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 \$1,128 for smart meter rates and from \$870 to \$1,191 for traditional accumulation meter rates. The estimated annual cost of \$2,148 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.

Key words: cost, grid-tied, net metering, smart meter, solar panel

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 watt/m² at Idabel (33° 49' 48" N 94° 52' 49" W) in the southeast, to an elevation of 1,267 m with 46 cm of annual rainfall, and average solar radiation of 220 watt/m² 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 (kWh) 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 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:

$$(1) P = 0.001(I A \eta_{PV} \varphi),$$

where P is the power output (kW); I is the solar radiation (W/m²); A is the area of the PV in m²; 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:

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

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 j^{th} month and r^{th} block (\$/kWh); and G_{jr} is the net quantity of electricity used (kWh) in r^{th} block and j^{th} month, and D_j is the number days in the j^{th} month, if $j = 1, 3, 5, 7, 8, 10, \text{ or } 12$ then $D_j = 31$, if $j = 4, 6, 9, \text{ or } 11$ 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:

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

where $ECSM$ is the annual electricity cost for the household using the smart meter rate, and $ERSM_{ijr}$ is the OCC smart meter rate (\$/kWh); 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 i^{th} hour and r^{th} block during the j^{th} month, where $i = 1, 2, 3, \dots, 24$.

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:

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

where $ECTMN$ is the annual electricity cost for the household, and P_{jr} (kWh) is the electricity produced by the solar panel in r^{th} block, during the j^{th} 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:

$$(5) \text{ EC SMN} = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j \sum_{i=1}^{24} \text{ERSM}_{ijr} ((G_{ijr} \varepsilon PC_{ijr}) - P_{ijr}),$$

where *EC SMN* 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 $(G_{jr} - P_{jr}) \geq 0$.

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:

$$(6) \text{ BETM} = \frac{\sum_{t=1}^T \text{ECTM}_t}{(1+r)^t} - \frac{\sum_{t=1}^T \text{ECTMN}_t}{(1+r)^t},$$

where *BETM* is the solar panel breakeven price for traditional meter rate households; *t* is the years, where $t = 1, 2, \dots, T$; and *r* is the discount factor rate.

For the households that are charged smart meter rates, the breakeven price is:

$$(7) \text{ BESM} = \frac{\sum_{t=1}^T \text{EC SM}_t}{(1+r)^t} - \frac{\sum_{t=1}^T \text{EC SMN}_t}{(1+r)^t},$$

where *BESM* is the solar panel breakeven price for smart meter rate households.

2.4. Estimation of percentage change of the electricity price rates to break even with the solar panels

For the prevailing prices for grid electricity as reported in Appendix A, grid-tied solar panel systems are more costly to the households than grid-only electricity. A mathematical programming model may be formulated to determine the percentage increase in the prices reported in Appendix A at which the cost of the grid-tied solar panel system is equal to the cost of grid-only electricity. Consider the model that follows (equations 8, 9, and 10) for households paying traditional meter rates.

$$(8) \text{ Min}_{PR} Z = |ECTM - ASPCT| \text{ subject to}$$

$$(9) ECTM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j (ERTM_{jr} * PR)(\sum_{i=1}^{24} G_{ijr})$$

$$(10) ECTM = ASPCT,$$

where equation 10 is set to equate the annual electricity cost for a household using grid-only electricity ($ECTM$) with the annual cost of the solar panel system ($ASPCT$). Equation 8, the objective function, is set up to minimize the absolute value of the difference between $ECTM$ and $ASPCT$ which will optimally be zero when the two are equal. In equation 9, the model solves for the level of PR , the choice variable that represents the percentage change in the prices, at which the two costs will be equal. Other variables are as previously defined.

For the households paying smart net metering rates, equations 11, 12, and 13 may be solved to determine the percentage change in rates (PR) required for the solar panel system to break even with grid-only electricity.

$$(11) \text{ Min}_{PR} Z = |ECSM - ASPCS| \text{ subject to}$$

$$(12) ECSM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j (\sum_{i=1}^{24} (ERSM_{ijr} * PR)G_{ijr})$$

$$(13) ECSM = ASPCS,$$

where $APSCS$ is the annual cost of the solar panel using smart net metering rates.

2.5. Estimation of the annual cost of the solar panel.

Households that invest in a solar panel system in the case study region will incur ownership costs. These costs may be categorized as depreciation, interest, insurance, and property tax [23]. Depreciation is the cost resulting from the reduction in the value of an asset with the passage of time. Interest is the cost incurred because the money invested in the solar panel is not available for investing elsewhere, or alternatively it is the cost of the money borrowed to finance the asset. Insurance against loss to catastrophes such as fire and tornadoes

also is costly. Finally, in the case study region, property taxes are assessed based on value. An addition of solar panels would result in a greater assessed value and added annual property tax.

The following equations were used to estimate the annual cost of the solar systems [24]

$$(14) \quad \text{Depreciation } \left(\frac{\$}{\text{year}} \right) = \frac{(\text{Purchase Price} - \text{Salvage Value})}{\text{Years of Life}},$$

where purchase price is the cost of the system (\$), salvage value is the estimated resale value of the system at the end of its useful life (\$), and years of life is the estimated useful life of the system.

$$(15) \quad \text{Interest } \left(\frac{\$}{\text{year}} \right) = \frac{\text{Purchase Price} + \text{Salvage Value}}{2} * \text{Interest Rate},$$

where interest rate is the opportunity cost of capital.

$$(16) \quad \text{Insurance } \left(\frac{\$}{\text{year}} \right) = \frac{\text{Purchase Price} + \text{Salvage Value}}{2} * \text{Insurance Rate},$$

where insurance rate is the market rate for household insurance.

$$(17) \quad \text{Property Tax } \left(\frac{\$}{\text{year}} \right) = \text{Average Assessed Value} * \text{Tax Rate},$$

where average assessed value of the system in dollars is taxed at a rate per dollar of value.

3. Data and Method

3.1. Hourly weather data

Hourly weather data were obtained for each location from the Oklahoma Mesonet. The solar radiation and temperature values were used in combination with equation (1) to produce an estimate of power output for each of 24 hours for each of 12 months. For example, the power output estimate for hour one for January is the mean of 620 observed values; 31 days of hour one observations for each of 20 years. These data may be used to estimate the expected power output from solar panel systems at a specific site for each hour of the day for each month.

3.2. Residential hourly electricity data

Residential hourly electricity simulated load profiles for each of the five households were obtained from the U.S. Department of Energy [13]. The characteristics of the house and household to be modeled are reported in Table 1. These load profiles produced point estimates of electricity use for a representative average household for each hour for each month for each location. These point estimates are assumed to be appropriate for households subject to traditional meter rates and do not reflect household response to changes in electricity prices depending on time of use.

Table 1: Characteristics of the House and Household being Modeled

Characteristics	Description/Unit	
	Mixed Humid†	Mixed Dry
Building Fuel Types		
Space Heating	Natural Gas	Natural Gas
Air Conditioning	Yes	Yes
Water Heating	Natural Gas	Natural Gas
Building Structure Types		
Total Size	236.5 (m ²)	185.8 (m ²)
Number of Stories/Level	1 Story	1 Story
Bedrooms	3	3
Bathrooms	1	2
Basement	No	No
Type of Glass in Windows	Double-pane Glass	Single-pane Glass

Source: National Renewable Energy Laboratory

† Hollis, Shawnee, Miami, and Idabel are included in the mixed humid region. Boise City is included in the mixed dry region.

3.3. Traditional and smart meter rates residential electricity demand

Alternative II smart meter systems and block rates are intended to incentivize shifts in electricity use from peak to off-peak time periods (Appendix A). These systems are intended to

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4 221 reduce the utility's total peak electricity production requirement and thereby reduce expensive
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6 222 peak load production. The substantially higher prices for block E are expected to encourage
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9 223 households to shift some electricity use such as that used for laundry, dishwashing, and baking
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11 224 from block E to block F. Households have less flexibility for shifting use for heating and cooling.
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14 225 However, a higher price for electricity used to power air conditioners provides an incentive to
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16 226 adjust household thermostats.
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19 227 Household electricity demand price elasticity is a measure of household response to
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21 228 electricity price changes. An elasticity estimate in combination with information regarding the
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23 229 percentage change in price may be used to estimate the expected change in electricity
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25 230 consumption during a block when a household shifts from traditional (Alternative I) to smart
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27 231 meter (Alternative II) pricing. Bernstein and Griffin [25] estimate a household electricity demand
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29 232 price elasticity of -0.174. By this measure, households would be expected to respond to a 1.0%
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31 233 increase in the electricity price by decreasing use by 0.174%. Thus, for the block E price change
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33 234 of 125% (from \$0.0811 to \$0.1826 /kWh) and the elasticity estimate of -0.174, the household is
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35 235 expected to reduce electricity use by 21.75%. For block F for which the price is reduced by 39%
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37 236 (from \$0.0795 to \$0.0481/kWh) and the elasticity estimate of -0.174, the household is expected
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39 237 to reduce electricity use by 6.8%.
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45 238 3.4. Net Metering System 46 47

48 239 Some households with installed grid-tied PV solar panels may engage in contractual
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50 240 arrangements with their local utilities that permit net metering. Under net metering, households
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52 241 are charged for the difference between the total electricity removed from the grid (during the
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54 242 billing period) and the total electricity provided to the grid (during the billing period) by the
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56 243 household's solar panels. During nights and cloudy days when the PV panels do not produce
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electricity, the household will use electricity from the grid. When sunshine is available and the household's solar panels are producing more electricity than household use, the excess can be sent to the grid for use by others. Households with net metering are charged for the quantity of electricity removed from the grid minus the quantity of electricity provided to the grid during the billing period. By OCC policy, households are not compensated for production in excess of use during a billing period [26]. However by OCC policy, if a household system is tied to the grid, any excess electricity produced must be made available to the grid. If net metering is not in effect, the household would be required to pay for each kWh removed from the grid and receive zero compensation for all production in excess of household use.

Households that have smart meters may opt to enroll in the alternative I or alternative II pricing systems subject to 12 month contracts that may be renewed each year. Smart meter net-metering charges to a household are determined by use during each block (on-peak and off-peak) for each billing period (monthly), as shown in Appendix A [5]. For example, when totaled over a typical 30 day billing period, production in excess of household use during block E cannot be used to offset use during block F. And, as noted, if total production during block E for the billing period exceeds total household use during the same period, the net excess is provided to the grid. For example, suppose that during the first 15 days of a billing period during block E the solar panels produced zero electricity but the household used 500 kWh. Further, suppose during days 16 through 30 the household used another 500 kWh and the solar panels produced 1,200 kWh. Without net metering, the household would be charged for 500 kWh (\$13 base charge plus $\$0.1826/\text{kWh} * 500 \text{ kWh} = \104.30 for the billing period). With net metering, the household would be charged only the \$13 base charge. In effect, with net metering the utility purchases 500 kWh from the household at the retail price of \$0.1826/kWh and receives an additional 200 kWh

for a price of \$0.00/kWh. Without net metering the utility (the grid) would receive 700 kWh for no charge.

3.5. PV solar panel modules

Total annual estimated electricity consumption for the case study households ranged from approximately 9,000 kWh for the representative Boise City household to 14,000 kWh for the Hollis household. Given the average daily use, average number of solar hours per day, and the expected DC to AC transfer efficiency, a 4 kW solar panel system would be recommended for these households [27]. Vendors contacted to obtain price information for a 4 kW system, requested that economics also be determined for a 12 kW system. Installed cost information was obtained for both a 4 kW and a 12 kW system with 17% panel efficiency. These 4 kW and 12 kW systems would require 27.9 m² and 92.9 m² of roof area, respectively. The installed costs including all required components and wiring are estimated to be \$32,000 for the 4 kW system and \$65,000 for the 12 kW system [28].

3.6. PV solar panel efficiency loss

As noted, ϕ is included in equation (1) to account for efficiency losses that result between the electricity produced by the PV panels and the electricity available for use by the household [29, 30]. First, inverter losses result when the power output is transformed from direct current (DC) to alternating current (AC). The default loss due to the inverter is assumed to be 8%. Second, mismatch losses occur when the level of production differs across the solar cells included in the panels. For example, when one solar cell is not performing at full capacity while the other cells in the module are, the power generated by the "good" solar cells can be affected by the lower performance cell. The overall default loss of the PV solar panel due to mismatch is assumed to be 2%.

Third, loss occurs at connecting points and at diodes that are required to restrict the flow of electricity to one direction. Resistive loss is assumed to be 0.5%. Fourth, some power output is lost due to the cables and wires used throughout the system. DC cables result in losses between the PV module and the inverter. AC cables account for losses between the inverter and household use. DC and AC cable losses are assumed to be 2% and 1%, respectively. Fifth, dust, dirt, snow, or other foreign matter on the surface of the PV module will reduce the amount of solar radiation that the PV module can absorb. These soiling losses are assumed to be 5%.

Sixth and seventh are sun-tracking and shading losses, respectively. The losses from both factors are assumed to be zero. It is assumed that the system will be installed at the optimum orientation for sun-tracking and that the system will be installed in an area that is opened to sunshine and not subject to shading by either buildings or trees. The eighth factor that influences solar panel efficiency is ambient temperature. PV module efficiency is a function of temperature. For each degree higher than 25°C the efficiency of the PV module will decrease by 0.5% [30, 31].

3.7. Assumptions for estimating the annual cost of the solar panels

The solar panel systems are assumed to be installed and used for their estimated life of 40 years. The salvage value is assumed to be zero. A 5% interest rate and discount factor are assumed. The insurance rate is assumed to be 0.6%. The property tax rate was obtained from Addcox et al. [32]. Estimates of costs for both systems are reported in Table 2.

Table 2: Purchase price and annual cost for two solar panel systems

Description	Unit	12 kW Solar Panel	4 kW Solar Panel
Purchase Price	\$	65,000	32,000
Life	years	40	
Depreciation	\$/year	1,625	800
Interest on Average Investment	\$/year	1,625	800
Insurance	\$/year	195	96
Property Tax	\$/year	335	165
Repairs	\$/year	-	-
Total Annual Cost	\$/year	3,780	1,861

Source: Green Wind and Solar Company provided the purchase price for the solar panels. Salvage value is assumed to be zero at the end of life for each of the systems.

4. Results and Discussion

The electricity use estimates produced by the U.S. Department of Energy [16] are assumed to be quantities demanded in response to the traditional meter price structure as reported in appendix A. Table 3 includes expected electricity use estimates for each August 15th hour for Boise City and Hollis. The U.S. Department of Energy [16] estimates are reported in the traditional meter columns. Values in the smart meter columns reflect use adjustments expected if the household transitions from traditional to smart meter prices. These smart meter use levels are based on the elasticity estimate of -0.174 and the price changes reported in appendix A. Less use is expected for hours 14 through 19 in response to the 125% increase in price. More use is expected for hours 20 through 13 in response to the 39% decline in price. By this measure, a switch from traditional to smart meter rates is expected to decrease total expected August 15th electricity use by 3.8% at Boise City and by 3.9% at Hollis.

Table 3: August 15 expected electricity consumption for Boise City and Hollis households using traditional meter rates and smart meter rates

Hour	Boise City Traditional Meter Expected Consumption (kWh)	Boise City Smart Meter Expected Consumption (kWh)	Hollis Traditional Meter Expected Consumption (kWh)	Hollis Smart Meter Expected Consumption (kWh)
1	0.878	0.938	0.688	0.735
2	0.736	0.786	0.592	0.633
3	0.615	0.657	0.545	0.583
4	0.555	0.593	0.524	0.560
5	0.554	0.592	0.572	0.611
6	0.579	0.619	0.707	0.756
7	0.820	0.876	0.853	0.911
8	0.760	0.812	0.749	0.801
9	0.722	0.772	0.615	0.658
10	0.980	1.047	0.640	0.684
11	1.093	1.168	0.728	0.778
12	1.273	1.360	0.860	0.919
13	1.454	1.554	0.986	1.054
14	1.600	1.252	1.173	0.918
15	1.779	1.392	1.414	1.106
16	1.991	1.558	1.581	1.237
17	1.865	1.459	1.921	1.503
18	1.824	1.427	1.903	1.488
19	1.751	1.370	1.873	1.465
20	1.832	1.958	1.920	2.052
21	1.842	1.969	1.944	2.078
22	1.487	1.589	1.520	1.625
23	1.161	1.240	1.176	1.256
24	0.831	0.887	0.786	0.839

With the transition from traditional meter (block A) to smart meter (block E) rates (14 through 19), the expected electricity consumption for households using smart meter rates is decreased due to the respond of the household to the demand elasticity estimate of -0.174 and 125% increase in the price rates

With the transition from traditional meter (block A) to smart meter (block F) rates (20 through 23), the expected electricity consumption for households using smart meter rates is increased due to the respond of the household to the demand elasticity estimate of -0.174 and 39% decrease in the price rates

Estimates of monthly (assumed to be the billing period) and total annual electricity consumption for each of the five households for both traditional and smart meter rates are shown in appendices B through F. Implementation of the smart meter rates is expected to reduce total annual use by 1.4% at Miami and by 2.0% at Hollis. Annual use at Boise City, the lowest use household, is expected to be 36% less than that of the greatest use household at Hollis.

Appendices B through F also contain estimates of total electricity use; expected production from the solar systems; quantity withdrawn from the grid; quantity produced by the solar systems that is used by the household; quantity produced by the solar system that is made available to the grid; and quantity made available to the grid that is in excess of use for the billing period.

Total June electricity use for the Boise City household using a traditional meter is estimated to be 888 kWh (Appendix B). Total June production from the 4 kW system is estimated to be 867 kWh. However, since nothing is produced at night and since some days are cloudy, 427 kWh are used from the grid, and only 460 kWh (53%) of the 867 kWh produced by the 4 kW system are used by the household. An estimated 407 kWh are returned to the grid. If net metering is in effect, these 407 kWh may be used to offset 407 kWh withdrawn from the grid, and the household will be charged for only 20 kWh. If net metering is not in effect, the household would be charged for 427 kWh.

Total June electricity use for households using a smart meter and alternative II rates is estimated to be 852 kWh; 194 kWh during block E and 658 kWh during block F (Appendix B). Total household use is 36 kWh less than with the traditional meter since households are expected to respond to the price changes included in alternative II rates. During block E (hours 14 through 19), the 4 kW system is expected to produce 293 kWh. The household is expected to use 30 kWh from the grid and 163 kWh from the 4 kW system and to return 130 kWh to the grid. If net

metering is in effect, these 130 kWh may be used to offset 30 kWh removed from the grid, and the additional 100 kWh would be provided to the grid for no compensation. If net metering is not in effect, the household would be charged for 30 kWh. During June block F hours (hours 20 through 13), the 4 kW system for the Boise City household is expected to use 658 kWh and produce 574 kWh. However, the household is expected to use 389 kWh from the grid, since timing of solar production does not mesh with household use. If net metering is in effect, 305 kWh would be used to offset kWh withdrawn from the grid, and the household will be charged for 84 kWh. If net metering is not in effect, the household would be charged for 389 kWh.

Total estimated use for the Boise City smart meter alternative II rates household is 9,029 kWh. The 4 kW system is expected to produce 7,458 kWh (83% of use). However, production timing is such that only 3,735 kWh are produced at times that they can be used by the household. By this measure, the 4 kW system produces only 41% of the electricity used by the household. If net metering is not in effect, the household would be required to purchase 5,295 kWh from the grid, 59% of its total annual use. However, if net metering is in effect, the household would be able to sell 3,035 kWh to the grid to offset use and purchase a net of 2,259 kWh. Without net metering, the utility would charge the household for 59% of total annual kWh used. Net metering reduces that to 25%.

Total annual electricity production from a 4 kW system at Hollis is expected to be equal to 51% of the annual use. However, only 75% of the expected production is available at times during which it can be used by the household. If net metering is not in effect, the Hollis household would purchase 62% of total annual use from the grid. If net metering is in effect, the net purchase would be reduced to 49%. A 4kW system at Miami is expected to produce 50% of the annual quantity used. However, if net metering is not in effect, the Miami household would

purchase 64% of annual use. If net metering is in effect, net purchase would be reduced to 50% of annual use.

Figures 1, 2, and 3 show the electricity consumption for the traditional and smart meters and power output for each solar panel system for the five case study locations for the months of January, April, and July. In winter (January) and in spring (April), the electricity consumption is the same for the traditional and smart meter as the price rates are the same. As the charts illustrate, location and time of year matters, as production and consumption of electricity differ among locations.

[Insert Figure 1 near here]

Figure 1: : Estimates of electricity consumption and power output for two solar panel systems for the five locations, Oklahoma representative household in January.

[Insert Figure 2 near here]

Figure 2: Estimates of electricity consumption and power output for two solar panel systems for the five locations, Oklahoma representative household in April.

[Insert Figure 3 near here]

Figure 3: Estimates of electricity consumption and power output for two solar panel systems for the five locations, Oklahoma representative household in July.

The annual cost of installing and maintaining each of the solar panel systems is reported in Table 2. Payments to the utility and annual cost of electricity for the case study household for each location and each of ten alternatives are reported in Table 4. The ten alternatives are: (1) traditional meter, (2) smart meter, (3) traditional meter with 4 kW solar panel with net metering, (4) traditional meter with 12 kW solar panel with net metering, (5) smart meter with 4 kW solar panel with net metering, (6) smart meter with 12 kW solar panel with net metering, (7) traditional meter with 4 kW solar panel without net metering, (8) traditional meter with 12 kW solar panel without net metering, (9) smart meter with 4 kW solar panel without net metering, and (10) smart meter with 12 kW solar panel without net metering.

Given prices and use assumptions, neither of the solar panels is economically competitive at any of the five locations, for either rate structure or metering system. Average annual payment to the utility across the five households that do not have solar panels is \$1,075 for the traditional meter and \$1,024 for the smart meter. The annual cost range among the five locations is estimated to be \$845-\$1,128 for the smart meter system and \$870-\$1,191 for the traditional meter system. Based on the assumed price elasticity estimate of -0.174, the pricing structure provides a small incentive for the modeled household to select the smart meter rate structure.

Table 4 shows the estimated annual payment to the utility with and without net metering for both solar panel systems for each of the five locations. The annual payment range among the five locations is estimated to be \$425-\$563 for the smart meter system without net metering and \$156-\$181 for the smart meter system with net metering for the 12 kW system. The annual payment for traditional metering without and with net metering for the 12 kW system among the five locations is estimated to be \$525-\$718 and \$156-\$181, respectively.

For Boise City traditional meter households, the annual cost of electricity from the grid is \$870 per year. For an annual cost of \$3,780 for a 12 kW system, the household could reduce annual payments to the utility by \$345. Clearly, a choice to pay \$3,780 to save \$345 (or \$714 with net metering) would not be preferred by most households. Alternatively, for an annual cost of \$1,861 the household could install a 4 kW system and reduce annual payments to the utility by \$284 (or \$542 with net metering). The choice to pay \$1,861 to save \$542 would be declined by most households. The estimated annual cost of \$2,148 for the least costly 4 kW solar panel system for the Boise City household is more than two times greater than the annual cost of purchasing from the grid via a smart meter system. Given the budgeted price structure and the solar radiation resources, household solar panels are not economically viable alternatives for the region studied.

Utility company revenue would be impacted substantially if a number of their customers installed household solar systems. For example, annual revenue from the average household with an installed 12 kW system and a traditional meter would decrease by \$412 from \$1,075 to \$663 (Table 4). If net metering was in effect, the average annual revenue received from the household would decrease by \$910 to \$165. Some of these losses might be offset by the value of the electricity provided to the grid. However, utility companies clearly have an interest in the consequences of the development of household solar systems and in public policy regarding net metering.

Table 4: Annual cost of electricity for a representative five locations, Oklahoma household, for three alternative rate structures

Location	System	Unit	Alternative I: Traditional Meter				Alternative II: Smart Meter					
			Payment to Utility	Without Net Metering	With Net Metering	Total Cost without Net Metering	Total Cost with Net Metering	Payment to Utility	Without Net Metering	With Net Metering	Total Cost without Net Metering	Total Cost with Net Metering
Boise City	Grid-Only	\$/yr	870					845				
	12 kW Solar Panel	\$/yr		525	156†	4,305	3,936		425	156	4,205	3,936
	4 kW Solar Panel	\$/yr		586	328	2,447	2,189		482	287	2,343	2,148
Hollis	Grid-Only	\$/yr	1,191					1,128				
	12 kW Solar Panel	\$/yr		718	156	4,498	3,936		558	156	4,338	3,936
	4 kW Solar Panel	\$/yr		836	700	2,697	2,561		680	566	2,541	2,427
Shawnee	Grid-Only	\$/yr	1,122					1,066				
	12 kW Solar Panel	\$/yr		697	166‡	4,477	3,946		561	166	4,341	3,946
	4 kW Solar Panel	\$/yr		800	674	2,661	2,535		658	537	2,519	2,398
Miami	Grid-Only	\$/yr	1,066					1,010				
	12 kW Solar Panel	\$/yr		675	181	4,455	3,961		522	181	4,302	3,961
	4 kW Solar Panel	\$/yr		769	639	2,630	2,500		644	555	2,505	2,416
Idabel	Grid-Only	\$/yr	1,128					1,072				
	12 kW Solar Panel	\$/yr		701	169	4,481	3,949		563	169	4,343	3,949
	4 kW Solar Panel	\$/yr		809	696	2,670	2,557		669	563	2,530	2,424

The base charge = 12 * 13 = \$156 per yr. Any value above \$156 per yr will be considered as the payment for the kWh in the billing period

† Boise City household has to pay \$ 156 per yr for base charge only

‡ Shawnee household has to pay \$ 156 per yr for base charge, in addition \$ 10 per kWh per yr used from the grid

Table 5 shows the breakeven installation costs for both solar panel systems for each location, for both traditional meter and smart meter rates, with and without net metering. These breakeven prices can be compared to the estimated installation costs of \$65,000 for the 12 kW system and \$32,000 for the 4 kW system. Among the 10 12 kW situations evaluated, the greatest breakeven installation cost of \$17,758 is for the Hollis household on a traditional meter rate system with net metering. In other words, to break even with grid-only electricity, the installed cost of the system would have to decrease by \$47,242 (73%). If net metering is not in effect, then the installed cost of the 12 kW system on a traditional meter rates in Hollis would have to decrease from \$65,000 by 87.5% to \$8,123 for the cost of the 12 kW system to break even with purchasing electricity from the grid.

Equations 8, 9, and 10 are solved to determine the percentage change in electricity price rates at which grid-only electricity would break even with a household solar panel system for households paying traditional meter rates. For net metering at the Hollis household, the 12 kW system on a traditional meter rate would break even with grid-only electricity at a rate increase of 366%, from \$0.0811 and \$0.0918, \$0.0795, \$0.0359, \$0.0795, and \$0.0811 for Blocks A₁, A₂, B₁, B₂, C, and D respectively to \$0.2969, \$0.3361, \$0.2909, \$0.1314, \$0. 2909, and \$0. 2969 for Blocks A₁, A₂, B₁, B₂, C, and D respectively. For the 4kW system, the breakeven rate increase is 233%, from \$0.0811 and \$0.0918, \$0.0795, \$0.0359, \$0.0795, and \$0.0811 for Blocks A₁, A₂, B₁, B₂, C, and D respectively to \$0.189, \$0.2139, \$0.1852, \$0.0836, \$0. 1852, and \$0. 189 for Blocks A₁, A₂, B₁, B₂, C, and D respectively.

Table 5: Breakeven prices of the two solar panel systems for the Oklahoma five locations (\$), and the percentage increase in price rates to breakeven with the solar systems.

Location	System	Solar systems breakeven prices for household using Alternative I: Traditional Meter (\$)	Solar systems breakeven prices for household using Alternative I: Traditional Meter without Net Metering (\$)	Solar systems breakeven prices for household using Alternative II: Smart Meter (\$)	<i>Solar systems breakeven prices for household using Alternative II: Smart Meter without Net Metering (\$)</i>	Percentage increase in price rates to breakeven with the solar systems for household using Alternative I: Traditional Meter	Percentage increase in price rates to breakeven with the solar systems for household using Alternative I: Traditional Meter without Net Metering	Percentage increase in price rates to breakeven with the solar systems for household using Alternative II: Smart Meter	Percentage increase in price rates to breakeven with the solar systems for household using Alternative II: Smart Meter without Net Metering
Boise City	12 kW PV Panel	12,243†	5,911	11,829	7,214	531%‡	583%	550%	589%
	4 kW PV Panel	9,294†	4,865	9,582	6,236	285%	322%	290%	318%
Hollis	12 kW PV Panel	17,758	8,123	16,677	9,784	366%	420%	390%	431%
	4 kW PV Panel	8,431	6,098	9,647	7,691	233%	246%	234%	246%
Shawnee	12 kW PV Panel	16,401	7,290	15,435	8,657	393%	448%	418%	461%
	4 kW PV Panel	7,684	5,522	9,069	6,993	247%	260%	247%	260%
Miami	12 kW PV Panel	15,187	6,710	14,230	8,379	419%	473%	446%	486%
	4 kW PV Panel	7,328	5,097	7,813	6,286	258%	272%	265%	275%
Idabel	12 kW PV Panel	16,464	7,335	15,492	8,731	391%	446%	415%	458%
	4 kW PV Panel	7,421	5,482	8,731	6,912	247%	259%	248%	260%

† These breakeven prices can be compared to the estimated installation costs of \$65,000 for the 12 kW system and \$32,000 for the 4 kW system.

‡ The electricity rates could increase by 531%, for example from \$0.0811 and \$0.0918, \$0.0795, \$0.0359, \$0.0795, and \$0.0811 for Blocks A₁, A₂, B₁, B₂, C, and D respectively to \$0.4308, \$0.4876, \$0.4221, \$0.1906, \$0.4221, and \$0.4308 for Blocks A₁, A₂, B₁, B₂, C, and D respectively, at which level the cost of installing the 12 kW system at Boise City would breakeven with the grid.

5. Conclusion

This study was conducted to determine the annual cost of electricity for representative households at five locations in the case study region and to determine the economics of grid-tied solar panels. The average annual cost for grid-only electricity is estimated to be \$1,075 for the traditional meter and \$1,024 for the smart meter among the five households. Given prices and use assumptions, neither of the solar panels is economically competitive at any of the five locations, for either rate structure or metering system.

On average, for the \$65,000 12 kW system to be economically competitive with grid provided electricity, grid prices would have to increase by 420% and 444% for the traditional meter and smart meter rates, respectively. Grid price increases of 254% and 257% for the traditional meter and smart meter rates, respectively, would be required for the \$32,000 4 kW system to be competitive with grid provided electricity. In the absence of substantial rate increases, rather sizeable reductions in the cost of the solar systems would be required for solar systems to be competitive. Averaged across the five locations, the installed cost of the 12 kW system on a traditional meter rate would have to decrease from \$65,000 to \$15,611 (\$7,074 without net metering) for it to be economically competitive. The installed cost of the 4 kW system would have to decrease from \$32,000 to \$8,032 (\$5,413 without net metering).

The study also enables a determination of the extent to which location matters. A major finding is that the economic consequences of grid-tied household solar systems differ substantially among locations that are relatively close in proximity. Annual use estimates for households with similar characteristics may differ substantially. For example, the representative Hollis household is expected to consume 55% more electricity per year than the Boise City household even though they are separated by only 350 km.

Location also matters in production. Total annual production from an identical 4 kW system is estimated to be 18% greater at Boise City than at Miami. The proportion of electricity produced by the 4 kW system that is produced at a time when it can be used by the household ranges from 78% at Idabel to 52% at Boise City. A grid-tied 4 kW system at Boise City would provide 3,616 kWh annually to the grid, but an identical system at Idabel would provide only 1,412 kWh annually to the grid. The 4 kW system provides for 42% of total annual household use at Boise City but only 36% of total annual household use at Miami.

Economic consequences also differ among locations. Annual cost for electricity for the representative households, given the same price structure, is estimated to be 29% greater at Shawnee than at Boise City if on a traditional meter and 26% greater at Shawnee if using the smart meter rates. Based on the price structure approved for use in the region switching from traditional to smart meters is expected to reduce aggregate annual consumption by less than 2%.

The utility providing grid electricity to the households with operating 4 kW solar systems without net metering could expect to receive from \$284 to \$355 per household annual less gross revenue. The consequences of net metering on gross revenue collected by the utility providing electricity to the grid are also location specific. The gross revenue loss to the utility of providing net metering ranges from \$89/household/year for smart meter households at Miami to \$258/household/year for traditional meter households at Boise City (290% more).

Based on prevailing prices, and consumption and production estimates, the 4 kW system would increase annual household cost by \$1,300 to \$1,550 depending on location and grid pricing system. If external consequences of electricity generation and distribution are ignored, given current rate structures and the cost of installing solar systems, the grid-tied solar panel systems are not economically competitive for households in the region studied. Further research

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527 would be required to determine differences in environmental consequences between household
528 solar and grid provided electricity and the economics of these differences.

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