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Evaluation of Wind and Solar Energy Investments in Texas

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Abstract

The primary objective of the project is to evaluate the benefits of wind and solar energy and determine economical investment sites for wind and solar energy in Texas with economic parameters including payback periods. A 50 kW wind turbine system and a 42 kW PV system were used to collect field data. Data analysis enabled yearly energy production and payback period of the two systems.

The average payback period of a solar PV system was found to be within a range of 2-20 years because the large range of the payback period for PV systems were heavily influenced by incentives. This is in contrast to wind energy, where the most important factor was found to be wind resources of a region. Payback period for the installed wind system in Texas with federal tax credits was determined to be approximately 13 years.

Keywords

Renewable energy
Wind energy
Solar photovoltaic (PV) energy
Feasibility study
Payback period

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Highlights

- Economic analysis was performed to evaluate the economic feasibility.
- Two renewable energy (wind and solar) configurations were evaluated for an application in Texas.
- The payback periods are provided for specific locations in Texas for wind and solar energy investment.
- The overall feasibility study recommends the viable locations in Texas for solar and wind energy in the study.

1. INTRODUCTION

Access to affordable energy is essential for economic and social development. Energy may be obtained from conventional sources (fossil fuels such as oil, coal, and natural gas), or from renewable sources (solar, wind, geothermal, biomass, etc.). Wind and solar energy are the two most rapidly growing renewable energy sources in the world (See Figure 1). While the amount of electricity generated from other renewable sources in the U.S. has been almost constant, wind and solar technologies has been developed dramatically in electricity generation in recent years as shown in Figure 1.

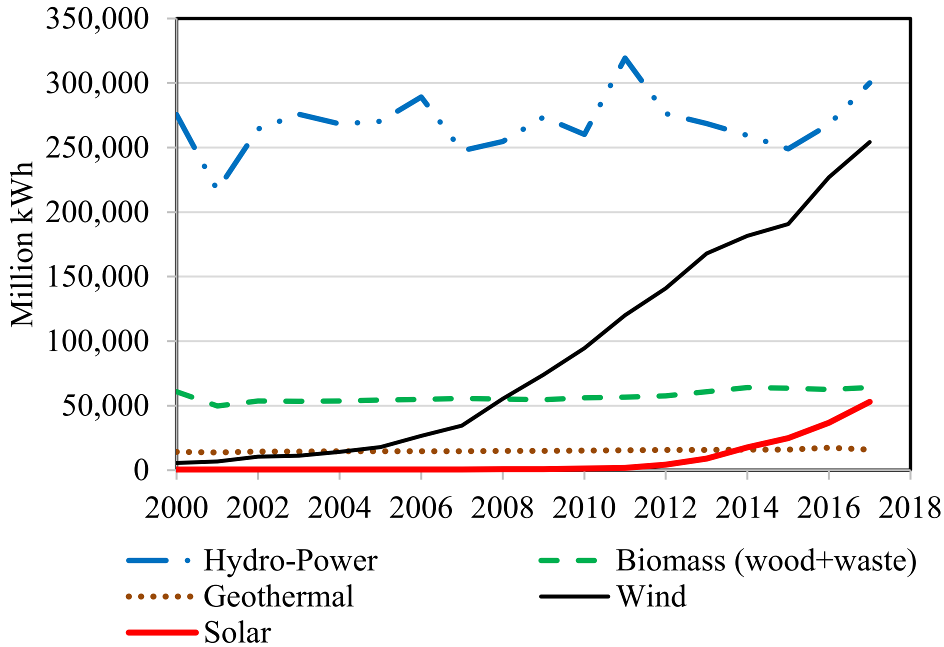

Figure. 1. U.S. electricity net generation [1]

A numerous feasibility studies have been conducted for wind and solar energy in the world. Berlin in Germany for solar PV systems [2], Korea for offshore wind turbine [3], China for solar power [4, 5], Qatar for solar PV systems [6], Turkey for renewable energy projection [7], Australia for renewable energy prospects [8], Kutubdia Island in Bangladesh for wind resources [9], Dhahran in Saudi Arabia for hybrid (wind/solar) power systems [10], and Pernambuco in Brazil for wind energy assessment [11] are the examples for renewable energy feasibility study. Table 1 summaries the scope of the project and brief findings from the previous studies.

The objective of this study was to evaluate the benefits of wind and solar energy and determine economical investment sites for wind and solar energy in Panhandle Texas through calculating payback periods based on quantified actual electricity generation. An AOC 15/50 50 kW wind turbine system and a 42 kW PV system at the Alternative Energy Institute (AEI) Wind Test Center (WTC) were used to collect actual field data. Weather data were also collected at the application sites to estimate yearly energy production of the two systems. The payback periods were calculated based on energy production, the cost of electricity, and incentives and rebates available for the project. Results were then extrapolated to other sites in the state of Texas by considering their specific geographic characteristics and weather patterns to determine the most economical sites for wind and solar energy in the state. Suitable areas for wind and solar energy

were determined and guidelines for the selection of these areas were recommended based on results of this study.

Table 1. Summary of wind and solar feasibility study

System	Location	Finding	Reference
Solar Tracking	Germany	Solar tracking is not feasible in hot area.	Sharaf-Eldin, 2016 [2]
Wind turbine susbstructure	Korea	Jacket and multipiles are cost-effective.	Shi, 2015 [2]
Concentrating solar power (CSP)	China	Concluded that China has sufficient potential for CSP.	Li, 2014 [3]
Wind farm	China	Concluded that Wind power in China is the most potential energy source.	Han, 1996 [4]
Solar PV	Qatar	PV stations are NOT economically feasible.	Marafia, 2001 [5]
Overall renewable energy	Turkey	Payback of 15 years or less is estimated in Turkey.	Melikoglu, 2013 [6]
Wind/Solar power system	Australia	Both solar/wind power systems are economically feasible.	Shafiullah, 2012 [7]
Wind energy	Bangladesh	The coastal area is sustainable for small turbines.	Khadem, 2006 [8]
Hybrid (Solar + Wind)	Saudi Arabia	The potential of renewable energy option of hybrid energy cannot be overlooked.	Elhadidy, 1999 [9]
Wind farm	Brazil	The assessment shows a Payback of 3 years.	Araujo Lima, 2010 [10]

The region analyzed in this study, Panhandle Texas, is the northern most region of the state of Texas consisting of 16 counties. In Panhandle Texas, the annual wind speed is between 6.5 to 7.5 m/s (11.2 to 16.8 mph) at 30 m (98 ft) above ground, with greater wind speeds at higher elevations [12]. The average annual insolation is about 4.0 to 6.0 kWh/m²/day. Therefore, both resources are sufficient to supply residential and commercial consumption.

2. INSTALLED TECHNOLOGIES AND RECENT DEVELOPMENTS

2.1 Wind Turbine System

A wind turbine converts kinetic energy of wind into mechanical energy, which is then harvested to generate electricity. Wind turbines are classified under two general categories: horizontal axis and vertical axis. The more commonly known horizontal axis wind turbine has its blades rotating on an axis parallel to the ground, whereas a vertical axis wind turbine has its blades rotating on an axis perpendicular to the ground [13]. A horizontal axis wind turbine was used in this study.

For the wind turbine system, Seaforth AOC 15/50 50 kW was chosen due to its advantages in durability, efficiency, and due to its lightweight properties. Table 2 presents detailed specifications of the Seaforth AOC 15/50 wind turbine system used in the study. The lightweight blades used in this design enhance startup and reduce wear on brakes and bearings, thus increase a design life of 30 years.

Table 2. AOC 15/50 50kW wind turbine specifications [14]

Component	Specification
Rated	50 kW at 12 m/s (27 mph)
Induction generator	480 VAC, 3 phase
Cut in and out wind speed	4.6 and 22.4 m/s (10 and 50 mph)
Peak survival wind speed	59.5 m/s (133 mph)
Blade length	7.2 m (23.7 ft)
Blade mass	140 kg (308 lbs)
Rotor diameter and Hun height	15 m (49.2 ft) and 37 m (120 ft)
Weight	2500 kg (5500 lbs) (turbine and blades only)
Downwind	passive yaw control
Operation	fixed pitch blades, stall controlled
Braking system	tip brakes, dynamic brake, parking brake
Control system	PLC based, remote monitoring
Design life	30 years

There have been previous attempts and studies to calculate the payback period of wind turbine systems. However, both the efficiency and the size of the system plays a determinant role in all feasibility analyses, and therefore only those studies that share similar characteristics can be used for comparison purposes. A study carried out for two wind turbines in Walsh, Colorado estimated a payback period of 16.3 years [15]. Another study analyzing a wind turbine in California estimated a payback period of 6.8 years [16]. The rated capacity of wind turbines in both studies was 50 kW, exactly the same as the rated capacity of turbine used in this study. An important factor resulting in the obvious and large variation of these results was the retail electricity cost used in these studies, together with estimates on annual electricity production. While the analysis for California assumed 70,000 kWh, the other conducted in Colorado assumed 132,500 kWh annually, nearly doubling the estimate of the former study. Such discrepancies can occur due to many factors. One of the strengths of the current study is not to solely rely on estimates or proposed default values but to use actual data gathered from the field through employed systems.

Figure 2 is an annual average wind speed map of Texas at 30 m (98 ft) height developed by NREL. As can be seen, Panhandle Texas is the most suitable region in the state for small wind project development. A similar map by NREL for utility-scale wind projects at 80 m (262 ft) height above ground also indicate that the Panhandle region would still be the most ideal region in the state.

Areas with good exposure to prevailing wind around 4 m/s and greater at a height of 30 m (98 ft) are generally considered to have a suitable wind resource for small wind projects, mostly for residential applications, which are typically installed between 15 and 40 m (49 and 131 ft) above ground [12]. Accordingly, most of Texas should be suitable for small scale wind generation projects. Figure 2 shows the northwest regions of Texas such as Amarillo and Abilene have greater wind resources than eastern Texas, with average annual wind speed in this region between 6.5 – 7.5 m/s (14.5 – 16.8 mph). The southern part of the state such as around Laredo and Brownsville also is suitable for small wind development, with annual wind speed in this area between 5.5 – 6.5 m/s (12.3 to 14.5 mph).

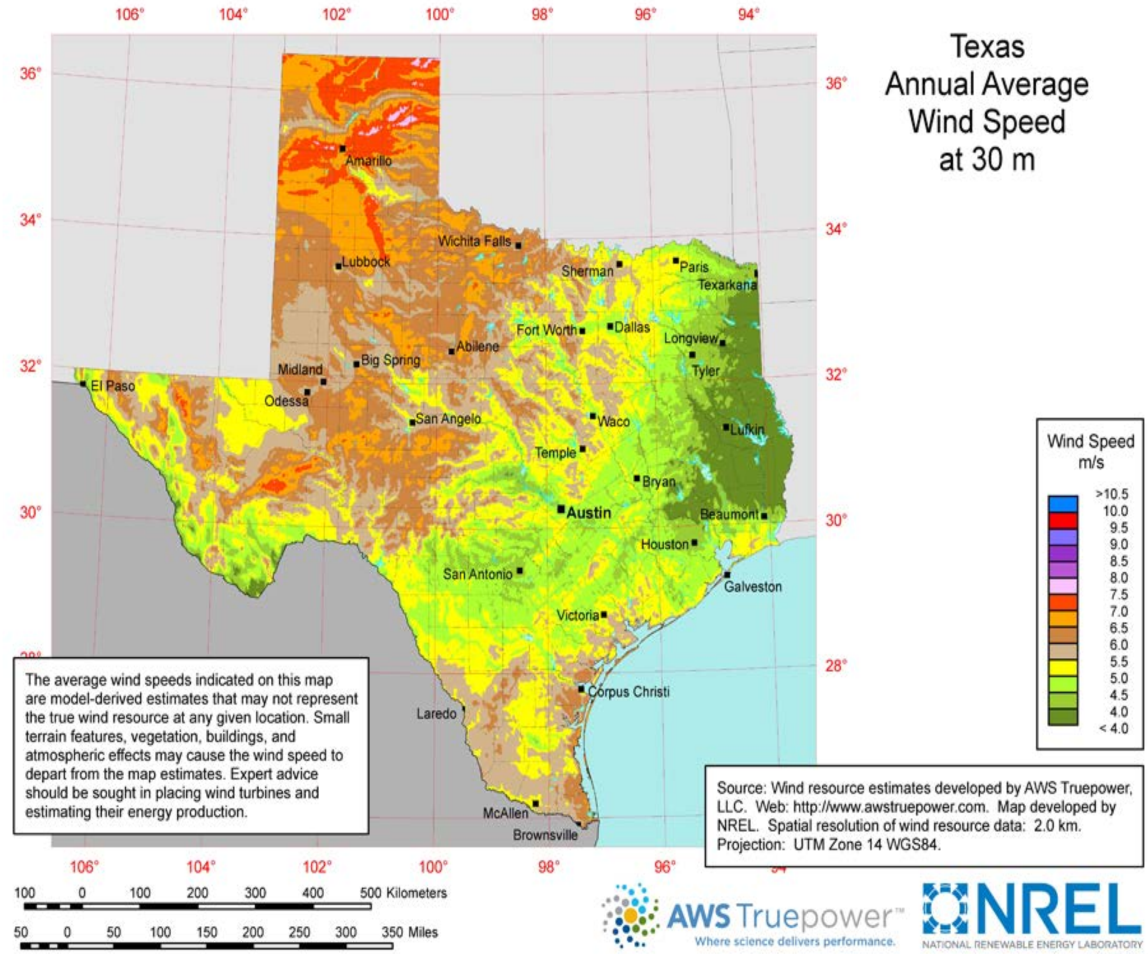

Figure. 2. Texas annual average wind speed at 30 meter height [12]

The market for wind turbine systems was developed rapidly in Texas because of its great wind resources. Texas produces more wind power than any other state in the U.S. Table 3 presents changes in Texas wind turbine installation capacity by year from 1999 to 2016. In the middle of 2017, approximately 21.45 GW capacity wind turbine systems were installed in Texas. As shown in Table 3, the wind energy capacity in Texas increased 1096 MW from 184 MW (496%) in 2001 because there were wind energy technology booms. About 40 new businesses and 30,000 construction jobs in 57 West Texas counties have been created in 2001 according to the Public Citizen Texas Office. In addition, the Texas Legislature enacted Competitive Renewable Energy Zones (CREZ) to increase the renewable energy use in 2005. The CREZ also created a fund to build more transmission lines connecting wind farms each other. This caused dramatic change in wind energy capacity between 2005 and 2009.

Table 3. Annual Texas installed wind turbine capacity [17]

Year	Capacity (MW)	Change (%)
1999	184	-
2000	184	0.00
2001	1,096	495.7

2002	1,096	0.0
2003	1,290	17.70
2004	1,290	0.0
2005	1,992	54.4
2006	2,736	37.4
2007	4,353	59.1
2008	7,113	63.4
2009	9,403	32.2
2010	10,089	7.30
2011	10,394	3.0
2012	12,214	17.5
2013	12,355	1.2
2014	14,098	14.1
2015	17,713	25.6
2016	20,321	14.7

2.2 Solar PV System

While there are different types of commercially available PV systems, most can be categorized as crystalline or amorphous, with further subdivisions under each category [18]. When considering PV modules commercially available to the general public, rather than high end products or those that are in development in laboratories, the differences between different technologies have become somewhat less significant. Still, crystalline PV modules have higher solar energy conversion efficiency than amorphous PV modules under direct sunlight, but are more expensive than amorphous modules on a per-unit area basis. Amorphous PV modules fare better under climatic conditions that limit direct sunlight. Therefore, the decision must be based on local climatic and geographic conditions.

Unlike any other electricity generation technology, PV modules have no moving parts, thus minimizing occurrence of mechanical breakdown due to part wear. Although PV systems tend to have relatively high up-front capital costs, their annual operation and maintenance costs are much lower than wind turbine systems. Tracker arrays and fixed panel arrays are the two common PV systems in the market. Tracker arrays produce more energy while the installation and maintenance cost are much higher than fixed panel arrays.

The installed solar PV system analyzed in this study was rated at 42 kW and consisted of two tracker arrays and eight fixed panel arrays. The PV system was grid connected through inverters and supported the energy requirements of the nearby Palo Duro Research Center (PDRC). The tracker array system consisted of 20 solar panels, where each panel was 1.65 m by 0.95 m (5.4 ft by 3.1 ft) in dimensions, and weighed 18.6 kg (41 lb). The grid connected solar energy system tracked the sun from dawn to dusk through a GPS system to accurately position the panels toward the sun. Such tracking arrays are more efficient and produce more electricity than roof mounted systems of the same size. The lifetime of the PV array system was estimated to be 25-30 years.

Electricity generated from the eight fixed panel arrays was also used to support the electricity of the buildings in the institution. Each fixed panel array system consisted of 20 solar panels which had the same physical and technical characteristics as those used in the tracker arrays. Rather than using default values proposed by references at low resolution, an additional analysis

was conducted for the tilt angles of the fixed panel arrays, where their tilt varied between 32-35 degrees to determine the most efficient angle at the installed location.

Similar to the already expanding wind energy market, Texas has the potential for a large solar energy market, and although capacity still remains small compared to wind power, market growth for PV has been substantial in recent years, as shown in Table 4. In 2016, Texas [19] installed about 676 MW of solar electric capacity, raking it ninth nationally. The top three states ae California, North Carolina, and Arizona.

Table 4. Annual Texas installed PV capacity [19]

Year	Capacity (MW)	Change (%)
2007	3.2	-
2008	4.4	37.5
2009	8.6	95.5
2010	34.5	301.2
2011	85.6	148.1
2012	140.3	63.9
2013	215.9	53.9
2014	387	79.2
2015	534	38.0
2016	676.3	126.6

There have been studies that aimed to quantify the benefit of tracking systems employed in PV applications. While results vary from 10-36% depending on location, and extent of tracking technology used, the studies by Tomson [20], Huang [21], and Asiabanpour [22] show that tracking does increase the efficiency of the PV array overall.

3. METHODOLOGY

3.1 Wind Turbine System

Yearly energy production and payback period are the two main performance criteria used to evaluate a wind turbine system. Data on energy production of the wind turbine system were collected about nine months because the AEI was reconstructing the testing center and the field monitoring was suspended frequently. Since available data were for less than one full year, it is necessary to estimate the annual energy production of the system based on collected data.

The wind data for the AOC wind turbine system were collected from HoboLink, a web-based software platform that enable remote monitoring and collection of data. The collected data in this study consisted of power, wind speed, and gust speed, recorded at five minute intervals.

An estimation of energy production can be developed from the histogram and power curve for the wind turbine. The calculated annual energy production is the sum of the respective products of the power curve value and the number of hours for each bin (Equation 1).

$$E = \sum P * H \quad (1)$$

where,

P is the power value, corrected for the elevation, and

H is the number of hours for each bin.

Wind speed histograms reflect annual values. Three years of AEI WTC wind data from 2010 were used for this study. A power curve of the AOC wind turbine was provided by the manufacturer. However, wind speed histograms and power curves need to be corrected to a specific height and adjusted for air density due to location differences since air density varies and affects the power of the wind turbine system directly. A new AOC wind turbine power curve using the actual data was necessary to ensure that the estimation was close to actual energy production.

Figure 3 presents the power curve of the wind turbine system based on actual data collected on-site in every 0.5 m/s. Peak power of 65,000 watts was reached when the wind speed was approximately 15 m/s (33 mph). However, power decreased soon after as the wind turbine would be stopped by its internal braking system when the wind speed was close to 22 m/s (50 mph).

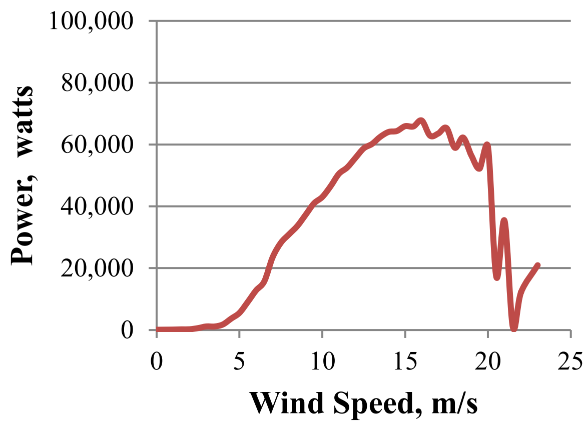

Figure 3. Power curve of the AOC wind turbine based on actual data collected on-site

The power curve presented in Figure 3 was used together with wind speed histograms to estimate annual energy production of the AOC wind turbine system. Wind speed data were collected at AEI WTC at three elevations: 20 m (66 ft), 30 m (98 ft), and 50 m (164 ft). Because the height of the AOC wind turbine is 37 m (120 ft), wind speed at 30 m (98 ft) was adjusted to 37 m (120 ft) by using Equation 2 [23].

$$V_S = V_Z \left[\frac{ln\left(\frac{Z_{ref}}{Z_{0ref}}\right) ln\left(\frac{H}{Z_0}\right)}{ln\left(\frac{H}{Z_{0ref}}\right) ln\left(\frac{Z}{Z_0}\right)} \right] \quad (2)$$

Where,

Z_{0ref} is the reference roughness length of 0.05 m (2 in);

Z_0 is the roughness length;

H is the rotor centre height;

Z_{ref} is the reference height of 10 m (33 ft), and

Z is the hub height.

3.2 PV System

The yearly energy production was estimated based on PVWATTS Calculator, a web-based grid data calculator [24]. Payback period of the PV system was then calculated based on the energy production estimates.

The PVWATTS Calculator estimated energy production of the two tracker array system. It determined the solar radiation incident on the PV array and the PV cell temperature for each hour of the year using typical meteorological weather data for the selected location. The DC energy for each hour was calculated from the PV system DC rating and the incident solar radiation and then corrected for the PV cell temperature. The AC energy for each hour was calculated by multiplying the DC energy by the overall DC-to-AC derate factor and adjusted for inverter efficiency as a function of load. A derate factor of 0.9 was used in the analysis conservatively. Hourly values of AC energy were then summed to calculate monthly and annual AC energy production.

Daily energy production of each fixed array panels could not be collected directly. To calculate daily output, Equations 3 and 4 were used as shown below. Equation 3 was used to calculate the total energy production before the i^{th} day while Equation 4 was used to calculate the daily energy production of the i^{th} day.

$$EB_i = E_{T1} - E_{T2} \tag{3}$$

$$E_{Di} = EB_{i+1} - EB_i \tag{4}$$

Where,

E_{T1} is total energy production from system start to the data collection time on the i^{th} day;

E_{T2} is energy production of the i^{th} day before the data collection time;

EB_i is the total energy production before the i^{th} day;

E_{Di} is the daily energy production of the i^{th} day.

4. RESULTS AND DISCUSSIONS

4.1 Wind Turbine System

The AEI WTC wind data used for this study were gathered over a three-year period. Based on Equation 1, energy production for each month during the period was calculated, and the average monthly energy production was also calculated. Table 5 shows that the energy production varied greatly from one month to the next month.

Table 5. Energy production estimation of AOC wind turbine

Month	**Average (kWh)**
January	18,732
February	20,071
March	20,093
April	23,807
May	22,065
June	22,295
July	15,590
August	13,755
September	14,544
October	17,702
November	21,101
December	18,770
Total	**228,531**

Table 6 shows the initial cost of the AOC wind turbine system is $291,750 and the turbine costs more than half, and the tower costs less than 20% of the total cost. Annual energy production

was estimated to be 228,531 kWh from Table 5. The system replaces an existing source of electricity costing approximately $0.09/kW in retail price which creates an annual savings of approximately $20,568/yr.

Table 6. Initial cost of the AOC wind turbine system

AOC wind turbine	Cost ($)
Turbine	176,750
120 ft tower	48,000
Spare parts	4,500
Shipping	10,000
Material	30,000
Disconnect	1,500
Shed	1,000
Labor	20,000
Subtotal	291,750

The total annual operation and maintenance charges represent a percentage of the installed cost, often quoted between 1.5% and 2%. The average value of 1.75% was used during calculations, resulting in $5,105 annual operation and maintenance cost. Incentives are tax breaks, subsidies, and mandates from the federal and states governments. Incentives are a very important factor for renewable energy investment as they have a direct role in determining the payback period.

4.2 Tracker PV Array System

The daily electricity production of the two tracker array system for the month of June was presented in Figure 4 as a sample. As can be seen from the figure, electricity generation varied considerably on a daily basis, within a range of 40-85 kWh for the month of June.

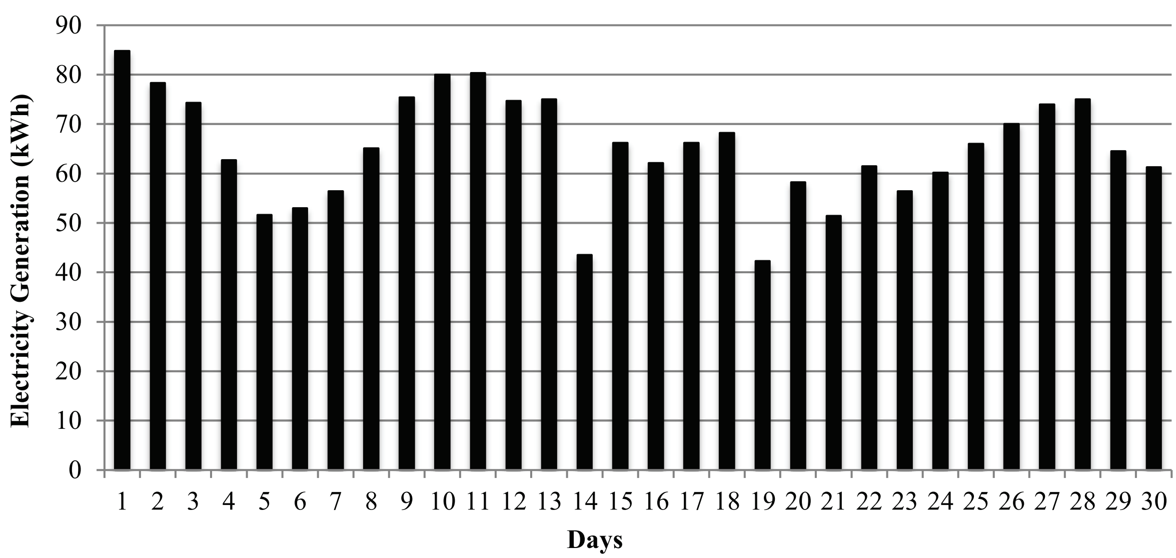

Figure 4. Sample of daily electricity production of the two tracker array systems

Table 7 shows the energy production of the two tracker array system by PVWATTS Calculator with the actual data. It used solar radiation (kWh/m^2/day) and projected PV electrical

energy production (kWh) by month for Canyon, Texas. The estimated yearly energy production of the two tracker array system was 20,587 kWh. The differences between the two values could come from variations in predicted weather for the months involved.

Table 7. Energy production of the two tracker array system by PVWATTS Calculator

Station Identification		Data				
Cell ID:	208377	Month	Solar Radiation (kWh/m²/day)	Est. AC Energy (kWh)	Actual AC Energy (kWh)	Energy Value ($)
State:	Texas	Jan*	6.53	1,536	1,376	138
Latitude:	35.0 ° N	Feb	6.40	1,335	1,552	120
Longitude:	101.9 ° W	Mar	7.90	1,788	1,979	161
PV System Specifications		Apr	9.00	1,939	1,810	175
DC Rating:	8.40 kW	May	8.93	1,942	2,074	175
Array Tilt:	N/A	Jun	9.69	1,981	1,959	178
Array Azimuth:	N/A	Jul	9.55	2,010	1,812	181
Energy Specifications		Aug	8.61	1,826	1,890	164
		Sep	7.89	1,643	1,761	148
		Oct*	7.90	1,747	1,664	157
		Nov*	6.51	1,425	1,327	128
		Dec*	6.02	1,415	1,301	127
		Year	**7.92**	**20,587**	**20,505**	**1,853**

Note: '*' denotes that the actual AC energy outputs were partially recorded in the month and normalized.

The breakdown of the initial cost of the tracker array system was presented in Table 8, with a total of $54,700. The system replaces an existing source of electricity costing approximately $0.09/kWh. When annual energy production was estimated as 20,587 kWh (from Table 7), an annual savings of approximately $1,852/yr is reached as a result of calculations.

Table 8. Initial cost of the two tracker array system

Tracker array system	Cost ($)
2 Tracker systems	48,200
Inverter	4,631
Module-Communications	206
Material	6,852
Pipe	1,055
Tracker foundation	1,500
Labor	5,000
Subtotal	67,444

4.3 Fixed PV Array System

The impact of tilt angle, varying between 32-35 degrees, had a minor effect when compared to the natural variation that exist in solar electricity generation. A clear trend could not be observed between energy generation and the tilt angles analyzed in this study. The same method with the tracker array system output estimation was used for the fixed array system. Table 9 shows the

energy production of each fixed array panel with different tilt angles by PVWATTS Calculator. The estimated yearly energy production of the fixed array system was calculated as 60,994 kWh based on a derate factor of 0.9.

Table 9. Estimated energy production by each fixed array panels with different tilt angle

	32 degree		33 degree		34 degree		35 degree	
Month	rad	kWh	rad	kWh	rad	kWh	rad	kWh
January	4.61	552	4.64	556	4.68	560	4.71	565
February	5.46	580	5.49	583	5.52	586	5.54	589
March	6.11	696	6.12	697	6.13	698	6.14	698
April	6.50	701	6.48	699	6.47	697	6.45	695
May	6.34	687	6.30	683	6.27	679	6.23	675
June	6.67	669	6.63	665	6.58	659	6.52	654
July	6.68	692	6.64	687	6.60	682	6.55	677
August	6.32	659	6.30	656	6.28	654	6.25	651
September	6.07	633	6.07	633	6.08	633	6.07	633
October	6.29	688	6.31	691	6.34	694	6.37	697
November	4.64	514	4.68	518	4.71	522	4.74	525
December	4.63	550	4.67	555	4.71	560	4.75	565
Year	5.86	7,622	5.86	7,625	5.86	7,626	5.86	7,624

The initial cost of the fixed array system was presented in Table 10. PV modules are responsible for nearly half of the total cost of $145,357. Annual energy production was estimated to be 60,994 kWh (see Table 9). The system replaces an existing source of electricity costing $0.09/kWh, creating an annual savings of approximately $5,489/yr.

Table 10. Initial cost of the fixed array system

Fixed array system	Cost ($)
Modules	77,166
Inverter	12,606
Module-Communications	560
Material	18,653
Pipe	2,872
Foundation	16,000
Labor	17,500
Subtotal	145,357

5. ECONOMIC EVALUATION OF WIND AND SOLAR ENERGY INVESTMENTS IN TEXAS

5.1 Feasibility Analysis

Various studies have looked into identifying factors that influence feasibility of wind and solar energy generation. Other than technical or geographical considerations such as proper panel installation, panel technology, overall system efficiency, intermittency, transmission loss, temperature, wind speed, political and economic parameters such as renewable energy credits,

utility rebates, tax incentives, inflation rate, capital cost, maintenance cost were also identified as playing a vital role in the feasibility of such systems [25-28].

Another study focusing on optimization of PV-wind hybrid energy systems compared to having the two systems separately concluded that the optimal combination of a hybrid system provided higher system performance and reliability than either of the single systems for the same cost for every battery storage capacity analyzed [29]. While the goal of the study was to identify ideal spots for wind or PV energy in Texas Panhandle, the discussion of results seek to address this important factor of efficiency gains in hybrid systems.

The most critical factors for economic evaluation is financially worthwhile are the initial cost of the installation and the annual energy production. A wind turbine or solar PV is economically feasible only if its overall earnings exceed its overall costs within a time period theoretically up to the lifetime of the system, in practice much sooner, within a few years upon project completion.

Payback Period (Equation 5), Net Present Value (NPV, Equation 6), Internal Rate of Return (IRR, Equation 7), and Profitability Index (PI, Equation 8) were used to determine the profitability and economic aspects for the systems: The life expectancy of all systems were assumed to be 25 years [30].

$$P = \frac{IC - In}{AE * PE - AOM} \tag{5}$$

Where,

IC is initial cost of installation;
In is value of the national or state incentives;
AE is annual energy production;
PE is the rate of electricity; and
AOM is annual operation and maintenance cost.

$$\text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \tag{6}$$

Where,

Ct is net cash inflow during the time period;
C_0 is the total initial investment costs;
r is discount rate;
t is the number of time periods

$$NPV = 0 = \sum_{y=1}^{y} \frac{C_y}{(1+IRR)^y} - C_0 \tag{7}$$

$$\text{PI} = \frac{NPV}{Initial\ Investment} + 1 \tag{8}$$

Table 11 summarizes the renewable energy system economic parameters. As shown in the table, the results of the economic analysis on the renewable energy systems at Panhandle Texas (Canyon and Amarillo area) show that the projects are profitable since payback period is less than the life time of the system, NPV is positive, and PI is larger than 1.0.

Table 11. Estimated Wind and Solar system economic parameters

Economic Parameter	Wind	Tracking Solar	Fixed Solar
Payback Period	13.2 years	21.1 years	17.9 years
Net Present Value (NPV)	$ 161,653	$ 1,116	$ 20,372
Internal Rate of Return (IRR)	5.12%	1.37%	2.74%
Simple Cash Flow (SCFy)	$ 231,923	$ 7,332	$ 38,787
Profitable Index (PI)	1.55	1.03	1.21

5.2 Wind Turbine System Investment in Texas

Renewable energy in general, and wind energy specifically has experienced rapid market growth in recent years globally and in the U.S. Currently, Texas produces more wind power than any other state in the U.S. The market for wind turbine systems has grown rapidly in Texas due to its large wind resource, which is about 4.5 – 7.5 m/s (10.1 – 16.8 mph) as an annual average wind speed at 30 m (98 ft) above ground, and due to other geographical advantages that enabled rapid expansion.

Ten cities and their wind speed data were selected to evaluate wind turbine system investments in Texas. The ten cities are: Abilene; Dalhart; Denton; El Paso; Midland; Lubbock; Corpus Christi; Laredo; Brownsville; and San Angelo. Figure 5 shows the locations of the selected cities for wind energy feasibility study in Texas. Amarillo in Panhandle was chosen for in-depth analysis as the representative sample city. None of the ten sites were selected from the eastern part of the state since the average wind speeds as Figure 2 shows below 4.0 m/s (9.0 mph), which is not ideal for wind farm.

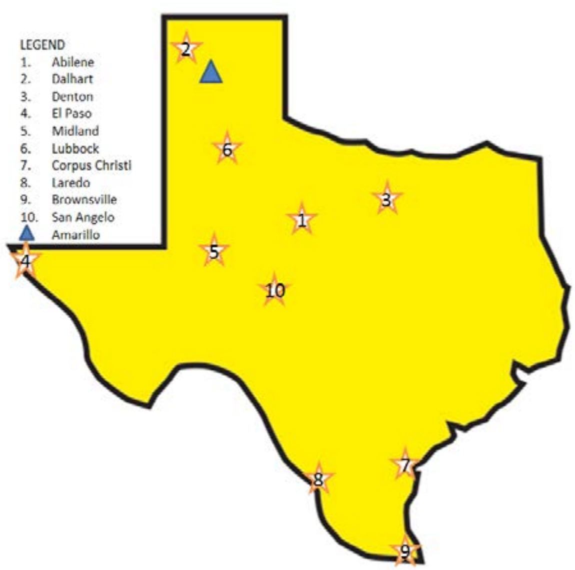

Figure 5. Selected cities for the wind turbine system

The 50kW wind turbine system was assumed to be installed in the ten cities. Hourly wind speed data from the ten cities were used for energy production calculations, therefore providing high resolution results. As the height of the installed wind turbine was 37 m (120 ft), values for the 10 m (33-ft) wind speed were converted to 37 m (120 ft) using Equation 2.

The initial installation and operating and maintenance cost of the wind turbine system were assumed to be the same as the system located at the AEI WTC. Table 12 shows the yearly energy

production and payback period estimation of the wind turbine system if it were installed in those ten cities. Electricity rates have a vital role in determining payback period. Payback period would be shorter than those listed in Table 12 in large cities that have higher electricity rates than smaller cities. The electricity rate was assumed to be the same throughout Texas in the current study, as significant variations were not expected. Federal incentives that are currently available to wind projects were included in the analysis however.

The 50 kW wind turbine system analyzed in the study may be suitable for small businesses as it is in excess of the needs of a typical residential unit. The federal Business Energy Investment Tax Credit (ITC) (see Appendix A) was available for this wind turbine system. The credit is equal to 30% of total installation cost. Eligible small wind property includes wind turbines up to 100 kW in capacity. Therefore, based on the installed cost of $291,750 the credit was a total of $87,525 for this system in Texas.

Table 12. Yearly wind energy production and payback period estimation of the ten cities

City	Yearly energy production (kWh)	Payback period (year)
Abilene	170,879	19.9
Dalhart	194,100	16.5
Denton	131,068	30.5
El Paso	91,123	66.0
Midland	172,306	19.6
Lubbock	163,507	21.2
Corpus Christi	180,176	18.4
Laredo	160,952	21.8
Brownsville	155,022	23.1
San Angelo	127,094	32.2
Amarillo	228,531	13.2

The payback period of the AOC wind turbine system located at the AEI WTC was discussed and determined to be 18 years, without any incentives due to reason discussed previously. Had the project received ITC incentives, the payback period would have been about 13 years, a significant change for this site.

5.3 PV System Investment in Texas

The solar map specific to the state of Texas shown in Figure 6 reveals that the solar radiation range was 4.0 – 7.5 kWh/m^2/day [31]. Solar radiance tends to follow a West to East trajectory in decreasing magnitude rather than a North-South variation, downplaying the importance of latitude for solar radiation. While Western part of the state receive 6.0 – 7.0 kWh/m^2/day, the eastern regions receive 4.0 – 4.5 kWh/m^2/day.

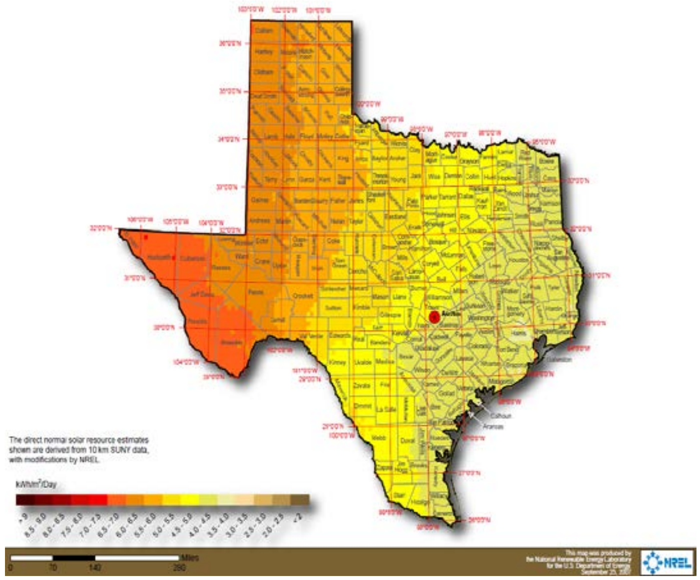

Figure 6. Texas annual average solar radiation map [31]

To evaluate PV system investment in Texas, twelve cities were selected as the sample cities. For PV systems, available incentives are an important factor for investment decisions; therefore, current utility rebates programs played a role in determining location selection. The twelve selected cities are: Sunset Valley; San Antonio; Denton; El Paso; Corinth; Midland; San Marcos; Sierra Blanca; Gonzales; San Angelo; Corpus Christi; and Wheeler. Figure 7 shows the locations of the twelve cities. Amarillo was indicated in the figure to indicate the actual location of the PV array installation.

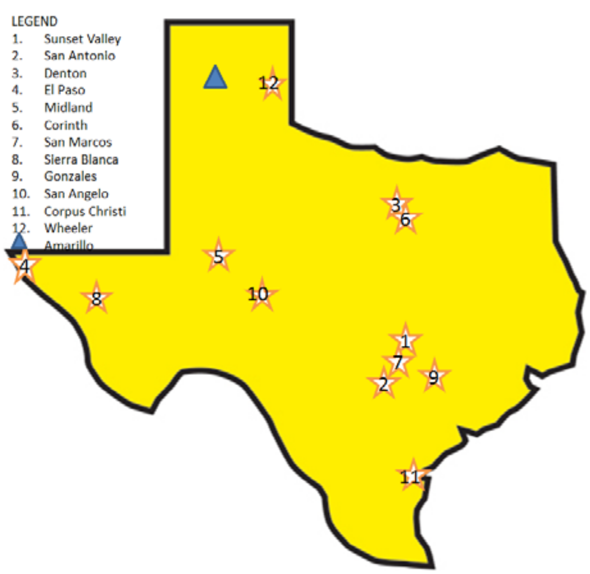

Figure 7. Selected cities for the PV system

Each tracker array and fixed array was assumed to be identical to the installed 4.2 kW system. The size is suitable for residential use, rather than for commercial use. The tracker array

and the fixed array were analyzed separately. Initial, operating, and maintenance costs of the PV system were assumed to be the same as the installed system costs located at PDRC.

Table 13 shows the yearly energy production and payback period estimation of the 4.2 kW tracker array systems in the sample cities. The yearly energy production was calculated based on PV WATTS Calculator and the payback period was calculated using Equation 5. For the PV system, the important factors are incentives (i.e., tax credits and rebates) that vary on states or cities. The Federal Residential Renewable Energy Tax Credit (Appendix B), was available for the tracker array system, and covered 30% of the installation cost. Utility rebates were different in the analyzed cities.

Table 13. Yearly PV energy production and payback period estimation of each tracker array system in the sample cities

City	Energy Production (kWh)	Utility Rebates ($)	Payback Period (years)
Sunset Valley	8,856	9,300	12.3
San Antonio	8,884	8,400	13.4
Denton	9,276	12,600	7.8
El Paso	11,279	7,500	11.5
Midland	10,178	2,263	18.4
Corinth	8,786	8,400	13.6
San Marcos	8,623	5,000	18.2
Sierra Blanca	11,279	0	18.9
Gonzales	8,572	8,000	14.4
San Angelo	9,785	6,300	14.6
Corpus Christi	8,073	6,300	17.7
Wheeler	10,525	6,300	13.6
Amarillo	10,293	0	21.1

The shortest payback period among analyzed cities was approximately eight years for the city of Denton. The payback period of the tracker array system originally installed at AEI WTC was calculated as 21 years if federal or utility incentive is included.

It is interesting to note that the City of Sierra Blanca has a large solar resource with one of the best in the state, and in the list of sample cities. However, without Utility Rebates, the payback period was calculated to be close to 18 years, ranking the city at the bottom of the list of analyzed sample cities. This example demonstrates the importance and dependence of solar PV projects on incentives that may be in the form of utility rebates or tax credits. Even the most favorable locations may become infeasible if comparable incentives are not offered.

Table 14 shows the yearly energy production and payback period estimation of the 4.2 kW fixed array system for the selected sample cities. The same analysis method with the tracker array system was used for the fixed array system. The installation cost of the fixed array system was less than the tracker array system. With a 30% FTC incentive, the Residential Renewable Energy Tax Credit came to $5,822. Because of a favorable utility rebate offered by Denton Municipal Electric – the Green Sense Solar Rebate Program (see Appendix C), the payback period of the fixed array system located in Denton was calculated to be 1.6 years.

Results indicate that offered incentives for PV systems are important factors for renewable energy investment in Texas since the retail electricity is cheaper than other states. Even at a

location with large amount of solar radiation like the city of Sierra Blanca, the payback period would be prohibitively long without federal and utility incentives, thus rendering such projects unfeasible. While solar resource is a significant factor in determining project success, federal and utility incentives play a more dominant role in solar energy investments. In Texas, Denton, Sunset Valley, El Paso San Antonio and Corinth were found to be the best five locations for PV system investments.

Table 14. Yearly energy production and payback period estimation of each fixed array panels in the sample cities

City	Energy Production (kWh)	Utility Rebates ($)	Payback period (years)
Sunset Valley	6,681	9,300	7.1
San Antonio	6,757	8,400	8.5
Denton	6,927	12,600	1.6
El Paso	8,132	7,500	8.3
Midland	7,404	2,263	17
Corinth	6,643	8,400	8.7
San Marcos	6,525	5,000	14.6
Sierra Blanca	8,132	0	18.6
Gonzales	6,517	8,000	9.5
San Angelo	7,223	6,300	11.2
Corpus Christi	6,119	6,300	13.2
Wheeler	7,686	6,300	10.5
Amarillo	7,626	0	17.9

6. CONCLUSIONS

The study described herein had two goals. The first goal was to evaluate the benefit of wind and solar energy in the Texas Panhandle area. To accomplish this, the AOC 15/50 50 kW wind turbine system at AEI WTC and the PV system located at PDRC were used as the research foundation in terms of collecting and analyzing data. By analyzing the collected data in conjuncture with the PV WATTS Calculator, yearly energy productions of the two systems were estimated to be 228,531 kWh and 81,581 kWh (total in solar), respectively. The payback periods were estimated to be approximately 13 years for wind and 19 years for solar (including both tracker and fixed arrays), respectively, for their installation site.

The second goal of this study was to determine economical investment sites for wind and solar energy in Texas. In order to accomplish this, the same wind turbine and PV systems were assumed to be located in different areas in Texas. At this stage of the analysis, the initial, operating and maintenance cost of the renewable energy systems, as well as the electricity rates in the selected cities were assumed to be the same as those of the original location. Publicly available wind and solar maps were used to guide the process of selecting different locations for the two analyses. The following conclusions can be drawn based on analysis results of the presented study:

- Since the only incentives for wind energy systems are at the federal level, rather than at the state or utility level, wind resource was found to be the most important factor for payback period calculations. Northern Texas, especially regions surrounding Panhandle area were

determined to be the best region for wind turbine system investments in Texas, with a payback period of around 13 years.

- Results indicate that offered incentives for PV systems are important factors for renewable energy investment in Texas. Even at a location with high levels of solar radiation like the city of Sierra Blanca, the payback period would be prohibitively long without federal and utility incentives, thus rendering such projects infeasible. Therefore, incentives may become a more important factor than solar resource for a particular region.
- The average payback period of tracker array systems were calculated to be about 15 years on average, with a range of 8-21 years. While companies may be interested in tracker system projects with payback periods closer to the lower end of the range, they would most likely seek other alternatives for sites with payback periods near the higher end of the range. For fixed array systems, the payback period was calculated to be about 11.5 years on average, with a range of 2-19 years. Even though a fixed array system generates less energy than a tracker array system, the initial cost of the latter significantly affect payback periods, and therefore limit their applications. This is further heightened by the fact that incentives in general currently to not distinguish between fixed array and tracker array systems. Less costly technological developments in the field, or a changing incentive structure that promotes one system over the other may shift market demand towards one technology in the future.

In conclusion, the results of the study demonstrated feasible sites for wind and solar system investments in Texas. An important novelty brought forward by this study would be the ease of repeating the presented methodology to conduct similar studies for other states in the U.S., or even for other countries as long as fundamental data is present. Based on local wind and solar maps for such states, and also by considering local utility rebates for each system, the feasibility of renewable energy investment sites could be evaluated for different states or locations.

The electricity rate was assumed to be the same throughout Texas in the current study, as significant variations were not expected. A further step towards improving the accuracy of the feasibility analysis would be to investigate local electricity rates in different areas of the state and incorporate that into the calculations.

Acknowledgement

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REFERENCES

[1] U.S. Energy Information Administration. (USEIA, 2018). Total Energy - Table 7.2a Electricity Net Generation: Total (All Sectors). Retrieved July 2018, from http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf

[2] Sharaf-Eldin S.A., Abd-Elhady, M.S., and Kandil, H.A. (2016) "Feasibility of solar tracking systems for PV panels in hot and cold regions" Renewable Energy 85, 228-233. doi: 10.1016/j.renene.2015.06.051.

[3] Shi, W., et.al. (2015) "Feasibility study of offshore wind turbine substructures for southwest offshore wind farm project in Korea" Renewable Energy 74, 406-413. doi: 10.1016/j.renene.2014.08.039.

[4] Li, Y., Liao, S. Rao, Z., and Liu, G. (2014) "A dynamic assessment based feasibility study of concentrating solar power in China", Renewable Energy 69, 34-42. doi: 10.1016/j.renene.2014.03.024.

[5] Han, Y. and Mays, I. (1996) "Feasibility study of wind energy potential in China" Renewable Energy 9, 810-814. doi:10.1016/0960-1481(96)88406-0.

[6] Marafia, A-Hamid (2001) "Feasibility study of photovoltaic technology in Qatar" Renewable Energy 24, 565-567. doi:10.1016/S0960-1481(01)00042-8.

[7] Melikoglu, Mehmet (2013) "Vision 2023: Feasibility analysis of Turkey's renewable energy projection" Renewable Energy 50, 570-575. doi: 10.1016/j.renene.2012.07.032.

[8] Shafiullah G.M., et. al. (2012) "Prospects of renewable energy – a feasibility study in the Australian context" Renewable Energy 39, 183-197. doi: 10.1016/j.renene.2011.08.016.

[9] Khadem S. and Hussain M. (2006) "A pre-feasibility study of wind resources in Kutubdia Island, Bangladesh" Renewable Energy 31, 2329-2341. doi:10.1016/j.renene.2006.02.011.

[10] Elhadidy, M.A. and Shaahid, S.M. (1999) "Feasibility of hybrid (wind + solar) power systems for Dhahran, Saudi Arabia" Renewable Energy 16, 970-976. doi:10.1016/S0960-1481(98)00344-9.

[11] Araujo Lima, L. and Bezerra Filho, C.R. (2010) "Wind energy assessment and wind farm simulation in Triunfo – Pernambuco, Brazil" Renewable Energy 35, 2705-2713. doi:10.1016/j.renene.2010.04.019.

[12] Office of Energy Efficiency and Renewable Energy (OEERE, 2012). Texas 30-Meter Residential-Scale Wind Resource Map. Retrieved July 2018, from https://windexchange.energy.gov/maps-data/232

[13] Nelson,V. (2009). Wind Energy: Renewable Energy and the Environment. Boca Raton, FL: CRC Press.

[14] Xie, Y., Chang, B., Starcher, K., Carr, D., Chen, D., and Leitch, K. (2013) "Installation of 42kW Solar Photovoltaics and 50kW Wind Turbine Systems" Journal of Green Building, Vol. 8, Issue 3. doi: 10.3992/jgb.8.3.78.

[15] Southeast Colorado Resource Conservation & Development Inc. (SCRCD, 2010). Final report for Colorado Department of Agriculture Advancing Colorado's Renewable Energy: Farm Scale Wind Implementation

[16] Meadows, B.; Forsyth, T.; Johnson, S.; Healow, D. (2010). Viability of Small Wind Distributed Generation for Farmers Who Irrigate. The WINDPOWER 2010 Conference, Dallas, Texas.

[17] Office of Energy Efficiency and Renewable Energy (2017). U.S. Installed and Potential Wind Power Capacity and Generation July 2018, from https://windexchange.energy.gov/maps-data/321
[18] Irene, M. and Brian, V. (2011). Solar Energy Use in U.S. Agriculture Overview and Policy Issues.
[19] Solar Energy Industries Association (SEIA, 2017). State Solar Policy: Texas Solar. Retrieved July 2018, from http://txses.org/data-on-solar-in-texas-and-the-u-s/
[20] Tomson, T. (2008). Discrete Two-Positional Tracking of Solar Collectors. Renewable Energy, 33, 400-405. doi: 10.1016/j.renene.2007.03.017.
[21] Huang, B.J., Ding, W.L., Huang, Y.C. (2011). Long-Term Field Test of Solar PV Power Generation Using One-axis 3-Position Sun Tracker. Solar Energy, 85, 1935-1944. doi:10.1016/j.solener.2011.05.001.
[22] Asiabanpour, B. et. al (2017) "Fixed versus sun tracking solar panels: an economic analysis" Clean Technology Environmental Policy 19, 1195-1203. doi:10.1007/s10098-016-1292-y.
[23] International Electrotechnical Commission (IEC, 2006). International Standard: Wind Turbine Generator Systems.
[24] National Renewable Energy Laboratory (NREL). (2014). Wind Resource Information. Retrieved July 2018, from http://www.nrel.gov/rredc/wind_resource.html
[25] Baldick, R. (2012). Wind and Energy Markets: A Case Study of Texas. Systems Journal, IEEE, 6(1), 27-34. doi:10.1109/JSYST.2011.2162798.
[26] Li, W., Yeh, T.H., Chen, Z. (2009). Benefit Evaluation of Wind Turbine Generators in Wind Farms Using Capacity-Factor Analysis and Economic-Cost Methods. Power Systems, IEEE, 24(2), 692-704. doi:10.1109/TPWRS.2009.2016519.
[27] Son, Y.S. (2005). Dispatchable Wind Power Valuation in Texas. Power Engineering Society General Meeting, IEEE, 2, 1944-1947. doi: 10.1109/PES.2005.1489405.
[28] Sedghisigarchi, K. (2009). Residential Solar Systems: Technology, Net-Metering, and Financial Payback. Electrical Power & Energy Conference, IEEE, 1-6. doi: 10.1109/EPEC.2009.5420778.
[29] Celik, A.N. (2002). Optimization and Techno-Economic Analysis of Autonomous Photovoltaic–Wind Hybrid Energy Systems in Comparison to Single Photovoltaic and Wind Systems. Energy Conversion and Management, 43(18), 2453-2468. doi:10.1016/S0196-8904(01)00198-4.
[30] Lee, J., Chang, B., Aktas, C., and Gorthala, R. (2016) "Economic feasibility of campus-wide photovoltaic systems in New England", Renewable Energy 99, 452-464. doi: 10.1016/j.renene.2016.07.009.
[31] National Renewable Energy Laboratory (NREL, 2007). Solar maps. Retrieved July 2018, from http://www.nrel.gov/gis/solar.html

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APPENDIX

A: Business Energy Investment Tax Credit (ITC)

State:	Federal
Incentive Type:	Corporate Tax Credit
Eligible Renewable/Other Technologies:	Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Fuel Cells, Geothermal Heat Pumps, Municipal Solid Waste, CHP/Cogeneration, Solar Hybrid Lighting, Hydrokinetic Power (i.e., Flowing Water), Anaerobic Digestion, Small Hydroelectric, Tidal Energy, Wave Energy, Ocean Thermal, Fuel Cells using Renewable Fuels, Microturbines, Geothermal Direct-Use
Applicable Sectors:	Commercial, Industrial, Utility, Agricultural
Amount:	30% for solar, fuel cells, small wind and PTC-eligible technologies;* 10% for geothermal, microturbines, and CHP*
Maximum Incentive:	Fuel cells: $1,500 per 0.5 kW Microturbines: $200 per kW Small wind turbines placed in service 10/4/08 - 12/31/08: $4,000 Small wind turbines placed in service after 12/31/08: no limit All other eligible technologies: no limit
Eligible System Size:	Small wind turbines: 100 kW or less (except unlimited for PTC-eligible wind)* Fuel cells: 0.5 kW or greater Microturbines: 2 MW or less CHP: 50 MW or less* Marine and Hydrokinetic: 150 kW or greater (as defined by PTC eligibility)
Equipment Requirements:	Fuel cells, microturbines, and CHP systems must meet specific energy-efficiency criteria
Authority 1:	26 USC § 48
Authority 2:	Instructions for IRS Form 3468
Authority 3:	IRS Form 3468
Authority 4: Date Enacted: Date Effective:	H.R. 8 (American Taxpayer Relief Act of 2012) 01/02/2013 01/02/2013

B: Residential Renewable Energy Tax Credit

State:	Federal
Incentive Type:	Personal Tax Credit
Eligible Renewable/Other Technologies:	Solar Water Heat, Photovoltaics, Wind, Fuel Cells, Geothermal Heat Pumps, Other Solar-Electric Technologies, Fuel Cells using Renewable Fuels
Applicable Sectors:	Residential
Amount:	30%
Maximum Incentive:	Solar-electric systems placed in service after 2008: no maximum Solar water heaters placed in service after 2008: no maximum Wind turbines placed in service after 2008: no maximum Geothermal heat pumps placed in service after 2008: no maximum Fuel cells: $500 per 0.5 kW
Eligible System Size:	Fuel cells: 0.5 kW minimum
Equipment Requirements:	Solar water heating property must be certified by SRCC or a comparable entity endorsed by the state where the system is installed. At least half the energy used to heat the dwelling's water must be from solar. Geothermal heat pumps must meet federal Energy Star criteria. Fuel cells must have electricity-only generation efficiency greater than 30%.
Carryover Provisions:	Excess credit generally may be carried forward to next tax year
Start Date:	1/1/2006
Expiration Date:	12/31/2016
Web Site:	http://www.energystar.gov/taxcredits
Authority 1: Date Enacted: Date Effective: Expiration Date:	26 USC § 25D 8/8/2005 (subsequently amended) 1/1/2006 12/31/2016
Authority 2:	IRS Form 5695 & Instructions: Residential Energy Credits

C: Denton Municipal Electric – Green Sense Solar Rebate Program

State:	Texas
Incentive Type:	Utility Rebate Program
Eligible Renewable/Other Technologies:	Solar Water Heat, Photovoltaics
Applicable Sectors:	Commercial, Residential
Amount:	PV: $3.00 per AC watt (based on the calculated expected performance of the system) Solar Water Heater: 50% of project cost
Maximum Incentive:	PV: $15,000 per structure Solar Water Heater: $300 per unit
Eligible System Size:	Customer must contact the DME Green Sense Program Manager for details
Equipment Requirements:	Solar Water Heaters must preheat water for a permanently installed electric water heater
Installation Requirements:	Installers and contractors must be registered with DME
Program Budget:	$120,000 (FY2011)
Start Date:	01/01/2009
Web Site:	http://www.cityofdenton.com/