Economic Analysis for Residential Solar System

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Abstract: The world today uses more energy than ever before. As a global society we must find more renewable and efficient sources to obtain our energy. Solar energy, as one of the many renewable energy resources, has been brought to the forefront through photovoltaic (PV) technologies. In this paper, the development trend of solar energy systems in the United States is illustrated and the cost factors of a PV system are addressed. The paper will further demonstrate through an example project how grid-tied PV systems can be used in residential applications. Attention will be paid to the economic aspects of a residential PV system including the overall cost of the system, the payback time of the system, and how functional the system will be in meeting the needs of the household.

Keywords: grid-tied PV, payback time, photovoltaic system, renewable energy.

I. INTRODUCTION

Energy is one of the most important resources in our modern society. Over the last forty years, energy consumption has increased 155% worldwide [1]. Today, the majority of the world's commercial energy supply, greater than 85%, is produced by fossil fuels [2]. Moving forward, with the decrease in the production and use of fossil fuels, there will need to be new energy sources developed that can keep up with the global energy needed to run facilities and homes. Several renewable energy sources are currently in use including wind power, thermal, and the use of photovoltaic solar cells.

The use of photovoltaic solar cells seems like a natural choice for renewable energy. After all, the sun puts out more energy everyday than we could ever think about using. This being said there are many barriers which must be overcome before solar energy can replace traditional sources of power. In an interview with the Bulletin of the Atomic Scientist, Standford Ovshinsky, a technical pioneer in the field of photovoltaics, said, "The very biggest barrier in the United States is that there is no energy policy that allows for new approaches. Progress is blocked all the time by oil, automobile, coal, and utility industries. These are special interests that feel much challenged and seek to postpone change as long as possible" [3]. Another barrier is that generating electricity using photovoltaics cost significantly more than from traditional power sources such as the burning of coal.

With the ever increasing demand for energy newer, cleaner, and more efficient solutions must be developed, researched, and implemented to meet our energy needs for the future in a timely and cost effective manner. The high cost of traditional non-renewable fossil fuels has prompted the need to seek newer alternatives for energy. In recent years many renewable "green" energy resources have become more readily available.

Creating energy using photovoltaic solar cells has many advantages over traditional energy sources such as burning fossil fuels, but this green energy source also has its own impact on our environment. Fossil fuels are used in the manufacturing process of photovoltaic cells [4]. In an article written by Charles Choi on emissions made from the manufacturing of solar cells, a researcher and environmental engineer named Vasilis Fthenakis with the Brookhaven National Laboratory in Upton, N.Y is quoted as saying, "One of the most promising photovoltaic technologies is based on cadmium telluride, but cadmium is one of the worst heavy metals. Still, if we compare direct emissions from production of cadmium telluride cells with coal power plants, toxic emissions would (end) up 300 times lower" [5]. The manufacturing process for photovoltaic cells requires large amounts of electricity and raw materials. That being said, a study that was completed between 2004 and 2006 by a group of scientist on the emissions of 13 solar cell manufacturing facilities found that the emissions made from the production of solar cells is still far less than that of traditional power plants [5]. The exact emissions from the manufacturing process of photovoltaic cells are hard to determine because of the many variables within the supply chain process including country of origin, cell type, and other environmental factors [6].

II. PHOTOVOLTAIC SYSTEM DEVELOPMENT IN THE UNITED STATES

The use of photovoltaic (PV) solar systems has increased greatly in the United States over the past few years. This is largely due to three contributing factors:

1. The rising cost of electricity
2. The decrease in the price of photovoltaic solar systems
3. Federal and State incentives for installing PV systems

The United States is an attractive investment opportunity for many people involved in the PV industry because of our high electrical demand, available land for large PV systems, and our isolation from other countries. Even though the use of PV systems has increased in the United States, we still lag behind several countries including Japan, and Germany, which had an installed capacity of 7.4GW [7]. The Department of Energy analyzed three policy changes that would have the greatest impact on solar use in the United States in their 2007 Renewable Systems Interconnection reports [8]:

1. Doing away with net metering caps and starting net metering in areas that currently don't use the program
2. Extending the federal investment tax credit
3. Improving interconnection standards

PV systems can be broken down into two main categories, grid-connected systems (tied to the electric grid) and off-grid systems. These categories can then each be broken down into sectors, residential, non-residential, and utility. Grid-connected systems have grown in popularity in all three sectors. In a grid-connected system the PV system is tied to the electrical grid. This allows the end user the ability to use the energy from the PV system during the day and use power from the utility at times when the PV system isn't producing enough power, such as nighttime or on overcast days. Figure 1 shows the rise in grid-connected systems over the past 10 years. As can be seen, in 2000 there were almost no grid-connected PV systems and only a little over 200MW of installed off-grid systems. By 2010 grid-connected systems made up approximately 2.1GW and off-grid systems made up 440MW of installed capacity [7].

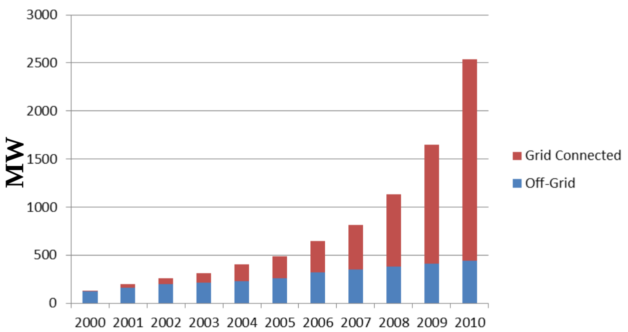

Figure 1. U.S. cumulative installed PV capacity by interconnection status [7]

Figure 2 breaks down the annual installed grid-connected PV capacity by sector over the past 10 years. "In, 2010, annual distributed grid-connected PV installations in the United States grew by 62%, to 606MW_{DC}" [9]. Also, notice that the sector that has grown the most over the last three years is the utility sector. Federal and State tax incentives along with renewable energy requirements in some states are the main reason for the growth in the utility sector. Between 2009 and 2011, utility-scale PV installations rose 630MW. The National Renewable Energy Laboratory states that there are around 16,043MW of solar projects currently in development in the United States [10].

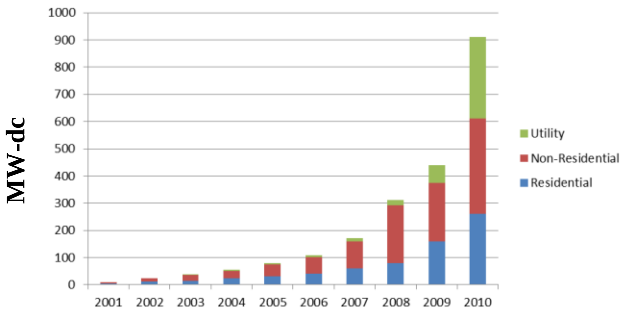

Figure 2. Annual installed grid-connected PV capacity by sector [9]

Incentives for installing non-residential photovoltaic systems occur on two different levels, federal and state. At the federal level, incentives are in three different forms, investment tax credit, accelerated tax depreciations, and tax credit bonds. Incentives at the state level vary depending on the state, but generally include items such as net metering, cash incentives, state tax incentives, and multipliers within the state renewable energy portfolio (RPS) policies. Net metering is a policy that allows for utility customers to get reimbursed for electricity that they feed onto the electric grid when their solar energy system produces more power than they consume. The customer gets reimbursed at a rate which is comparable to the money that they would have paid per kilowatt/hour. Forty-four states and the District of Columbia participate is some level of net metering.

III. Costs of a PV System

The cost of the different material types of solar cells leads to various costs of PV modules. The cost of PV modules has always been a major factor in choosing to install a solar energy system. Research indicates the costs of purchasing and installing photovoltaic systems as varying greatly from country to country.

Initially, the high cost and low energy output were a big turnoff for many customers. The cost of PV modules has steadily decreased since the 1980's and today along with tax incentives and more strict energy regulations have finally reached a point where they are economical to install [11]. Figure 3, below, shows the global average of PV modules across all PV technologies from 1980 through 2010 [12]. This graph indicates the average cost across all of the PV technologies. As discussed previously, some technologies are cheaper to produce than others. The cost increases between 1988 and 1990 due to a low supply and high demand for PV modules. The cost also increases from 2003 to mid-2008. This once again is due to strong demand for PV modules and a limited supply of materials such as polysilicon. The cost started to decrease again in 2008 due to the economic recession and a readily available supply of poly-silicon and modules [12].

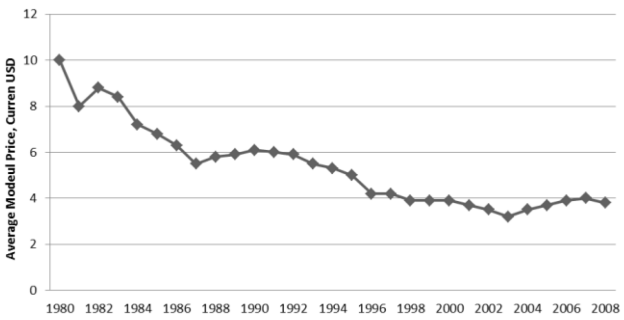

Figure 3. Average PV module prices, all technologies, 1980-2008 [12]

There are other cost that are associated with the a total photovoltaic solar system including the inverter, the racking or mounting system, miscellaneous electrical components including items such as combiner boxes and disconnect switches, and the cost associated with the planning and implementation of the system.

An inverter is the piece of equipment in a photovoltaic solar system that converts the direct current electricity coming from the solar array to alternating current that can be used to power standard electrical loads. The number of inverters needed and the cost varies depending on the size and design of the photovoltaic solar system. Typical cost can range from \$0.23/W to \$1.08/W [13]. Inverters also have a life expectancy of between ten around fifteen years, meaning that over the estimated twenty five year lifetime of a PV system, the inverter(s) will probably have to be replaced. Replacing the inverter is the most expensive cost of maintaining a PV system and cost between \$3,000 to \$20,000 [14].

The racking or mounting system for the solar panels themselves can also vary widely depending on the type of system; roof, ground, etc., used and the terrain that the system is being mounted. For example, it is easier to install ground mounted solar panels in a flat grassy field that at the base of a rocky hillside or mountain region. Racking or mounting usually cost between \$0.20/W and \$0.30/W, but can be much higher depending on the previously mentioned variables.

The cost of the various electrical components such as disconnects, combiner boxes, cable, and conduit are based on current market values and don't add that more cost to the project than any other typical electrical design. For example, a traditional electrical substation is going to have electrical component, cable, and conduit cost. These costs will vary depending on the size of the project and the physical location of the equipment. For example, a disconnect switch that can be mounted outdoors will cost more than a standard disconnect switch that would be mounted in an electrical room.

The cost of designing, maintaining, and managing a solar system can be very high. The cost of designing a system in the United States is on average 37% of the total system cost [13]. The cost of labor to install the system can also be high depending on the area of the country that the system is being placed.

IV. Payback Analysis of a Typical Residential PV System

A residential PV system can be broken down into three main components, as shown in Fig. 4:

1. Power Generation
2. Balance of System (BOS)
3. Power Consumption

Figure 4. A residential PV system

Power generation consist of several PV modules connected in series and/or parallel. This is known as a PV array. Sun light is converted to DC from this component.

The balance of system, shown in Fig. 5, includes devices such as inverters (converting the DC electricity into AC), safety devices (fuses and disconnects), energy storages devices, meters to the load and grid, and the PV system's racking/mounting and wiring. BOS can also include labor for install and maintenance.

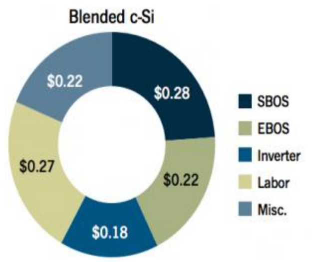

Figure 5. BOS cost breakdown

Power consumption consists of the various load devices that are connected to a system. Excess power that is not consumed by the load devices is returned to the power grid (net metering) or stored in batteries for later use.

There are several factors that will influence a PV system's cost, such as the PV system size, PV efficiency and model type, PV racking/mounting, the number of inverters, whether energy storage devices are used, and so forth.

The most expensive aspect of the PV system is the BOS, and it accounts, on average, for nearly 68% of the system cost.

The medium cost for residential and small commercial PV systems (10kW or less) in 2012 was $5.30/W.

Large commercial PV systems (100kW – 10,000kW) had a medium cost of $4.60/W.

Utility-scale systems (more than 10,000kW) registered lower prices generally ranging from $2.50/W to $4.00/W.

Various Federal, State, and utility incentives exist to help reduce the cost of installing a PV system. These incentives are mostly in the form of rebates, tax credits, and net metering.

Presently, grid connected photovoltaic (PV) solar systems are becoming the most important application of PV systems. In this type of system, power is created through the photovoltaic solar array, sent through an inverter to be converted into alternating current and then fed to a service panel. The advantage of this type of system is that power that is not used can be fed back onto the electrical grid. Using net metering, which was mentioned earlier, the power fed back into the grid allows the customer to get reimbursed from the utility. A typical residential grid tied PV system without a battery backup consists of the following devices:

- PV Array – The PV array is made up of PV modules that are made up of PV solar cells. These modules are what convert the sunlight to electrical energy.
- PV Array Circuit Combiner – The circuit combiner takes the individual circuits coming from each PV module and combines them into a single DC circuit.
- Ground Fault Protector – The ground fault protector is a device that will trip the system offline in case of a ground fault. This protects both the system and devices connected into the system at the electrical panel board.
- DC Fused Switch – This fused switch is a disconnect and an overcurrent device for the DC side of the inverter.
- DC/AC Inverter – The inverter converts the DC power from the solar array to AC power
- AC Fused Switch – This fused switch is a disconnect and an overcurrent device for the AC side of the inverter.
- Utility Switch – The utility switch is opened when the solar array is not producing power and the system is running off of the utility.
- Panel board – the electrical panel board is where the electrical loads are connected for the household.

A typical residential PV system is around 5kW. The following is a basic payback analysis for Missouri residential PV system to determine whether a 5,405W system will produce payback over 25 year period.

Table I shows the initial costs and the incentive benefits from federal and local. The incentive benefits drastically reduce the initial cost. Table II illustrates the calculated PV system energy production capacity and the household power demands.

Table I. Initial costs and incentive benefits

PAYBACK ANALYSIS				
Grid-Tied PV Array Kansas City, MO (Residential Sector) With State and Federal Renewable Energy Incentives 5,405W Photovoltaic Solar System				
INITIAL COSTS AND BENEFITS				
Initial System Cost	**Cost/W**	**Quantity**	**Unit Cost**	**Total Cost**
Sharp ND-Q235F4 Solar Panel 235 W	$1.70	23	$399.50	$9,189
Fronis IG plus 7.5 inverter	$0.30	1	$1,621.50	$1,622
Racking	$0.25	1	$1,351.25	$1,351
Wiring	$0.14	1	$756.70	$757
Other	$0.17	1	$918.85	$919
Permits	$0.01	1	$54.05	$54
System design, management, & marketing	$0.15	1	$810.75	$811
Installer overhead and labor	$0.57	1	$3,080.85	$3,081
Initial system cost total				$17,784
Federal Incentives	**Incentive**	**Cost of Material**	**Incentive Amount**	**After Incentive**
Residential Renewable Energy Tax Credit	30% of the cost of materials	$13,838	$4,151	$13,633
State Incentives	**Incentive**		**Incentive Amount**	**After Incentive**
KCP&L Solar Photovoltaic Rebate	$ 2.00/W up to $50,000		$10,810	$2,823
Total System Cost				**$2,823**

Table II. PV system production and household power usage

PV SYSTEM PRODUCTION AND HOUSEHOLD POWER USED					
Number of solar panels	23	Units	**PV Power Usage**		
STC rating in watts per panel	235	W	kWh/year from PV system	6315	kWh/year
Total watts per hour (optimum conditions)	5405	W	Household kWh/year during PV system utilization (4.0hr/day)	2292	kWh/year
Performance under real world conditions	80	%	**Household net metered power in kW**	**4023**	kWh/year
Adjusted watts per hour under real conditions	4324	W			
Average hours of sunlight per day	4	Hr	**Household Electricity Cost**		
Estimated kilowatt per day output	**17.3**	**kW**	Missouri average cost per kWh	$0.09	
			Net metering payback per kWh (approximately 20% of retail)	$0.02	
Total Household Power Needed			Electrical rate annual inflation assumption	4	%
Typical household service	12	kWh	Household net metered payback per year	$80.46	
Percent of household load used per hour	13.08	%	Household revenue from PV system per year	$206.28	
Average household load per hour	**1.5696**	kWh	**Total Payback Per Year**	**$287.00**	

Table III. Annual payback

REVENUE AND EXPENSES	ANNUAL PAYBACK												
Year	2013 Year 0	2014 Year 1	2015 Year 2	2016 Year 3	2017 Year 4	2018 Year 5	2019 Year 6	2020 Year 7	2021 Year 8	2022 Year 9	2023 Year 10	2024 Year 11	2025 Year 12
Initial system cost	($2,823)												
Electricity sales		$287	$298	$310	$322	$335	$348	$362	$376	$391	$407	$423	$440
Cumulative electricity sales		$287	$585	$895	$1,217	$1,552	$1,900	$2,262	$2,638	$3,029	$3,436	$3,859	$4,299
Inverter replacement (80% of original cost)													
Simple Payback (year cash flow turns positive)	**($2,823)**	**($2,536)**	**($2,238)**	**($1,928)**	**($1,606)**	**($1,271)**	**($923)**	**($561)**	**($185)**	**$206**	**$613**	**$1,036**	**$1,476**
Year	2026 Year 13	2027 Year 14	2028 Year 15	2029 Year 16	2030 Year 17	2031 Year 18	2032 Year 19	2033 Year 20	2033 Year 20	2034 Year 21	2035 Year 22	2036 Year 23	2037 Year 24
Initial system cost													
Electricity sales	$458	$476	$495	$515	$536	$557	$579	$602	$602	$626	$651	$677	$704
Cumulative electricity sales	$4,757	$5,233	$5,728	$6,243	$6,779	$7,336	$7,915	$8,517	$8,517	$9,143	$9,794	$10,471	$11,175
Inverter replacement (80% of original cost)			-1298										
Simple Payback (year cash flow turns positive)	**$1,934**	**$2,410**	**$1,607**	**$2,122**	**$2,658**	**$3,215**	**$3,794**	**$4,396**	**$4,396**	**$5,022**	**$5,673**	**$6,350**	**$7,054**

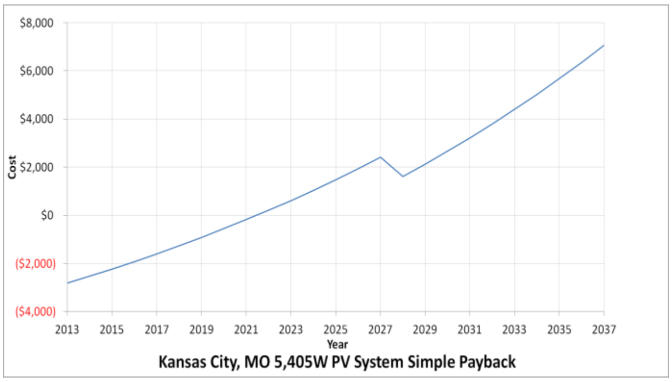

Figure 6. A typical Kansas City residential PV system payback

This data, from Table III and Fig. 6, demonstrates that a residential PV system in this region will produce a decent payout within a 25 year period. From Table III, by the 9th year the initial cost of the system ($2,823) was paid off with a surplus of $206. On the 15th year $1,298 was spent replacing the inverter. By the 25th year the system produced a total profit of $7,054. Federal tax credits and the KCP&L PV rebate program substantially reduce the initial cost of the overall system by $16,456. This was pivotal factor in the total payback of the system. Net metering also provided additional annual income from the excess electricity being sold back to the utility company.

V. CONCLUSION

Photovoltaic systems have started to gain ground in the United States, especially in the past couple of years. Federal and state incentives and tax breaks along with the rising cost of energy and lower PV cost have brought solar use to the forefront. Photovoltaics are a clean and affordable renewable option for any residential consumer looking to reduce or eliminate their ever increasing electricity bill. With the right planning, incentives, geographic location, and power needs a PV system can generate enough electricity to not only payoff the initial system install cost but also produce a surplus profit. However, the payback period and amount made from the PV system may vary with the location, utility rebates and incentives, and the initial cost of the system. The payback of the PV system could further be affected by maintenance costs that are not accounted for in this study. This study also does not include systems that have a battery system for energy storage. The addition of a battery system would add cost to the design, but could also have an impact on the payback period.

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