

THE INCORPORATION OF SOLAR PHOTOVOLTAICS
INTO A MODEL OF RESIDENTIAL ENERGY DEMAND

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Introduction

Solar photovoltaics (PV) provides electricity users with an array of alternatives to grid-connected electricity - the alternatives are more capital intensive and less grid-electricity intensive than traditional electricity sources. The added capital intensity is generated by combinations of photovoltaic solar cells and storage devices. Of course, once the PV installations are in place, less grid-connected electricity will be required to provide a given level of electrical output [4].

The Department of Energy is currently conducting analyses to assess the commercial potential for PV in various user sectors. The residential sector is one that is receiving close scrutiny. In order to analyze and estimate the commercial potential for PV, the demand for electricity and electrical residential appliances must be measured. This can be accomplished realistically only within an interfuel substitution model of residential energy demand that appropriately differentiates between the long-run demand for energy using appliances and the short-run utilization of those appliances. Such a model is described elsewhere [1-3]. This paper builds into that model the techniques required to analyze and measure PV potential.

1) A Model of PV Potential

Residential demand for energy using appliances consists of three decisions that determine the size and characteristics of the

appliance stock and the utilization of that stock [1-3]. These decisions are

- 1) The decision to buy a fuel-burning durable good capable of providing a particular comfort service.
- 2) The decision about the technical characteristics of and the fuel used by the equipment purchased and whether the equipment embodies a new technology.
- 3) Given the purchase of the equipment, the decision about the frequency and intensity of use.

These decisions are conditional upon many factors (income, climate/weather, socio-economic conditions, consumer discount rate, etc.) and electricity prices. However, there exists a simultaneous decision that is affected by appliance purchase and utilization decisions and in turn affects the price of electricity. In particular,

- 4) The decision concerning the extent to which solar photovoltaics will be used to supply household electricity needs.

The equations necessary for modeling decisions 1-3 are developed elsewhere [1-3]. For appliance choice, technology trade-off curves are required to portray the alternative bundles of capital and fuel services available to households for varying levels of end-use¹

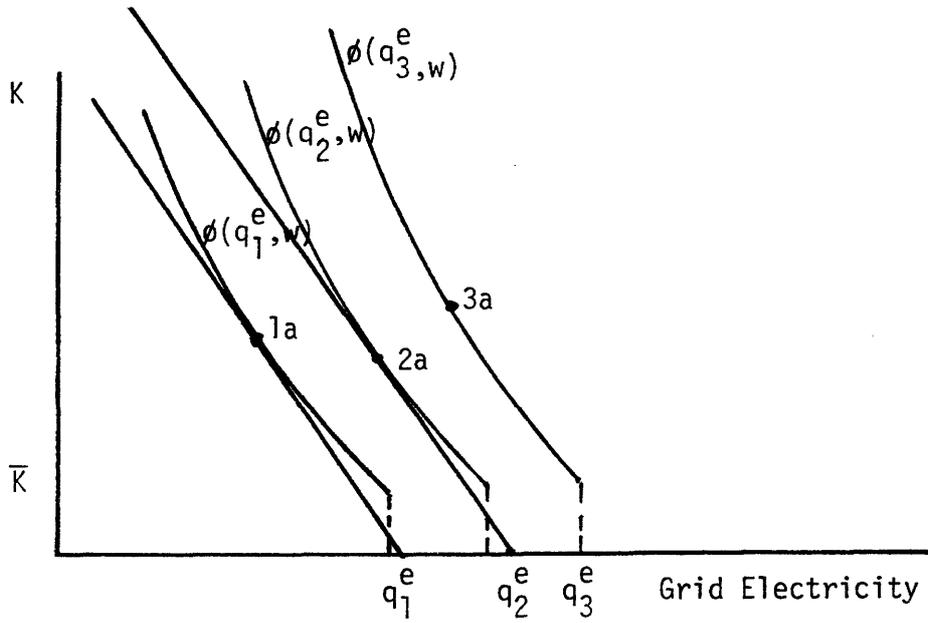
¹Where end uses include space heating, air conditioning, water heating, clothes washing, clothes drying, cooking, refrigeration/freezing, dishwashing and all other electrical.

service demand. The model uses these appliance technology trade-off curves and notions of household utility maximization to estimate the shares of appliances purchased by fuel type and technology (for example within space heating, the shares of gas, oil and electric devices; and within electric space heating equipment, the shares among forced hot air furnaces, hot water or steam boilers, baseboards, ceiling cable, heat pumps and solar thermal units). The choice among fuels and technologies is determined by fuel prices, the discount rate of the household (which determines cost of capital services) and climate, income and other socio-economic factors [1-2].

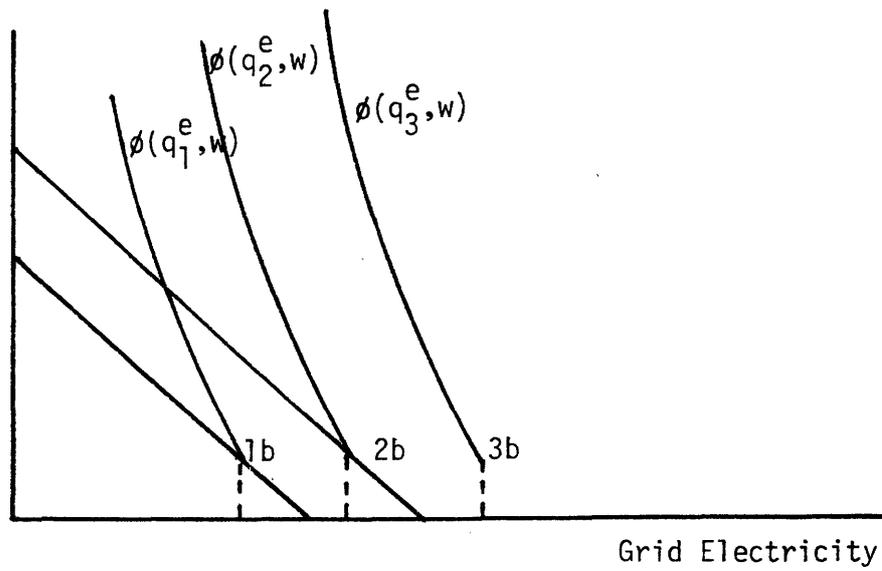
Decision 4) is guided by the same factors. Households face technology trade-off curves that summarize by geographic area combinations of grid-connected electricity and PV devices (solar arrays and storage) required to provide a given level of electricity. Figure 1a) and 1b) present two sets of technology trade-off curves $\phi(q_i^e)$ where q_i^e is the level of electricity demand (KwH), $i=1\dots n$. Given q_i^e and conditional on the price of grid-connected electricity (p^e), household discount rates (d), income (y), climate/weather (w) and other socioeconomic factors (se), households will determine the share of q_i^e to be supplied by PV (S_{pv}), where

$$S_{pv} = S_{pv}(q^e, d, p^e, y, w, se). \quad (1)$$

Figure 1a) presents technology trade-off curves and relative factor prices (p^e/p_k , where p_k is determined by the discount rate) such



a) $S_{pv} > 0$



b) $S_{dv} = 0$

Figure 1: Electricity Technology Trade-Off Curves

that $S_{pv} \neq 0$ at 1a, 2a, 3a. \bar{K} is the minimum capital input required for grid connection. In Figure 1b, the technology trade-off curves are such that conditional on p^e and d , $S_{pv} = 0$; as a result, grid electricity alone is chosen (1b, 2b, 3b).

Clearly, PV penetration will depend upon ϕ , q_i^e , p^e , d (hence p_k) and weather/climate (w), income (y) and se . If planners can affect ϕ , q_i^e , p^e and d (p_k) they will be able to alter PV potential. Section 2 discusses each policy option.

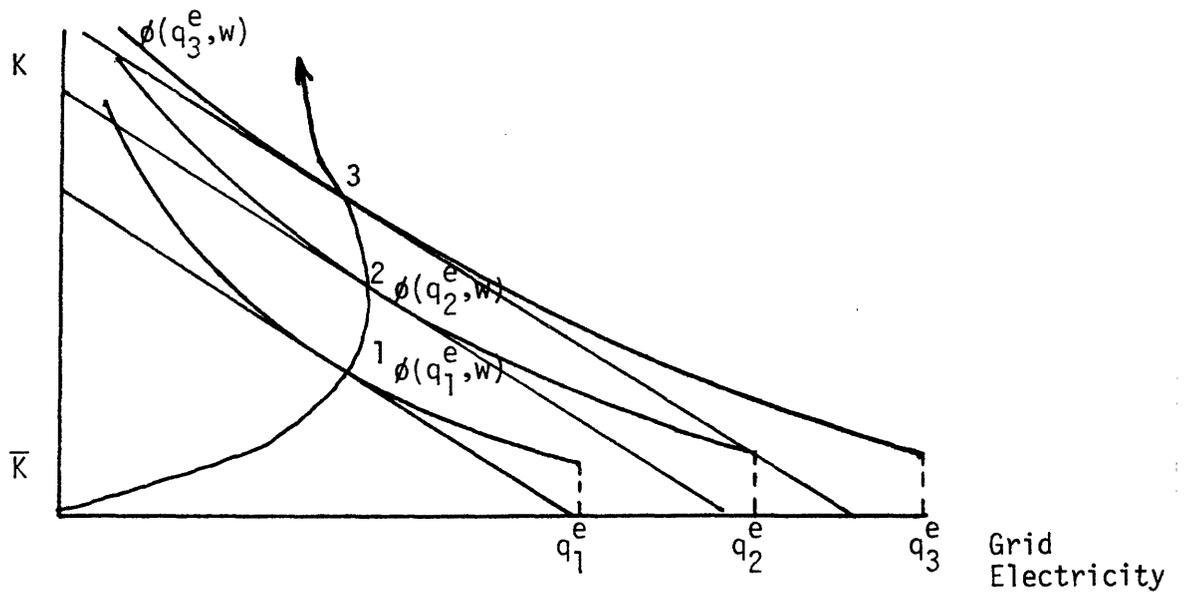
2) Policy Uses of the Model

The factors affecting PV commercialization potential have been indicated above. This Section examines each of them in greater detail.

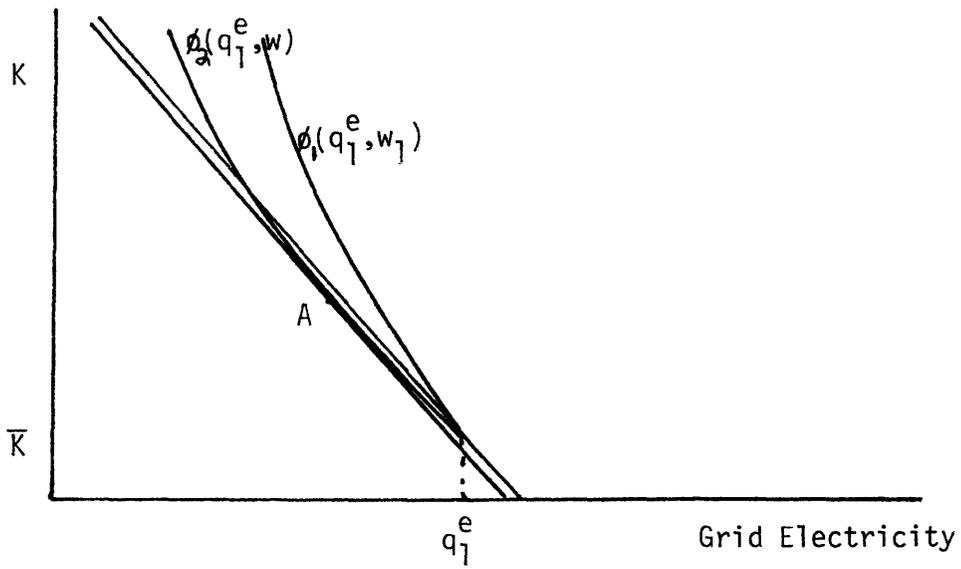
• Technology Trade-Off Curves - $\phi(q_i^e)$

Figure 1a and 1b indicated how the shape of $\phi(q_i^e)$ will determine PV potential. Figure 1a shows PV potential with minimum life cycle costs at 1a, 2a and 3a. Minimum life cycle costs in Figure 1b suggest only grid electricity will be used.

The $\phi(q_i^e)$ frontier clearly needs to be precisely estimated by region to be able to quantify when PV will be purchased, conditional on p^e and the cost of capital services. For example, if analysis found that the $\phi(q_i^e)$ in Figure 1b obtained, it would be possible to indicate the changes in ϕ required to obtain the PV penetration such as in Figure 1a. Such technological changes may be impossible; however, the extent of change required to achieve a given level of penetration can be estimated (again, conditional on p^e and $p^k(d)$).



a) PV - Using Scale Effects



b) Regional Effects Due To Insolation

Figure 2: Alternative Technology Trade-Off Curves

The ϕ frontier depends upon weather/climate and q_i^e . The dependence of ϕ on q_i^e is indicated in Figure 1; greater analysis is required to determine whether the ϕ are homogeneous or non-homothetic. For example, in Figure 2a, non-homothetic technology trade-off curves are presented. In such a case there will be a shift toward proportionally greater PV potential as the scale of household electricity demand rises. Thus, any policy that increases (decreases) household electricity demand (such as appliance efficiency standards, appliance utilization standards, fuel taxes, fuel price changes) will increase (decrease) PV potential more than proportionally.

Figure 2b) shows the effect of different geographical conditions, in particular greater insolation in region 2 such that $\phi_2(q_i^e) < \phi_1(q_i^e)$ for any scale of PV installation (i.e. for any K , the amount of grid electricity needed to supply household demand q_i^e is less). In this case, PV will not penetrate in region 1; however conditional upon the same factor prices (p^e and p_k) PV will penetrate in region 2 (at A) at a lower total cost.

- Changes in the price of grid electricity - p^e

The cost of grid electricity can be altered by a wide range of policies - rate restructuring, peak-load pricing and energy taxes. Any such policy which increases the price of electricity, will increase the relative desirability of PV as shown in Figure 3, conditional on w and q_i^e . In Figure 3, rational consumers will choose 3a over 3b given the increase in p^e . However it should

be recalled that changes in p^e will also affect residential appliance demand and utilization decisions - hence q_i^e [1-2]. Hence, a model of such appliance demand is necessary to assess the scale effects on q_i^e of changes in p^e ; these effects will in turn affect PV potential as indicated in Figure 2.

- Changes in the Costs of Capital Services - p_k

Policies which affect the cost of capital services will likewise affect PV potential. If the relative cost of capital services declines relative to p^e , PV potential increases, as indicated by point 4a showing greater PV potential than point 4b in Figure 4. Such declines can be accomplished by changing PV capital subsidies, lowering consumer discount rates (d) to the true cost of capital and increasing utility buy-back rates. Such policies can be translated into exact estimates of p_k and, given the estimates of $\phi(q_i^e)$, the effects on PV potential can be assessed.

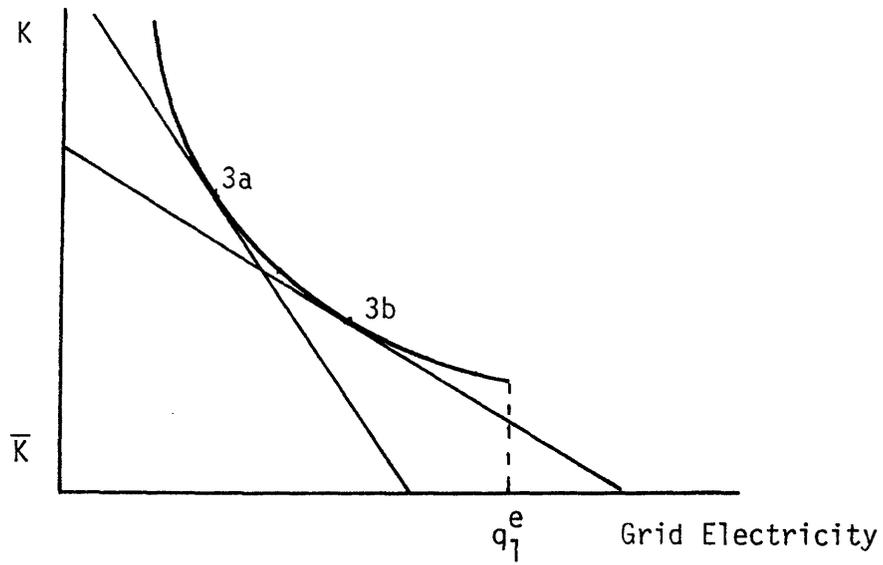


Figure 3: Effects of Increases In The Price of Grid Electricity

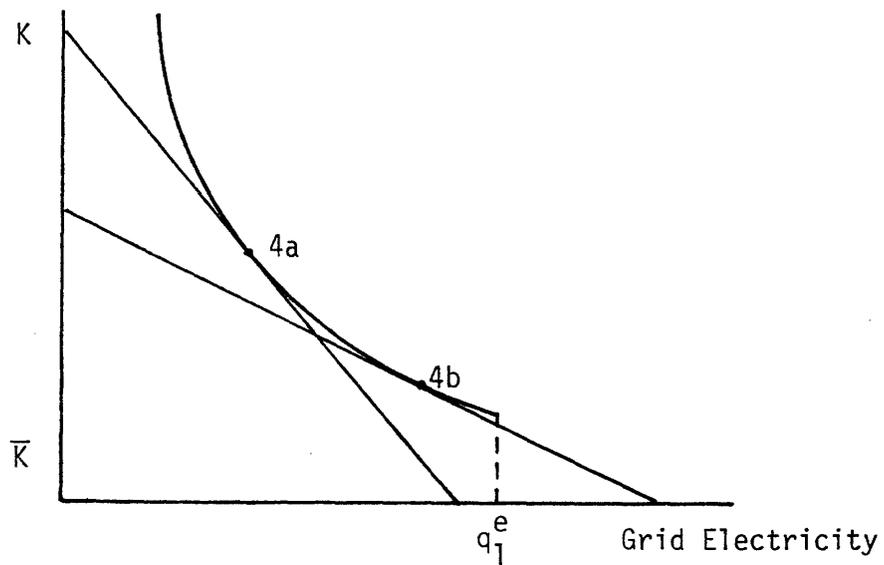


Figure 4: Effects of Decreases in the Price of Capital Services

References

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- 2) Hartman, Raymond S., "Discrete Consumer Choice Among Alternative Fuels and Technologies for Residential Energy Using Appliances," MIT Energy Laboratory Working Paper # MIT-EL 79-049 WP, August, 1979.
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