Solar Energy and the Derived Demand for Electricity: An Irrigated Farm Example*

by

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ABSTRACT

The potential utilization of solar generated electricity to pump water on irrigated farms presents several interesting challenges to farm managers. The cost of producing solar electricity with solar systems is not currently known. Examining several solar energy utilization alternatives shows that solar energy will most likely be utilized in an environment that provides an opportunity to sell excess power. The selection of crops on the average farm will change depending on the utilization pattern of solar electricity and the availability of water. The derived demand for electricity on an irrigated farm shows that farmers will not invest in solar power units without considerable subsidies even if the price of alternative energy triples from current lends.

INTRODUCTION

No single factor has influenced the viability of the pump irrigated farms of the western United States as much as the price of the energy required to run the pumps used to draw the water. Certainly, energy price increases have hit all sectors of the national economy. Pump irrigated agriculture, however, has a unique dependence on energy pricing since the cost of the major input, water, is directly linked to the cost of energy.

Proposals to use solar energy to pump irrigation water are often heard. Indeed, several prototype solar pumped irrigation systems currently exist in the Sunbelt of the Southwest. The largest of these systems was completed in the Fall of 1979 near Coolidge in Central Arizona. The scaled down system generates approximately 150 KW_e[1/] for approximately 8 hours each day. This electricity provides the required energy to run three irrigation pumps and irrigate approximately 100 acres of cropland.

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1/ KW_e and KWh_e are used to designate Kilowatts of electricity and Kilowatt-Hours of electricity, respectively.

However, even this current state-of-the-art solar energy technology does not produce economically competitive electricity. This fact accentuates the need for a clear understanding of the management alternatives as solar energy becomes more competitive.

Of considerable interest when examining the performance of solar pumped irrigation systems is how such systems can be managed to provide maximum profits. If a solar pump system with fixed capacity is used exclusively as the energy source of an irrigated farm, the limited availability of energy to pump water may affect farm management decisions, and consequently, profits.

The purpose of this paper is to analyze the requirements for energy to pump water on a representative farm and to evaluate several alternative management schemes associated with a solar pumped system. This paper, after briefly discussing the model and alternative farm situations used in the study, analyzes the requirements for electrical energy for irrigation pumping on a typical Arizona farm. Then several specific solar farm management alternatives are analyzed. Finally, the results of the research are summarized and several implications are drawn regarding the use of solar pumping on irrigated farms.

THE SOLAR FARM MANAGEMENT MODEL

The analyses of this research were carried out using a solar farm management model which incorporates the salient features of solar energy including availability of solar radiation. The model is a linear programming model which maximizes farm returns above variable cost of producing crops subject to the normal resource constraints and constraints imposed by a solar pumping unit. The details of this model can be found in Lierman (1979).

The key information in a decision model such as the one used in this study is the availability of limiting resources. This model is keyed on available solar radiation for conversion to electricity and available irrigation water in each of 24 semi-monthly periods. The available solar radiation, computed from climatological data, is the major limiting resource of the model. The limitations on available pumpwater based on the number of potential pump hours in each day and the capacity of the pumps are also important. Tables 1 and 2 summarize the basic characteristics of the modeled farm.

DERIVED DEMAND FOR ELECTRICITY

In analyzing energy use in irrigated agriculture, the question of how much can agriculture afford to pay for electricity often arises. By using the model developed for this study, an estimate can be made of the farm level demand for electricity for a representative farm in Pinal County. This estimate of derived demand shows the potential changes in crop production as electricity prices increase.

For definitional purposes, derived demand is the quantity of electricity demanded by the representative farm to produce the profit maximizing crop mix assuming the mix must not exceed average annual production of each commodity. Although the mix of crops changes slightly over time, the basic components of the mix remain essentially unchanged. Thus, for this analysis, the 1974 crop mix data is used as an upper limit in estimating the derived demand.

The derived demand for electricity to pump irrigation water on the representative farm decreases significantly as the price of electricity increases (Figure 1). This demand curve shows two major breaks in production as crops become less profitable. The first occurs at approximately 40 mills ($\$.040/KWh_e$) when small grains become unprofitable. The second break occurs at approximately 75 mills where Upland cotton is no longer a viable crop. If electricity costs more than 80 mills, the only profitable crop is Pima cotton which is a small proportion of the base crop mix.

The relatively low electricity rate of 18.24 mills experienced in parts of Pinal County (1978) provides a rather optimistic view of potential production. This power rate is based in part on hydroelectric contracts which will not continue past the early 1980s as existing contracts expire. A comparison with the 1978 Tucson Gas and Electric Company rates for irrigation pumping shows that under the rates not affected by long term hydroelectric contracts current production would not be substantially changed but profits would certainly be less (Tucson Gas and Electric Co., 1961). More important, however, only a slight increase in the electric rate would make farming much less profitable.

In this analysis no attempt has been made to estimate the cost of producing solar generated electricity for pumping irrigation water. However, a range of electricity prices which farm managers could reasonably consider using solar energy have been derived. If the total cost per KWh_e

of producing solar generated electricity falls below 75 mills, the farm could continue to operate at a profit by producing Upland and Pima cotton, and certain speciality crops. Returns would, however, be substantially lower. The financial problems of borrowing capital to build a solar unit large enough to generate needed energy are not analyzed here except to note the energy cost associated with profit maximizing utilization of electricity as its cost increases.

SOLAR FARM MANAGEMENT ALTERNATIVES ANALYZED

The decision model previously described also serves as a suitable tool with which to analyze some alternatives in the management of a solar farm. Analysis of management strategies is based on 5 alternative plans. These plans are outlined briefly in Table 3. Since little is known about the operational cost of a commercial solar pumping unit, each of the alternatives is analyzed using several potential cost of generating solar electricity. Comparisons for several variable (from 0 to 40 mills) cost of solar energy give a good indication of the range of operations of a farm using a solar electric system similar to the one constructed in Arizona. The electricity demand of the farm modeled clearly exceed the generating potential of the original demonstration 150 KW_e system. However, some useful information on the management potentials of a solar irrigated farm can be clearly outlined from the results of an analysis that scales a solar system to fit the expected demands of the representative farm. The scale of the anticipated solar system is the major operating condition of the analysis.

MANAGEMENT ANALYSIS

Sizing of the Solar Unit

Observing that the original solar unit is inadequate to irrigate the land base of the representative farm, the question of scaling a solar unit comes to the fore. The data from the Base Farm was used to determine the optimal demands for electricity when priced at the current market rate of 18.24 mills. The average daily demand for electricity in each of 24 semi-monthly periods was computed for the Base Farm. This analysis shows that the profit maximizing Base Farm has semi-monthly peak average daily electricity demands in the first halves of February and May of 22,681 KWh_e. Peak monthly demands occur in July and September with 21,169 KWh_e average daily demand.

These peak demands illustrate that on the representative farm a 1500 KW_e solar pumping unit with a 6 hour solar storage capacity would be required to operate the farm effectively. The semi-monthly peaks in February and May could be averaged over the entire month. Thus, the critical periods are in the summer months. Under the same assumptions a peak requirement of 2100 KW_e system would be required if no storage were provided.

The additional analysis of the solar systems is carried out assuming a 1500 KW_e solar electric unit operating with average solar radiation and no solar thermal storage.

Some Results

Tables 4 shows some of results for the alternative farms. These results are of considerable interest in assessing the managerial decisions associated with a solar pumped irrigated farm.

Solar Farm 1 which can buy and sell solar electricity at the electric utility rate (\$.01824/KWh_e) has increased returns above total cost over the Base Farm for low variable cost of solar electricity. The increase in returns is substantial at zero variable cost of generating solar electricity and results from selling solar electricity (\$49,735) and the decreased cost of pumping (\$56,473).

The variable cost of producing solar electricity is analyzed from 0 to 40 mills with the cost of purchasing electricity from the utility set at 18.24 mills. When the farm has the opportunity to both buy and sell electricity at the 18.24 mills price, solar electricity will be used on farms and sells of surplus solar electricity will be made if the variable cost is below 18.24 mills. Otherwise, the farm will revert to the Base Farm situation using only purchased utility electricity.

Solar Farm 2 which may not sell solar electricity is a profitable unit. The profits are adequate if the variable cost of solar remains below the purchase cost of utility electricity. However, as the variable cost of solar electricity increase the profits of the farm decrease until it is no longer profitable to use solar electricity (at a variable cost of 18.24 mills). The crop mix for Solar Farm 2 shows some differences from the Base Farm. These differences result from the shifting of crops to meet energy availability.

Profits on Solar Farms 1 and 2 are limited by the availability of water in critical periods. Solar Farm 1 crops a total of 1212 acres and Solar Farm 2 crops 1290 acres but with less profit.

Solar Farms 3 and 4 are not allowed to purchase utility electricity. Table 4 shows a substantial variation in crop mix and total land cropped from the three farms analyzed previously. However, Solar Farm 4, i.e., a farm which can use only solar generated electricity for pumping water, is profitable only at low variable cost of solar electricity and if the farm can sell the surplus electricity at the utility rate.

Table 4 gives most of the financial information for the operation of the various farms. Only when some interaction between the solar farm and the utility occur are the returns substantial and certainly not sufficient to pay for an expensive solar energy generating system. Profits[3/] are maximized when the farm may buy electricity from or sell electricity to the utility (Solar Farm 1).

Figure 2, illustrates the electricity utilization patterns of the four Solar Farms considered in this Analysis. These farms all have the same power to generate solar electricity. However, each has a different management option for the utilization of solar electricity. On Solar Farms 1 and 2 (Variable Cost = 0) surplus electricity is sold to the utility and slack electricity is bought from the utility at 18.24 mills. In each case the utilization of electricity is dominated by summer pumping with sales of surplus water is in the Spring and Fall. Solar Farms 3 and 4, however, change crop mixes to compensate to limited total electricity available. The limiting resource is often water rather than solar electricity.

The 150 KW_e demonstration unit costs in excess of four million dollars to design and construct. Cost for larger production systems are expected to be substantially lower per unit electricity. However, the range of expected cost are not yet known. Without the option of buying utility electricity the amount of cropland that can be irrigated with the solar demonstration unit is small and the fixed cost of the relatively large farm makes all situations losses. The solar unit obviously must be larger and cheaper than the demonstration unit for solar pumped irrigation to be profitable in a solar only environment.

[3/] Profits are defined as returns above total farm cost excluding management, risk and the proposed solar pumping unit. The level of profits are limited by the available water on the solar farm. The 16 wells modeled for this analysis produce only enough water to irrigate a maximum of 1212 of the farm's 1854 net acres.

CONCLUSIONS

These analyses suggest that the critical (and yet unknown) factor in evaluating management of a solar farm is the cost of solar electricity generation. The derived demand function of Figure 1 shows the profitable range of each crop with increasing cost of electricity and 1978 crop prices. Profitability is influenced by factors other than the price of electricity. Yet, the price of electricity is a major concern. If solar electricity can be produced for prices near or below 60 mills, the farm production structure will not change substantially, Otherwise, significant changes in management may be required.

Technological development and farm level risk may substantially affect the management decisions. The utilization of alternate water-efficient technologies in the production of crops will certainly affect the potential utilization of solar energy. Sprinkler systems or other irrigation system improvements offer significant savings of water but often require additional energy inputs. Other technical improvements may do more to save energy. The use of such systems will certinly affect the utilization pattern of solar energy.

The adoption of solar generated electrical systems in irrigated agriculture also depends substantially on the existence of a system of interchange of electricity during peak demand periods and the ability of the farm to sell or utilize profitably the surplus electricity generated when water is not needed for crops.

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Table 1, Farm Characteristics [a/]

Total Farm Size	1854 acres
Irrigation Wells	16
Well Characteristics (all wells assumed to have the same average characteristics)	
well depth	585 feet
bowl depth	385 feet
pump lift	385 feet
power unit size	150 horsepower
pump well capacity	830 gallons/minute
annual pumping	552-acre-feet
Average purchase electricity price	\$ .01824 per KWH_e
Solar power plant capacity	150 KW_e

a/ Details of the representative farm including commodity production cost estimates can be found in Lierman, 1979.

Table 2, Crops potentially grown on representative farm

Potential Commodities	Units	Yield (Units/Acre)	Price ($/Unit)
Pima Cotton			
lint	lbs	699	.90
seed	tons	.484	70.00
Upland Cotton			
lint	lbs	942	.52
seed	tons	.865	70.00
Milo	cwt	3.5	4.15
Barley	cwt	3.62	4.60
Wheat	cwt	4.2	4.75
Safflower	tons	1.0	180.00
Sugarbeets	tons	19.0	25.00
Alfalfa Hay	tons	16.1	55.00

Table 3, Alternatives for the representative farm, Pinal County, Arizona

Alternative	Utility Electricity Pumping	Variable Cost Solar Electricity (mills)	Solar Electricity Pumping	Solar Electricity Selling
Base Farm	Yes	-	No	No
Solar Farm 1	Yes	0 to 40	Yes	Yes
Solar Farm 2	Yes	0 to 40	Yes	No
Solar Farm 3	No	0 to 40	Yes	Yes
Solar Farm 4	No	0 to 40	Yes	No

Table 4, Summary Results of Representative Solar Farm Model, Pinal County, Arizona

Type of Farm	Crops Produced (Acres): Upland Cotton	Pima Cotton	Wheat	Milo	Sugar & Beets	Returns Above Variable Cost (dollars)	Value of Solar Energy Sold (dollars)	Total Variable Cost of Energy For Irrigation: Utility (dollars)	Solar (dollars)	Returns[a/] to Management Risk and Solar Pumping System (dollars)
Base Farm	1035	60	117			218,330	0	67,641	0	7,977
Solar Farm 1										
VC[c/]=0	1035	60	117			324,538	49,735	11,168	0	114,000
VC=10	1035	60	117			266,310	49,735	11,168	30,961	55,772
VC=20[b/]	1035	60	117			218,330	0	67,641	0	7,977
Solar Farm 2										
VC=0	1006	60	117	19	44	275,286	0	11,645	0	64,748
VC=10	1035	60	117	78		243,948	0	13,862	31,623	33,410
VC=20[b]	1035	60	117			218,330	0	67,641	0	7,977
Solar Farm 3										
VC=0	549	60	362			244,772	26,515	0	0	34,234
VC=10	549	60	362			186,544	26,515	0	58,200	-23,994
VC=20	549	60	362			133,979	0	0	52,000	-76,559
VC=30	549	60	362			107,930	0	0	78,000	-102,608
VC=40	549	60	362			81,881	0	0	104,000	-128,657
Solar Farm 4										
VC=0	549	60	362			192,111	0	0	0	-18,427
VC=10	549	60	362			162,662	0	0	29,400	-47,876
VC=20	549	60	362			133,979	0	0	52,000	-76,559
VC=30	549	60	362			107,930	0	0	78,000	-102,608
VC=40	549	60	362			81,881	0	0	104,000	-128,657

[a/] Net returns above total variable and fixed costs excluding the cost of a solar plant (Fixed Cost of Wells = $103,664; Fixed Cost of Farm Equipment = $101,815 and Fixed Cost of Land = $5,059, Total Fixed Cost = $210,538).

[b/] For VC>20 mills the solution remains unchanged.

[c/] Variable cost of producing solar electricity.

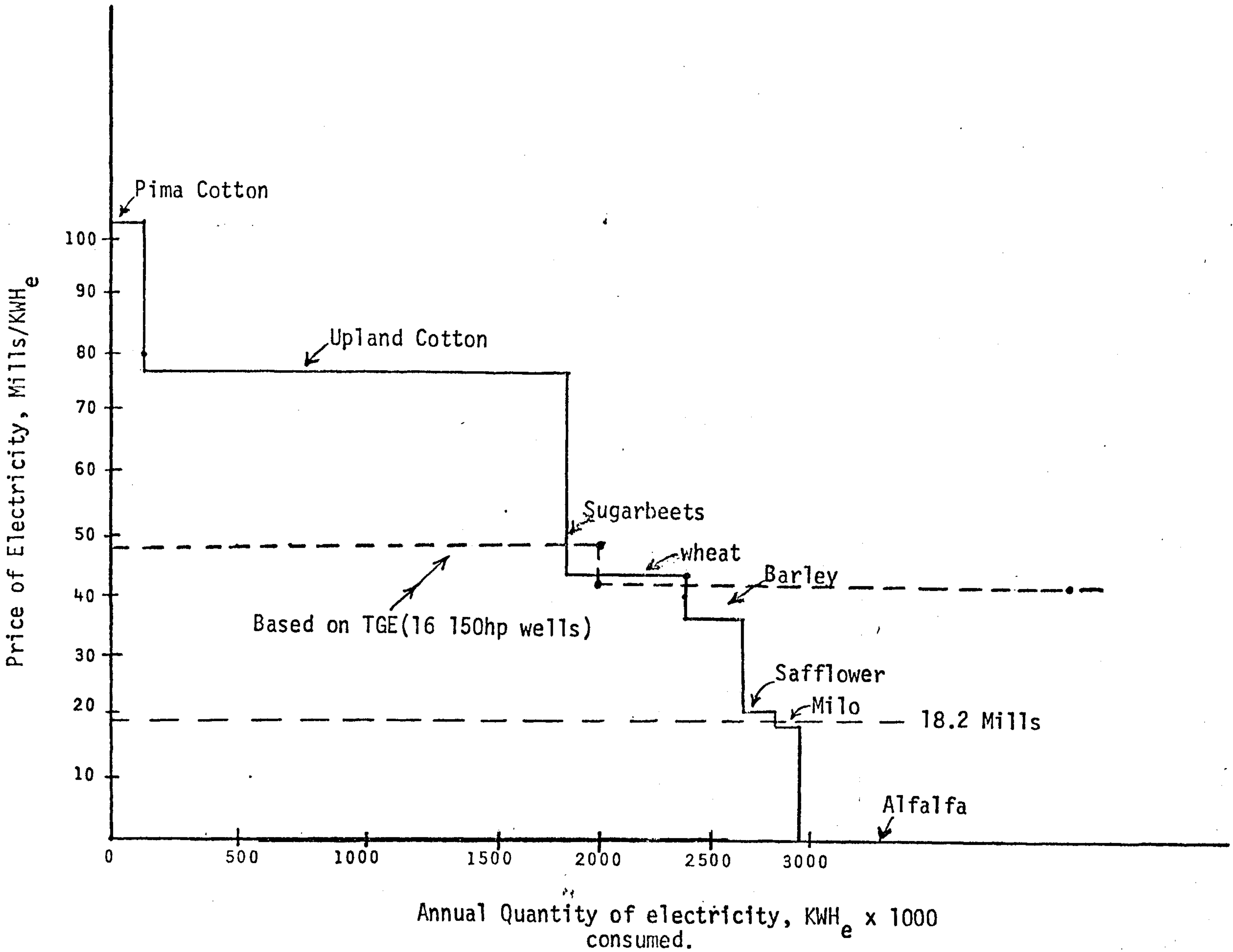

Figure 1. Representative Farm Derived Demand for electricity for pump irrigation (crop names indicate crops dropping from solution with increasing electric prices. 5.5% of the cropland in this model is reserved for crops not allowed in the representative farm.

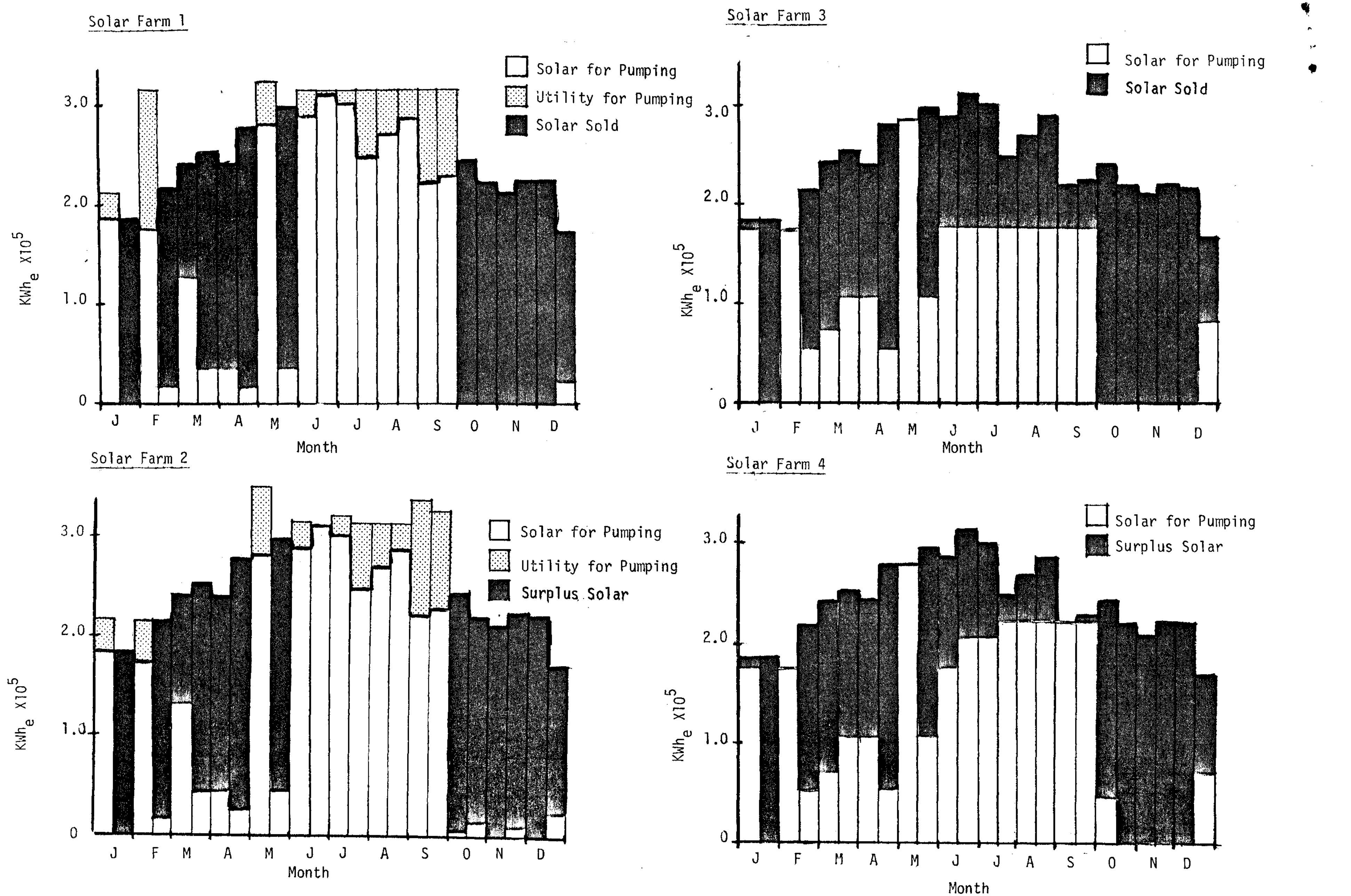

Figure 2, Electricity Utilization on Alternative Solar Farms (heavy dark horizental line indicated solar capacity)