltaic power tends to be generated on peak and as a result it replaces the more expensive power generation and fuel costs sources first then begins slowly to provide power in intermediate periods. While photovoltaics can have an influence on the amount of base load capacity optimally carried by a utility it cannot in any generation sense replace more than a fraction of that capacity.

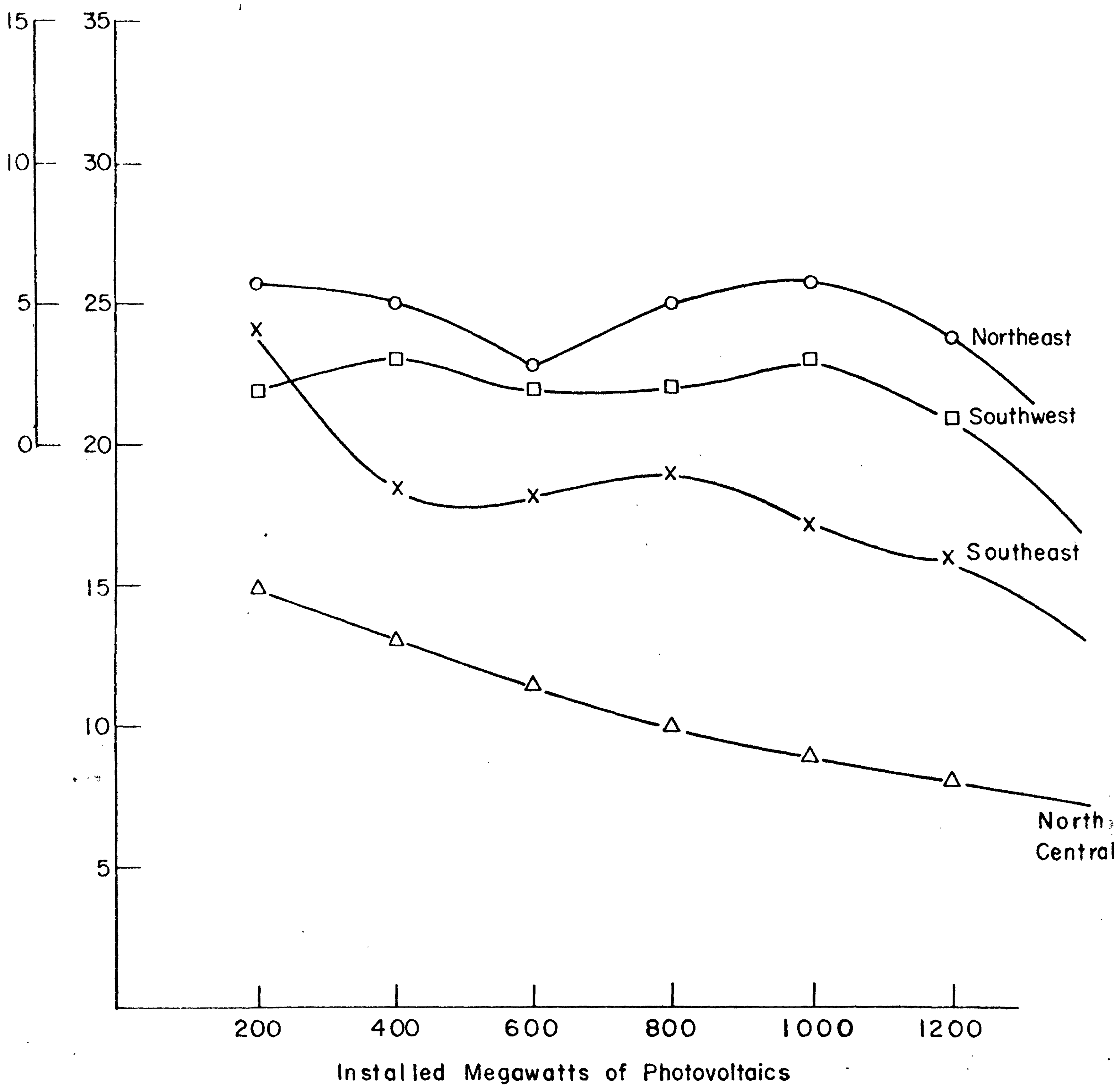
The worth of central power photovoltaic systems is less than was the case for either residential or commercial/industrial applications. The cost of capital is again a significant contributor as is the cost of land and other requirements in operations and maintenance inherent in megawatt scaled installations. On the other hand there are economies of scale in power conditioning equipment which work in favor of the large scale applications. Figure 9 contains two scales on the vertical axis which represent two assumptions concerning the balance of systems costs inherent in such systems. The left axis assumes a balance of systems cost of $.50 per watt peak while the right axis assumes a value of $.30 per watt peak. As can be seen at $.50 per watt peak only the Northeast and Southwest show positive values in breakeven capital cost given the base line analyses undertaken.

In summary the analyses undertaken on individual sectors has pointed to the significance of balance of systems costs and their guaranteed reduction over time, to the significance of the economic parameters of discount rate and/or required rate of return and significantly to the interaction between the customer and the utility in terms of the buyback rate for electric power. Using only the simplified models discussed above the next step in the analysis need be the interaction between utility and application penetration level to analyze the impact of increased penetration upon the actual utility rates which would result.

Further Research

The results of the models described above are limited in scope. They do not go beyond a set of assumptions about the behavior of the consumer and are limited in flexibility in looking at the overall potential for the technology in contributing to the U.S. energy economy. This factor is made more serious by the static nature of the analysis both in terms of its temporal assumptions and in terms of its structural assumptions concerning the nature of the electrical power system beyond 1985 and the pricing systems which will be in use beyond 1985. (12,13) As a result there are two directions in which additional research need go and is proceeding.

FIGURE 9

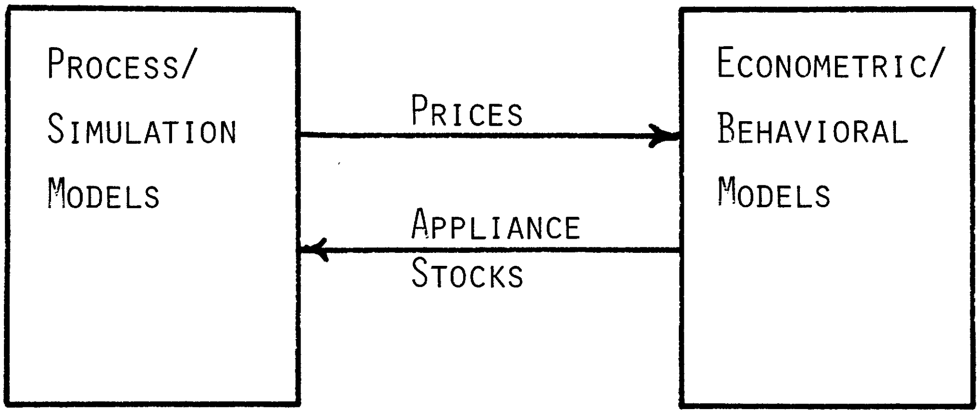

15
10
5
0
35
30
25
20
15
10
5
Northeast
Southwest
Southeast
North
Central
200
400
600
800
1000
1200
Installed Megawatts of Photovoltaics

The first direction is to remain within the basic structure discussed above but to evolve additional behavioral information into the analysis. An example of such additional information is in terms of the likely behavioral response of consumers to changes in price of electricity. While limited effort has been made in this direction within the residential modeling activity little has been done or can be done in the commercial and industrial sectors without basic changes in the structure of the models. Additional flexibility in the basic structure can be added by incorporating alternative structures of utility systems and utility pricing in the two decades ahead. Work in this area has become a significant portion of research activities within the Utility Systems Program at MIT. (14) Other work in this area requires more effective consideration of competing alternative energy systems such as photovoltaics and wind energy systems when utilized wthin the same utility structure.

The second major area of additional research needs to be in the area of bridging the gap between traditional econometric behavioral models of technology acceptance and the engineering process models discussed in this paper. (15,16) Work has begun on bridging the gap between these modeling types though at the time of this writing only the most preliminary structural efforts have been completed. Figure 10 indicates a proposed effort within the residential sector to analyze the consumer choice decision involving alternative energy sources within the home. The ties are at this stage weak and conceptual but it is expected that they will be strengthened as further research work is carried out. As can be seen the process or simulation modeling effort produces a price for electrical power. The behavioral models take price as a given and

FIGURE 10

PRELIMINARY ITERATIVE SOLUTION
SYSTEM FOR MODEL BRIDGE



calculate the mix of appliances within a given residence which would result from a given set of prices for alternative fuels. This mix of appliances can be used within the process modeling to set the level of electrical energy demand and as a result begin the process of iteration toward a uniform solution.

Efforts under way in the commercial and industrial sectors have not proceeded to the point of being able to draw a flow diagram to connect together the results of the two modeling activities. At this early stage, however, it is clear that additional information must be gathered and analyses undertaken to evaluate the capital requirements of the new technologies and to look at these new technologies not as entities unto themselves in a life cycle cost structure but to look also at these technologies as competing for scarce capital available to the given firm. (17) In this way the traditional production function must be expanded conceptually to include not only capital, energy and labor but to look at capital has having both an energy and a more traditional productive capital component.

Conclusions

The work described to date has been focused upon answering a narrow band of questions relating to a solar technology: "At what price would photovoltaic power sytems be competitive on a life cycle basis with traditionally generated electrical power at a set of locations within the United States, given a set of assumptions concerning the performance of such systems and the economic characteristics of their consumers?" It is necessary to develop the tools to carry this analysis further to answer far more complicated questions associated with the amount of potential volume one might anticipate for photovoltaic sales, the decision criterion which would be applied by the owners of such systems and the operating flexibility which those owners would then show to accommodate their consumption to the availability of power. To accomplish these objectives requires both the further development of the models as described in the sections above and the development and verification of experimental technical and market/economic data on consumer economic and market perception.

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