An Economic Analysis for Residential Rooftop Solar Photovoltaic Panels in the State of Texas

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Abstract

The renewable energy industry in the United States is growing at record rates. In the last decade, more renewable energy has grown in terms of capacity as well as demand because of the population growth and the need for environmentally friendly energy resources. Solar energy is one of the most promising renewable energy sources in Texas because of the climate and solar resource potential. With the continuous growth and advances in the industry, homeowners can install solar rooftop photovoltaic (PV) systems for electricity generation instead of relying on the power grid. While the environmental benefits of solar energy are of importance and urgency, the economic benefits for homeowners are still to be determined. This research represents an economic assessment of a 7-kW residential rooftop solar system with a 3kW/6kW storage bank, in the state of Texas based on economic parameters such as the internal rate of return (IRR), the payback period (PP), and the net present value (NPV). These rooftop PV systems are installed on single-family residences and is economically beneficial in the state of Texas. These systems resulted in an NPV of $6333.01, IRR of 8.61%, PP of 13 years, which is an economic benefit to Texas homeowners.

Keywords
Residential Solar Panels, Energy Savings, Internal Rate of Return, Payback period, Net Present Value

1. Introduction
Electrical energy consumption in the United States of America is continuously increasing because of economic growth, population growth, rising household incomes, and the electrification of heat and transportation. Fossil fuels - including coal, oil, and natural gas - currently generate 79% of the United States supply while renewable energy only generates 12% as of 2020. The dependence on fossil fuels has caused an increase of greenhouse gas (GHG) emissions, air pollution and global warming. North America is the second largest regional emitter of GHGs at 18% of global emissions, with Asia being the largest emitter accounting for 53% of global emissions.

An alternative to fossil fuels is renewable or clean energy. The Natural Resource Defense Council (NRDC) defines renewable energy as energy that comes from natural sources or processes that are constantly replenished. Some of the renewable energy sources are solar energy, wind energy, hydroelectric energy, geothermal energy, and biomass energy. It is today widely accepted that using fossil fuels and the emission of GHGs is negatively impacting the world's climate and ecosystem. Given the rapid population growth and increase in energy demands, investing in renewable energy is key for sustainable growth. IRENA (International Renewable Energy Agency) has put together a map called REmap to double the share of renewables by 2030 compared to 2010 and reach 36% in total final energy consumption globally. In its economic analysis of the REmap, IRENA shows that by doubling the shares of renewables in the global energy mix, four primary areas would be greatly impacted: the GDP, welfare, jobs, and the trade industry. The global GDP would increase by 0.6% to 1.1% equivalent to $700 billion $1.3 trillion. The welfare of humans will also increase by 3.7% due to the economic, social, and environmental impacts of renewable energy adoption. The global renewable energy job industry will increase by 24.4 million in 2030. Finally, the change to renewables will impact fuel importers and exporters by decreasing the coil imports by 50% and oil and gas imports by 70% while in parallel, the demand for investment goods and services such as solar panels, turbines, and construction materials will rise in trade. Thus, the adoption of renewable energies can offer solutions to ensure economic growth as well as decarbonize economies across the globe.

2. Literature Review

Solar photovoltaic (PV) systems in residential settings have decreased in costs over the last decade in the United States. PV systems that convert the light of the sun to electric power and are the universal means of adopting to the principles of solar energy. The National Renewable Energy Laboratory's (NREL) U.S Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020 shows how the prices of Residential PV decreased by 64% and the efficiency increased by 34% from 2010 to 2021. In 2010, the cost of PV, including the uncontrolled costs such as transmission lines, sales tax, overhead, and installation labor, hardware costs, inverter costs and module costs - was \$7.58/W_{DC} and has now reached a cost of \$2.71/W_{DC}. With the prices of PV systems going down, their efficiency has been continuously improving because of the continuous innovation in the field. The efficiency of monocrystalline PV systems increased from 15% in 2010 to 20% in 2021.

The residential sectors in the United State account for 22% of total energy consumption and could benefit from the adoption of residential solar panels. PV systems are highly suitable to be used in buildings because of their reliability, ease of installation, predictable annual yields, as well as their capacity to power electric appliances in homes, lighting, heaters, as well as heat pumps (Biswas 2016). There are two main ways to adopt PV systems in residential settings, they can be either grid-connected systems and/or stand-alone systems. Grid-connected systems are systems that are connected to the grid and can have energy supplied from the grid when the power produced by the solar panel does not meet the power needs. A stand-alone system is not connected to the grid and uses batteries to store the surplus of power produced to use it when needed. Grid-connected systems are most used in the United States, and they can also integrate storage batteries to reduce the power supplied from the grid.

In the United States, Texas possesses the second-highest yield of solar capacity units installed at 11,062.82MW; this enough to power to furnish 1,297,592 homes. Texas also projected to be ranked first with an increased capacity of 26,995.00MW over the next 5 years for a total of 3.8GW of installed capacity. Texas is continuously investing in the solar industry and has invested 12,989.79 million dollars this year. Texas is poised to become a national leader in the solar industry thanks to the weather, NREL estimated an annual generation potential of 83.2TWh/year for rooftop PV in small buildings in Texas. In addition, the potential for solar energy growth, is associated with homeowners in cities throughout Texas who can use the rebate programs for financial incentives which can help cover the costs of the residential PV panels. Some of the available programs are the Austin Energy - Residential Solar PV Rebate Program often offer up to a \$2,500 rebate. The federal financial incentive Residential Renewable Energy Tax Credits can offer up to 26% of the original cost. Additionally, Texas has a regulatory policy known as the Texas Solar Rights which protects the homeowners' rights when installing a solar energy device on their residential properties. With the measures the USA is taking, and more specifically Texas, homeowners are encouraged to adopt PV panels in their homes as a source of energy.

3. Methods

The residential sector has an immense potential for the growth of photovoltaic systems (Al-Otaibi et al. 2015), this sector has a quicker installation timeframe than other renewable energy technologies for residential applications,yet does not include the need for the additional procurement of land, and reduces the dependence on the grid and fossil fuels (Al-Aboosi 2021). Additionally, today's solar technologies are robust and can provide homeowners with electricity in case of natural disasters occurring that might disturb the electricity generation from the grid. An example of that happened in Houston, Texas when it was hit by hurricane "Harvey" in August 2017 after which 156 solar - powered LED fixtures in Gene Green Park continued to shine with no interruption (Pagliaro and Meneguzz 2019).
Photovoltaic (PV) cells describe the device that converts sunlight directly into electricity. The PV cells constitute the basic building block of a PV panel (EIA, 2021). Several PV panels put together constitute a PV array. In residential settings, a rooftop PV system consists of the PV array, an inverter, a power meter, and optionally, a charge controller with a battery bank. In Texas, the residential PV systems are mostly on-grid systems, which means the PV system is connected to the grid Figure 1 illustrates a typical on-grid PV system and its components when installed on a rooftop.

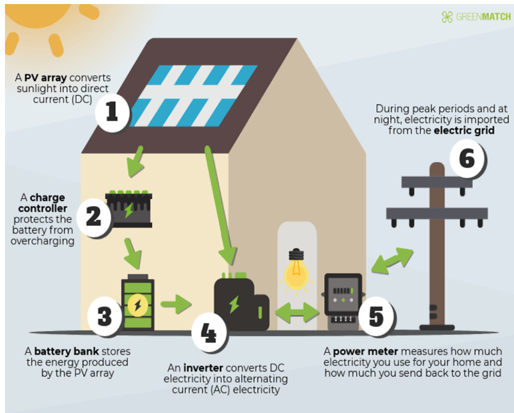

Figure 1. Residential On-grid PV System (Kunz 2021).

As shown on Figure 1, the PV array converts the sunlight collected into direct current (DC) electricity, which is then converted into alternating current (AC) electricity by the inverter. The power meter serves as a measurement tool that indicates how much electricity is used in the house. When the electricity used is more than the electricity produced, the electric grid provides the power needed. If the power used is less than the power produced, the excess electricity produced is fed to the grid. It is optional for homeowners to add battery banks to their PV system which is used to store the excess energy produced for a later use, and a charge controller to protect the battery banks. However, excess electricity generation from the PV system is mostly sold to the grid because of the high prices of battery banks for residential buildings (Arababadi, Parrish 2017).

The output of a PV system depends on the efficiency and performance of the system, which depends on both the PV array efficiency as well as the inverter efficiency (Hernandez, Baier, 2021). Multiple factors that influence the performance of a PV system including cleanliness of the panels, the panel temperature, humidity, wind speed and light reception angles. (Asiabanpour et al. 2016). The lifespan of photovoltaic panels today ranges between 20 to 25 years. In addition, the efficiency of the solar panels decreases over time due to aging and material degradation and the median value of the degradation rate is generally 0.5% per year (Jordan and Kurtz 2013).

4. Data Collection

The electrical energy output produced by PV systems varies from location to location due to its dependence on the solar irradiance. Texas is a growing leader in solar energy across the United States and is currently ranked second in the nation in terms of total solar capacity installed. Due to its available solar resources, Texas has great potential for small-scale and utility-scale solar PV applications (Gold and Webber 2015). The global horizontal solar irradiance (GHI) used by flat-plate solar collectors in Texas ranges from 4.75 to 5.75KWh/m^2/day. The National Renewable Energy Laboratory (NREL) of the U.S Department of Energy published a map indicating the GHI based on satellite data from 1998 to 2016 across the U.S and is shown in Figure 2. The GHI represents the energy resource available to a fixed flat plate collector, such as PV panels, oriented due south at a tilt angle equal to the latitude of the PV panel location (Schwarz 2017).

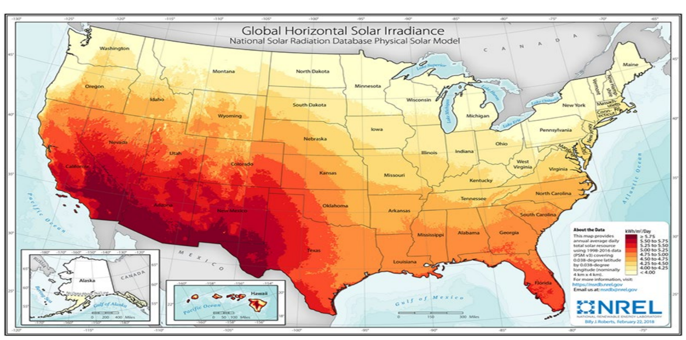

Figure 2. U.S Photovoltaic Solar Resource Potential Map (EIA. 2021).

In Texas, the residential sector accounts for 12.4% of the end-user energy consumption with a total of 1,767.3 trillion Btu according to 2019 statistics from the U.S Energy Information Administration. To encourage homeowners to adopt solar energy, there are a multitude of federal, state and utility incentives that aim at reducing the costs of the solar panels for it to be more affordable. While the federal and state incentives are in the form of percentage of the initial cost, the utility incentives are in the form of net metering. The Solar Energy Industry Association (SEIA) defines net metering as a billing mechanism that credits solar system owners for the electricity they add to the grid. With the availability of the incentives, the demand for solar demand in small-scale industries. Figure 3 shows the small-scale solar PV generation by state in 2020. The residential sector accounted for 61% of the total small-scale PV generation. In Texas, 1.612 billion kWh, or 5500.37 billion Btu, was generated by small-scale PV systems.

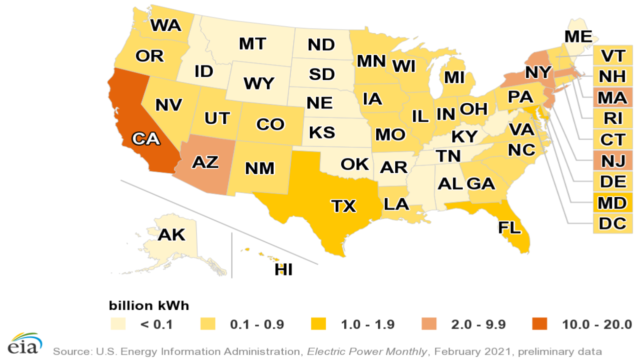

Figure 3. Small-Scale PV System Generation in the United States in 2020 (EIA, 2021).

With the growing shift towards renewable energy, specifically solar energy in the residential sector. An economic analysis of solar PV systems is essential to determine their economic feasibility for homeowners.

5. Results and Discussion

Engineering management refers to the art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component (Shah and Nowocin 2019). Engineering management consists of multiple sub-subjects, one of which is financial resource management that uses engineering economic principles. Engineering economy aims at finding the equivalent values for cash flow that occurs at various times so that it is accounting for the value of money (Shah and Nowocin 2019). This project uses engineering management knowledge, and more specifically, engineering economy to study if the adoption of residential PV systems in Texas is economically beneficial for homeowners in the long term. The study takes into consideration initial investments for procuring a rooftop PV system, including installation and other soft costs, as well as the saved electricity rates from using the PV system. Engineering economy parameters such as net present value, internal rate of return, profitability index and payback period are used in this study.

5. Numerical Results

The average house in Texas is 2,031 square feet and uses an average of 1,176 kWh per month. The study will focus on single-family homes because they account for 67% of housing in Texas according to a residential survey conducted by EIA in 2009. An average house in Texas uses 18% of its energy usage for air conditioning, 19% for water heating, 22% for space heating, and 59% for home appliances and lighting. The air conditioning percentage in Texas is among the highest in the nation, the majority of U.S states use only 6% of their electricity usage on air conditioning compared to 18% in Texas. Solar energy is highly correlated with air-conditioning demand which shows again the high potential of residential solar systems in Texas (Leonard and Michaelides 2018).

In Texas, the four main electric utility companies are Oncor, CenterPoint Energy, AEP Texas, and Texas-New Mexico Power. The electric rate for householders varies from city to another and depends on which utility company is used. A state average of electricity rates however is estimated to be 11.36¢/kWh according to State Data resulting in an average of $133.6 in monthly electricity bills or $1603.2 yearly. The electricity rates, according to EIA, have increased 1.8% per year in the United States for the past 25 years. The yearly electricity rates as well as their increase are taken into consideration in this study.

To add rooftop solar PV systems to a residential area, a homeowner must first know how much electricity their house consumes on average to avoid under-sizing or oversizing the solar system, as well as make sure there is enough roof space available to install the solar panels. To provide the average energy usage of 1,176 kWh in single family households in Texas, a 7kW solar system will be used. A 7kW solar system produces 450 kWh per month in areas with low solar resources and up to 1200 kWh per month for areas with rich solar resources such as Texas. The solar systems in Texas are mostly on-grid systems, which means the homes will draw their energy needs from the grid in case the solar system does not generate enough electricity. According to NREL, the costs of residential PV systems are $2.71 per watt DC, or $3.12 per watt AC and include the solar module costs, inverter costs, hardware such as structural and electrical components, installation labor, sales tax, land acquisition and considers the profits for the solar providers. Using the average PV costs, a 7kW PV system would cost $18,970 to purchase. For this study, the costs used are provided by NREL estimates for a 7kW residential system with 3kW/6kW of storage and are an average of $27,262 (NREL 2021).

The federal solar tax credit, known as the Investment tax credit (ITC), deducts 26% of costs of installing solar energy from the federal taxes of homeowners or businesses that install solar systems in 2021. The costs included in the deduction are the costs of the solar panels, the labor costs of installation, and the solar equipment costs such as the inverters, wiring and mounting hardware. For the cost estimates used in the study, the ITC would deduct 26% of the cost resulting in savings of $7,088.12. Thus, the final initial investment considered for the study is $20,173.88. The NREL also provides an equity discount rate used in the U.S solar market in 2020 of 6.1% as well as a residential PV system lifetime of 30 years which will be used in the economic analysis of the system.

To evaluate the economic aspects of using residential rooftop solar PV systems, the net present value (NPV), the internal rate of return (IRR), the payback period (PP), and the profitability index (PI) are evaluated. The case study will use Excel to calculate the economic parameters associated with the PV system. The economic parameters are used together to ensure most aspects of the project costs are taken into consideration and a comprehensive economic analysis is conducted.

The NPV of a project refers to the difference between the present value of the cash inflows and the present value of the cash outflows over a period. A positive NPV indicates a project is profitable, and the higher the NPV, the more profitable the project is. NPV is used to ensure the time value of money is taken into consideration (Zeraatpisheh, Arababadi, Pour, 2018). The NPV is calculated using equation (1).

$$NPV = -I_0 + \sum_{j=1}^{n} \frac{CF_j}{(1+i)^j} \tag{1}$$

In this equation I_0 represents the initial investment, n represents the period of time, I represent the discounting rate, and CF_j represents the cash flow in the j^{th} period. For this study, the cash flows correspond to the electricity rate savings incurred by adopting the residential PV system.

The IRR of a project is used to determine the profitability of a project and it represents the annual rate of growth an investment is expected to generate. It is calculated by equating the NPV formula to zero and solving for the discounting rate. An IRR thus is the discount rate that would cause the project to have an NPV of zero and is calculated using equation (2).

$$-I_0 + \sum_{j=1}^{n} \frac{CF_j}{(1+IRR)^j} = 0 \tag{2}$$

The PP is used to determine the amount of time it takes to recover the initial investment of a project. It is a simple method used to get an approximate of the time needed for a project to pay for itself. Payback period however does not consider the time value of money. It is determined using equation (3).

$$PP = \frac{Initial\ Investment}{Cash\ Savings\ per\ Year} \tag{3}$$

The PI describes an index that represents the relationship between the costs and the benefits of a project. A loss-making investment results in a PI smaller than one, a profitable investment results in a PI higher than one, and a PI equaling one shows that a project has the lowest acceptable benefits, which corresponds to an NPV of $0. The PI is calculated using equation (4).

$$PI = 1 + \frac{NPV}{Initial\ Investment} \tag{4}$$

5.2 Graphical Results

The economic analysis for the residential rooftop PV system was conducted using Excel. The yearly electricity rates savings were first calculated for the time consisting of 30 years by incrementally adding 1.8% per year starting with $1,603.20. The obtained values correspond to the cash flow values of CF_j in Equation (1). Table 1 shows the yearly electricity rates for 30-year periods as well as the CF_j values.

Table 1. Yearly Electricity Rates for a 30-year Period.

Year (j)	Yearly Savings (CF_j)	$CF_j/(1+i)^j$	Year (j)	Yearly Savings (CF_j)	$CF_j/(1+i)^j$
1	$1,603.20	$1,511.03	16	$2,095.10	$812.38
2	$1,632.06	$1,449.79	17	$2,132.81	$779.45
3	$1,661.43	$1,391.03	18	$2,171.20	$747.86
4	$1,691.34	$1,334.66	19	$2,210.28	$717.56
5	$1,721.78	$1,280.57	20	$2,250.07	$688.47
6	$1,752.78	$1,228.67	21	$2,290.57	$660.57
7	$1,784.33	$1,178.87	22	$2,331.80	$633.80
8	$1,816.44	$1,131.09	23	$2,373.77	$608.11
9	$1,849.14	$1,085.25	24	$2,416.50	$583.47
10	$1,882.43	$1,041.27	25	$2,460.00	$559.82
11	$1,916.31	$999.07	26	$2,504.28	$537.13
12	$1,950.80	$958.58	27	$2,549.35	$515.36
13	$1,985.92	$919.73	28	$2,595.24	$494.48
14	$2,021.66	$882.46	29	$2,641.96	$474.44
15	$2,058.05	$846.69	30	$2,689.51	$455.21

Using the values shown in Table 2, an initial value of investment of $20,173.88, and a discounting rate of 6.1%, the economic parameters were calculated using equations (1) through (4). Equation (1) yielded an NPV of $6333.01 which shows that investing in a rooftop PV system is profitable since it has a positive net present value. Equation (2) resulted in an IRR of 8.61% which is higher than the discounted rate of 6.1% which further shows the investment is profitable. Equation (3) yielded a payback period of 13 years, which means that the rooftop PV system will recover its initial investment after a duration of 13 years from the accumulated yearly savings in electricity rates. Finally, equation (4) yielded a profitability index of 1.31 which is higher than 1.0 indicating a profitable investment. All the economic parameters are summarized in exhibit 5.

Table 2. Economic Parameters Summary.

Parameters	Value
Yearly Electricity Rate increase (%)	1.80%
Discounting Rate i (%)	6.10%
Initial Investment for Residential PV System ($)	$20,173.88
Study period (in years)	30
Net Present Value NPV ($)	$6,333.01
Internal Rate of Return IRR (%)	8.61%
Payback Period using initial yearly savings (years)	13
Profitability Index	1.31

5.4 Validation

This study utilized a 7kW grid-connected rooftop PV system with 3kW/6kW of battery storage. The costs of the system as well as the electricity rates and energy consumption levels in household are state averages provided by the National Renewable Energy Laboratory and the U.S Energy Information Administration, respectively. Using the state averages, the study yielded a net present value of $6,333.01 which shows that a residential rooftop PV system is economically beneficial for homeowners. The PV system has also a payback period of 13 years, which is less than half the life of a PV system of approximately 30 years. The PV system also has an IRR of 8.61% and a profitability index of 1.31 which further shows that the investment is beneficial. With the solar technology improving steadily over the years, the rooftop PV system costs are projected to further lower in costs, resulting in a lower initial investment, while the electricity rates are only increasing which results in higher savings in electricity rates. With the PV system costs focused on the 2020 costs, and with the assistance of federal, state and utilities incentives, the adoption of a rooftop PV system in a residential setting proves to be economically beneficial for the single-family homeowner in the State of Texas.

6. Conclusions

This study examines the financial performance of a rooftop PV system in single-family homes in Texas. The costs and parameters used in this paper are only intended to represent the state of Texas and are not valid for other states within the United States due to the changes in costs, average residential energy consumption, electricity rates, and availability of solar resources. The environment impacts of the PV systems is not taken into consideration into this study, the profitability of the rooftop PV system is investigated from a purely economic perspective.

The results of this study can be used for other types of homes and other PV systems sizes by using the average PV system costs provided in the analysis, as well as the average electricity rates in the state of Texas only. It can be used as a basis of financial or economic analysis for homeowners interested in adding a residential PV system to their residential properties to ensure their addition will be economically beneficial.

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Biographies

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Ahlam Safouhi, EIT, is a mechanical engineer at HM3 Engineering Consultants LLC. She holds a B.S in Mechanical Engineering from Arkansas State University and is currently towards her master's in engineering management from Arkansas State University. Ahlam is currently working as an MEP engineer for HM3 Engineering Consultants LLC where she focuses on designing HVAC system layouts and performing energy performance simulations.

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