BENEFIT COST ANALYSIS OF SOLAR POWER OVER ON-GRID ELECTRICITY FOR RESIDENTIAL SYSTEMS: IS PHOTOVOLTAIC TECHNOLOGY REALLY EFFECTIVE?

A Thesis

by

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ABSTRACT

In the past two decades, alternative energies have emerged in a more sustainable way to resolve the scarcity issue of natural energy resources. However, project owners' general perception believes that a one-time high installation cost hampers the adoption of an alternative energy system like solar power. This study investigates the effectiveness of the solar-powered photovoltaic system over the conventional and hybrid systems through a benefit-cost analysis. Benefit and cost components were quantified from the economic and environmental perspectives. An economic sensitivity analysis was then followed with three measurements such benefit-cost ratios, net present values, and profitability indices.

Three case studies demonstrate the applicability of the proposed analysis framework in real-world projects. Benefit-cost ratios, net present values and profitability indices have been used for the analysis. The results of this study will promote a wider adoption of solar power towards green and increase investments from small and medium scale investors.

DEDICATION

To the most special people in my life

Dharam Vir Parmar

Vandana Parmar

Kunal Khosla

Dharna Khosla

Kaashvi Khosla

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I would like to express my gratitude to my committee chair, Dr. Kunhee Choi, for his guidance and patience over the course of this research study. I would also like to thank my committee members, Dr. Boong Yeol Ryoo and Dr. Jun Hyun Kim for their invaluable support, advice and comments. I strongly believe that I was able to improve analysis and my knowledge further due to their insightful comments.

Finally, I am grateful to my parents for infinite love, support and encouragement to work harder. I wish them the best for their good health and spirits. I dedicate my Master of Science degree to them.

NOMENCLATURE

AC	Alternating Current
B/C	Benefit/Costs
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratios
C	Cash flows
C_O	Initial Investments
CO_2	Carbon Dioxide
DC	Direct Current
GHGs	Greenhouse gases
IEEE	Institute of Electrical and Electronics Engineers
IRR	Internal Rate of Return
NBA	National Building Administration
NEC	National Electrical Code
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PI	Profitability Index
PV	Photovoltaic
R%	Discount Rate
ROI	Return on Investments
SKSS	See CO_2 Know CO_2 Show CO_2 Stabilize CO_2

SUS	Straight Up Solar
T	Time Period
UL	Universal Laboratories
US	United States
USIA	United States Information Administration
W	Watts

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1. INTRODUCTION

1.1 Background to the Study

Emerging construction technologies focusing on the research and development of energy preserving equipment can play a substantial role in deciphering a massive range of environmental and natural resource problems such as fossil fuels, greenhouse gases and non-renewable sources of energy. Alternative energy such as solar, wind energy, geothermal energy and biogas are becoming noticed by residential developers because of its potential of becoming more economically feasible option when compared to current energy electricity sources (Wei and Temitope 2014).

Photovoltaic technology, one of the cleanest and greenest sources of electricity has attracted several different types of customers with different federal incentive initiatives and returns. Alternative energy technologies are becoming popular for residential owners due to the potential economic benefits compared to conventional energy sources (Kats and Capital 2003).

The benefits of solar energy as an alternative source of power supply includes providing a considerable proportion of a system's electricity requirement, minimizing operational costs, curtailing the use of electricity through fossil fuels and energy cost (Chakrabarti and Chakrabarti 2002).

Renewable energy systems such as the photovoltaic (PV) system reduces emissions of greenhouse gases and fossil fuels (Vorobiev et al 2006). The use of solar energy via PV system helps to reduce greenhouse gas and has the potential to save cost of energy expenditures. As fossil fuel prices have risen and concerns over global climate change have increased which has resulted in adopting more alternative technologies for producing electricity. Figure 1 shows the overall energy production through different sources (IER 2015).

Among the diverse technologies that could help address these climatic concerns is photovoltaic cells (PVs), which captures solar irradiation and converts it directly into electrical power. Such cells are located at the site of the end user or any power producing station and is regarded as a form of distributed generation. The economic returns generated by a PV investment differ from market segments based on the requirements of the customer.

Each market segment uses a different economic performance analysis such as Net Present Value, Profitability Index, Internal Rate of Return, Benefit Cost Ratios, Payback times, Monthly Savings and Cost of Energy to deeply understand the effectiveness of different types of economic returns from a PV investment. Therefore, there is a strong need to understand the variability of investment value through different economic performance metrics and compare the PV technology with natural gas power generation costs.

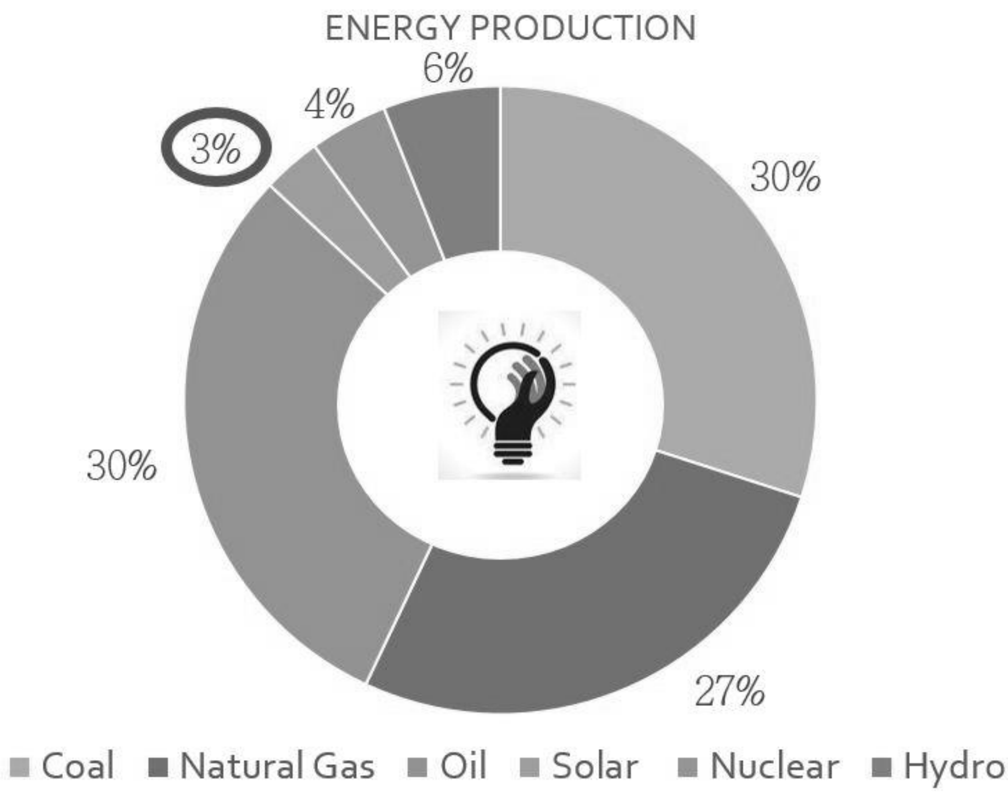

Figure 1: Energy Production through Different Sources (Source: IER, 2015)

1.2 Fundamentals of Solar Power in Residential Systems

The solar panels mounted on roof space generate a direct flow of electrons producing direct current (DC). Electricity output is maximized on the basis of average peak hours in a day, which is different for every state based on the solar irradiance levels. Since, we use alternating current (AC) power supply in our households, DC electricity is converted to AC electricity through macro-inverters.

As per Figure 2, schematic configuration is connected to a distribution panel, which distributes electricity in our electrical devices and energy meters which displays the amount of energy produced during the day. To reduce the dependency on on-grid electricity we install small battery banks to accommodate energy usage during night and off-peak hours.

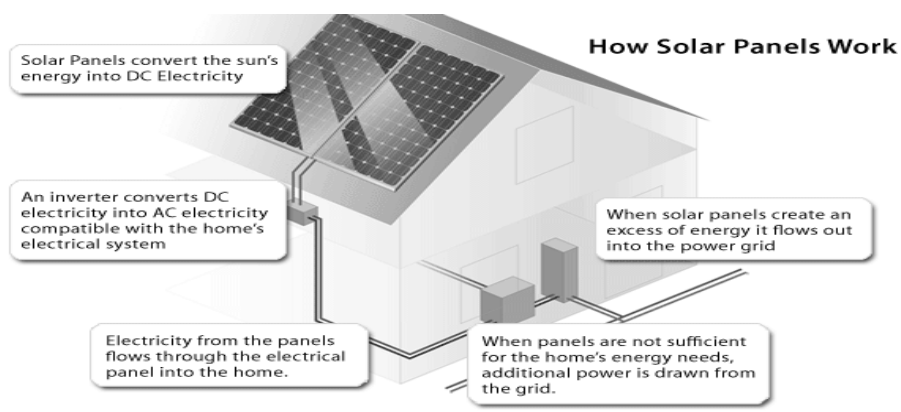

Figure 2: Solar Power Process Diagram (Source: Solar One Systems: Technical Library, 2016)

2. RESEARCH QUESTIONS AND SCOPE OF RESEARCH

2.1 Problem Statement

There has been a substantial increase in the rising costs of energy production and distribution, regardless of the energy generation techniques used. The initial cost of installation and revenues in high scale and low scale PV projects, non-price project parameters and standard business models of traditional power generation have affected the PV economics. This has been regarded as one of the major challenges that impede the adoption of photovoltaic energy technologies.

An extensive but intensive literature survey to the existing body of knowledge pertaining to energy investment and its cost benefit analysis reveals that studies related to decision making factors such as the B/C ratio, risk analysis of initial investment and net present value for adopting photovoltaic technology or traditional power generation methods are lacking (Drury E. et al. 2011).

2.2 Research Objectives

"The main research objective is to investigate the effectiveness of adopting a solar-powered photovoltaic system over the conventional and hybrid systems through a benefit-cost approach."

From the perspective of CBA, this research has the following sub-objectives:

- There is a strong need to understand the variability of investment value through different economic performance metrics and compare the PV technology with conventional power generation costs.
- To critically define the cost benefit economic parameters for adopting photovoltaic technology/traditional technology through benefit cost ratio, net present value, profitability index and internal rate of return analysis.
- To educate potential customers about the value of PV investment/traditional technology investment and help they make more informed adoption decisions.
- To understand the carbon emissions avoided with respect to different conventional sources.

2.3 Research Hypothesis

To meet the aforementioned research objectives, this research would compare the effectiveness of photovoltaic technology and traditional energy generation methods through benefit cost analysis and other economic performance characteristics. Approaches such as Benefit to Cost (B/C) ratio, profitability index (PI), net present value, internal rate of return would be used as methodologies. The comparative analysis between PV and traditional generation would test the following research hypothesis:

- There is a significant reduction in project duration of solar power plants as compared to other generation methods.
- Initial investment in engineering, procurement and construction of solar power plants is significantly higher as compared to other generation methods.
- There is an extensive reduction in the fuel costs as solar power generating stations use sun’s energy.

2.4 Research Questions

The following research questions will address the effectiveness of photovoltaic technology over on-grid conventional energy systems:

- Among 3 energy choices, which is the most economic and sustainable choice for future generations?
- What will be the monetary savings after solar installation?
- What would be the annual benefit cash inflows after installing solar systems?
- Which power source gives the shortest payback time?
- What are the carbon emissions reduced due to comprehensive solar systems and hybrid solar installations on residential systems?

2.5 Significance of Research

The research project will provide users and energy investors a crystal clear view with a systematic analytical method outlining various risk factors such as initial cost of investment and its long term benefits for adopting photovoltaic source of energy over conventional sources. It will significantly increase investments in photovoltaic energy from medium scale and small scale investors. The cost benefit comparative analysis will validate the payback period rate and develop unproblematic PV business models.

The overall framework will not only compare the PV technology with conventional generation costs for benefits but also, outline general guidelines to potential customers and investors about PV technology. Finally, the research study will directly impact low and medium scale investments in the energy sector leading to more efficient and sustainable flow of electricity and other energy uses throughout the country.

3. REVIEW OF LITERATURE

3.1 Existing Industry Practices

Solar energy is generated during daylight hours and is maximized when the intensity of sun increases during peak hours. As a result, in summer-peaking electricity systems, such as California and most of the U.S. states, power from solar cells is produced disproportionately when the electricity value changes abruptly.

Electricity cost gets higher when system demand increases because wholesale grid prices of electricity are greater and proportion of first hand power lost through heat dissipation during electricity transmission and distribution increases. Regardless of PV power generation on site, heavy inversion losses are incurred during DC to AC transformation. (Borenstein 2008). The economic, environmental and direct employment benefits of alternative energy vs traditional forms of power generation are highly debatable in the industry.

To critically examine the direct impact of integrating renewables into an electricity supply grid, the value of coherent benefits must be minutely weighed against the inevitable costs that may arise from choosing renewable sources. Economic characteristics such as PV prices, revenues, state/federal benefits, tax incentives and third party financing options often affect the relative value of a PV investment in different market segments such as residential users, commercial owners, public sector undertakings, third party installers, non-profit users and large system integrators (Barbose et al 2011).

Significant research has been carried out in the development of solar power components which defines that renewable energy adoption has consistently proved to be a lucrative alternative to conventional forms of power generation. (Clear Sky Advisors 2014).

Unfortunately, this existing analysis typically requires huge number of spreadsheets and complex findings that are extremely challenging to communicate to those outside the industry like residential owners and commercial developers. During the early 21st century, 37 out of 50 U.S. states experienced a hike in their average cost per kilowatt for electricity. On average over the five years, utility electricity costs for residential systems in the U.S. has increased by an exuberating 4.1 percent and is projected to increase further (Peterson et al. 2013).

In dollar amounts, the average cost/kWh increased by a total of 1.65¢ (cents) from 2006-2010. This is a substantial increase that pinpoints rising costs of producing and transmitting energy, regardless of the generation methods used. (United States Energy Information Administration 2013). The initial cost of installation, revenues in high scale/low scale PV projects, non-price project parameters and business models of traditional power generation have affected the PV economics. This has been one of the major challenges for adopting alternative energy technologies with no exception to the PV system (Mills 2014).

3.2 Current Scenario

Most PV developers have purchased and maintained their own PV system and recouped project costs using the revenues generated by their system. However, several new business models have entered the PV market in recent years, and the different ownership structures can impact economic performance. For example, PV systems can be owned and operated by a third-party organization, which can lease PV equipment or distribute PV electricity to the building owners (NREL 2009; Kollins et al 2010).

PV project costs and revenues are typically taxed differently for third-party owned PV systems than user adapted systems, which could probably lead to higher PV returns for third-party owned systems. However, third-party companies are likely to have a higher cost of capital than customers installing their own systems.

Third-party companies typically finance PV projects using several sources of capital including tax-equity investors, equity investors, and debt investors. Most investors will require a higher rate of return than the cost of dedicated debt financing available to several residential and commercial customers. Also, the cost of capital will vary based on the third-party company, deal structure, and the PV market. For example, the cost of financing third-party residential systems may be higher than commercial systems based on increased investment risk (NREL 2009; Kollins et al 2010).

3.3 Dependency on Conventional Energy Sources

Increased levels of carbon emissions have significantly increased environmental disturbances throughout the world leading to climate changes, poor air quality and irregular changes in energy prices. These irregularities have resulted in adopting several alternative strategies such renewable forms of energy which could mitigate global environmental concerns (NREL 2012). Figure 3 below depicts the 2.5% increase in carbon emissions over the past decade in the United States (SKSS CO2, 2016).

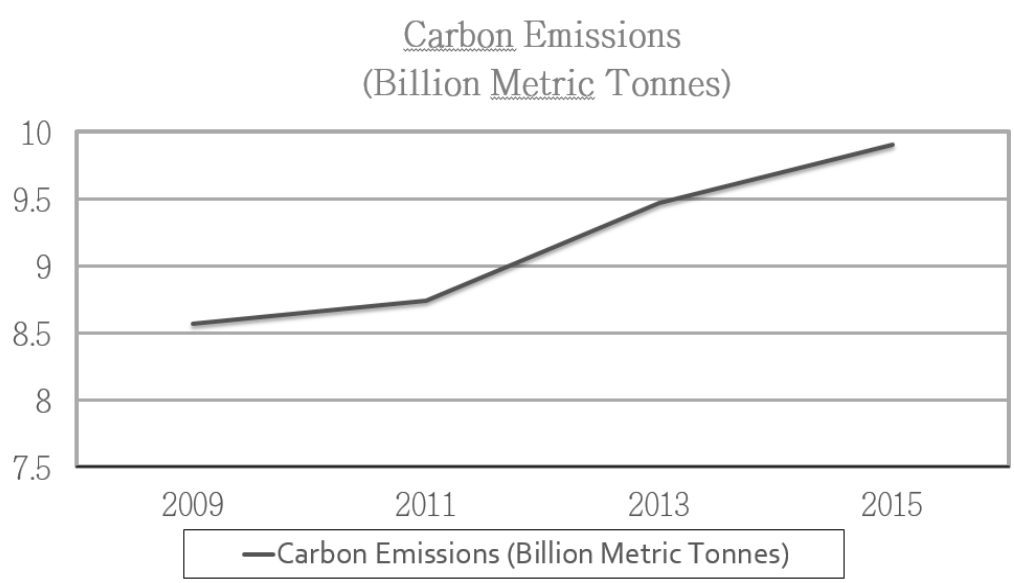

Figure 3: Carbon Emissions Footprint in United States (Source: SKSS CO2, 2016)

The status of energy generation in US suggests that oil and natural gases are getting depleted and there is strong need to counter this impending energy source shortage. As a result of which, the utility energy prices continue to rise abruptly and increase energy costs for residential, commercial and industrial users (Simhauser P. 2016). Today's cost comparisons between conventional and solar energy assumes that renewable source if advertised on a global scale could reduce energy costs in the form of shorter payback periods and non-escalated prices (Fraas L. 2014).

3.4 Market Analysis and Trends

The cost of commissioning PV systems can vary depending on the system size, type of solar cells used, and whether the power system is grid connected or has a storage unit to store excess energy for future usage (Kelly 2007). Energy costs can be recovered in a system if approximately $150/year for a 7.5 kW system can be generated within the building itself with extra savings during the payback periods.

Furthermore, when electricity is produced and consumed within the same location, T&D losses are avoided and cost of maintenance is curtailed, which diminishes the power utility's initial capital and service costs (Vorobiev et al 2006). The payback period on solar heating systems ranges from 11 to 18 years depending on the fuel cost mitigated and the complex configuration of the power system (Mills 2014).

However, there is an understanding within the construction industry regarding the use of PV system and additional energy efficient technologies which could increase costs with respect to traditional sources of energy (Yudelson 2008). To understand this diverse construction cost in PV and traditional electricity generation model, the profitability index (PI) with the help of the net present value of PV system and the initial investment cost was generated to perform decision making models. The benefit cost ratio represents the discounted system revenues and discounted system costs. PV users frequently use different economic performance metrics such as benefit cost ratio and profitability index because they prioritize PV investment risk and returns differently.

For example, home owners might be interested in PV systems with shorter payback times because they are uncertain about how long they will reside in their current house and how a potential PV investment will affect their domestic household value. Research has suggested that residential customers and commercial customers are more likely to use payback times to characterize the value of a PV investment or other energy-saving investments (Sidiras and Koukios 2005). Residential and commercial customers may believe that PV value in terms of residential monthly utility electric bills will decrease if they invest in PV, and third-party owned PV companies frequently market PV products using bill savings metrics.

Potential commercial PV customers may think of PV as a longer-term investment than residential customers and may be more likely to characterize PV value as an annualized return on investment (Chabot 1998; Talavera et al. 2007; Talavera et al 2010). Commercial customers may use B/C ratios, PIs, Internal Rate of Returns to compare potential PV returns relative to other investment opportunities.

4. RESEARCH METHODOLOGY

4.1 Benefit Cost Model

The benefit–cost analysis (BCA) is decision making model to estimate the expenditures and revenue of alternatives that satisfy cash flows and operations for a venture. The venture in this research analysis is the adoption of solar power for residential systems over on-grid electricity.

It is a technique that is used to determine alternative for the adoption in terms of benefits in labor, time, future maintenance and cost savings.

The analysis can be divided into two critical aspects of decision making:-

- Determine a sound investment/decision for the business by evaluating the justification and its feasibility.
- Helps to choose a feasible option in a way that the benefits outweigh the costs.

The benefits and costs in this analysis are expressed in monetary terms so as to calculate the overall project cost which includes the installation cost, operational cost and the future maintenance cost and benefits in terms of carbon reductions and total energy savings (As defined in Figure 4 below). These cost variations occur at different time periods in the project and can be expressed in terms of the net present value.

Different parameters such as payback period, net present value, internal rate of return, profitability index and benefit cost ratio have been considered to critically evaluate the economics of photovoltaic technology over on-grid electricity.

In this model, we will critically examine the cost and benefit components of on-grid conventional power systems, off-grid solar systems and a hybrid of conventional and solar systems. For quantification and analysis, power production/consumption is kept equivalent for all the three energy systems.

The model will enable end customers to make a decision based on system parameters and its corresponding results in means of power savings and dollar amounts. This model is a conglomeration of solar system studies and its direct impact on end customers on an annual basis.

For accuracy and precision of this cost benefit model, we have used real time data such as current energy prices for residential systems, solar system costs from different agencies, costs of power components, construction and labor costs from solar and roofing contractors, carbon emission reduction data through different conventional sources. Furthermore, we have analyzed the cost and benefit components of the PV over on-grid model and stipulated its direct effects on the users.

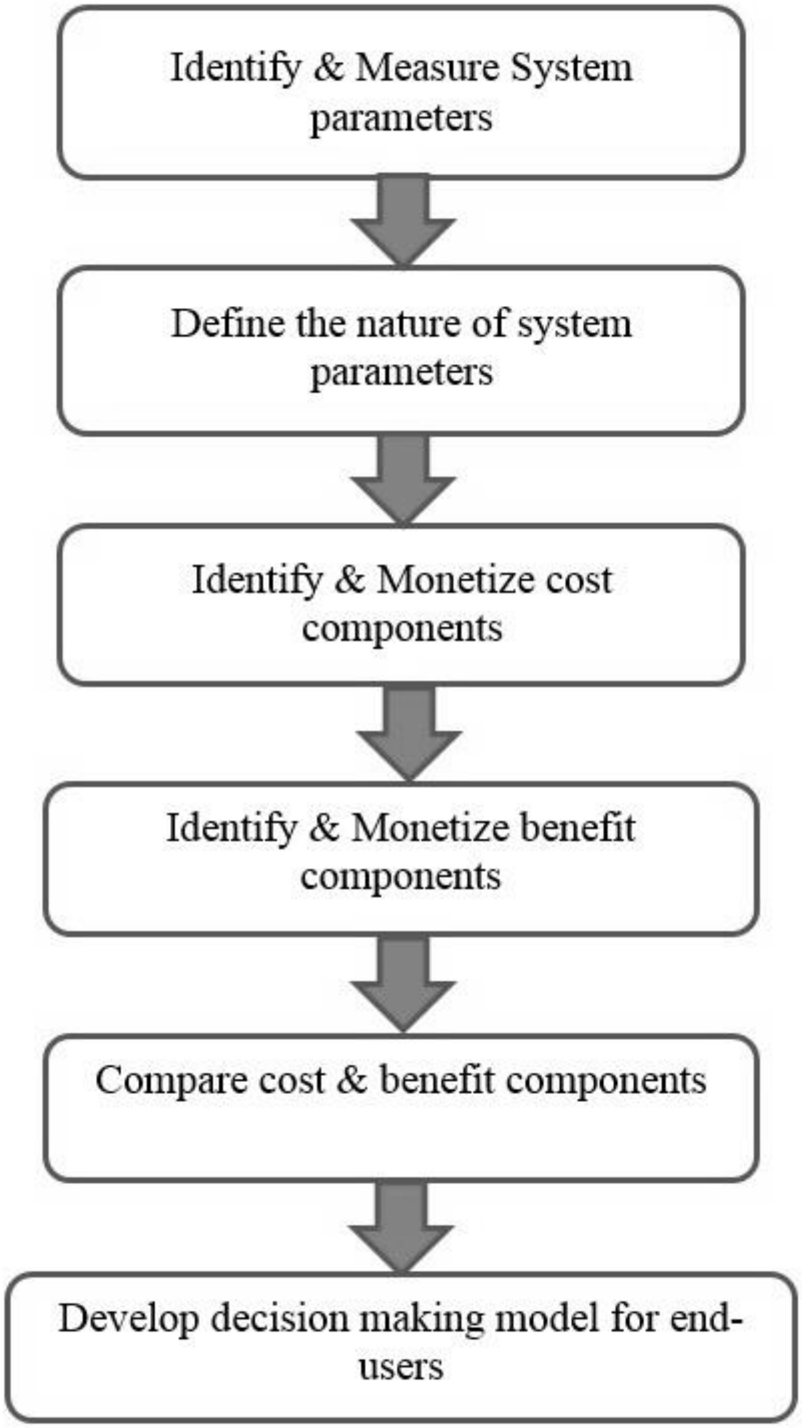

Figure 4: Cost-Benefit Process Diagram (Source: Snell M. 2011)

4.1.1 Cost of an Off-Grid Solar System

The cost of installing a solar system is primarily dependent on the system size which in this case is 15kW. The system size determines the number of solar modules based on the available roof space for installation. Solar modules are manufactured by different suppliers across United States which are differentiated on the basis of their system performance and efficiency. The racking system or the mechanical structures on which the solar modules are mounted account for one of the major components in this installation.

The racking system is generally made of high strength stainless steel, galvanized steel or aluminum alloys. Different power components such as junction box, disconnect switch, wire management, service panels and backup complete the circuit in a system installation. Freight also adds up to a minute cost component in the installation of solar modules as it involves logistics of solar modules, racking structure and other electrical components.

The construction cost of solar systems is the second most expensive component in this configuration. Total labor workforce cost is majorly dependent on the location where the solar systems are installed. The installation of a residential solar system involves a joint effort from a roofing contractor and solar general contractor. The roofing contractor lays down specific guidelines for installing panels and approves the pre-existing roofing material.

The pre-installed roofing material has to be of required strength for structure bolting and riveting before solar panel installations. After adequate feasibility checks and approvals from roofing inspectors, solar contractors chalk out a comprehensive installation plan. Feasibility studies, inspection costs, labor & material costs for both roofing and solar installers account for the “total construction cost”. Table 1 below gives the overall cost components of solar system installations.

Table 1: Cost of Solar System Installations (Source: SUS 2014)

Cost of Installation of a Solar System	
PV modules	$20,000.00
Racking System	$3,100.00
Junction Box	$100.00
Disconnect Switch	$350.00
Wiring	$350.00
Service Panel	$300.00
Backup Generator/Batteries	$600.00
Construction & Installation cost	$12,000.00
Average Freight	$200.00
Total	**$37,000.00**

4.1.2 Cost of an On-Grid Conventional Energy System

Conventional systems derive their energy through non-renewable sources such as natural gas, coal and oil. As of today, they are still the most dependent source of electricity in residential and commercial setups. They are presumed to be relatively cheaper as compared to various other renewable sources of energy such as solar, wind, geothermal and biogas. Table 2 gives the overall cost components of conventional on-grid systems.

Table 2: Cost of On-Grid Conventional Systems (Source: US EIA 2015)

Cost of Installation of on-grid system (1kW-15kW)	
Utility connections	$150.00
Wiring	$150.00
Service Panel	$600.00
Electric Meter	$100.00
Construction & Installation cost	$300.00
Total	**$1,300.00**
Note: Price Variation between 1kW-15kW is 5% which has been absorbed in the total installation cost.	

The cost of installing an on-grid system in a residential system is based on definite utility components such as the wire management, service panel for rectifying break downs and electric meters. All the power components are accumulated to account for major cost components in the installation of a conventional system.

The costs of each component is derived from every state's standard utility manual which is compiled by the United States Information Administration on a monthly basis. The utility connections for conventional on grid systems are standardized by the USIA for residential setups under a 1kW-15kW range.

The construction and installation cost comprises wire conduits, cable glands and lugs, labor costs and concealed wire meshes. The wire conduits connects the service panels to electric meters and mains supply in our homes which consume the maximum labor hours in this setup. The labor for conventional system installations is relatively cheap as compared to other energy installations. All generating functions are established by the federal contracted power producing agencies before the consumers start using these systems.

The price variations in 1kW-15kW power systems is approximately $\pm$5% which has been absorbed in the overall installation and material cost. These conventional systems have an annual maintenance rate of 5-8% depending on the type of location and labor available for damage rectification and refurbishment.

4.1.3 Cost of On-Grid Conventional + Off-Grid Solar Systems (Hybrid)

The on-grid and off-grid hybrid systems are a combined generating source which are dependent on each other. An off grid connected solar system powers the residential systems only during peak hours of the day whereas the on-grid systems supports the energy consumption during night and off-peak hours.

Excessive electricity produced by these systems is transmitted back to the grid for which the government offers rebates on future utility bills. The off grid system reduces the dependency on batteries and generators for fulfilling the needs of household usage. Table 3 shows the cost components of hybrid systems which includes solar and conventional sources.

Table 3: Cost of Hybrid Systems (Source: Straight Up Solar 2014)

Cost of Installation of a Hybrid System	
PV modules	$16,000.00
Racking System	$3,100.00
Junction Box	$200.00
Disconnect Switch	$350.00
Wiring	$500.00
Service Panel	$900.00
Backup Generator/Batteries	$600.00
Construction & Installation cost	$12,300.00
Utility Connections	$150.00
Average Freight	$200.00
Total	**$34,300.00**

The hybrid system involves cost components from both on-grid conventional systems and off-grid solar systems which produce the same amount as a full-fledged conventional system. However, the power quality in the conventional and small solar energy system is slightly different due to switching production hours. In this system, the cost of solar modules curtails down by approximately 20% which is compensated by the installation of conventional power source.

All other on-grid and off-grid components are similar to single dynamic systems which produce the same energy output levels. The construction cost of hybrid systems comprises material, labor, energy equipment and inspection charges of both power utility and renewable agencies. A number of industry standards established by IEEE, NEC and UL have to be in compliance with specific codes and policies of the equipment used and generation systems installed.

The annual maintenance cost of the hybrid system is approximately $\pm$5-7% which comprises solar modules repairs, terminal connections, racking structure damage repairs and carbon emission filters.

4.2 System Parameters Considered in the CBA Model

4.2.1 Basic System Inputs

Table 4: Basic System Input Parameters for Rooftop Installations

System Parameters			
	Photovoltaic		**Units**
VARIABLE	Power Capacity	**10000**	W
	Maximum Power/Module	250	W
	No. of Modules	40	nos.
	Lifetime Warranty	20	years

The power capacity for residential solar systems shall vary depending on the power requirement, grid connectivity and square footage area of the roof where solar modules are to be installed. As a standard assumption for rooftop installations, the power output for every solar module is considered to be 250W. The number of modules are based on power requirement and space available for installation.

The manufacturer's standard lifetime warranty for solar modules is 20 years which can be extended if the system meets all federal energy policies and procedures. The system is decommissioned and checked for internal errors and efficiency responses. After configuring all parameters mentioned in Table 4, the system is re-commissioned for further usage and energy production.

4.2.2 Dimensions/Number of the Solar Modules as per Domestic Requirement

Table 5: Square Footage Area as per Dimensions of the Module

Dimensions of the solar module	**Inches**	**Feet**
Length	60	5.00
Breadth	36	3.00
Depth	1.37	0.11
Cross-Sectional Area (sq.ft.)		15.00
Available square footage area (sq.ft.)		600
No. of solar modules		40

To calculate the number of solar modules on any given roof space, we first inspect the area available for installation and its connections to the domestic service electric panels from where the electricity will be distributed. The feasibility studies for construction and installation of solar modules, racking structures and wire management is also carried out on the available roof space. Other ulterior factors such as right of way and environmental clearances are also taken into consideration during the inspection and project feasibility stage. The dimensions of a standard solar module is approximately 5 feet in length and 3 feet in breadth. Since, the solar panels are stacked in parallel arrays, we can assume that there would 40 solar modules spread over six hundred square feet. As per Table 5, we can also compute the total power output through solar modules after considering conversion losses. The number of solar modules are totally dependent on available square footage area and power requirement of the facility.

4.2.3 Energy Production as per System Size

Table 6: Analysis through Avg. Peak Hours (Source: SUS 2014)

kW-kWh analysis on the basis of Avg. peak hours through solar production	
Avg. peak hours/day	4
Total Days	365
Avg. peak hours/yr	1460
System size(kW)	**10**
DC Power output(kWh)	14600
Approximate losses for DC-AC conversion	18%
AC Power output(kWh)	11972
Note: Average peak hours can change depending on different locations	

The household power that we consume in our homes is called mains power supply electricity which is in alternating current (AC) whereas solar power is produced in direct current (DC) through solar modules. The solar power is produced through the movement of electrons in single direction from one side of the solar cell to another. The conversion of DC to AC is carried out with the help of an inverter which depreciates the power yield by approximately 15-18%. As per Table 6, we can compute the DC and AC power outputs by analyzing the conversion losses in the system.

On the basis of different locations and solar irradiance studies, we calculate the average peak hours per day and subsequently we calculate the annual peak hours in that particular location. The annual average peak hours when multiplied by the system size (kW) gives the DC power output in kWh. This DC power output is the system produce which is depreciated after the inversion. AC power output is the exact yield that we receive in our households throughout the year. Therefore, we can configure the AC power output by changing the dependent variables.

The dependent variables in this table are average peak hours and system size (kW). In Table no. 3, the average peak hours are considered to be 4 hours which gives a total of 1460 average peak hours throughout the year. The system size is considered to be 10kW which is multiplied to the annual average peak hours to produce the DC power yield in kWh. As per the conversion rate of 18%, AC power output computed is approximately 12000kWh throughout the year. The unit kWh is also called as power units in our utility bills.

4.2.4 Utility Energy Prices for Residential Systems

Table 7: Utility Energy Prices for Residential Systems

Utility Energy Prices (Residential)		
Energy Prices ($/kWh)	Nov-15	Jul-15
Texas	$0.1151	$0.1211
California	**$0.1824**	$0.1735
New York	$0.1844	$0.1812
New Mexico	$0.1335	$0.1241
Hawaii	$0.2987	$0.3021
Massachusetts	$0.1799	$0.2071

The United States Information Administration releases an electric power monthly data for ultimate customers under their independent statistics and analysis journal. The utility energy price variations are dependent on certain critical factors such as the seasons, energy production, energy consumption, energy storage, construction, transmission & distribution, power losses, operation and maintenance of energy producing stations.

As per Table 7, in Nov 2015, Texas had a lower utility energy price for residential systems as compared to previous months, whereas the energy price in California increased by approximately 4-5%. However, this marginal difference does not affect the overall solar system analysis since all values considered are as per average peak hours. There is a slight escalation or depreciation of about ±10% in the overall energy production and utility energy prices throughout the year.

4.2.5 System Analysis through Utility Prices and Power Consumption

Table 8: System Analysis

System Analysis	
Annual Power requirement by residential setup(kWh)	15000
Annual Power cost as per utility energy prices($)	$2,736.00
Monthly Power cost($)	$228.00
Annual solar production through installed system (kWh)	11972
Annual grid requirement after solar installation(kWh)	3028
Solar system savings($/year)	$2,183.69
Solar system savings($/month)	$181.97
Monthly Power cost after solar installation($)	$46.03
Annual Power cost after solar installation ($)	$552.31
Payback period (Years)	**15.87**

For quantifying the annual solar system savings, we setup a base annual power requirement for a residential system. The base value of this residential system is considered to be 15000 kWh or 15000 power units. To calculate the annual power cost of this residential system, we multiply the utility energy prices with the power requirement.

The annual power cost for all states is different due to variability in different utility energy prices and construction cost. After comparing the AC solar power output and actual power requirement, we compute the reduction in dollar amounts and power units after solar system installations.

The system size installed in this residential system is dependent on the available roof space, construction/installation access, grid requirements and average peak hours/day. The average peak hours per day is a variable factor which increases or decreases the solar system production and affects the system savings in kWh and dollar amounts.

The annual grid requirement is factor which is totally dependent on power required vs power produced and is also measured in kWh. For calculating the payback period of the installed system, we consider two important parameters. The most imperative factor in calculating the payback period is the cost of solar power equipment, accessories and installation cost. The average cost of solar system is dependent on the type of solar modules, solar system size and available roof space. Table 8 clearly shows the overall system analysis considering all input parameters.

The other parameter considered in system analysis is the annual solar savings ($) which is computed on the basis of system size and utility energy prices. The overall system and installation cost ($) divided by the annual solar savings ($) results in the least payback period of the system. Figure 5 clearly shows the inter-relationship between annual solar savings in dollars and state's utility energy prices.

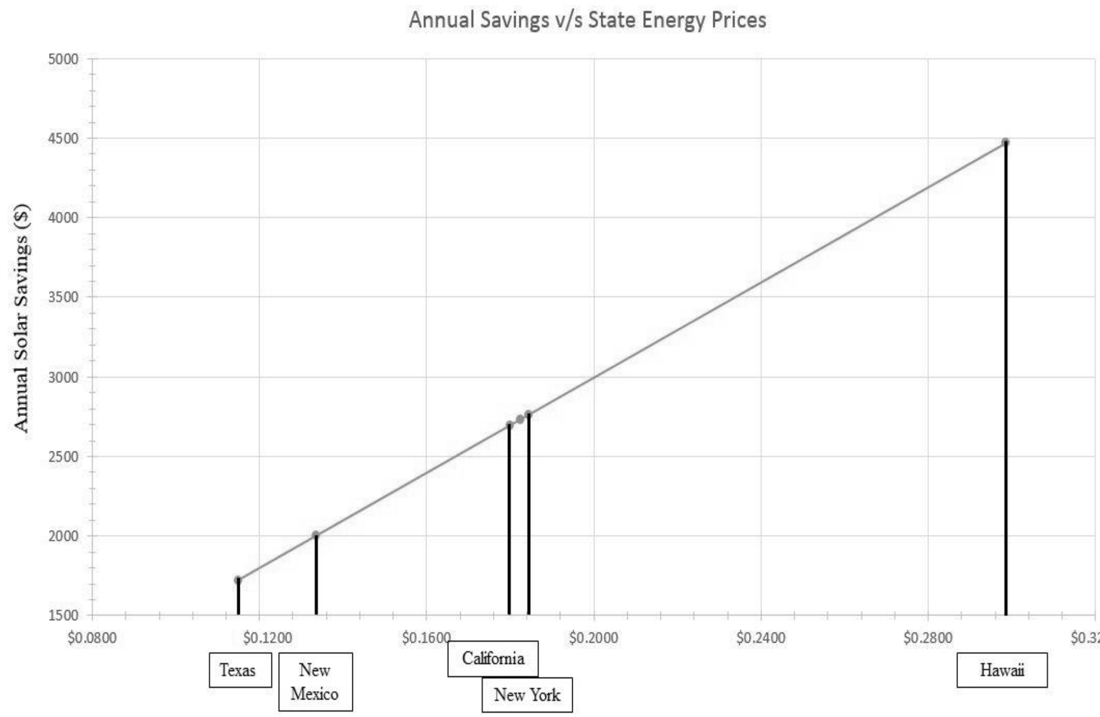

Figure 5: Annual Solar Savings vs State Energy Prices

4.2.6 Research Model Assumptions

To quantify the cost and benefit components of three energy systems, we have taken certain assumptions in this decision making model:

- The solar power output is kept at a standard AC level of 15000kWh for all the three energy systems.
- The power output capacity of each solar module is considered to be 250W with an efficiency rate of 97% for the first twenty years.
- The dimensions of a solar module (panel) is 5 feet in length and 3 feet in breadth.
- The average cost of each solar module used in solar and hybrid systems is $400.00
- The approximate power losses when DC is converted to AC is approximately 15-18%.
- The average peak hours per day is 4-6 hours which is highly dependent on the location of the residential system.
- The standard cost of installation is considered to be $12,000.00 throughout the United States. (The price variation is approximately 8% which is absorbed in the total installation cost.)
- The expected rate of return as consumer is 10% annually.
- The cost per kWh is purely dependent on USIA's data for utility energy prices based on different states.
- Taxation costs and Subsidies have been absorbed in the overall installation cost of the energy systems.

4.3 Total Costs at a Glance

Table 9: Overall Cost of Solar, Conventional and Hybrid Systems (Source: US EIA 2015, SUS 2014)

Overall Expenses/Costs			
Different systems giving same power output ~ 15000kWh	**Solar system**	**Conventional**	**Hybrid**
System Size (kW)	12.5	15	10+3
Cost of Installation + Construction + Balance of system	$37,000.00	$1,300.00	$34,300.00
Annual Maintenance Charges	$1,850.00	$65.00	$1,715.00
Total Expenses	$38,850.00	$1,365.00	$36,015.00

The benefit cost model for all three energy systems has an equivalent power output of 15000kWh which can be quantified using its cost components as depicted in Table 9 above. The 12.5kW solar system produces 14965kWh which is approximately 15000kWh power units of conventional energy. The 100% solar system costs about $37,000.00 as a one-time initial investment cost which includes the installation cost, construction cost and balance of system such as power components and logistics.

The hybrid system consists of a 10kW solar system which produces 11972kWh of AC power and 3kW conventional energy system which has a relative efficiency of 98%. The hybrid systems costs about $34,300.00 which includes $33,000.00 as the initial investment cost of solar systems and $1,300.00 as the cost of installing conventional energy systems.

Furthermore, all the three energy systems have an efficiency ratio of 0.97 which is highly favorable for residential systems. After considering the overall costs of solar systems, conventional energy systems and hybrid systems we determine that the 12.5kW solar system is the most expensive energy producing setup for our residential systems as compared to the conventional setups.

The annual maintenance charges for the 12.5kW solar systems, 15kW conventional energy systems and hybrid systems are considered to be 4-5%. This maintenance cost includes spraying cold water on solar modules on a bi-weekly basis, alignment of solar modules done by skilled solar contractors, observing efficiency management readings through service panels and utility connections through proper wire management.

All the costs incurred during installation of solar systems are relatively higher as compared to conventional systems due to high initial investment costs which is clearly shown in Figure 6 below. The costs of solar modules, racking structures, power components and construction/installation cost encompasses the overall expenditure of the solar system.

The cost components also vary on the basis of the type of modules used, quality levels of the racking structure and labor costs of states where the modules are being installed. The higher the system size, the higher will be the initial investment of the solar systems.

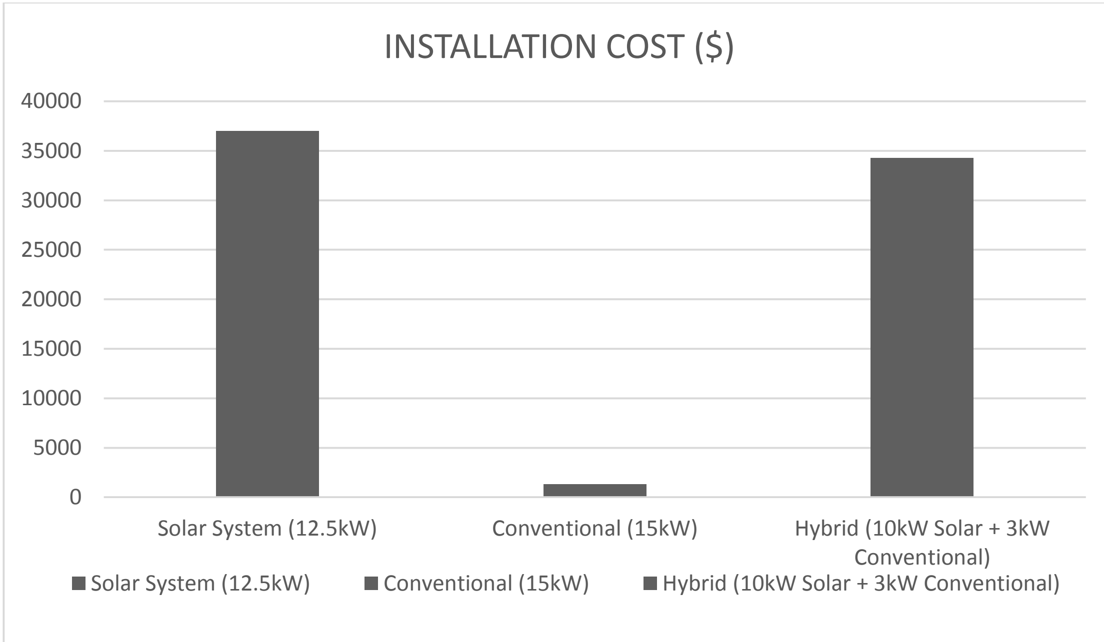

Figure 6: Total Installation Costs ($)

4.4 Total Benefits at a Glance

Table 10: Overall Benefits of Solar, Conventional and Hybrid Systems

Overall Benefits			
Different systems giving same power output ~ 15000kWh	**Solar system**	**Conventional system**	**Hybrid (Solar+ Conventional)**
Dependency on conventional system (kWh)	35	15000	3028
Annual Power savings after solar installation ($)	$2,729.62	0	$2,183.69
CO_2 emission reduction lbs/yr (Assumption: 1.21lbs/kWh)	18107.7	0	14486.1

4.4.1 Dependency on Conventional Systems (kWh)

The higher the system size, the lower will be the dependency on our on-grid conventional systems as computed through Table 10 above. For producing 15000kWh, we install a solar system of 12.5kW which produces 14965kWh of power units on an annual basis. After considering the variability in solar system performances, we compute that 12.5kW systems are sufficient to sustain a household which has an annual power requirement of 15000kWh. On the other hand, hybrid systems are relatively more dependent on conventional systems due to their energy production during off-peak and night hours.

10kW solar systems in a hybrid setup produces 11972kWh of power units on an annual basis whereas, there is still a strong dependency on conventional energy systems for 3028kWh of power units. The conventional energy primitive systems are totally dependent on non-renewable sources of energy such as natural gas, coal and oil reserves. Therefore, the total dependency on on-grid conventional systems is approximately 15000kWh to support the power consumption for a household on an annual basis.

4.4.2 Annual Power Savings after Solar Installation ($)

The end customer receives annual power savings directly after solar installation starting from the very first year. Monthly utility charges are negligible and the consumers start recouping their initial investments on solar systems. After installing a 12.5kW solar system which produces 14965kWh of power units, every end customer saves $2730.00 on an annual basis.

Primitive energy systems which are dependent on conventional sources do not save any dollar amounts due to obvious reasons. Hybrid solar + conventional systems which are configured to have 10kW solar systems producing 11972kWh of electricity saves about $2183.69 on an annual basis. These power savings can be increased or decreased on the basis of state’s energy utility prices.

The higher the prices, the more savings are made by end customers annually. In addition to this, the system size is directly dependent to energy savings. Therefore, we can certainly increase the system size to encounter more energy savings in our systems.

4.4.3 CO_2 Emission Reductions (lbs/yr)

Carbon emissions are directly proportional to kind of systems installed as an energy source for residential, commercial and industrial systems. As per See CO_2, Know CO_2 magazine, carbon emissions increase about 2.5% every year.

The carbon footprint across the US is increasing giving rise to more renewable energy power resources. Different sources such as natural gas, oil and coal produce different carbon contents levels in lbs/kWh throughout the year.

USIA releases data for the amount of carbon dioxide produced for particular fossil fuels through heat and electricity of the power generator. Coal produces 2.17lbs of CO_2 per kWh whereas natural gas produces 1.21lbs of CO_2 per kWh. In the cost benefit model, we have considered the values of natural gas, coal and oil based on state’s power stations.

After installing 12.5kW solar systems, we figured that the total carbon emission reductions are approximately 18100lbs annually which were saved due to installation of renewable resources. On the other hand, hybrid systems which have 10kW solar systems produce 11972kW of electricity and save 14486lbs of CO_2 annually. The difference in both the systems is due to the integration of conventional energy source in the hybrid residential setups. Carbon emission reductions are an integral factor considered in the benefits of having roof-top solar systems.

4.5 Economic Sensitivity Analysis

4.5.1 Overall Assessment

The economic sensitivity analysis is done to mathematically integrate the assumptions made by the system parameters and predictions in the cost benefit model so as to validate the outcomes of the decisions made. Sensitivity in this model is affected by its cost and benefit components which predict the feasibility to pursue solar power systems over conventional power systems for residential setups. We have made certain assumptions in the research model and monetized cost and benefit components in order to predict the futuristic rate of return annually and its present value.

To consolidate a decision making business model for adoption of solar power on residential systems, we critically define costs and benefits parameters of this system and devise a comprehensive plan for potential investors and end users. Therefore, economic parameters such as internal rate of return, net present value, profitability index, payback periods and benefit cost ratios will determine the feasibility of this model through critical examination of real time data and sources.

As mentioned in Table 11 below, basic input factors such as system size and location, annual power requirement of a residential system, average peak hours, and utility energy prices will provide a platform for economic sensitivity analysis. These factors have been carried out in different states which produce the maximum solar irradiance levels in the United States. The following economic parameters have been evaluated on 12.5kW solar system.

Table 11: First Year Savings on Initial Investment

System size (kW)	First year savings	On Grid Power Cost/Yr	Benefit inflows/Yr	Initial Investment
4	$873.50	$1,862.52	$873.50	$23,400.00
4.5	$982.70	$1,753.34	$982.70	$24,200.00
5	$1,091.80	$1,644.15	$1,091.80	$25,000.00
5.5	$1,201.00	$1,534.97	$1,201.00	$25,800.00
6	$1,310.20	$1,425.78	$1,310.20	$26,600.00
6.5	$1,419.40	$1,316.60	$1,419.40	$27,400.00
7	$1,528.60	$1,207.42	$1,528.60	$28,200.00
7.5	$1,637.80	$1,098.23	$1,637.80	$29,000.00
8	$1,747.0	$989.1	$1,747.0	$29,800.00
10	$2,183.7	$552.3	$2,183.7	$33,000.00
11	$2,402.1	$333.9	$2,402.1	$34,600.00
12.5	$2,729.6	$6.4	$2,729.6	$37,000.00

4.5.2 Benefit Inflows vs On Grid Power Cost

The benefit inflows are an outcome of solar energy produced and state's utility energy prices on an annual basis. Cash inflows are directly dependent on the savings received after commissioning solar systems throughout its lifetime. After recouping the benefits of the system, end customers benefit from the cash inflows at an expected rate of 10% every year.

Higher the system size (kW), higher is the dollar amount for cash inflows throughout the system life period. Hybrid systems have a slow rate of cash flows due to their dependency on conventional energy systems. If we install a 4kW hybrid solar system with its major energy production derived from conventional sources, we would receive $873.00 every year as our solar system savings but, we will have to pay a higher amount to sustain the residential requirement through conventional sources. As a result of which, we will have our earnings at a minimal rate for recouping our initial investment of $23400.00.

On the other hand, if we consider installing a 12.5kW fully equipped solar system without any dependencies on the conventional sources, we would recoup our benefits at a faster rate. Our first year benefit cash inflow earnings would turn out to be $2730.00. The on-grid cost for residential solar systems will be negligible and would be recouped within days of solar installation. Our initial investment of $37,000.00 for a 12.5kW solar system will proceed to transform into earnings at a higher rate of return as shown in Figure 7 below.

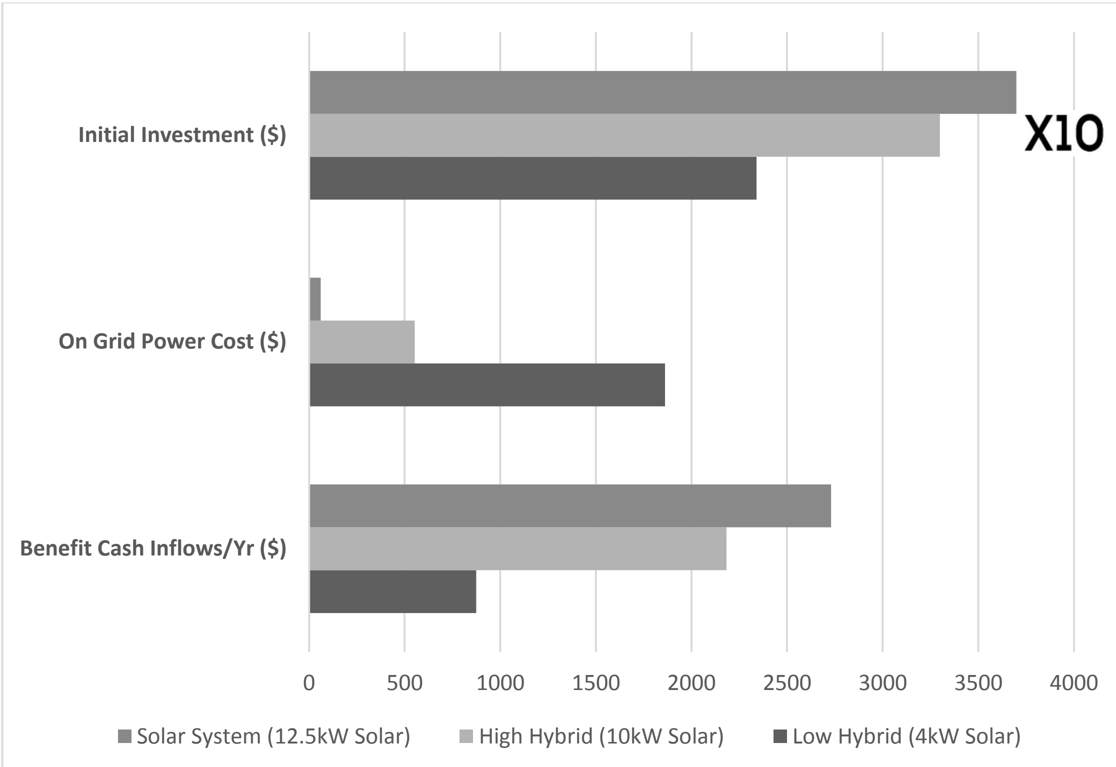

Figure 7: Benefit Cash Inflows ($) for Solar Systems

4.5.3 Net Present Value

The concept of net present value suffices the interrelation between the cash inflows and cash outflows of a project. The main objective of this economic characteristic is to quantify the projected profit margins and sustainability of the project. The net present value of any venture is based on four critical components such as initial investment, cash flows, discount rate and time period of the project. The discount rate is the rate of return which an end customer expects out of the project monthly or annually.

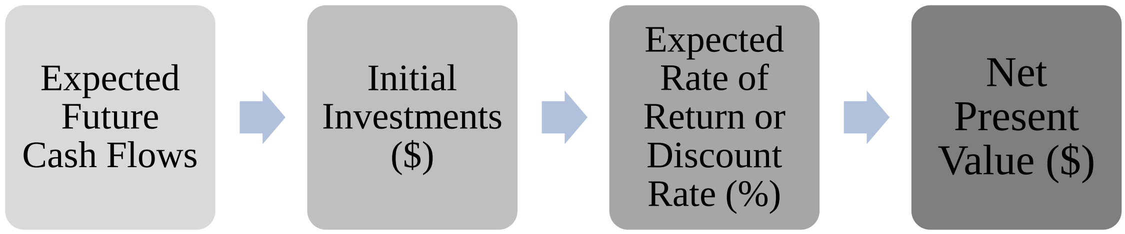

Figure 8: Net Present Value Process Diagram (Source: Javellana A. 2012)

Net present value (NPV) is a key economic indicator to comprehend the profitability of a project. A positive NPV value indicates the feasibility of the project and is absolutely ready to add value to the owner, whereas a negative NPV indicates that project would subtract economic value from the owner. An end- customer should never pursue a project which has negative NPV values. The discount rate or the expected rate of return can be customized on the situation of market which changes rapidly due to inflation and changes in utility's energy prices. Figure 8 clearly shows the different processes involved in computing the net present value for any venture.

Table 12: Factors Affecting Net Present Value (NPV)

System size (kW)	Benefit inflows/Yr	Initial Investment	Discount Rate	Net Present Value (NPV)
4	$873.50	$23,400.00	10%	$14,630.22
4.5	$982.70	$24,200.00	10%	$14,527.08
5	$1,091.80	$25,000.00	10%	$14,424.71
5.5	$1,201.00	$25,800.00	10%	$14,321.57
6	$1,310.20	$26,600.00	10%	$14,218.44
6.5	$1,419.40	$27,400.00	10%	$14,115.30
7	$1,528.60	$28,200.00	10%	$14,012.17
7.5	$1,637.80	$29,000.00	10%	$13,909.03
8	$1,747.0	$29,800.00	10%	$13,805.90
10	$2,183.7	$33,000.00	10%	$13,394.19
11	$2,402.1	$34,600.00	10%	$13,188.15
12.5	$2,729.6	$37,000.00	10%	$12,879.04

The net present value is primarily based on four major components in the solar system analysis over on-grid electricity, they are benefit cash inflows, initial investment, discount rate and the duration of the project as depicted in Table 12. The benefit cash inflows are a resultant of solar power produced and its subsequent system size. Larger the system size, higher is the benefit cash inflow dollar amounts annually, as per model we can compute that the net present value decreases as the benefit cash flows increases.

Therefore, an initial investment of $37,000.00 in a 12.5kW solar system results in a net present value of $12,879.04 over a warranty period of 20 years. This present value is determined by analyzing the benefit cash inflows at an expected consumer rate of return at 10% annually. This relative rate of return is predisposed on the location of the residential system, availability of skilled manpower and electrical components for the balance of system. Figure 9 shows the inter dependability of initial investments and net present values.

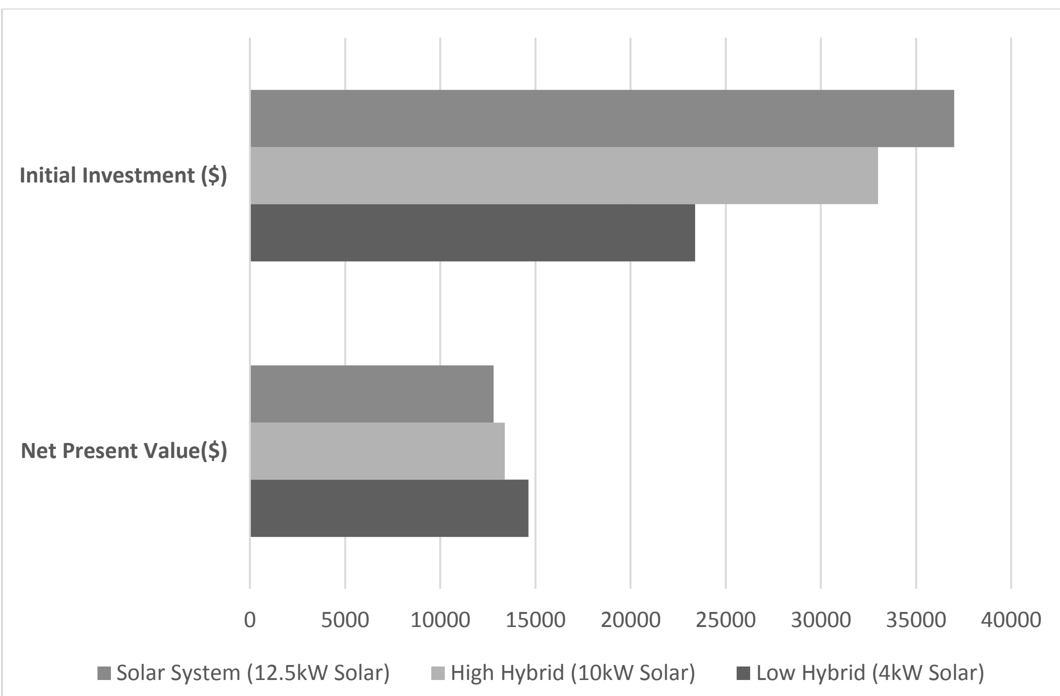

Figure 9: Net Present Value vs Initial Investments

4.5.4 Payback Periods or Return on Investments and Benefit Cost Ratios

Table 13: Payback Periods and Benefit Cost Ratios

System size (kW)	**On Grid Power Cost/Yr**	**Benefit inflows/Yr**	**Initial Investment**	**Payback Periods**	**Benefit Cost Ratio**
4	$1,862.52	$873.50	$23,400.00	**28.13**	0.037329
5	$1,644.15	$1,091.80	$25,000.00	24.04	0.043672
6	$1,425.78	$1,310.20	$26,600.00	21.32	0.049256
7	$1,207.42	$1,528.60	$28,200.00	19.37	0.054206
8	$989.1	$1,747.0	$29,800.00	17.91	0.058624
10	$552.3	$2,183.7	$33,000.00	**15.87**	0.066172
12.5	$6.4	$2,729.6	$37,000.00	**14.23**	0.073774

The payback period is the amount of time (years) taken by the project to reclaim its initial investment cost generated by the system along with the risks associated in the project. The payback period or return on investment (ROI) is a progressive measure which helps recuperate investments in fractions as depicted in Table 13.

In this model, the payback periods are a result of the total investment of the solar system which is $37,000.00 for 12.5kW solar system and total energy savings after solar installation. Through the correlation between energy savings and initial investment cost, we get a payback period of approximately 14.23 years. Figure 10 shows the different levels of initial investments and their respective payback periods.

A low hybrid system which involves 4kW of solar installation and 10kW of conventional energy gives a return on investment at 28.13 years whereas, higher hybrid systems with 10kW of solar energy gives a payback period of 15.87 years.

The benefit cost ratios is the correlation between the initial investments and benefit cash inflows over a period of time. The duration in this model is assumed as 20 years which is also the lifetime warranty of solar modules. It is observed that after 20 years, the efficiency of solar modules is reduced to 75% which declines the system performance and disturbs the economics behind solar power installation.

The benefit cost ratios for low scale hybrid system is 0.037 which is resultant of low benefit cash inflow and less investment whereas the benefit cost ratios of 12.5kW solar systems increases to 0.073 with a higher benefit inflow of $2729.6 and high initial investment of $37,000.00.

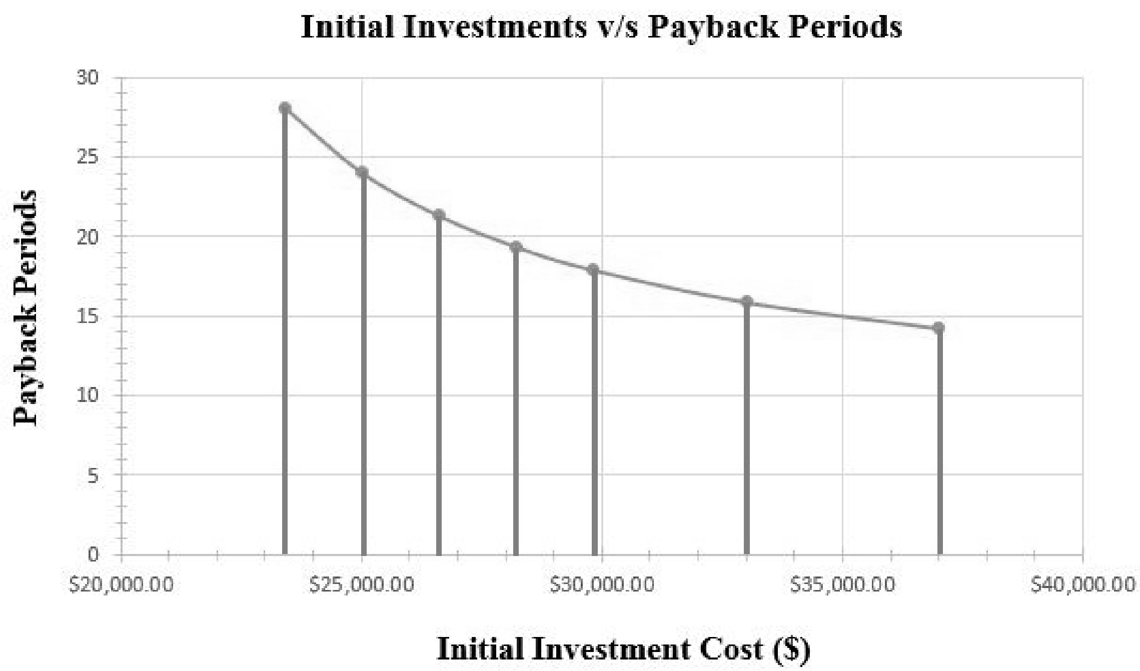

Figure 10: Payback Periods vs Initial Investments

5. ILLUSTRATIVE CASE STUDIES FOR BENEFIT COST ANALYSIS OF PV OVER ON-GRID ELECTRICITY

To validate the system analysis of three energy systems, we have conducted studies on three states and considered different economic parameters to outline general guidelines for end customers. The system parameters for these studies vary on the basis of size of the project, location, utility energy prices and construction/installation cost. California, Hawaii and Texas are the three states where we have analyzed system parameters to produce decision making guidelines for residential home owners.

5.1 Texas

Utility energy prices in the state of Texas are comparatively cheaper as compared to other states in US due to its high order dependency on conventional sources of energy like natural gas and oil. This cost benefit model will analyze the input parameters such as average utility energy prices, construction/installation cost of solar systems and average peak hours per day for solar production.

The average utility energy prices in Texas fluctuate about 5% every year which depends on energy generation and consumption of residential owners. On an average, a residential system in Texas consumes 15000kWh or power units annually which can be supported by 12.5kW solar system. As per Table 14, the average utility prices in Texas were about \$0.11 - \$0.12 throughout 2015 and are expected to increase further over the next couple of years.

Table 14: Average Utility Energy Prices in Texas

Utility Energy Prices (Residential)		
Energy Prices (\$/kWh)	Nov-15	Jul-15
Texas	**\$0.1151**	**\$0.1211**
California	\$0.1824	\$0.1735
Hawaii	\$0.2987	\$0.3021

5.1.1 Cost of Installing Solar Systems in Texas

Table 15 below shows the cost components of a 12.5kW solar system which produces 15000kWh of power units (research model).

Table 15: Cost of Installation of a Solar System in Texas (Source: US EIA 2015, SUS 2014)

Cost of Installation of a Solar system	
PV modules	$20,000.00
Racking System	$3,100.00
Junction Box	$100.00
Disconnect Switch	$350.00
Wiring	$350.00
Service Panel	$300.00
Backup Generator/Batteries	$600.00
Construction & Installation cost	**$8,000.00**
Average Freight	$200.00
Total	**$33,000.00**

We require 50 solar modules to generate 15000kWh power units which costs about $20,000.00 as an initial investment on source and other electrical components which account for about 25% of the total system cost. One of major cost components of this system is the construction or installation cost which includes the labor cost, permit compliances cost, inspection charges by the authorities and engineering expenditures during the course of construction. The construction cost and utility energy prices are relatively cheaper in Texas as compared to other states.

5.1.2 System Analysis through Utility Prices and Power Consumption in Texas

Table 16: System Analysis through Texas Energy Prices

Solar System Analysis in Texas	
Annual Power requirement by residential setup(kWh)	15000
Annual Power cost as per utility energy prices($)	$1,726.50
Monthly Power cost($)	$143.88
Annual solar production through installed system (kWh)	14965
Annual grid requirement after solar installation(kWh)	35
Solar system savings($/year)	$1,722.47
Solar system savings($/month)	$143.54
Monthly Power cost after solar installation($)	$0.34
Annual Power cost after solar installation ($)	$4.03
Payback period (Years)	**20.12**

For quantifying the annual solar system savings in Texas, we setup a base annual power requirement for a residential system. As per our cost benefit model and Table 16, the base value of this residential system is considered to be 15000 kWh or 15000 power units. To calculate the annual power cost of this residential system, we multiply the Texas utility energy prices with the power requirement.

In this case, the utility price in Texas is about $0.11 which gives us the $1,722.47 in annual solar savings. After comparing the AC solar power output and actual power requirement, we determine the reduction in dollar amounts and power units after solar system installations.

The system size installed in this residential system is dependent on the available roof space, construction/installation access, grid requirements and average peak hours/day. The average peak hours/ day is a variable factor which increases or decreases the solar system production and affects the system savings in kWh and dollar amounts.

The average peak hours per day in Texas are 4 hours as per the United States Information Administration (USIA). The annual grid requirement is totally dependent on power required vs power produced annually. For calculating the payback period of the installed system, we consider two important parameters.

The most imperative factor in calculating the payback period is the cost of solar equipment and installation cost and the average cost of solar system is dependent on the type of solar modules, solar system size and available roof space. The average cost of installing a solar system is about $33,000.00 when divided by $1,722.47 (solar savings) gives the payback period which is about 20.12 years in Texas.

5.1.3 Overall Benefits in Texas

Table 17: Overall Benefits of Solar, Conventional and Hybrid Systems in Texas

Overall Benefits in Texas			
Different systems giving same power output ~ 15000kWh	**Solar system**	**Conventional system**	**Hybrid (Solar+ Conventional)**
Dependency on conventional system (kWh)	35	15000	3028
Annual Power savings after solar installation ($)	$1,722.47	0	$1,377.98
CO_2 emission reduction lbs/yr (Assumption: 1.21lbs/kWh)	18107.7	0	14486.1

5.1.3.1 Dependency on Conventional Systems (kWh)

As per Table 17 above, higher the system size, the lower will be the dependency on our on-grid conventional systems. For producing 15000kWh, we install a solar system of 12.5kW which produces 14965kWh of power units on an annual basis. After considering the variability in solar system performances, we compute that 12.5kW systems are sufficient to sustain a household which has an annual power requirement of 15000kWh. On the other hand, hybrid systems are relatively more dependent on conventional systems due to their energy production during off-peak and night hours.

10kW solar systems in a hybrid setup produces 11972kWh of power units on an annual basis whereas, there is still a strong dependency on conventional energy systems for 3028kWh of power units. Therefore, the total dependency on on-grid conventional

systems is approximately 15000kWh to support the power consumption for a household annually.

5.1.3.2 Annual Power Savings after Solar Installation ($)

The end customer receives annual power savings directly after solar installation starting from the very first year. After installing a 12.5kW solar system which produces 14965kWh of power units, every end customer in Texas saves about $1722.47 on an annual basis. Hybrid solar + conventional systems which are configured to have 10kW solar systems producing 11972kWh of electricity saves about $1377.98.

5.1.3.3 CO_2 Emission Reductions (lbs/yr)

Every year, the United States Information Administration releases data for the amount of carbon dioxide produced for particular fossil fuels through heat and electricity of the power generator. Coal produces 2.17lbs of CO_2 per kWh whereas natural gas produces 1.21lbs of CO_2 per kWh. In Texas, most of the conventional energy is produced through natural gas, therefore the CO_2 per kWh is approximately 1.21lbs.

After installing 12.5kW solar systems, we figured that the total carbon emission reductions is approximately 18100lbs annually which were saved due to installation of renewable resources. On the other hand, hybrid systems which have 10kW solar systems produce 11972kW of electricity and save 14486lbs of CO_2 annually. The difference in both the systems is due to the integration of conventional energy source in the hybrid residential setups.

5.1.4 Comparative Analysis of 15kW Conventional System vs Hybrid System vs 12.5kW Solar System (Texas)

Table 18: Summary Table of Benefit and Cost Components

Comparative Analysis of Conventional system vs Hybrid system vs 12.5kW Solar system				
	Input Parameters	**Conventional system**	**Hybrid**	**Solar system**
Initial Investment ($)		$1,300.00	$30,300.00	$33,000.00
Total Energy Savings, kWh/yr	10	0	11972	14965
Total Energy Savings, $/yr	-	0	$1,377.98	$1,722.47
Payback Period (Years)	-	0	22.10	20.12
CO2 Emission Reduction/yr (lbs/yr)	1.21	0	14486.1	18107.7

As per Table 18 above, initial investment cost of 12.5kW solar systems is approximately $33,000.00 which has a payback period of about 20.12 years and saves 14965 kWh of power units every year. The carbon emission reductions for this system is about 18107.7lbs per year.

5.2 California

Utility energy prices in the state of California are comparatively higher as compared to other states in US due to its extremely low dependency on conventional sources of energy like natural gas and oil. This cost benefit model will analyze the input parameters such as average utility energy prices, construction/installation cost of solar systems and average peak hours per day for solar production.

The average utility energy prices in California fluctuate about 7% every year which depends on energy generation and consumption of residential owners. On an average, a residential system in California consumes 15000kWh or power units annually which can be supported by 12.5kW solar system. As per Table 19, average utility prices in California were about \$0.17 - \$0.18 throughout 2015 and are expected to increase further over the next couple of years.

Table 19: Average Utility Energy Prices in California

Utility Energy Prices (Residential)		
Energy Prices ($/kWh)	Nov-15	Jul-15
Texas	$0.1151	$0.1211
California	**$0.1824**	**$0.1735**
Hawaii	$0.2987	$0.3021

5.2.1 Cost of Installing Solar Systems in California

Table 20 below shows the cost components of a 12.5kW solar system which produces 15000kWh of power units (research model):

Table 20: Cost of Installation of a Solar System in California (Source: US EIA 2015, SUS 2014)

Cost of Installation of a Solar system	
PV modules	$20,000.00
Racking System	$3,100.00
Junction Box	$100.00
Disconnect Switch	$350.00
Wiring	$350.00
Service Panel	$300.00
Backup Generator/Batteries	$600.00
Construction & Installation cost	**$12,000.00**
Average Freight	$200.00
Total	**$37,000.00**

We require 50 solar modules to generate 15000kWh power units which costs about $20,000.00 as an initial investment on source and other electrical components which account for about 60% of the total system cost. One of major cost components of this system is the construction or installation cost which includes the labor cost, permit compliances cost, inspection charges by the authorities and engineering expenditures during the course of construction.

5.2.2 System Analysis through Utility Prices and Power Consumption in California

Table 21: System Analysis through California Energy Prices

Solar System Analysis in California	
Annual Power requirement by residential setup(kWh)	15000
Annual Power cost as per utility energy prices($)	$2,736.00
Monthly Power cost($)	$228.00
Annual solar production through installed system (kWh)	14965
Annual grid requirement after solar installation(kWh)	35
Solar system savings($/year)	$2,729.62
Solar system savings($/month)	$227.47
Monthly Power cost after solar installation($)	$0.53
Annual Power cost after solar installation ($)	$6.38
Payback period (Years)	**14.23**

For quantifying the annual solar system savings in California, we setup a base annual power requirement for a residential system. As per our cost benefit model and

Table 21, base value of this residential system is considered to be 15000 kWh or 15000 power units. To calculate the annual power cost of this residential system, we multiply the California utility energy prices with the power requirement.

In this case, the utility price in California is about $0.18 which gives us the $2,729.62 in annual solar savings. After comparing the AC solar power output and actual power requirement, we compute the reduction in dollar amounts and power units after solar system installations.

The system size installed in this residential system is dependent on the available roof space, construction/installation access, grid requirements and average peak hours/day. The average peak hours/ day is a variable factor which increases or decreases the solar system production and affects the system savings in kWh and dollar amounts.

The average peak hours per day are 5 hours as per the United States Information Administration (USIA). The annual grid requirement is factor which is totally dependent on power required vs power produced on an annual basis and is also measured in kWh. For calculating the payback period of the installed system, we consider two important parameters.

The most imperative factor in calculating the payback period is the cost of solar equipment and installation cost and the average cost of solar system is dependent on the type of solar modules, solar system size and available roof space. The average cost of installing a solar system is about $37,000.00 when divided by $2,729.62 (solar savings) gives the payback period which is about 14.23 years in California.

5.2.3 Overall Benefits in California

Table 22: Overall Benefits of Solar, Conventional and Hybrid Systems in California

Overall Benefits in California			
Different systems giving same power output ~ 15000kWh	**Solar system**	**Conventional system**	**Hybrid (Solar+ Conventional)**
Dependency on conventional system (kWh)	35	15000	3028
Annual Power savings after solar installation ($)	$2,729.62	0	$2,183.69
CO_2 emission reduction lbs/yr (Assumption: 1.21lbs/kWh)	30977.66	0	24782.00

5.2.3.1 Dependency on Conventional Systems (kWh)

As clearly mentioned in Table 22, higher the system size, the lower will be the dependency on our on-grid conventional systems. For producing 15000kWh, we install a solar system of 12.5kW which produces 14965kWh of power units on an annual basis. After considering the variability in solar system performances, we compute that 12.5kW systems are sufficient to sustain a household which has an annual power requirement of 15000kWh. On the other hand, hybrid systems are relatively more dependent on conventional systems due to their energy production during off-peak and night hours.

10kW solar systems in a hybrid setup produces 11972kWh of power units on an annual basis whereas, there is still a strong dependency on conventional energy systems for 3028kWh of power units. Therefore, the total dependency on on-grid conventional

systems is approximately 15000kWh to support the power consumption for a household annually.

5.2.3.2 Annual Power Savings after Solar Installation ($)

The end customer receives annual power savings directly after solar installation starting from the very first year. After installing a 12.5kW solar system which produces 14965kWh of power units, every end customer in California saves about $2729.62 on an annual basis. Hybrid solar + conventional systems which are configured to have 10kW solar systems producing 11972kWh of electricity saves about $2183.69.

5.2.3.3 CO_2 Emission Reductions (lbs/yr)

Every year, the United States Information Administration releases data for the amount of carbon dioxide produced for particular fossil fuels through heat and electricity of the power generator. Coal produces 2.17lbs of CO_2 per kWh whereas natural gas produces 1.21lbs of CO_2 per kWh. In California, most of the conventional energy is produced through coal, therefore the CO_2 per kWh is approximately 2.07lbs.

After installing 12.5kW solar systems, we figured that the total carbon emission reductions is approximately 30977.66lbs annually which were saved due to installation of renewable resources. On the other hand, hybrid systems which have 10kW solar systems produce 11972kW of electricity and save 24782lbs of CO_2 annually.

5.2.4 Comparative Analysis of 15kW Conventional System vs Hybrid System vs 12.5kW Solar System (California)

Table 23: Summary Table of Benefit and Cost Components

Comparative Analysis of Conventional system vs Hybrid system vs 12.5kW Solar system				
	Input Parameters	**Conventional system**	**Hybrid**	**Solar system**
Initial Investment ($)		$1,300.00	$34,300.00	$37,000.00
Total Energy Savings, kWh/yr	10	0	11972	14965
Total Energy Savings, $/yr	-	0	$2,183.69	$2,729.62
Payback Period (Years)	-	0	15.87	14.23
CO2 Emission Reduction/yr (lbs/yr)	2.07	0	24782.0	30977.66

As per Table 23, initial investment cost of 12.5kW solar systems is approximately $37,000.00 which has a payback period of about 14.23 years and saves 14965 kWh of power units every year. The carbon emission reductions for this system is about 30977.66lbs per year.

5.3 Hawaii

Utility energy prices in the state of Hawaii are comparatively higher as compared to other states in US due to its extremely low dependency on conventional sources of energy like natural gas and oil. This cost benefit model will analyze the input parameters such as average utility energy prices, construction/installation cost of solar systems and average peak hours per day for solar production.

The average utility energy prices in Hawaii fluctuate about 8% every year which depends on energy generation and consumption of residential owners. On an average, a residential system in Hawaii consumes 15000kWh or power units annually which can be supported by 12.5kW solar system. As per Table 24 below, average utility prices in Hawaii were about \$0.29 - \$0.30 throughout 2015 and is expected to increase further over the next couple of years.

Table 24: Average Utility Energy Prices in Hawaii (Source: US EIA 2015)

Utility Energy Prices (Residential)		
Energy Prices (\$/kWh)	Nov-15	Jul-15
Texas	\$0.1151	\$0.1211
California	\$0.1824	\$0.1735
Hawaii	**\$0.2987**	**\$0.3021**

5.3.1 Cost of Installing Solar Systems in Hawaii

Table 25 below shows the cost components of a 12.5kW solar system which produces 15000kWh of power units (research model):

Table 25: Cost of Installation of a Solar System in Hawaii (Source: US EIA 2015)

Cost of Installation of a solar system	
PV modules	$20,000.00
Racking System	$3,100.00
Junction Box	$100.00
Disconnect Switch	$350.00
Wiring	$350.00
Service Panel	$300.00
Backup Generator/Batteries	$600.00
Construction & Installation cost	**$16,000.00**
Average Freight	$200.00
Total	**$41,000.00**

We require 50 solar modules to generate 15000kWh power units which costs about $20,000.00 as an initial investment on source and other electrical components which account for about 50% of the total system cost. One of major cost components of this system is the construction or installation cost which includes the labor cost, permit compliances cost, inspection charges by the authorities and engineering expenditures during the course of construction.

5.3.2 System Analysis through Utility Prices and Power Consumption in Hawaii

Table 26: System Analysis through Hawaii Energy Prices

Solar System Analysis in Hawaii	
Annual Power requirement by residential setup(kWh)	15000
Annual Power cost as per utility energy prices($)	$4,480.50
Monthly Power cost($)	$373.38
Annual solar production through installed system (kWh)	14965
Annual grid requirement after solar installation(kWh)	35
Solar system savings($/year)	$4,470.05
Solar system savings($/month)	$372.50
Monthly Power cost after solar installation($)	$0.87
Annual Power cost after solar installation ($)	$10.45
Payback period (Years)	**9.63**

For quantifying the annual solar system savings in Hawaii, we setup a base annual power requirement for a residential system. As per our cost benefit model and Table 26, base value of this residential system is considered to be 15000 kWh or 15000 power units.

To calculate the annual power cost of this residential system, we multiply the Hawaii utility energy prices with the power requirement.

In this case, the utility price in Hawaii is about $0.29 which gives us the $4,480.50 in annual solar savings. After comparing the AC solar power output and actual power requirement, we compute the reduction in dollar amounts and power units after solar system installations.

The system size installed in this residential system is dependent on the available roof space, construction/installation access, grid requirements and average peak hours/day. The average peak hours/ day is a variable factor which increases or decreases the solar system production and affects the system savings in kWh and dollar amounts.

The average peak hours per day are 4.5 hours as per the United States Information Administration (USIA). The annual grid requirement is factor which is totally dependent on power required vs power produced on an annual basis and is also measured in kWh. For calculating the payback period of the installed system, we consider two important parameters.

The most imperative factor in calculating the payback period is the cost of solar equipment and installation cost and the average cost of solar system is dependent on the type of solar modules, solar system size and available roof space. The average cost of installing a solar system is about $41,000.00 when divided by $4,480.50 (solar savings) gives the payback period which is about 9.63 years in Hawaii.

5.3.3 Overall Benefits in Hawaii

Table 27: Overall Benefits of Solar, Conventional and Hybrid Systems in Hawaii

Overall Benefits in Hawaii			
Different systems giving same power output ~ 15000kWh	**Solar system**	**Conventional system**	**Hybrid (Solar+ Conventional)**
Dependency on conventional system (kWh)	35	15000	3028
Annual Power savings after solar installation ($)	$4,480.5	0	$3,576.04
CO_2 emission reduction lbs/yr (Assumption: 1.21lbs/kWh)	24991.6	0	19993.2

5.3.3.1 Dependency on Conventional Systems (kWh)

As per Table 27, higher the system size, the lower will be the dependency on our on-grid conventional systems. For producing 15000kWh, we install a solar system of 12.5kW which produces 14965kWh of power units on an annual basis. After considering the variability in solar system performances, we compute that 12.5kW systems are sufficient to sustain a household which has an annual power requirement of 15000kWh. On the other hand, hybrid systems are relatively more dependent on conventional systems due to their energy production during off-peak and night hours.

10kW solar systems in a hybrid setup produces 11972kWh of power units on an annual basis whereas, there is still a strong dependency on conventional energy systems for 3028kWh of power units. Therefore, the total dependency on on-grid conventional

systems is approximately 15000kWh to support the power consumption for a household annually.

5.3.3.2 Annual Power Savings after Solar Installation ($)

The end customer receives annual power savings directly after solar installation starting from the very first year. After installing a 12.5kW solar system which produces 14965kWh of power units, every end customer in Hawaii saves about $4,480.50 on an annual basis. Hybrid solar + conventional systems which are configured to have 10kW solar systems producing 11972kWh of electricity saves about $3576.04.

5.3.3.3 CO_2 Emission Reductions (lbs/yr)

Every year, the United States Information Administration releases data for the amount of carbon dioxide produced for particular fossil fuels through heat and electricity of the power generator. Coal produces 2.17lbs of CO_2 per kWh whereas natural gas produces 1.21lbs of CO_2 per kWh. In Hawaii, most of the conventional energy is produced through coal, therefore the CO_2 per kWh is approximately 1.67lbs.

After installing 12.5kW solar systems, we figured that the total carbon emission reductions is approximately 24991.6lbs annually which were saved due to installation of renewable resources. On the other hand, hybrid systems which have 10kW solar systems produce 11972kW of electricity and save 19993.2lbs of CO_2 annually. The difference in both the systems is due to the integration of conventional energy source in the hybrid residential setups.

5.3.4 Comparative Analysis of 15kW Conventional System vs Hybrid System vs 12.5kW Solar System (Hawaii)

Table 28: Summary Table of Benefit and Cost Components

Comparative Analysis of Conventional system vs Hybrid system vs 12.5kW Solar system				
	Input Parameters	**Conventional system**	**Hybrid**	**Solar system**
Initial Investment ($)		$1,300.00	$38,300.00	$41,000.00
Total Energy Savings, kWh/yr	10	0	11972	14965
Total Energy Savings, $/yr	-	0	$3,576.04	$4,480.50
Payback Period (Years)	-	0	10.86	9.63
CO2 Emission Reduction/yr (lbs/yr)	1.67	0	19993.2	24991.6

As per Table 28, initial investment cost of 12.5kW solar systems is approximately $41,000.00 which has a payback period of about 9.63 years and saves 14965 kWh of power units every year. The carbon emission reductions for this system is about 24991.6lbs per year.

6. CONCLUSIONS AND FUTURE RESEARCH

6.1 Conclusions

The cost benefit model for solar systems over on-grid conventional energy has proved that photovoltaic energy is certainly effective in residential systems. The statistical analysis used in the model to quantify the cost and benefits components were dependent on the system parameters. The benefits of solar powered system relies heavily on location of installed system and a number of special factors such as weather, average solar peak hours, manpower cost, utility's energy prices and government incentives.

The extensive literature review on previous research studies showed that end customers fail to understand the economics behind installing residential solar systems. Therefore, this study has provided effective guidelines to outline unproblematic financial models for adoption of solar systems. This research study has compared the net project benefits and total investment costs for a period of twenty years through economic sensitivity analysis.

The analysis used concepts of return on investment, net present value, benefit cost ratio and annual benefit cash inflows. Through the United States Energy Administration data for carbon emissions, we also found out the carbon emissions reduced for every residential system of different capacities. The cost benefit model will certainly increase investments from low scale and medium scale residential owners. After evaluating the three energy systems statistically, we computed the following results in this research model:

- The research model shows that the 12.5kW solar system is most economical and sustainable source of energy for residential systems in states of Texas, California, New Mexico, New York, Hawaii and Massachusetts. This conclusion is based on system parameters such as annual solar savings, payback periods, CO_2 emission reductions and benefit cash inflows. The summary table below shows statistical analysis which validates that photovoltaic technology is more effective than conventional energy systems. Table 29 below clearly shows the comprehensive system and economic analysis for all the six states and provides guidelines for potential investors.
- As per the research model, the dependency on on-grid conventional systems is reduced to 75-80% after solar installations. This reduction directly impacts the annual savings experienced due to significant payback period rates and return on investments. These economic characteristics are formulated on the basis of geographical performance indicators such as utility energy prices, average peak hours per day and construction cost.
- The end customers or residential home owners have an expected rate of return of 10% every year due to benefit cash inflows and overall capital gains on investment. The warranty of solar or hybrid systems is approximately twenty years as stated by the manufacturers which directly impacts the internal rate of return.
- In this decision making model, we have computed the maximum carbon emissions avoided based on the source through power is generated in every state. The carbon

emissions avoided also add to the benefits component and outlines captivating guidelines for environmental authorities.

- Using rooftop solar systems has also significantly reduced the cost of energy over the period of time as the end customers experience energy savings at a high efficiency rate. This efficiency rate is determined by the benefit cost ratios as mentioned in the summary table below.
- This model also provides guidelines for residential owners who produce more energy from there solar systems than their actual requirement. Low scale and medium scale investors can certainly negotiate with their respective utilities for surplus energy produced and to acquire favorable energy rates. This concept is termed as "net metering" which favors residential owners through excessive solar energy production.
- The resale value of the house increases about 15-20% which adds on to the financial benefits of installing solar modules.

Table 29: Summary Table with System & Economic Analysis

System Analysis					
State	**Type of System**	**Initial Investment($)**	**Annual Solar System Savings ($)**	**Payback Period (Yrs)**	**CO2 Emission Reduction (lbs/yr)**
Texas	Solar	$33,000.00	$1,722.47	20.12	18107.7
	Hybrid	$29,000.00	$1,377.98	22.1	14486.1
California	Solar	$37,000.00	$2,729.62	14.23	30977.6
	Hybrid	$33,000.00	$2,183.69	15.87	24781.9
New York	Solar	$37,000.00	$2,759.55	14.08	24542.6
	Hybrid	$33,000.00	$2,207.64	15.7	19634.1
New Mexico	Solar	$35,000.00	$1,997.83	18.39	20502.1
	Hybrid	$31,000.00	$1,598.26	20.37	16401.6
Hawaii	Solar	$41,000.00	$4,470.05	9.63	24991.6
	Hybrid	$37,000.00	$3,576.04	10.86	19993.2
Massachusetts	Solar	$34,500.00	$2,692.20	13.46	22297.9
	Hybrid	$30,500.00	$2,153.76	14.87	17838.3

Economic Sensitivity Analysis					
State	**Type of System**	**On Grid Power cost/Yr ($)**	**Benefit Cash Inflows/Yr($)**	**Net Present Value ($)**	**Benefit Cost Ratios**
Texas	Solar	$4.03	$1,722.47	$19,236.49	0.042
	Hybrid	$348.52	$1,377.98	$15,884.82	0.048
California	Solar	$6.38	$2,729.62	$12,879.04	0.074
	Hybrid	$552.31	$2,183.69	$13,394.19	0.066
New York	Solar	$6.45	$2,759.55	$12,651.44	0.075
	Hybrid	$558.36	$2,207.64	$13,212.06	0.067
New Mexico	Solar	$4.67	$1,997.83	$16,625.74	0.057
	Hybrid	$404.24	$1,598.26	$16,027.89	0.052
Hawaii	Solar	$10.45	$4,470.05	$10,078.83	0.087
	Hybrid	$904.46	$3,576.04	$356.01	0.12
Massachusetts	Solar	$6.30	$2,692.00	$10,892.40	0.078
	Hybrid	$544.74	$2,153.76	$11,349.06	0.071

6.2 Future Research

Integration of different technologies such as building integrated photovoltaic interiors and photovoltaic devices in residential systems is gaining pace across the United States. Researchers are focused on reducing the cost of PV modules which impedes a wider adoption of this technology. They believe that fundamental solar components such as silicon can be replaced by non-silicon films of cadmium and titanium which would sharply decline the cost of solar modules.

The National Building Administration and several architects can work on developing roof spaces which can accommodate maximum solar modules for more energy production and reduced energy prices. From an architect’s perspective, these roof spaces can be accommodated with plumbing vents and exhaust fans to mitigate possible shortages for installing solar modules.

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