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A UNIFORM ECONOMIC VALUATION METHODOLOGY FOR SOLAR PHOTOVOLTAIC APPLICATIONS COMPETING IN A UTILITY ENVIRONMENT

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ABSTRACT

The question of how the economic benefits of weather-dependent electric generation technologies should be measured is addressed, with specific reference to dispersed, user-owned photovoltaic systems. The approach to photovoltaic R&D investment that has historically been practiced by the Federal Government is described in order to demonstrate the need for an economic value measure. Two methods presently in common use, busbar energy costs and total systems costs, are presented and their strengths and weaknesses highlighted. A methodology is then presented which measures the "worth" of a system to a user and the implications of this analysis for R&D investment are discussed. Finally, a simple simulation model of a photovoltaic residence is designed which demonstrates the use of the suggested methodology.

I. HISTORY

Since its inception in the early 1970's, the Photovoltaics Program within the Energy Research and Development Administration (now Department of Energy) has focused its effort on driving the costs of photovoltaic devices down. This approach is manifested in several program objectives, actors and concepts.

The specific objectives of the National Photovoltaic Conversion Program were first articulated at the NSF/RANN Cherry Hill, New Jersey Conference in the fall of 1973. Program goals were here for the first time described in terms of array costs. "It is anticipated that large-scale application of solar photovoltaic technology will become economically viable by approximately 1980. This will be made possible by the reduction of solar array cost to less than $0.50/watt (peak)."[1,2] At the time this number was not supported with economic analysis of potential applications. It was later established by ERDA as its 1986 Photovoltaics Program goal.[3] Given the state of knowledge of photovoltaic technology and its applications at the time, the Cherry Hill statement of program objectives was not unreasonable.* But much faith has been placed in that number as a target for economic value, independent of any particular applications environment or region.

Given the history of the photovoltaic conversion technology as a satellite power system, it is not surprising that many of the actors in the Photovoltaics Program were also actively involved in the space program. The Jet Propulsion Laboratory through its Low Cost Silicon

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* Since $0.50/watt(p) represented a good estimate of 5¢/kWh translated to photovoltaic array terms.

Solar Array Project is one such organization that now has primary responsibility for the development of a low-cost silicon technology.[4] "The primary goal of the LSSA Project is to develop by 1986 the technological and industrial capability to produce silicon solar photovoltaic arrays at a rate of more than 500 peak MW per year, having an efficiency of greater than 10 percent and a 20-year minimum lifetime, at a market price of less than $500 per peak KW, ($0.50/watt(peak)).[5] Thus, the JPL program is utilizing its experience in space program management to generate technical and production advances (supply-side phenomena) to meet the 1986 Cherry Hill/ERDA objective. The Aerospace Corporation, another space program actor, has performed a set of "Mission Analyses" of photovoltaic applications in residential, commercial and central station applications which brought together first-order technical performance and financial analyses.[6] In the majority of the research and development effort to date the program has placed primary effort on attainment of the goals, a legacy of the space program, and secondary emphasis on the costs of accomplishing this research and development.

Given the program objectives and actors it is not hard to understand the concept behind the commercialization of photovoltaics in the program, a concept that has been characterized as a "market-pull" philosophy. The essence of this concept is that government purchases of photovoltaic cells, independent of their use in particular applications, is enough of a stimulus to drive the photovoltaic industry down the experience curve and thus meet the 1986 cost goals. This was articulated in the 1976 Photovoltaics Program plan:

> It is expected that ERDA purchases of approximately 600 KWe through FY78, coupled with purchases by other federal agencies with ERDA's support, will result in a factor of 4 reduction in the present cost of silicon-based solar cells...A total government purchase of approximately 11 MW through FY 1983 is planned. Costs for silicon solar cell arrays are expected to drop to $1000 per peak KW by 1984.[7]

"Market-pull" is a concept that is rational given the objectives and actors described above, especially in a situation where achieving cost goals is the primary objective. At present, however, there appears to be a greater realization that future strategies for the commercialization of photovoltaics require that attention be focused on the marketplace, particularly the marketplace in which electric utilities reside.

More recently, in the latest National Photovoltaic Program Plan,[8] an even more aggressive eight-cycle, eight-year photovoltaic procurement initiative has been proposed that would cost the government approximately $380 million. The purpose of this new initiative is to accelerate by several years the diffusion of photovoltaic devices into the marketplace.[9] The "market-pull" concept has been institutionalized in terms of the so-called PRDA (Program Research and Development Announcement) which is the mechanism whereby the government solicits proposals from private sector interests to be recipients of these government-purchased modules for tests and applications purposes. This new plan includes the same program goals as described above but they are now time-phased as follows.[10]

- Near-term

  To achieve prices of $2 per peak watt (1975 dollars) at an annual production rate of 20 peak megawatts in 1982.

- Mid-term

  To achieve prices of $0.50 per peak watt, and an annual production rate of 500 peak megawatts in 1986.

- Far-term

  To achieve prices of $0.10 to $0.30 per peak watt in 1990, and an annual production rate of 10-20 peak gigawatts in 2000.

MOTIVATION

The description above was provided in order to place the question of the economic valuation of photovoltaics in perspective. One can hypothesize that photovoltaics cost goals and the "market-pull" concept evolved due to a lack of knowledge about the nature of the economics of actual photovoltaic applications. Now that this knowledge is growing, there is a need to understand the factors that influence the economics and to specify a uniform methodology to take these factors into account. There are at least three major requirements or features which this methodology must exhibit. These issues will be more fully elaborated in the course of the discussion later.

First, there is a need for a methodology that provides full economic valuation for the unique features of weather-dependent technologies. As will be seen, the sunlight dependence of solar systems results in both advantages and disadvantages to the user. The methodology, whether it is purely analytic or involves simulation, must explicitly value these effects.

Second, the methodology should be able to allow the direct comparison of alternative technologies on "equal footing". The comparison should not be influenced by scale, region or climate beyond the influence of these variables on the economics of the system in its applications environment.

Third, the methodology should allow for the consideration of various government policy actions. The great disadvantage of cost goals is that they do not allow for the effects of policy on the demand side. For example, changes in exogenous factors such as the cost of alternative fuels may make the achievement of a specific cost goal such as $.50/wp unnecessary. Other methodologies which utilize logistic diffusion curves, such as the market penetration models mentioned above, feature a type of inevitability or are potential "self-fulfilling prophesies". Since the logistic specification lacks casual variables one is not able to study the potential impact of various R&D investments or policy alternatives with these models.

If a methodology can be agreed upon that exhibits the three features suggested above then it will provide two chief benefits, the first of which is a market-related technology R&D investment goal. This goal will be meaningful in that it provides a benchmark for the achievement of true economic competitiveness with current technology. In the case of photovoltaics it can be a valuable input to the JPL technology development program since it not only indicates a cost target, but it indicates the particular configuration of the technology which applies to that cost.

Second, the methodology will provide the parameters necessary to make comparisons between technologies. One important component of R&D investment decisions is the economic benefits which a given technology will exhibit in its applications environment. Comparison of these demand-side benefits between technologies is at least as important as the consideration of supply-side progress. Of course, the combination of the demand-side benefit measure with a supply-side cost measure would provide the best economic viability measure for differing technologies. R&D investment decisions can and probably should be made based on the distance certain technologies are from economic viability. This appears to be a more important criteria than ultimate market penetration and is motivated by the increased concern in the Department of Energy that government get out of the technology development business as soon as the technology is able to compete in the private sector. Henry Marvin, Director of the ERDA Division of Solar Energy, has suggested that the photovoltaics program be restructured to focus on near term goals under the assumption "that the market will enter an explosive self-sustaining growth phase at an array price of $1 to $2 per peak watt."[11] Dale D. Myers, Undersecretary of DOE, who is responsible for overseeing the development of technology, recently stated, "My objective is to move it all into the industry and get the hell out of the business."[12] Both of these statements indicate the importance of knowing in advance not only the nature of the long-run markets for photovoltaics, but more importantly, knowing at what price technologies at initial penetrations become competitive with current technologies.

The purpose of this paper is to evaluate critically the economic valuation approaches that have been used in the recent past and to suggest an approach that will meet the requirements discussed above. The next section describes the nature of the economic valuation question. The unique features of weather-dependent technologies and their impact on the economic valuation question will be discussed in Section III. Section IV looks at previous approaches to economic valuation, particularly levelized busbar costs and total utility system costs. A suggested simulation methodology is presented in Section V and in Section VI an example calculation is made using a simplified simulation of a photovoltaic residence.

While the methodology should be general enough to apply to all technologies, the example of photovoltaic systems is used for descriptive purposes in this paper.

II. ECONOMIC VALUATION OF PHOTOVOLTAICS

The term economic "benefits" or "valuation", as used in this report is meant to be device-ownership specific, in that it is a valuation based on the fuel bill saved for the owner. Specifying the valuation in this manner implies that it takes into account three things.

First, it is owner-specific in that it values the photovoltaic energy based on the alternative fuel source which that particular consumer faces and it is also configuration-specific in that it requires that the particular application and device output in that application be described.

Second, it is region-specific in that it is a valuation based on the local cost of alternative fuels.

And third, with utility-ownership it also includes a measure of the foregone cost of electric generation capacity (if any) and the value of improved (or degraded) reliability and generation and transmission efficiency.

This valuation does not claim to indicate whether or not the photovoltaic systems will actually be purchased. The purchase decision is more complex than simple comparative life cycle costs would indicate. Furthermore, one can argue that the economic valuation of a new technology should be made in the context of some future environment, such as in comparison with other renewable resources.[13] In this report economic valuation is interpreted to mean the result of an economic comparison of photovoltaic devices with current electric generation technologies. Finally, the benefits measured here do not include potential social, environmental or national security benefits.

III. UNIQUE FEATURES OF PHOTOVOLTAICS WHICH AFFECT ECONOMIC VALUATION

There are several characteristics unique to photovoltaic technology which bear examination because they have a direct impact on how one goes about valuing the worth of the technology.

Photovoltaic arrays are modular in nature and thus the applications for which they are appropriate are many and varied, ranging from small remote power stations to homes, schools and load centers. This modularity is notably uncharacteristic of conventional means to generate electricity and as a result, methods of calculating the value of the energy produced by photovoltaics cannot be divorced from the particular applications in which they are configured. This makes simple analytic valuation methods intractable, requiring instead more detailed simulation.

The second, often overlooked, feature of photovoltaics is that its energy output (a function of solar radiation) is generally coincident with the peak demand periods for electricity. This correlation is particularly important for air-conditioned residences, most schools and summer-peaking utilities. The fact that photovoltaic output tends to be present at peak demand periods means that there is a "quality" component in the energy that must be specifically valued by the methodology. The implication is that the calculations must be made for short time slices, perhaps by the hour, and that methodologies which employ average solar insolation values together with an overall system efficiency are likely to misrepresent the potential economic impact of the solar devices.

Third, in applications that are utility grid-interconnected, the electric utility will have no direct control of the output of the photovoltaic device. This is analogous to the situation utilities confront with respect to "run-of-the-river" hydroelectric power. The valuation method for calculating the impact of the devices on utilities must be sophisticated enough to account for the effects of this "run-of-the-sun" feature. As we shall see, this also affects how one determines the "buy-back" price at which utilities are willing to buy surplus power fed back into the grid from user-owned systems.

The last feature that bears acknowledgement is the site-dependency of photovoltaics, mentioned earlier. Since the value of the device is so heavily dependent on the local climatic conditions and utility environment, the calculations must be performed initially only for specific device configurations in particular regions for specific utilities. The aggregation effects of photovoltaic devices on utilities is thus a non-trivial problem that requires explicit consideration in the methodology, perhaps through stochastic processes.

In summary, specific characteristics of photovoltaic systems make the economic valuation question more complicated than the question of the value of conventional technologies. In the next section, we will examine some of the approaches to measuring the economic value of alternative electric-generation technologies to see if they fit these requirements and needs.

IV. PREVIOUS APPROACHES TO ECONOMIC VALUATION

All of the methodological approaches that have been used to date to evaluate the economic worth of photovoltaics were developed originally under the assumption of utility ownership. As we shall see this presents problems when the methodology is attempted to be applied to non-utility owners. The two approaches to be discussed in this section are the Levelized Busbar Cost approach[14] used by the Aerospace Corporation in its Photovoltaics Mission Analyses[6] and the Total System Cost approach[15] used by both General Electric and Westinghouse Corporations in their Photovoltaics Requirements Assessments Studies.[16,17]

LEVELIZED BUSBAR COSTS

As the name implies this is a costing not a valuation methodology. In this method the cost of supplying electricity from a single generating plant, or photovoltaic device, is calculated independent of any other plants in the system at a specified annual capacity factor. Thus, in any configuraton where the energy producing device is connected to the grid, the rest of the plants on the system are ignored. The costs are calculated in mills per KWH according to the following formula:

$$BBEC = \frac{C_t \cdot FCR}{8.76 \cdot PCF} + \overline{O\ \&\ M} + \overline{FL}$$

Where:

C_t = Capital cost at time t, in dollars per KWH

FCR = Fixed charge rate, per unit

PCF = Plant capacity factor, annual

O & M = Annualized O & M costs, in mills/KWH

FL = Annualized fuel costs, in mills/KWH
(FL would be zero for photovoltaic plants)

8.76 = Factor to convert hours to years and dollars to mills

Notice that this is not an economic valuation measure as we have defined the term. It allocates capital costs over a specified lifetime implicit in the fixed charge rate. The performance characteristics of the plant are contained within the single plant capacity factor number.

There are a number of reasons why levelized busbar cost is an inadequate methodology for the economic comparison of two methods of supplying electricity. First, in order to be valid the capacity factors must be the same for the two systems being compared. Capacity factor is defined as the ratio of the average load on a machine or equipment for the period of time considered, to the rating of the machine or equipment. Thermal power plants have capacity factors lower than 100 percent due to unexpected or planned system outages. Photovoltaic plants generally have very low capacity factors since here the capacity factor is a function of sunshine availability. "It is impossible therefore for a (photovoltaic) plant to have a capacity factor as high as the highest of conventional thermal plants..."[18] Of course, comparisons could be made over a range of capacity factors, holding them the same for both plants, but even this would not allow one to choose the appropriate systems because the answer will change as the capacity factor changes.

Second, busbar costs do not account for the "effective" capacity of the two plants. Effective capacity has been defined as the amount of conventional capacity that would be displaced upon the installation of a photovoltaics plant of a certain rated capacity. This is related to the discussion earlier where it was argued that photovoltaic energy has a "quality" component related to the time of day. "The insolation tends to be available at a time in the daily work cycle when the loads are highest; and depending upon the relationship of the timing of the insolation peak and the daily load peak, (photovoltaic plant) effective capacity can be considerably higher than capacity factor."[19]

Finally, busbar costs do not place a valuation on the impact of the power plant on the total utility system. It is never the case that one is just comparing a photovoltaics plant with a coal plant, in isolation. A photovoltaics plant will behave very differently with respect to the utility system when it is installed than would a coal plant, even if they had the same capacity factor. Thus, busbar costs is not a sufficiently detailed method to determine the value of a photovoltaic system to its utility owner. It is also questionable whether the results it gives even allow the decision-maker to make rough-cut, technology rankings.

TOTAL UTILITY SYSTEMS COST

In contrast to busbar cost, which is a purely analytic method, Total Utility Systems Cost is a method that relies upon simulation. As we shall see, this method, when implemented correctly, is the type of analysis needed to perform the economic valuation of photovoltaics from the utility point of view. If the photovoltaic system is utility-owned, then we can stop here. If the systems are user-owned, however, total systems costs provides only one part of the analysis necessary.

The Total Systems Cost Methodology involves a detailed hourly stochastic simulation of the utility system reliability. This is accomplished in terms of the widely-used expected value of systems outage known as the loss of load probability (LOLP). The economic valuation of a photovoltaic plant is calculated based on its ability to contribute to the overall generation system reliability. A photovoltaic plant is added to the system, its output being considered a negative load on the system, and conventional capacity is added to the simulation until the system reliability returns to its pre-set LOLP value. This amount of conventional capacity "displacement" is referred to as the photovoltaic plant "effective capacity". The economic valuation is completed by summing the value of the energy displaced and the value of this effective capacity. In order to assess the energy displacement characteristics of a photovoltaic plant it is necessary to analyze the entire utility generation system operation through a production cost simulation model. This model dispatches generating capacity to meet the total system load at minimum cost. Since the photovoltaic plant output is sunlight dependent ("run-of-the-sun") it must first be modeled and then the rest of the utility plants are dispatched around it in the simulation. Running the simulation with and without the photovoltaic plant addition yields a valuation which includes both the displaced conventional capacity and the displaced energy all at constant system reliability.[20]

This approach was used successfully by General Electric in their Requirements Assessment of Photovoltaic Electric Power Systems[14] to show that photovoltaic plants did not necessarily require 100 percent conventional capacity backup, as was widely believed in the literature. There are, however, several necessary conditions that must be accounted for in this methodology, conditions that General Electric did not meet in their study:

First, the solar insolation data which determines the output of the photovoltaic plant must be matched precisely with the utility system load data. This could be especially critical for summer-peaking utilities where the presence of sunshine will increase the air conditioning load. Energy demand and insolation are not independent variables.

Second, this methodology is not sufficient by itself for dispersed, utility-owned systems. Explicit consideration must be taken of transmission-distribution loss and reliability improvements that will be enjoyed with dispersed photovoltaic systems. The so-called residential shingle scenario studied by General Electric is a misnomor, because no effort was made to model the transmission-distribution system. The answer would have been the same if all of the dispersed shingles had been aggregated in a central power plant.

Finally, as alluded to earlier, the use of the total utility system cost methodology by itself to calculate the economic value of photovoltaic systems implies necessarily that utilities own the system. This too was recognized by General Electric: "It is not possible to define the breakeven capital cost for a user-owned (photovoltaic) plant in the same way as has been done for utility-owned plants. This is because the economic incentive to purchase and install such a plant lies in the savings in purchased electricity costs accruing to the user."[21]

In the next section a methodology will be suggested that calculates the user-owned economic valuation of photovoltaic plants in concert with the improved total system cost methodology.

V. SUGGESTED USER-OWNED ECONOMIC VALUATION METHODOLOGY

It is important at the outset to distinguish between the methodology in general and the particular way in which it will be configured to examine user-owned photovoltaics. In general, the methodology defines two numbers. The first is called the "break-even" capital cost and is calculated by finding the difference between the user's electricity bills with and without the device according to the following formula:

$$\text{BECC} = \frac{\left[\displaystyle\sum_{J=1}^{n} \frac{\displaystyle\sum_{i=1}^{8760} \left(X_{Oi} - X_{Di} \right) \cdot \text{EFACT}(J) \cdot \text{DFACT}(J)}{(1 + \rho)^{J} \cdot \text{ACOL}} \right] - \left(\dfrac{\text{FIXEDC}}{\text{ACOL}} + \text{VARC} \right)}{\eta_{\text{system}} \cdot 1000\ \text{w/m}^2}$$

Where:

BECC = Break-even capital cost in \$/W(peak) <u>system</u>*

oi = Utility bill for hour i without device in \$

Di = Utility bill for hour i with device in \$

EFACT(J) = weighted fuel price escalation factor for year J based on fuel price component of rate structure

DFACT(J) = benefits degradation factor for year J based on module degradation

= discount rate appropriate to user

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[*] To calculate \$/w(peak) module, the traditional value used by the Photovoltaic Program η module should be substituted for η system in the denominator of the equation.

n = lifetime of device

ACOL = collector area in m^2

FIXEDC = fixed subsystem costs (including installation, power conditioning, lightning protection, etc.) in \$

VARC = variable subsystem costs (including installation = O&M, markups, insurance, taxes, etc.) in $\$/m^2$

η system = system efficiency.[*]

BECC can be considered an economic indifference value - that price at which the user would be economically indifferent between having and not having the device. This formula contains a number of features. First, the valuation which is the difference in the utility bills to the user, is determined by the utility rate structure and whatever the utility is willing to pay for surplus energy supplied by the owner to the grid. If the rate structure reflects the load demand on the utility (as under peak-load pricing), then this valuation explicitly values the "quality" component of the energy supplied by the device. Second, it is a figure defined in dollar units. This automatically adjusts for the scale of the device and allows direct comparison between two devices in the same application.

The second number that this methodology allows one to calculate is a dimensionless "break-even index". It is calculated by dividing the break-even capital cost by the cost at which the technology is available today for that particular application:

$$BEI = \frac{BECC}{CC}$$

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[*] See footnote on previous page.

Where:

BEI = Breakeven index

BECC = breakeven capital cost

CC = Current Capital Cost

This measure is an attempt to implement in a simple manner the demand-side, supply-side interaction mentioned earlier. The numerator, BECC, constitutes the demand-side benefit measure while CC represents the supply-side cost measure which indicates availability.

In a situation where future costs (CC) were perfectly known, this index would allow one to compare different technologies in the same application (what the busbar energy cost figure claims to do). BEI would, under these circumstances, tell the investment decision-maker "how far away" the technology is from break-even. Unfortunately, CC is not known with certainty, and thus this measure is also imperfect. But by introducing judgements as to possible future supply costs with probabalistic distributions around these costs, it may be possible to use this index for technology comparison.[22]

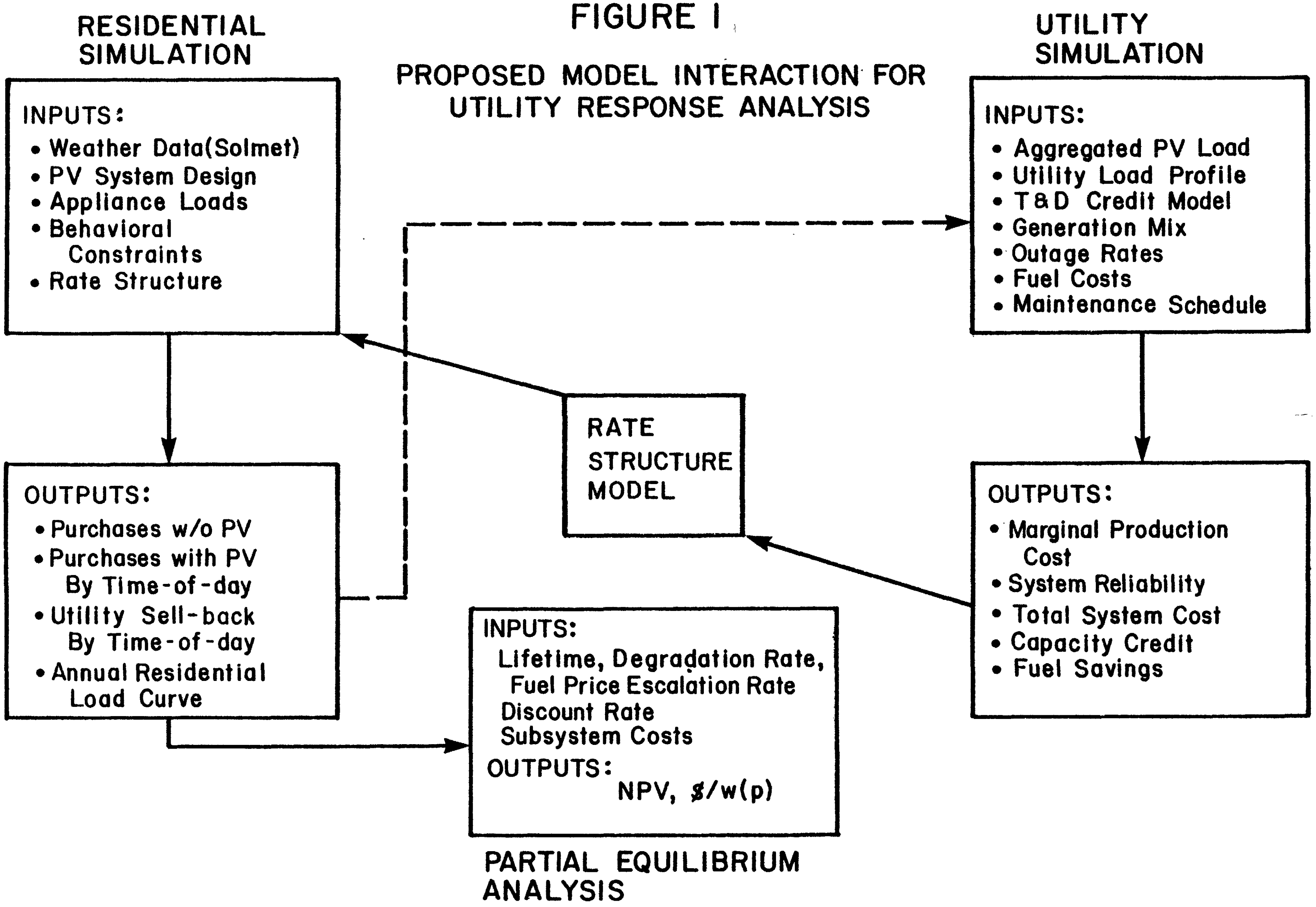
While there is a fine line between what one would call an analytic model and a simulation model, the fact that this methodology requires hour-by-hour analysis suggests the necessity of simulation.

IMPLEMENTATION FOR PHOTOVOLTAICS

The approach to finding the break-even capital cost for photovoltaics in a residential, grid-interconnected environment can be described as a dynamic (iterative) process between two simulation models. The diagram on the following page shows the inputs and outputs of each model and how

FIGURE I

PROPOSED MODEL INTERACTION FOR UTILITY RESPONSE ANALYSIS



they interact. As indicated, the first model is a residential photovoltaics simulation which takes hourly sunshine data, a given PV array configuration, appliance and use information and a utility rate structure to produce two outputs. First, it constructs the electricity demand for the house to reflect "optimal" use of the photovoltaic device within certain behavioral constraints. Second, based on the utility rate structure, it calculates the annual electricity bill from the utility, subtracting the value of the surplus energy sent back to the grid, if any. By zeroing the photovoltaic device and rerunning the model it is possible to calculate the annual utility bill without the device and thus the break-even capital cost (BECC) can be calculated. BECC must contain all costs associated with the device including installation, O&M and support structure. The break-even cost of the arrays themselves can be "backed-out" through a subtraction of these costs. At this point, by assuming the impact on the utility is negligible at the small penetrations of the devices, one can immediately determine the price at which photovoltaics could economically compete in the generation of electricity for this application.

If one wishes to deal with larger penetrations, however, one needs to worry about the utility response which will be manifested in the rate structure or buy-back rate. To assess this effect the load curves for the individual residences are aggregated to determine the "negative" load that the utility now faces each hour of the day. This negative load is the standard input to the utility total systems cost simulation described earlier with the exception that the transmission distribution gains (losses) and reliability are now explicitly modeled. The results of the second simulation will indicate the effects of the photovoltaic penetration on marginal production cost, systems reliability and capacity. Since utility rate-setting is a very political process, these results must be reflected through the Public Utilities Commission (PUC) before they can be passed on in the rate structure. This then suggests an iterative process between the residential simulation and the utility system simulation.

It is also highly desirable that a considerable amount of sensitivity analysis be performed to examine the effects of system efficiency, buyback price, array size and discount rate. This is the great advantage of simulation in that various policy options can be tested, such as subsidized interest rates, subsidized buyback, and R&D investment in the technology, among others.

VI. EXAMPLE SIMULATION FOR PHOTOVOLTAIC RESIDENCE

In order to demonstrate simply how a residential simulation and analysis might be performed a computer program was designed to approximate the actions of a live instrumented residence (see appendix). This is a partial equilibrium framework since we are assuming no significant photovoltaics penetration at the time of installation and thus no immediate utility response.

The program takes monthly hour averages of solar insolation[23] for Los Angeles, California, and a representative hourly electricity demand for a residence in Los Angeles for weekdays and weekends[24] and calculates based on the Los Angeles suggested time-of-day rate structure an annual utility bill for the house with and without a photovoltaic device. The following table summarizes the input assumptions made and the results obtained. It should be recognized that this is not a full implementation of the model and thus only reflects sample results. Several caveats that should be highlighted include: 1) The model takes a given demand and assumes constancy throughout the year, it does not construct the load to best use the solar output. In this sense it is conservative. 2) It uses hourly averages of insolation for each month, not actual hour-by-hour sunshine. It is not a worst-case sunshine example.

To reiterate, one should not draw conclusions from these results other than to notice the way in which the results are presented and the ability to perform sensitivity analysis.

INPUT ASSUMPTIONS: LOS ANGELES RESIDENCE

ARRAY SIZE:	42M^2 AND 25M^2
DISCOUNT RATE:	5% REAL AND 2% REAL
BUYBACK PRICE:	0, 25% OF RATE AT TIME, 52% OF RATE AT TIME
SYSTEM EFFICIENCY:	6%
RATE STRUCTURE:	4.6556/KWH (PEAK 8AM-8PM) 2.496¢/KWH (OFF-PEAK)

RESULTS:

2% DISCOUNT RATE (REAL)

ARRAY SIZE	42 M^2			25 M^2		
Buy-back Rate	Annual[2] Worth	20 Year[2]	\$/Wp[1]	Annual[2] Worth	20 Year[2]	\$/Wp[1]
0%	148	2420	.54	90	1492	.56
25%	194	3172	.84	113	1848	.82
52%	245	4006	1.17	138	2257	1.09
		5% DISCOUNT RATE (REAL)				
0%	148	1844	.32	90	1122	.33
25%	194	2418	.54	113	1408	.52
52%	245	3053	.79	138	1720	.73

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[1] These array prices were backed-out by assuming \$25/M^2 in array support, installation and O&M costs, for comparison purposes with the \$.50/watt (peak) goals.

[2] In constant, 1977 dollars.

VII. CONCLUSION

The discussion above was designed to illustrate a methodology for valuing photovoltaic devices on a user-specific basis. The history of the Federal Photovoltaics Program indicates a basic lack of information of the position of photovoltaics in the electricity market, lack of knowledge which has contributed to the cost goal and "market pull" approaches to the development of the technology. With better information concerning the interaction between photovoltaic devices and electric utilities, it was suggested that government R&D (including field test) investment decisions should be guided by a knowledge of the price at which photovoltaics will enter certain markets. The methodology presented allows one to determine that price in a manner which accurately reflects system ownership.

VIII. Appendix and References

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PVWORTH: PROC OPTIONS (MAIN);
DCL SUN(12,24) FIXED DEC(8,2) ;
DCL (DEMAND_WD, DEMAND_WE, PRICE)(24) FIXED DEC(15,3) INIT((24)0.0);
DCL SOLAR FILE INPUT;
DCL PRLOAD FILE INPUT;
DCL EFF FIXED DEC(4,2);
DCL AREA FIXED DEC(5);
DCL BUYRATE FIXED DEC(4,2);
DCL NOPVBILLE,NOPVBILLD,  FIXED DEC(15,2) INIT(0.0);
DCL (EXDEMAND,DXDEMAND)(24) FIXED DEC(15,2) INIT((24)0);
DCL (DPVBILL,EPVBILL,PVBILL)(12) FIXED DEC(15,2) INIT((12)0.0);
DCL BUYPRICE FIXED DEC(6,3) INIT(0.0);
DCL PVBILLT,NOPVBILL FIXED DEC(15,2) INIT(0.0);
DCL ANNUAL_WORTH FIXED DEC(15,2) INIT(0.0);
GET FILE(PRLOAD) LIST(EFF,AREA,BUYRATE);

DO I=1 TO 12;
  DO J=1 TO 24;
          GET FILE(SOLAR) LIST (SUN(I,J));
         SUN(I,J) = (EFF*AREA*SUN(I,J))/1000;
   END;
END;
GET FILE(PRLOAD) LIST((DEMAND_WD(K),DEMAND_WE(K),PRICE(K)
     DO K=1 TO 24));
DO K=1 TO 24;
     DEMAND_WD(K)=DEMAND_WD(K)/1000;
     DEMAND_WE(K)=DEMAND_WE(K)/1000;
       NOPVBILLD=NOPVBILLD+(DEMAND_WD(K)*PRICE(K));
      NOPVBILLE=NOPVBILLE+(DEMAND_WE(K)*PRICE(K));
END;
     NOPVBILL=(22*NOPVBILLD+8.42*NOPVBILLE)*12;
DO M=1 TO 12;
     DO N = 1 TO 24;
          EXDEMAND(N)=DEMAND_WE(N)-SUN(M,N);
          DXDEMAND(N)=DEMAND_WD(N)-SUN(M,N);
          IF DXDEMAND(N)<0 THEN DO;
               BUYPRICE=PRICE(N)*BUYRATE;
         DPVBILL(M)=DPVBILL(M)+(DXDEMAND(N)*BUYPRICE);
          END;
         ELSE DPVBILL(M)=DPVBILL(M)+(DXDEMAND(N)*PRICE(N));
          IF EXDEMAND(N)<0 THEN DO;
               BUYPRICE=PRICE(N)*BUYRATE;
               EPVBILL(M)=EPVBILL(M)+(EXDEMAND(N)*BUYPRICE);
          END;
         ELSE EPVBILL(M)=EPVBILL(M)+(EXDEMAND(N)*PRICE(N));
     END;
      PVBILL(M)=8.42*EPVBILL(M)+22*DPVBILL(M);
      PVBILLT=PVBILLT+PVBILL(M);
END;
ANNUAL_WORTH = (NOPVBILL-PVBILLT)/100;
PUT SKIP(2) LIST('NOPVBILL=',NOPVBILL/100,'PVBILLT=',PVBILLT/100);
PUT SKIP(3) LIST ('ANNUAL WORTH=',ANNUAL_WORTH);
END PVWORTH;

R;
```

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1. The $0.50/watt(peak) goal is in contrast to current array costs of $10.00 to $15.00 per watt(peak). One kW (peak) corresponds to the amount of solar radiation falling on one square meter of a horizontal surface on a clear day with the sun directly overhead at one atmosphere pressure and at 28°C.

2 Bleiden, H.R., "A National Plan for Photovoltaic Conversion of Solar Energy", in Workshop Proceedings, *Photovoltaic Conversion of Solar Energy for Terrestrial Applications,* Vol. 1, October 23-25, 1973, Cherry Hill, N.J., NSF-RA-N-74-013.

3. Energy Research and Development Administration, Division of Solar Energy, *Photovoltaic Conversion Program, Summary Report*, Washington, D.C., November 1976.

4. Although the LSSA Project charter is now being expanded to encompass nonsilicon technologies as well.

5. Low-Cost Silicon Solar Array Project, "Division 31 Support Plan for FY77 Project Analysis and Integration Activities", Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. April 25, 1977.

6. Aerospace Corporation, *Mission Analysis of Photovoltaic Solar Energy Conversion*, For ERDA/Sandia, SAN/1101-77/1, March 1977.

7. ERDA, *op. cit.,* p. 2.

8. U.S. Department of Energy, Division of Solar Technology, *National Photovoltaic Program Plan,* Washington, D.C., February 3, 1978.

9. Information memorandum, December 21, 1977, to the Undersecretary from the Acting Program Director for Solar, Geothermal, Electric, and Storage Systems concerning "A Strategy for a Multi-Year Procurement Initiative on Photovoltaics," (Acts No. ET-002).

10. U.S. Department of Energy, *op. cit*., pp. 6-7.

11. H.H. Marvin, Letter to Photovoltaic Program participants on "Photovoltaic Program Plan Restructure," August 5, 1977.

12. Dale D. Myers, Quoted in *The New York Times,* December 5, 1977, p.61.

13. Amory Lovins, *Soft Energy Paths,* Ballinger Publishing Company, Cambridge, Mass., 1977, p.69.

    > "...Since we are obliged to begin committing resources now to the long-term replacement of historically cheap fuels, we must compare all potential long-term replacement technologies *with each other, not with the* cheap fuels, in order to avoid a serious misallocation of resources."

14. J. W. Doane, et. al., *The Cost of Energy From Utility-Owned Solar Electric Systems*, JPL/EPRI-1012-76/3, Jet Propulsion Laboratory, Pasadena, CA, June 1976.

15. C. R. Chowaniec, P.F. Pittman, D.W. Marshall, "A Reliability Assessment Technique for Generating Systems with Photovoltaic Power Plants," *IEEE PAS,* April 21, 1977.

16. General Electric Co., *Requirements Assessment of Photovoltaic Electric Power Systems,* Draft Final Report, for EPRI RP651-1, Schenectady, NY, June 1977.

17. Westinghouse Electric Co., *Utility Assessment of Photovoltaic Electric Power Systems,* Follow-on Project Under ERDA Contract E(11-1)-2744 "Conceptual Design and Systems Analysis of Photovoltaic Power Systems", 1977.

18. General Electric Co., *op. cit*., p. L-3.

19. *ibid,* p. 1-4.

20. For more detailed description of the total systems cost methodology, see reference 13, Appendix F.

21. General Electric Co., *op. cit*., p. M-6.

22. It must be emphasized that this index provides only a part of the information necessary to make R&D investment choices and decisions. No one measure can make these decisions in isolation since it is necessary to understand how alternative R&D budget allocations affect future technology development along many dimensions. The claim is made, however, that knowledge of at what point technologies reach economic "break-even" in the marketplace is a vital piece of the information that is needed.

23. National Bureau of Standards, U.S. Department of Commerce, *Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada*, Washington, D.C., April 1977.

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