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Economics of grid-tied household solar panel systems versus grid-only electricity

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ABSTRACT

Photovoltaic (PV) technology is available for purchase and use to provide households with electricity. The objective of this research is to determine the economic consequences of installing microgeneration grid-tied solar panel systems (4 kW; 12 kW), given alternative pricing structures for households, at five locations with different solar radiation resources. Twenty years of hourly solar radiation and temperature data, and hourly electricity use data for representative households, were obtained for each location. These data, electricity pricing rate schedules, and purchase prices and power output response functions for each solar panel system are used to address the objective. The annual household electricity cost among the five locations ranges from $845 to $1128 for smart meter rates and from $870 to $1191 for traditional accumulation meter rates. The estimated annual cost of $2148 for the least costly household grid-tied 4 kW solar panel system with net metering is two-times greater than the annual cost of purchasing from the grid. If external consequences of electricity generation and distribution are ignored, given region specific rate structures and prices, household solar panel electricity generation systems are not economically competitive in the region studied. A major finding is that the economic consequences of grid-tied household solar systems differ substantially among locations that are relatively close in proximity.

1. Introduction

Photovoltaic (PV) technology was developed in the 1950s, and work has continued to improve its efficiency [1]. PV solar panels for electricity microgeneration are manufactured by private companies, and advertised for sale to on-grid households. The economics of grid-tied household solar panel electricity generation systems have not been fully explored. Economics depends on a number of factors such as investment cost, the price of grid electricity, and the type of metering system. A comprehensive economic analysis also requires information that is more difficult to obtain, such as hourly information regarding site-specific solar radiation and temperature.

The USA state of Oklahoma has installed a unique Mesonet weather system that has recorded 20 years of hourly solar radiation and temperature data for more than 100 sites across the state [2]. The geography and climate of the state is quite diverse ranging from an elevation of 110 m with 132 cm of annual rainfall, and average solar radiation of 189 W/m^2 at Idabel (33° 49′ 48″ N 94° 52′ 49′′ W) in the southeast, to an elevation of 1267 m with 46 cm of annual rainfall, and average solar radiation of 220 W/m^2 at Boise City (36° 41′ 33′′ N 102° 29' 49" W) in the northwest [2].

Some Oklahoma households purchase electricity from investor-owned electric utilities, and others are serviced by rural electric cooperatives. The investor-owned electric utilities are natural monopolies. In the USA, rates charged by investor-owned public utilities are regulated by state authorities. The Constitution of the State of Oklahoma provides the Oklahoma Corporation Commission (OCC) with the authority and responsibility to supervise, regulate, and control Oklahoma investor-owned electric utilities [3]. The OCC is charged with the responsibility of ensuring adequate service, preventing unfair charges to the public, protecting the utilities from unreasonable demands, and enabling a fair return to investors [4].

The OCC has approved two pricing rates currently offered to farms and households-alternative I and alternative II-as shown in Appendix A [5]. Alternative I is based on the traditional (accumulation) meter, where fixed prices per kilowatt-hour (kW h) are charged independent of the time of day the electricity is consumed. Traditional meters measure total consumption, but do not provide information on when the energy is used during the time period of interest [6]. Households are charged based on the total electricity consumed in the billing period (assumed to be one month).

Some households in the region are equipped with smart meters that enable two-way communication between the electric company and their customers. They facilitate real-time monitoring of electricity flows and are

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designed to enhance both the technical and allocative efficiency of electricity markets. Smart meters enable the utility to charge different rates during different times of the day. Different rates for different hours of the day may be used to incentivize reductions in electricity use during traditional peak time periods (for example, between 2 p.m. and 8 p.m. on hot summer days when electricity is used to power air conditioners). The OCC approved alternative II, as shown in Appendix A, in conjunction with the introduction and application of smart meters [7].

This study builds on prior research and extends it in several important aspects [8–12]. First, 20 years of hourly solar radiation data as recorded by the Mesonet weather monitoring system enables empirical estimates of solar panel electricity production for each hour of each month for each of the five unique locations [2]. Second, the modeling system also accounts for differences in temperature when estimating electricity production. Third, representative households as defined from census data for structure size and characteristics and number of occupants were defined for each of the five locations. Estimates of household electricity consumption by these representative households for each hour for each month for each location were obtained from simulations by the USA Department of Energy [13]. These simulations find that each location has a unique average load profile resulting from differences in climate and household characteristics. Fourth, the representative household use estimates are based on expected response to traditional accumulation meter prices. Smart meter systems use different prices for different times of the day to incentivize households to shift some consumption from peak to off peak times. An electricity demand price elasticity estimate is used to estimate household use response to price changes associated with a switch from a traditional meter to a smart meter. Fifth, cost estimates are produced for both traditional accumulation meter and smart meter rate structures. In the case study region, households with smart meters encounter four different rates depending on hour of the day, month of the year, and quantity of household use during the billing period. The major unique contribution of the study is that the 20 years of site specific hourly data enables a rather precise determination of the extent to which the economics of grid-tied solar systems differ among locations that are geographically in close proximity.

Several studies have been conducted to determine the economics of off-grid stand-alone systems that include either a diesel generator, or battery, or fuel cell to be used in combination with solar panels [14–21]. The present study is limited to grid-tied systems. The objective of this research is to determine the economic consequences of installing microgeneration grid-tied solar panel systems (4 kW; 12 kW) given alternative pricing structures (traditional accumulation meter; smart meter), with and without net metering, for households at five Oklahoma locations. Solar radiation resources differ substantially across the state. The five sites were chosen to encompass the range of variability in the state's solar radiation resources; Boise City in the Northwest (36° 41′ 33″ N 102° 29′ 49″ W), Miami in the Northeast (36° 53′ 17″ N 94° 50′ 39″ W), Shawnee in the center (35° 21′ 53″ N 96° 56′ 53″ W), Hollis in the Southwest (34° 41′ 7″ N 99° 49′ 59″ W), and Idabel in the Southeast (33° 49′ 48″ N 94° 52′ 49″ W)). The purchase price at which each of the solar panel systems breaks even with the grid-only system will be determined. In addition, the percentage change in grid prices required for the household solar systems to break even with grid-only purchased electricity will be determined for both traditional and smart meters. The findings will enable a determination of the economic consequences of household solar microgeneration systems for each location. Thus, the precise price data, in combination with the precise weather data, enable precise site-specific estimates of the economic consequences and economic potential of grid-tied household solar systems.

2. Conceptual framework

The economics of a household grid-tied solar panel system depend on the cost of owning and operating the system, the amount and timing of electricity produced by the system, the quantity and timing of electricity required by the household, the net cost of electricity from the grid, the grid pricing structure, and the absence or presence of net metering.

2.1. Estimation of solar panel power output

Theoretically, the power output produced by a solar panel is a function of the panel's area, mechanical efficiency (proportion of energy in the solar radiation transferred into electricity), solar radiation, and temperature [22]. The electricity output (kW) from a solar panel can be described as:

$$P\ =0.\ 001(IA\eta_{PV}\varphi), \tag{1}$$

where P is the power output (kW); I is the solar radiation (W/m^2); A is the area of the PV in m^2; and η_{PV} is the mechanical efficiency (overall efficiency of the PV panels) in percentage; and φ is included to account for efficiency losses.

2.2. Estimation of the annual electricity cost for each alternative

For a household serviced by a traditional meter, the annual cost of electricity is calculated as:

$$ECTM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j ERTM_{jr} G_{jr}, \tag{2}$$

where $ECTM$ is the annual electricity cost for a household using a traditional meter; BC_j is a fixed base charge per month independent of electricity use; $ERTM_{jr}$ is the OCC traditional meter rate for the jth month and rth block ($/kW h); and G_{jr} is the net quantity of electricity used (kW h) in rth block and jth month, and D_j is the number days in the jth month, if j=1, 3, 5, 7, 8, 10, or 12 then D_j=31, if j=4, 6, 9, or 11 then D_j=30, and if j=2 then D_j=28.

For a household serviced by a smart meter, the annual cost of electricity is calculated as:

$$ECSM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j \sum_{i=1}^{24} ERSM_{ijr}(G_{ijr} \varepsilon PC_{ijr}), \tag{3}$$

where $ECSM$ is the annual electricity cost for the household using the smart meter rate, and $ERSM_{ijr}$ is the OCC smart meter rate ($/kW h); ε is the demand price electricity elasticity; and PC_{ijr} is the percent change in electricity prices from traditional meter to smart meter rates for the ith hour and rth block during the jth month, where i=1, 2, 3, ..., 24.

The annual charge for net electricity withdrawn from the grid for a household with a grid-tied solar panel based on the traditional meter rate schedule with net metering would be:

$$ECTMN = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j ERTM_{jr}(G_{jr} - P_{jr}), \tag{4}$$

where $ECTMN$ is the annual electricity cost for the household, and P_{jr} (kW h) is the electricity produced by the solar panel in rth block, during the jth month, where $(G_{jr}-P_{jr}) \geq 0$.

The annual charge for net electricity withdrawn from the grid for a household with a grid-tied solar panel based on the smart meter rate schedule with net metering would be:

$$ECSMN = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j \sum_{i=1}^{24} ERSM_{ijr}((G_{ijr} \varepsilon PC_{ijr}) - P_{ijr}), \tag{5}$$

where $ECSMN$ is the annual electricity cost for the household with the grid-tied solar system using the smart meter rates with the opportunity of net metering, where $((G_{ijr}\varepsilon PC_{ijr})-P_{ijr}) \geq 0$.

2.3. Estimation of breakeven price of the solar panel

To determine the purchase price at which an investment in a solar panel system would break even with grid only electricity, the difference between the present value of the cost before and after adopting the solar panel is determined.

For the households paying traditional meter rates, the breakeven price is:

$$BETM = \frac{\sum_{t=1}^{T} ECTM_t}{(1+r)^t} - \frac{\sum_{t=1}^{T} ECTMN_t}{(1+r)^t}, \tag{6}$$