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Cost of Oklahoma Grid-tied Solar Panel and Wind Turbine Systems for a Representative Household

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Abstract

Oklahoma households serviced by investor owned electric utilities that have smart meters may select to be charged based on either a traditional meter rate schedule, a smart meter schedule, or they may install a household grid-tied wind turbine or solar panel system and be subject to a different rate schedule. The objective of the research is to determine the annual cost of electricity for a case study household for six alternative situations: grid purchased with traditional meter rates, grid with smart meter rates, and four household Renewable Distributed Generation (RDG) systems tied to the grid with unique rates under consideration for implementation. Twenty years of hourly information regarding wind and solar quantity were obtained from the Oklahoma Mesonet weather system. Hourly use data for a representative household were obtained from the Department of Energy. These data, the Oklahoma Corporation Commission rate schedules, and purchase prices and power output response functions, for each of the four household systems were used to address the objective. The annual cost of electricity for the modeled household is estimated to be $710 for the smart meter system and $812 for the traditional meter system. The estimated annual cost of $2,343 for the least costly household grid tied production system, a 4 kW solar system, is 3.3 times greater than the annual cost of purchasing from the grid via a smart meter system. If external consequences of electricity generation and distribution are ignored, given current and proposed rate structures and prices, household generation systems are not economically competitive in the region.

Key words: cost, grid-tied, renewable distributed generation, solar energy, solar panel, wind energy, wind turbine

JEL codes: Q28, Q42

Introduction

A 2009 census survey found that 20 Oklahoma farms reported an installed wind turbine and 187 reported having either installed a photovoltaic (PV) or thermal solar panels for on-farm use (Vilsack and Clark, 2011). There are about 80,000 farms in Oklahoma (NASS, 2015). Thus, these data suggest that less than one-half of one percent of Oklahoma farms have a farm-based solar panel or wind turbine system.

Some Oklahoma farms purchase electricity from rural electric cooperatives. However, much of rural Oklahoma is serviced by investor-owned electric utilities that are natural monopolies. In the U.S., 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 (Oklahoma Legislature). The OCC is charged with the responsibility of insuring adequate service, preventing unfair charges to the public, protecting the utilities from unreasonable demands, and enabling a fair return to investor equity (OCC, 2014).

Electric meters measure the quantity of electricity removed from the electrical grid at the metered site. Traditional (accumulation) meters measure total consumption and do not provide information of when the energy was used during the time period of interest (Blumsack and Fernandez, 2012). Historically, rates approved by the OCC followed from the technical constraint imposed by traditional meters and billing systems. OCC rates approved for one utility to apply to farms and households with traditional meters are shown as alternative I in Table 1 (OCC, 2015). A fixed price per kilowatt-hour (kWh) is charged independent of the time of day

the electricity is consumed. The regulated prices are assumed to be greater than the marginal cost at off-peak load times, and lower than the marginal cost at peak load times.

Figure 1 illustrates marginal costs for hypothetical base load and peak load situations. Base load is assumed to be generated by the lowest cost fuel source, which, in Oklahoma, if externalities including the consequences of carbon released into the atmosphere are ignored, is coal. During hot summer afternoons, for example between 2 p.m. and 7 p.m., when electric powered air conditioners are operating near capacity, electricity use peaks (OCC, 2015). During the peak-load period, use may exceed base load plant capacity. In Oklahoma, most requirements in excess of base load are generated by natural gas powered plants. If the external consequences are ignored, the marginal cost of using natural gas is greater than the marginal cost of using coal (Figure 1). For example, in October 2015 the cost of producing one kWh from coal was 61% as much as the cost of producing one kWh from natural gas (U.S. Energy Information Administration, 2015).

Introduction of alternative pricing systems to more nearly align prices with marginal costs has been limited by the prevalence of traditional meters (Joskow and Wolform, 2012; Boiteux, 1960; Kahn 1970). Smart meters provide a way of measuring site-specific information, allowing regulators to permit utility companies to charge different rates based on time of use. Different rates for different hours of the day may be used to incentivize reductions in use during traditional peak time periods. Theoretically, smart meters that enable two-way communications between the utility and their customers, facilitate real-time monitoring of electricity flows, and enhance both the technical and allocative efficiency of electricity markets. Smart meters enable the utility to charge a different rate for each hour of the day for each day of the year. Alternative II rates as shown in Table 1 have been approved for one utility by the OCC (OCC, 2015) for

Oklahoma users that have smart meters (The Edison Foundation, 2014). Customers that have smart meters may select either the alternative I or alternative II pricing system subject to 12 month contracts that may be renewed each year.

As noted, solar panel and wind turbine systems are installed on some Oklahoma farms. Most of these systems are connected to the grid to enable purchase of electricity from the grid when production from the on-farm system is less than use. A unique alternative rate structure has been submitted to the OCC by a major utility for consideration for implementation for customers that install solar and/or wind grid tie systems (installed after October 31, 2014). If approved by the OCC, alternative III rates as shown in Table 1 would be applicable for farms with on-farm Renewable Distributed Generation (RDG) systems tied to the grid. RDG customers would be assessed a greater monthly base charge ($18 rather than $13) than traditional and smart meter customers, plus a charge based on peak withdrawal from the grid. This peak (maximum demand) charge would be determined based on the maximum 15-minute period withdrawal from the grid during the billing period (assumed to be monthly). For example, for a month with 30 days, the utility would determine the quarter hour from among the 2,880 15-minute periods during the month with the maximum usage. The quantity of electricity (kWh) withdrawn from the grid during that quarter hour would then be multiplied by the $2.68 proposed rate (Oklahoma Gas & Electric, 2012; Champion, 2016). In addition, for weekday usage between 2 p.m. and 7 p.m. during the months of June through October, RDG customers would be charged $0.173/kWh. This is 23.6% more than the smart meter rate for this time segment without solar or wind distributed generation.

The utility maintains that the proposed rates for RDG customers are designed in part to compensate for the additional investments in equipment required to safely manage the reliability

of the grid when electricity produced on the farm is sent to the grid (Brown and Bunyan, 2014). In addition, since solar panels and wind turbines depend on the quantity of sunshine and wind, respectively, they cannot be relied on to be available during peak load periods. Customers would be charged for each kWh withdrawn from the grid, however, they would not be compensated for electricity generated on the farm and provided to the grid.

The objective of the research is to determine the annual cost of electricity for a case study household based on (1) traditional meter rates; (2) smart meter rates; (3) RDG rates for a 10 kW wind turbine system; (4) RDG rates for a 6 kW wind turbine system; (5) RDG rates for a 12 kW solar panel system; and (6) RDG rates for a 4 kW solar panel system. For the RDG alternatives, annual costs are estimated with and without a 30% income tax credit for wind or solar equipment costs.

A comprehensive analysis requires hourly information regarding wind and solar quantity as well as hourly information regarding usage. Lack of hourly data has limited and hampered prior studies of the economics of grid tie systems (Elhadidy, 2002; Iqbal, 2004; Elkinton, McBrown, and Manwell, 2009; Ramadhan and Naseeb, 2011; and Darbali-Zamora, Gomez-Mwndez, and Diaz-Castillo, 2015). Based on the rate schedules, hourly data are required to determine the relative economics of the six alternatives. The Oklahoma Mesonet weather system has recorded 20 years of hourly solar and wind data for many locations in the state including the case study location. These data, the rate schedules, and purchase prices and power output response functions, for each of the four on-farm systems, can be used to address the objective.

Theory

The economics of an on-farm solar panel or wind turbine system depends 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, and the cost of purchasing electricity from the grid. For a household serviced by a traditional meter , the annual cost of electricity is calculated as:

$$(1)\ ECTM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j\ ERTM_j(\sum_{i=1}^{24} G_{ij})$$

where, $ECTM$ is the annual electricity cost for the household using the traditional meter, $ERTM_j$ is the OCC rate for the traditional meter rate during the jth month, G_{ij} is the electricity used in the ith hour, during the jth month where i = 1, 2, …, 24, D_j is the number days of 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, and BC_j is a fixed base charge per month independent of electricity use.

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

$$(2)\ ECSM = \sum_{j=1}^{12} BC_j + \sum_{j=1}^{12} D_j\ (\sum_{i=1}^{24} ERSM_{ij} G_{ij})$$

where, $ECSM$ is the annual electricity cost for the household using the smart meter rate, $ERTM_j$ is the OCC rate for the smart meter rate in the ith hour during the jth month.

The annual charge for electricity withdrawn from the grid and for the opportunity of having a grid tie for a household that installs an RDG system based on the proposed rate schedule would be:

$$(3)\ ECGT = \sum_{j=1}^{12} BCGT_j + \sum_{j=1}^{12} (\frac{H_j}{4})\ 2.68 + \sum_{j=1}^{12} D_j\ (\sum_{i=1}^{24} ERGT_{ij} G_{ij})$$

where $ECGT$ is the annual electricity cost for the household with the grid tied RDG system, $BCGT_j$ is the base charge for a grid tied system, H_j is the quantity (kW) withdrawn from the grid during the highest consumption hour of electricity withdrawn in the jth month, and $ERGT_{ij}$ is the proposed RDG rate for the the ith hour during the jth month.

The following equations were used to estimate the annual cost of the RDG systems (Doye and Sahs, 2014)

$$(4)\ \text{Depreciation}\ \left(\frac{\$}{\text{year}}\right) = \frac{(\text{Purchase Price} - \text{Salvage Value})}{\text{Years of Life}},$$

$$(5)\ \text{Interest}\ \left(\frac{\$}{\text{year}}\right) = \frac{\text{Purchase Price} + \text{Salvage Value}}{2} * \text{Real Interest Rate},$$

$$(6)\ \text{Insurance}\ \left(\frac{\$}{\text{year}}\right) = \frac{\text{Purchase Price} + \text{Salvage Value}}{2} * \text{Insurance Rate, and}$$

$$(7)\ \text{Property Tax}\ \left(\frac{\$}{\text{year}}\right) = \text{Average System Price} * \text{Assessed Rate} * 0.086.$$

Data and Method

Hourly weather data were obtained from the Oklahoma Mesonet. The Mesonet consists of 120 automated weather stations. Many of these stations have been collecting precise weather data since 1994. Data collected includes wind speed (m/s), air pressure (inches of mercury), air temperature (F^o), relative humidity (%), and solar radiation (watt/m^2). For the present study, average values of power output for each of 24 hours for each of 12 months were obtained, as the wind turbine power output is a function of wind speed. 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 and wind turbine systems at a specific site for each hour of the day for each month. These estimates could be used in combination with information regarding the expected cost of owning and operating a RDG system, the quantity and timing of electricity used by the farm, and the cost of purchasing electricity from the grid, to determine the expected economics of an RDG system.

The residential hourly profile for a Shawnee, Oklahoma household was obtained from the U.S. Department of Energy (Wilson et al., 2014). Simulated load profiles are averages over

many households. Shawnee is included in the mixed humid region. The characteristics of the house and household to be modeled are reported in Table 2.

The modeled solar panel systems have capacity ratings of 4 kW and 12 kW[i] with a 17% polyvoltaic (PV) panel efficiency. These 4 kW and 12 kW systems would require 28 m^2 and 93 m^2 of roof area, respectively (Green Wind and Solar Company, 2015). The installed costs are estimated to be $32,000 for the 4 kW system and $65,000 for the 12 kW system. The useful life of both systems is estimated to be 40 years. The power output response to solar radiation for each PV panel during hour *i* can be computed by the following formula (Maleki and Askarzadeh, 2014):

$$(8)\ P_{PV(i)} = KI_i\, A\, \eta_{PV}$$

where $P_{PV(i)}$ is the power output during hour *i* (kW); K is the coefficient to transfer the power output from a solar panel system from W to kW (0.001); I_i is the solar radiation during hour *i* (W/m^2); $i = 1, 2, \ldots, 24$; A is the area of the PV in m^2; and η_{PV} is the overall efficiency of the PV panels.

Industry standards for small wind turbines have been developed by the American Wind Energy Association (AWEA) in association with the U.S. Department of Energy (AWEA, 2016). In this paper two wind turbine systems (Bergey Excel 10, Bergey Excel 6) that are commercially available and that have been certified to the AWAE's small wind turbine performance and safety standards are modeled as proxies for a representative 10 kW and 6 kW system, respectively. The Small Wind Certification Council (SWCC) tests the power output of commercially available machines. The SWCC report includes the power curve; the power (kW) output response as a function of wind speed. To enable comparison across machines, power output for a wind speed of 11 m/s (24.6 mph) is used to compute the AWAE rated power. The power curve is reported

over the range of wind speeds from 0.5 to 20.5 m/s (1 to 46 mph) for the Excel 10 (SWCC, 2015a) and from 0.5 to 18.5 m/s (1 to 41 mph) for the Excel 6 (SWCC, 2015b). For the case study location, the maximum average wind speed across the 288 hour-month combinations was 15 m/s (33 mph). Power output from the Excel 10 tracks the theoretical power output curve from 0.5 to 11 m/s (0 to 24.6 mph). Output continues to increase at a decreasing rate from 11 to 15 m/s (24.6 to 33.6 mph) after which output plateaus.

The modeled wind turbine systems are 10 kW and 6 kW, with 7 m and 6.2 m rotor diameter, respectively. The installed cost of the 10 kW turbine is estimated to be $65,000 ($32,000 for the turbine; $15,000 for the 30.5 m tower; $15,000 for installation and foundation preparation; $3,000 for permits). The installed cost for the 6 kW turbine is estimated to be $55,000 ($22,000 for the turbine with other costs the same as for the 10 kW). The useful life of the turbines is assumed to be 20 years, with no maintenance cost the first five years and maintenance cost in years 6-10 of $250 annually; years 11-15 of $500 annually; and years 16-20 of $1000 annually. Both systems are equipped with automatic furling systems that enable power output over a range of wind speeds while protecting the integrity of the equipment.

Turbine power output is estimated to be (Baroudi, Dinavahi, and Knight, 2007)

$$(9)\quad P = \begin{cases} 0 & V < V_{Cut-in} \\ K\, C_p\, \frac{1}{2}\, \rho\, A\, V^3 & V_{Cut-in} \leq V \leq V_p \\ P_r & V > V_p \end{cases}$$

where, P is the power output (kW), P_r is the plateau output level (kW), K is equal to 0.001, which is a constant to transfer the power output from W to kW, C_p is the maximum power coefficient, ranging from 0.25 to 0.45, ρ is the air density (kg/m^3), A is the rotor sweep area (m^2), V is wind speed (m/s), V_{Cut-in} is the minimal wind speed required to initiate production, and V_p is the wind speed at which production is at a plateau level.

The RDG system is assumed to be installed and used for its entire life; 20 years for the wind turbines and 40 years for the solar panels. 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 assessed proportion for property tax is assumed to be 12% (Addcox, Schieffer, and Lansford, 2013). Estimates of costs for each RDG system are reported in Table 3.

The federal residential energy efficient property tax credit (IRC §25D), allows taxpayers to claim an income tax credit for installed residential systems that generate renewable energy (e.g., solar panels, small wind energy) (Margot and Sherlock 2014). The income tax credit (that is scheduled to expire at the end of 2016) is calculated as 30% of installation costs.

Results and Discussion

Figures 2 and 3 show the electricity consumption and power output for each RDG system for the representative Shawnee, Oklahoma household for the months of January, April, and July. The turbines produce sufficient electricity to provide most of the winter and spring electricity consumption. The 10 kW and 6 kW turbine systems produce 88% and 80% of electricity consumption, respectively (Table 4). Both solar panel systems produce sufficient electricity for the modeled household from 8 a.m. to 5 p.m. during the summer. Of course, solar production is zero at night. The 12 kW and 4 kW solar systems provide 48% and 39%, respectively, of the modeled household requirements.

Although turbines produce a greater proportion of total household use, the solar panels produce electricity during the June through October high rate hours. Table 4 shows the percentage of the power production used by the household. For example, 65% of the power produced by the 4 kW solar panel system is used by the household. As noted, excess production may be provided to the grid, but it does not produce revenue for the household.

The annual cost for installing and maintaining each of the RDG systems is reported in Table 3. Payments to the utility and annual cost of electricity for the case study household for each of the six alternatives, (1) traditional meter, (2) smart meter, (3) 10 kW wind turbine, (4) 6 kW wind turbine, (5) 12 kW solar panel, and (6) 4 kW solar panel are reported in Table 5.

The annual cost is estimated to be $710 for the smart meter system and $812 for the traditional meter system. If there is no cost to the household for adopting a smart meter, the pricing structure provides an incentive for the modeled household to select the smart meter rate structure. These findings are based on the assumption that switching from the traditional to smart meter rate structure does not alter household behavior. If the household adjusted time of electricity use to reduce consumption during the June through October weekday afternoon (2 p.m. to 7 p.m.) high rate time period, savings to the household from adopting the smart meter rate structure would be greater than those estimated. Presumably, the utility could also benefit from the reduction in use during the high cost peak load time period.

The results as reported in Table 5 also show that none of the four on-farm RDG systems are economically competitive with grid provided electricity. The estimated annual cost of $2,343 for the least costly RDG system, the 4 kW solar system, is 3.3 times greater than the annual cost of purchasing from the grid via a smart meter system. If the investment cost was reduced by 30% via the federal income tax credit, the annual cost of the 4 kW solar system, would be almost twice that of purchasing from the grid via a smart meter system.

Conclusion

The study was conducted to determine the annual cost of electricity for a case study Shawnee, Oklahoma household for six alternative situations. The alternatives included (1) grid purchased with traditional meter rates, (2) grid purchased with smart meter rates, and four grid-

tied household renewable distributed generation systems with unique rates under consideration for implementation. The four grid-tied systems include (3) a 10 kW wind turbine, (4) a 6 kW wind turbine, (5) a 12 kW solar panel system, and (6) a 4 kW solar panel system.

Household use and rates charged differ throughout the day and across months. Electricity production from solar panels and wind turbines depend on the quantity of sunshine and wind, respectively, that also varies throughout the day and year. The study was made possible because 20 years of hourly information regarding wind and solar quantity were available from the Oklahoma Mesonet weather system. Hourly use data for the representative Shawnee, Oklahoma household were obtained from the Department of Energy. These data, the Oklahoma Corporation Commission rate schedules, and purchase prices and power output response functions, for each of the four grid-tie systems were used to estimate the annual cost of electricity.

For the modeled household, annual electricity cost was estimated to be $710 for the smart meter system and $812 for the traditional meter system. The estimated annual cost of $2,343 for the least costly household grid tied production system, a 4 kW solar system, is 3.3 times greater than the annual cost of purchasing from the grid via a smart meter system. If external consequences of electricity generation and distribution are ignored, given current and proposed rate structures and prices, the grid-tied solar and wind systems are not economically competitive.

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Table 1: Oklahoma Gas and Electric Company Electricity Pricing Rates

Time and quantity of electricity used	Price ($ per month)	Price (¢ per kWh)
Alternative I: Traditional Meter[a]		
Base Charge	13.00	
June through September		
0 ≤ kWh per month ≤ 1,400		5.73
kWh per month > 1,400		6.68
November through April		
0 ≤ kWh per month ≤ 600		5.73
kWh per month > 600		1.37
May and October		5.73
Alternative II: Smart Meter[a]		
Base Charge	13.00	
June through October		
2 p.m. through 7 p.m. weekdays		14.00
7:01 p.m. through 1:59 p.m., and weekends		2.70
November through May		
First 600 kWh per month		5.73
Additional kWh		1.37
Proposed Alternative III: Smart plus RDG		
Base Charge	18.00	
Maximum 15-minute Period Monthly Charge	[b]	
June through October		
2 p.m. through 7 p.m. weekdays		17.30
7:01 p.m. through 1:59 p.m., and weekends		1.37
November through May		1.37

Source: Oklahoma Corporation Commission

[a] These rates do not include the fuel cost adjustment factor that fluctuates with prices of natural gas and coal.

[b] The "maximum demand" charge is determined by multiplying use (kWh) during the 15-minute period during the month for which withdrawal from the grid was greatest by $2.68 (Oklahoma Gas & Electric, 2012; Champion, 2016). Thus, this charge varies with each month and each system. For the representative household it ranged from $1.38 for the month of April to $2.24 for the month of August. Since 15-minute period data were not available, withdrawal from the grid for the hour of the month with the greatest withdrawal was divided by four.

Table 2: Characteristics of the House and Household being Modeled

Characteristics	Description/Unit Mixed Humid
Building Fuel Types	
Space Heating	Natural Gas
Air Conditioning	Yes
Water Heating	Natural Gas
Building Structure Types	
Total Size	2546 (ft^2)
Number of Stories/Level	1 Story
Bedrooms	3
Bathrooms	1
Basement	No
Type of Glass in Windows	Double-pane Glass

Source: National Renewable Energy Laboratory

Table 3: Purchase price and annual cost for two wind turbine and two solar systems

Description	Unit	10 kW Wind Turbine		6 kW Wind Turbine		12 kW Solar Panel		4 kW Solar Panel	
		Without 30% Tax Incentive	With 30% Tax Incentive	Without 30% Tax Incentive	With 30% Tax Incentive	Without 30% Tax Incentive	With 30% Tax Incentive	Without 30% Tax Incentive	With 30% Tax Incentive
Purchase Price	$	65,000	45,500	55,000	38,500	65,000	45,500	32,000	22,400
Life	years	20		20		40		40	
Depreciation	$/year	3,250	2,275	2,750	1,925	1,625	1,138	800	560
Interest on Average Investment	$/year	1,625	1,138	1,375	963	1,625	1,138	800	560
Insurance	$/year	195		165		195		96	
Property Tax	$/year	352		298		344		169	
Repairs	$/year	437		437		0		0	
Total Annual Cost	$/year	5,860	4,398	5,025	3,788	3,789	2,815	1,865	1,385

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

Table 4: Annual electricity consumed, produced, used, and the percentage of the representative household consumption produced by each of the four RDG systems

System	Units		10 kW Wind Turbine	6 kW Wind Turbine	12 kW Solar Panel	4 kW Solar Panel
Electricity Consumption	kWh/Year	13,502				
Power Production	kWh/Year		22,008	16,976	26,614	8,017
Power Production Used	kWh/Year		11,851	10,759	6,544	5,210
Power Production Used	%		54%	63%	25%	65%
Percentage of Household Consumption Produced by RDG	%		88%	80%	48%	39%

Table 5: Annual cost of electricity for a representative Shawnee, Oklahoma household, for three alternative rate structures.

System		Unit		10 kW Wind Turbine	6 kW Wind Turbine	12 kW Solar Panel	4 kW Solar Panel
Alternative I: Traditional Meter							
	Payment to Utility	$/yr	812				
Alternative II: Smart Meter							
	Payment to Utility	$/yr	710				
Proposed Alternative III: Smart plus RDG							
	Payment to Utility	$/yr		323	368	409	478
	Cost of on-farm system	$/yr		5,860	5,025	3,789	1,865
	Total Cost	$/yr		6,183	5,393	4,198	2,343
	Cost of On-farm System After Tax Credit	$/yr		4,398	3,788	2,815	1,385
	Total Cost After Tax Credit	$/yr		4,721	4,156	3,224	1,863

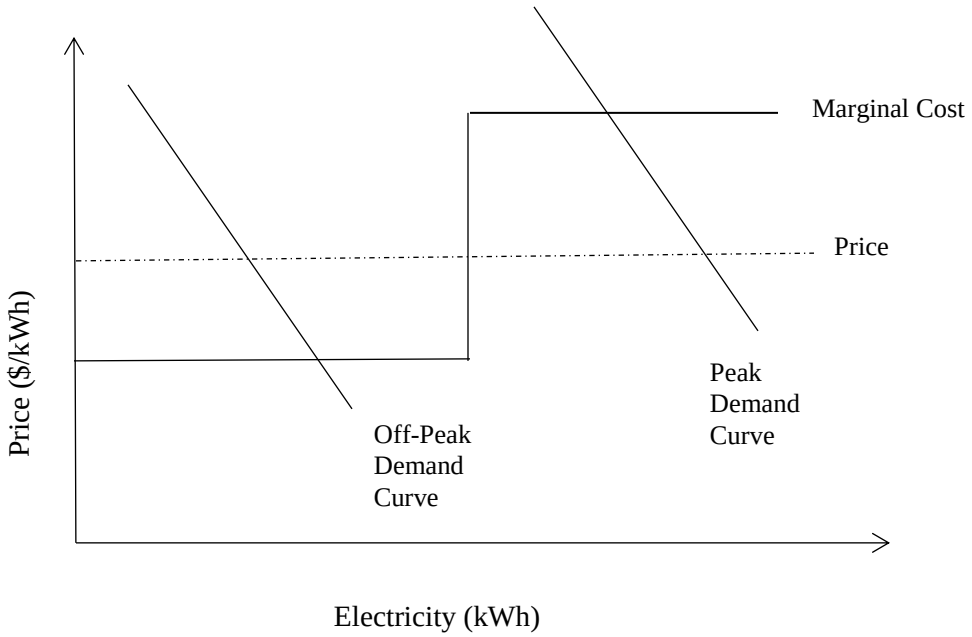

Figure 1: Household Electricity Marginal Cost, Peak Demand, and Off-Peak Demand

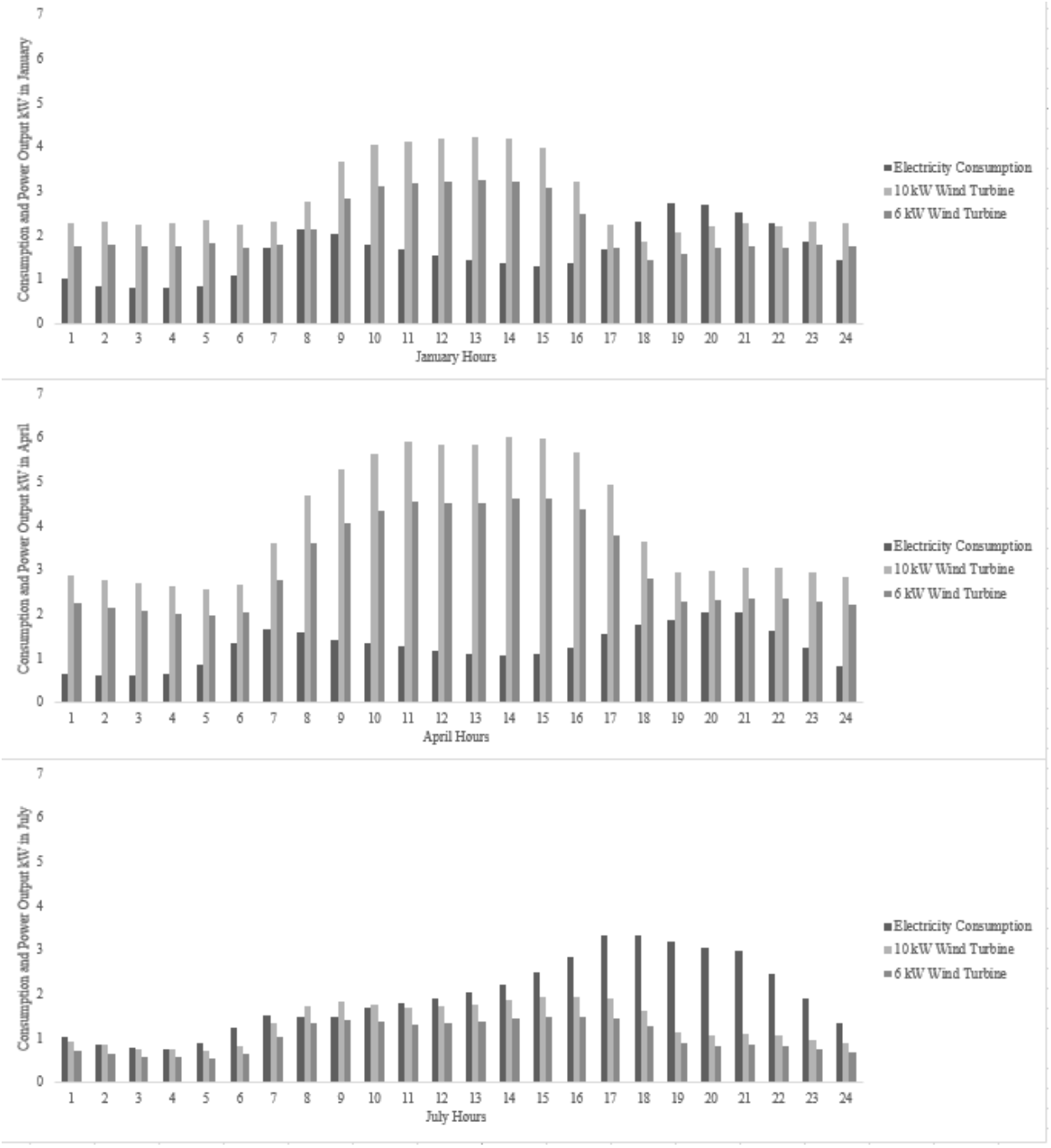

Figure 2: Estimates of electricity consumption and power output for two wind turbine systems for a Shawnee, Oklahoma representative household.

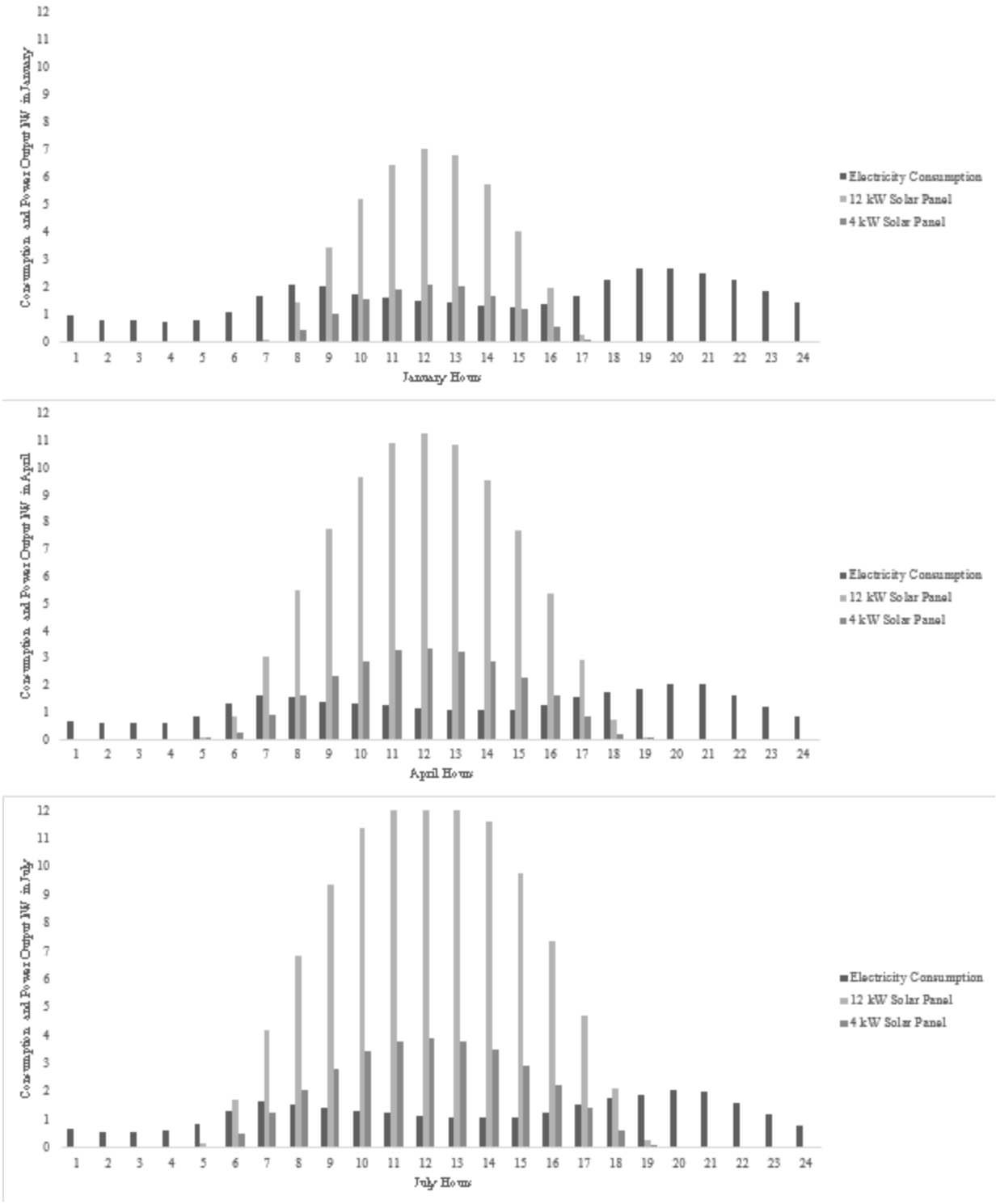

Figure 3: Estimates of electricity consumption and power output for two solar panel systems for a Shawnee, Oklahoma representative household.

Endnote

[i] The 4 kW and 12 kW represent the electricity production capacity of the solar panel system. The capacity is a function of the efficiency of the PV cells, and the area of the solar panel. The panels are sized to meet the 4 kW and 12 kW production capacities. Electricity production is limited by system capacity.