KTH Industrial Engineering and Management

A techno-economic analysis of a residential solar Photovoltaic system installed in 2010

A comparative case study between California and Germany

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Abstract

With environmental concerns and energy needs increasing, many regions in the world are promoting renewable energy technologies making use of various policy instruments. Although today the PV systems price is decreasing, which gives it a competitive edge; we see the technology still being dependent on policy instruments for its dissemination.

The aim of this study is to research on whether or not a solar PV system is economically viable under certain circumstances. The study analyzes this by performing a cost beneficial analysis for the lifetime of the solar PV system making use of a discounted savings model. The systems being considered in this study are from California and Germany as these regions are leading in solar PV dissemination in their respective regions. The policies that are aiding the deployment of solar PV technologies are varied and thus this study compares benefits from different policy instrument for a residential customer investing in a solar PV system.

The research objectives in this study are pursued making use of major concepts such as Grid Parity, Levelized Cost of Electricity and financial methods such as discounting. Further, to understand how the different independent variables such as retail electricity prices, PV system pricing, WACC, self-consumption rate and storage availability are having an impact and how the results change with variation in these variables, a sensitivity analysis is conducted.

The results obtained in this study show that a solar PV system installed in California and Germany both make net benefits over their lifetime. When compared, the Californian solar PV system under the Net Energy Metering policy is making more net economic benefits in the range of $ 40,351 in Eureka and $53,510 in San Francisco; when compared to the German solar PV systems under the Feed in Tariff ranging $4,465 in Berlin and $11,769 in Munich. Furthermore the Californian solar PV systems still prove to be more beneficial even when compared to the German solar PV systems under the self-consumption law of the Feed in Tariff ranging $ 6,443 in Berlin and $ 13,141 in Munich. But when the self-consumption rate is increased in the German case, it is noted that the associated benefits increase.

The study at hand thus results in the California Net Energy Meter policy instrument proving to be more beneficial to a residential customer than the German Feed in tariff with and without self-consumption. Another important finding made in this study is that despite the German solar PV system making lesser benefits than the Californian ones, they attain Grid Parity before the ones in California.

Keywords:Solar PV, Grid Parity, Levelized Cost of Electricity,Discounted Savings, Policy Instruments Net Energy Meeting and Feed in Tariff.

Executive Summary

Global energy needs continue to grow, whilst fossil fuels still outstrip renewable energy in terms of supportive policies and subsidies. With growing concern towards climate change, many countries across the world are rethinking their energy strategy and incorporation alternative methods of energy generation. Of all the different modes of renewable energy technologies, Solar PV technology has caught the most attention. In order for this technology to develop further and cater to the energy needs we face today, effective policies are required to drive the Solar PV sector to compete with the fossil fuel sector.

Two regions in the world namely California and Germany have managed to bring into motion two very different policy instruments that are aiding the growth of the Solar PV market in their respective region. Thus this study aims at evaluating the policy instruments used in these regions and check for its effectiveness in making the Solar PV technology economically viable.
This thesis focuses on the residential sector, leading to evaluation of the various policy instruments being implemented to promote the growth of the Solar PV technology in this sector.

In California, the California Solar Initiative and Federal Tax Credit coupled with the Net Energy Metering policy acts as the main drivers. Whereas in Germany, Feed in Tariff policy, is the major driver that facilitates market growth. Thus essentially the objective of this thesis is to check if a residential customer is making any savings by investing into a Solar PV system in these regions for the time period of 2010 until 2035. Furthermore, if the residential customer generates savings, analysis is done to check which policy instrument is generating the most savings and which individual parameters contribute towards such savings.

The methodology used in this research is a multi-method approach. With methodologies such as comparative research, case study and mixed method analysis being used, the research preliminarily led to a literature survey, followed my mapping the energy profile of these regions , understanding of the various policy instruments and its linkages, analyzing these policy instruments and finally leading to conclusions drawn from the analysis.

Concepts such as Grid Parity, Levelized Cost of Electricity and financial methods such as discounting were used to analyze the impact of the policy instruments. A techno-economic analysis on residential PV system was conducted to perform the analysis. It involved the design of a discounted savings method to compare the benefits made by the different policy instruments on a common basis – *savings made per kWh consumption.* At the same time the Levelized Cost of Electricity (LCOE) tool was used to assess when PV technologies can compete with conventional technologies.

Many individual parameters such as retail electricity prices, PV system pricing, WACC, self-consumption rate and storage availability contribute significantly towards the outcome and thus a sensitivity analysis was conducted additionally to check for variation is the results with change in values. Although the research focused on Solar PV systems set up in 2010, the sensitivity analysis also provides us with results for the current year 2012.

The German Feed in Tariff law was analyzed in two main variations, one being the case where the entire electricity generated was sent to the grid, second being the case under self-consumption. The self-consumption was further analyzed for cases without a storage unit and with a storage unit.

The results obtained in this study indicate that the Solar PV systems installed in California are making more savings than the systems installed in Germany under all variations.

The conclusions drawn from this research study conclude that solar PV systems, independent of which policy instrument is being applied are economically viable to the investors of residential sector. The Levelized Cost of Electricity for Solar PV systems in the residential sector of California and Germany are in close proximity owing to their respective energy policy instruments. And lastly another interesting finding indicates that a solar PV system is competitive from its time of installation and not necessarily dependent on when Grid Parity is reached.

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I would like to begin by thanking my supervisors for guiding me and providing their valuable suggestions throughout my thesis work. Firstly I would like to thank my supervisor at Fraunhofer ISE, Stephan Schindele for giving me the opportunity to join Fraunhofer ISE and for his supportive discussions on the various aspects of energy policy. Also for providing the opportunity to meet and discuss with various experts and organization involved in renewable energy sector. On the whole I would like to thank you for being a great mentor and it was my pleasure working with you.

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Nomenclature

AC	Alternating Current
β	Riskiness of the Stock relative to Market
CAPM	Capital Asset Pricing Model
CBA	Cost Benefit Analysis
CEC	California Energy Commission
CF’s	Cash Flows
CPUC	California Public Utilities Commission
CSI	California Solar Initiative
Ct	Annual Cash Flow in year t
d	Annual discount factor
D	Market Value of the Debt
DC	Direct Current
DCF	Discounted Cash Flows
deg	Annual degradation rate of the system
DF	Discount Factor
DGP	Discounting Grid Parity
DG	Distributed Generation
dn	Nominal Discount Factor
dr	Real Discount Factor
DSM	Discounted Savings Model
E	Market Value of the Equity
EEG	Renewable Energy Law

EGP	Early Grid Parity
EPBB	Expected Performance Based Buydown
E(Ri)	Expected Return on Stocks
E(Rm)	Expected Return on Market Portfolio
ERP	Emerging Renewable Program
ETA	Energy Tax Act
ETR	Ecological Tax Reform
FITC	Federal Investment Tax Credit
FiT	Feed in Tariff
FiT- Self	Feed in tariff with Self Consumption
FiT- Self+B	Feed in tariff with Self Consumption with battery
GM CSI	CSI General Market Program
GSC	Go Solar California
HLP	Hourly Load Profile
I	Initial capital cost
IGP	Individual Grid Parity
IOUs	Investor Owned Utilities
IPPs	Independent Power Producers
Kd	Cost of Debt
Ke	Cost of Equity
KW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelized cost of Electricity
LP	Load Profile

MASH	Multifamily Affordable Solar Homes
MIP	Market Incentive Program
MLP	Monthly Load Profile
MSW	Municipal Solid Waste
MW	Megawatt
N	Lifetime of the project
NDF	Nominal Discount Factor
NEM	Net Energy Metering
NPV	Net Present Value
NSHP	New Solar Homes Partnership
PA	Program Administrators
PBI	Performance Based Incentive
PG&E	Pacific Gas and Electric Company
POUs	Publicly Owned Utilities
PV	Photovoltaic
Qt	Energy generated by the system in kWh in year t
R	Inflation Rate
RAM	Renewable Auction Mechanism
RDF	Real Discount Factor
REG	Renewable Electricity Generation
RETs	Renewable Energy Technologies
Rf	Nominal Yield on Risk Free Asset
Rt	Incentive Revenue in year t
SASH	Single-family Affordable Solar Homes

SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
StrEG	Federal Electricity Feed Law
Tc	Tax Rate
TGP	Total Grid Parity
TLCC	Total Life Cycle Cost
TLEP	Total Lifetime Energy Production
TOU	Time of Use
W	Watt
Wh	Watt hour
Wp	WattPeak
WACC	Weighted Average Cost of Capital
$	USA Dollar value at 2010

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1. Introduction

Mankind's ability to adapt, improve and change in order to survive has been evident since beginning of time. In today's world this theory of evolution is no different. The rapid growth of population and fast pace of development has led to a large energy requirement. This energy requirement is met using a varied range of resources. One of the most widely asked question today is "Is our development sustainable?" Today, this is one of the critical issues that need to be understood and tackled. Almost all definitions of sustainable development look at the world as an interconnected system through space and time where even a minute change has an impact on the overall system over time. (Brundtland Report, 1987)

It is a well-known fact that conventional resources are fast depleting, leaving us with no option but to look at alternative resources such as the renewable energy resources. Along with increase in energy needs, we see a rise in pollution, which is endangering the very existence of earth. Renewable energy resources are thus essentially contributing towards world energy security by reducing dependency on fossil fuels and simultaneously providing opportunities to reduce the greenhouse gases, prevention of bio diversity, improved health, job creation, energy access, making it a win-win situation. (IEA, 2007) (REN 21, 2012)

Different energy policies encouraged clean energy, subsequently leading to renewable energy resources supplying 16.7% of the global energy consumption in the year 2010. (REN 21, 2012). Implementation of efficient policies is a crucial tool for development of the renewable energy industry. Thus, it is important to analyze the current policies which are being implemented to deploy renewable energy technologies. Such an analysis will be helpful in understanding the strengths and weakness of each policy initiative and also ascertain its effectiveness.

An energy policy is said to be designed keeping in mind three major factors that are the *Eco-Centric* concern, *Socio-Economic* concern and the *Techno-Economic* concern. After implementation of a policy, time to time the above factors need to be monitored to check for the effectiveness of the policy (Clift, 2005). Eco-centric concerns deal with the availability of resources, which in the case of renewable is abundantly available. Socio-economic concern tells us about the nature of human expectations and the willingness to invest in a technology. Techno-economic concerns help assess the constraints involved in deploying the chosen technology making use of the economic options available. If all these factors are well balanced for a given technology, then higher will be its acceptance. The research at hand will work on all the three concerns but focus on the techno-economic variables.

Energy from the sun can be harnessed to suffice the needs of humankind's energy demands as it is the most abundantly available resource of all the renewable energy resources. All renewable energy sources can also be defined as either a direct or indirect form of solar energy. (Meyers, 1995). Subsequently in this study thesolar Photovoltaic (PV) is under scrutiny. What makes it interesting to evaluate the feasibility of promoting this technologyis that; it is non-polluting, noise free, requires low maintenance, has an average life of 25 years and a unique feature that allows the system to be sized from a small size system to a large size plant based on the application. This flexibility that the solar PV technology provides makes it one of the most promising technologies of all renewable energy technologies (RETs). This technology also happened to grow the fastest amongst all renewable energy technologies in the last few years with a global installed capacity of 40 GW in 2010, which was seven times the capacity in place five years prior to 2010. (REN21, 2011).

1.1 Scope and Limitations

Various policy instruments are being used to aid the fast growth of renewable energy technologies. California in the U.S and Germany in the EU have the largest solar PV installations in their respective regions making them the hotspot for solar PV dissemination and the object of this study. Both these countries support the growth of solar PV technologies using different policy instruments, so it would be interesting to evaluate which policy instrument is being more effective and efficient.

In order to understand how California and Germany support renewable energy technologies an energy profile for the respective places has been prepared based on literature review, laying out the key indicators and the policy instruments used towards dissemination of renewable energy technologies with more emphasis given to solar PV technology. The analysis is made from the perspective of a residential customer and for the period 2010 – 2035. Two locations have been selected in Germany (Berlin and Munich) and California (Eureka and San Francisco) taking into account a low solar insolation region and a high solar insolation region respectively.

Geographically, Germany on the whole has been considered as the policies are general in nature for the entire country. But in the case of California a specific Investor Owned Utility- PG&E has been narrowed down to improve the quality of this study.

Since the study considers residential solar PV systems, the size of the system varies with location in terms of California. In the case of Germany, a common system size has been considered for all locations. The reason behind such choices is mentioned more in detail in the forthcoming chapters.

The cost benefit analysis in this study is conducted using varying values for each solar system based on its location. Thus the study does not focus on comparing one system with the other directly, but to check if the Solar PV system is having a positive economic benefit on the whole and to compare the different policy instruments. The specific assumptions made for each parameter considered in this study is mentioned in the chapter0 and certain assumptions made will directly reflect in the results obtained.

1.2 Problem Description

The biggest challenge today for renewable energy technologies is to compete with conventional modes of energy generation. Many researchers have been debating on how one should measure and quantify this linkage between renewable energy technologies and conventional technologies. The general notion about solar PV technology is that it is capital intensive and is not cost competitive to a residential investor; despite many policy instruments supporting this technology. The growth of solar PV technology depends on the acceptance of the technology, only when this technology shows positive benefits to an investor, will it gain more importance. For long the most commonly used concept especially in the field of solar power is *Grid Parity*. It is assumed that only when solarPV technologies reach grid parity, would it be considered that these technologies can compete with the conventional sources of energy. Thus solar PV systems generation costs need to compete with the retail electricity prices and on the long term with the whole sale electricity prices. This study focuses on the decentralized retail PV market in California and Germany. Thus retail electricity prices will be the focus. However reaching Grid Parity does not mean the solar PV market can be self-sustaining. Are policies in place still be needed to support PV dissemination in the future?

1.3 Objective and Research Question

The main objective of this research is to find out '*If there a discounted savings effect for a residential solar PV system installed in California and Germany for the time period 2010-2035?'*

If a discounted savings effect is observed then the further research questions are:

'To find out how the independent variables contribute towards the discounted savings effect' and

'To find out which energy policy instrument is having the highest discounted savings effect'

In order to reach the objectives of this thesis, we conduct a techno-economic analysis. Firstly we determine when grid parity is reached by a residential solar PV system in California and Germany by calculating the Levelized Cost of Electricity (LCOE). Secondly to compare which of the policies is more economically viable a Discounted Savings Model (DSM) was designed to analyze the costs and benefits associated with the residential solar PV system over the lifetime of the system.

1.4 Methodology

In order to formulate this thesis work, different methodologies were used at various stages of the project such as the comparative research design, case study and mixed -method comparative analysis. With both California and Germany having the largest solar power installations in their respective regions, aided by different set of policy instruments, the research design for this study is *'Most Different Cases- Most Similar Outcomes'*. Thus a comparative case study is conducted to compare California and Germany in this study, where most of the input variables are calculated a fresh. Tools such as the NPV, LCOE and DSM are used and the results of these tools are controlled and varied to perform a sensitivity analysis.

To consummate the case study, a mixed-method comparative analysis is being used. This approach has the advantage of addressing the research objectives by combining elements of qualitative and quantitative analysis. By doing so, the shortcomings of each method used will be overcome by the other methods. One cannot possibly incorporate a wide variety of methods to improve the quality of the study. Therefore for this mixed method analysis, from the four types of data triangulation mentioned by Denzin, three of them were considered namely- *Investigator triangulation, Theoretical triangulation and Methodological triangulation*. Discussions with fellow researchers on the interpretation of the results obtained in this study enabled investigator triangulation. Making use of various literature reports, documents, information from websites of organizations, companies and governmental bodies and statistical data from institutions and authorities facilitated methodological triangulation. Lastly making use for more than one theoretical concept and tools to perform the study integrated theoretical triangulation. (Denzin, 1970) (Pluye, 2009) (Johnson, 2007)

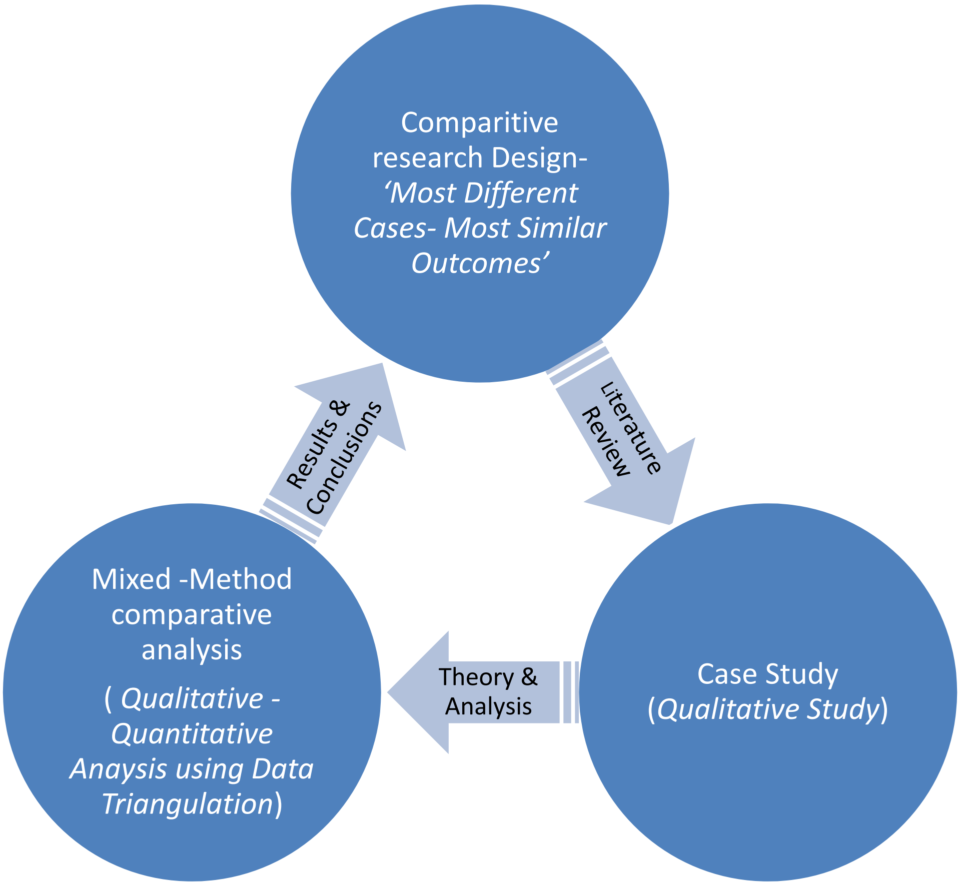


Figure 1-1 Thesis Methodology Scheme(Author, 2012)

1.5Thesis Outline

This report has been structured in the following order:

Chapter One deals with the motivation and reasons for conducting this study by laying out the research questions addressed in this study.

Chapter Two provides information about the California and Germany energy scenario. The first section begins with a brief background of California leading into a discussion on the energy matrix of the state. The chapter lays out the various energy policies of California and its stakeholders. It further focuses on the solar PV residential policies in detail and corresponding data required for analyzing these policies. Similarly the background, energy matrix and policies are laid out for Germany in the second section. Finally we compare and discuss the various parameters which were listed with regards to California and Germany.

Chapter Three deals with the main concept used to define the research questions of this study. A thorough knowledge of the basic theoretical concepts used in this study is required and thus the later part of this chapter elaborates these concepts, which need to be understood in order to analyze and compare the two very different policies of solar PV dissemination in California and Germany.

Chapter Four focuses on the data background and calculation procedures used in the study. It specifies where and how the data collected is being used in the study and which variables are applied in the sensitivity analysis.

Chapter Five presents the results for the theory and methodology discussed in the previous chapter pertaining to the techno-economic analysis of a solar PV system in California and Germany. The first section layout the LCOE calculations for California for solar PV systems in Eureka and SanFrancisco and the next part will use the LCOE to check when individual grid parity is reached for the solar PV systems for both the locations. Lastly the DSM values will be represented for California. The second section will layout the LCOE calculations for Germany for solar PV systems in Berlin and Munich and the next part will use the LCOE to check when individual grid parity is reached for the solar PV systems for both the locations. Lastly the DSM values will be represented for Germany. The third section presents the results of the sensitivity analysis performed on the techno-economic analysis of California and Germany.

Chapter Six will discuss the observations made from the results of California and Germany and further discuss the effect of the important parameters in determining the end results. The conclusions made from this study will be presented and necessary policy advice for California and Germany will be provided. Lastly the scope for further research is indicated.

2. Energy Profile

2.1 California – Energy Profile

This section provides information about California and its energy scene. The section begins with a brief background of California leading into a discussion on the energy matrix of the state. The section lays out the various energy policies of California and its stakeholders. It further focuses on the solar PV residential policies in detail and corresponding data required for analyzing these policies.

2.1.1 California

The state of California in the United States of America has a population of approximately 37 million spread over an area of 411,046 km². The population density is 92 persons per km², with per capita personal income of $42,514.(U.S. Dept. of Commerce, 2012) California was the world's ninth-largest economy in 2010, with a Gross Domestic Product (GDP) per capita of $51,470.(CCSCE, 2012). The average person per households is 2.89 (United States Census Bureau, 2012)and the household electricity consumption in 2010 is 6,714 kWh.

2.1.2 Energy Matrix

California is rich in conventional and renewable energy resource potential. It has reserves of crude oil and natural gas along with the second largest hydroelectric power potential in the United States. Substantial wind and geothermal power resources are found along the coastal mountain range and high solar energy potential in the deserts of the state. In terms of total energy demand, the state ranks second in the country, conversely, it also has one of the lowest per capita energy consumption. The reason for the low per capita energy consumption when compared to other states in U.S is due to the mild weather conditions that reduces the energy demand for heating and cooling and also owing to the energy efficient measures taken by the California government. California imports more electricity than any other state due to its high electricity demands. (EIA, 2009)

The figure below illustrates California's Energy Sources and also gives you the breakup of self-generation and imports.

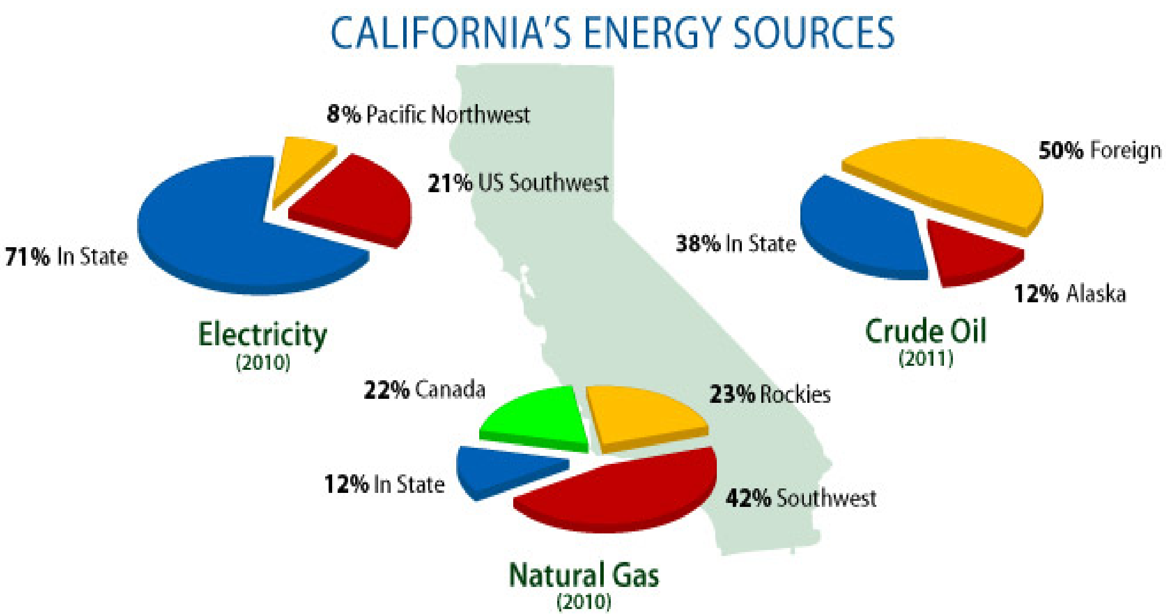


Figure 2-1California's Energy Source 2010(CEC, 2012)

The primary sources of electricity generation in the state are natural gas, coal, large hydro, nuclear and renewable energy. The percentage breakup of these resources for the year 2010 is given in the figure below.

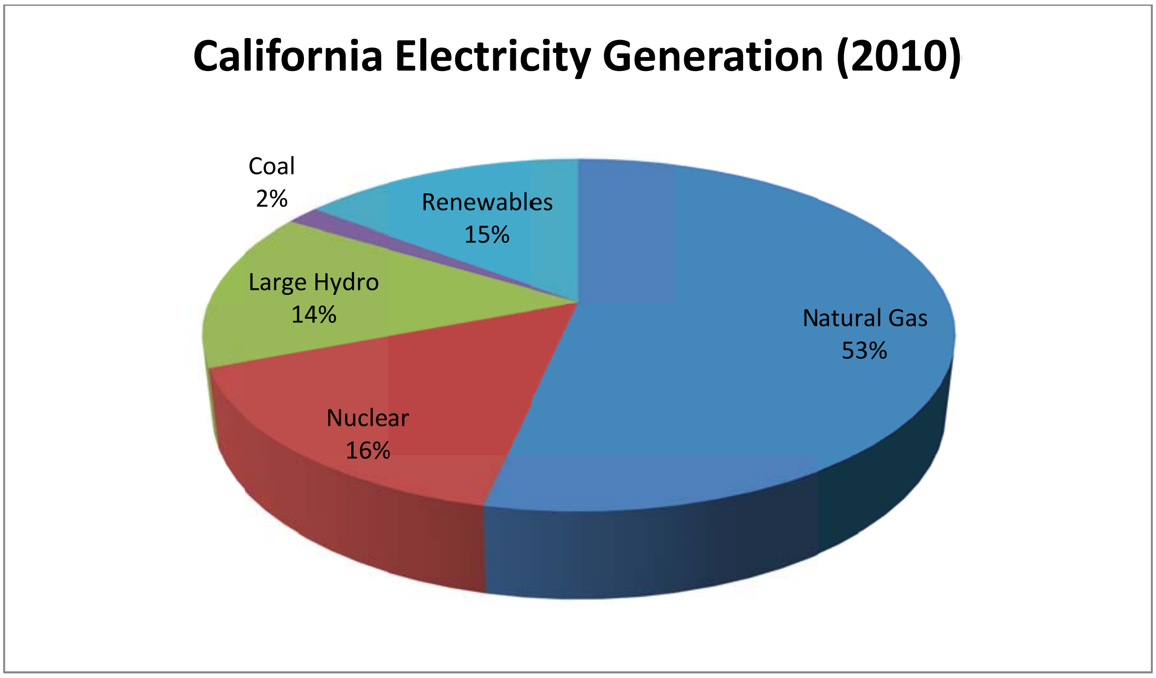


Figure 2-2California's Electricity Generation in 2010(CEC, 2012)

The total net electricity capacity of the state is 67,326 MW and the total net electricity generation is 204,126 GWh.

California leads the nation in terms of the largest non-hydroelectricity renewable energy based electricity generation such as geothermal, solar and wind. It is ranked second in terms of net capacity and net generation of renewable energy based electricity in the country. It generates renewable electricity using wind, geothermal, solar, small hydro, fuel wood, municipal solid waste (MSW) and landfills gas resources. (EIA, 2009).

The table below gives details of the total net renewable installed capacity for the year 2010 in California.

Type	Capacity Value (MW)	Percentage of State Total
Total	7,714	11.3
Geothermal	2,004	3.0
Solar	475	0.7
Small Hydro	1,395	2.0
Wind	2,812	4.2
Wood/Wood Waste	639	0.9
MSW/Landfill Gas	292	0.4
Other Biomass	97	0.1

Table 2-1California's Net Renewable Installed Capacity in 2010 (EIA, 2012) (CEC, 2011)

The table below gives details of the total net renewable electricity generation for the year 2010 in California.

Type	Generation Value(GWh)	Percentage of State Total
Total	29,891	14.6
Geothermal	12,600	6.2
Solar	769	0.4
Small Hydro	4,441	2.1
Wind	6,079	3.1
Wood/Wood Waste	3,551	1.7
MSW/Landfill Gas	1,812	0.9
Other Biomass	639	0.3

Table 2-2California's Net Renewable Electricity Generation in 2010 (EIA, 2012) (CEC, 2011)

2.1.3 Stakeholders

There are various organizations, institutions, research facilities and interest groups that influence and direct PV dissemination in California. Each of their roles and responsibilities are laid out in the tables below.

Organization	Key Functions	Type
Federal Energy Regulatory Commission (FERC)	• Regulates interstate transmission of energy resources • Overlooks environmental matters related to the various energy resources	Federal Network Agency
California Public utilities Commission (CPUC)	• Regulates privately owned electric, natural gas, telecommunication, water, railroad, rail transit and passenger companies • Regulate utility services, stimulate innovation and promote competitive market where ever possible	Federal Network Agency
U.S Energy Information Administration (EIA) Independent Statistics and Analysis.	• Collects, Analyzes and disseminates independent & impartial energy information for sound policy making and understanding	Energy Information and Administration
California Energy Commission (CEC)	• Primary energy planning and policy making agency for California. • Support R&D and demonstrative projects • Poster renewable energy by providing market support	Energy Information and Administration

California Air Resources Board (CARB)	• Attains and maintains air quality • Conducts research on air pollution	Agency to implement GHG regulations
California Independent System Operator (CAISO)	• Operates the wholesale market and the grid • Mange the demand for electricity • Ensure equal access to the grid • Transmission system operator for the grid	Electricity Stock Market
California Solar Energy Industrial Association (CalSEIA)	• Supports widespread adaptation of solar technologies • Works alongside the American Solar Energy Society (ASES) and the Solar Electric Power Association (SEPA)	Industrial Association
Electricity Service Providers (POUs, IOUs and others)	• Distribution operators for the grid	Electricity Distribution Operators
Intersolar North & Solar Power International	• Solar Exhibitions • Development of business opportunities	Exhibition
Berkely Lab, Schatz Energy Research Center (SERC), Energy and Resources Group (ERG), California renewable Energy Center (CREC) and Global Climate Energy Project (GCEP)	• Facilitate research and development	Research Facilities

Table 2-3 Organizations that support solar PV dissemination in California(Schindele, 2011)

2.1.4 Policy Instruments

California's interest to promote renewable energy dates back to the 1970s. In 1978 the Public Utility Regulatory Policy Act or PURPA provided a first step towards the creation of a solar energy policy at a state level. The legislation allowed independent power producers to interconnect with the local utility distribution system. Another legislative document called the energy tax act (ETA) was passed in the same year, which encouraged the house owners to invest in solar, wind and energy conservation projects through tax credits. The Arab oil embargo of the 1970s stimulated policies that aided renewable energy technologies. (CEC & CPUC, 2011)

In 1997 came the next big step namely California Energy Commission's Renewable Energy Program. The related policy promoted the deregulation of the state's investor owned utilities (IOUs) and encouraged grid tied PV systems by providing incentives. The primary aim was to create a self-sustaining market for emerging renewable energy technologies in distributed generation (DG) application, by offering rebates to bring down the upfront cost to the customer. (CEC, 2011)

The California Energy Commissions' (CEC) Renewable Energy Program was classified into five major categories:

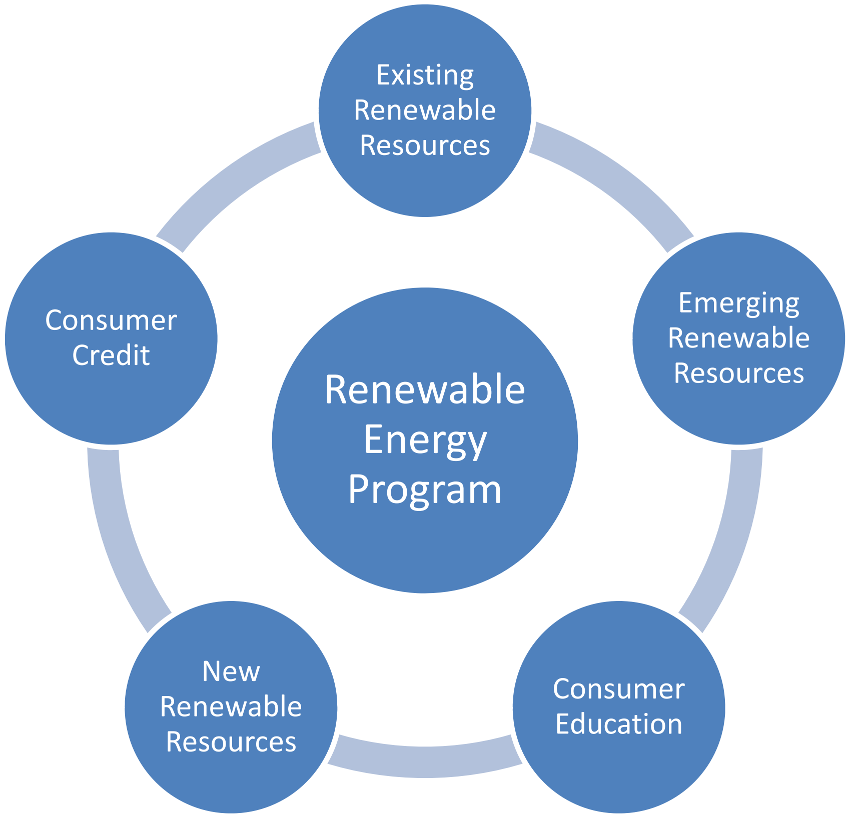


Figure 2-3California's Renewable Energy Programs (CEC, 2011)(Author, 2012)

The existing renewable resources section focused on supporting the existing in-state renewable energy technologies (RETs), whereas the emerging renewable resources section focused on stimulating market growth for the on-site RETs. Consumer education worked on building awareness about clean technologies. Coming to the new renewable energy resources and consumer credit, both were abolished in 2008 and 2004 respectively, which focused on promoting prospective renewable electricity generation projects and renewable energy service providers through incentives. (CEC, 2011)

California has numerous policies which can broadly be classified into two major categories; one concentrating on the utility side of generation (commercial) and the other concentrating on the customer side of generation (residential). In this study, emphasis is given to the customer side of generation using solar photo voltaic (PV).

The policies for renewable electricity generation (REG) on the utility side are generally based on the top –down approach which targets IOUs and independent power producers (IPPs). In 2002 California initiated the Renewable Portfolio Standards (RPS) which aimed at increasing share of renewable energy in the state's electricity mix by 20% by December 31, 2013, 25% by December 31, 2016 and 33% by 2020.This policy applies to all the retail electricity sellers in the state such as publicly owned utilities (POUs), municipal utilities, IOUs, electricity service providers, and community choice aggregators. (U.S Department of Energy , 2011).

Policy instruments such as Renewable Auction Mechanism (RAM) and Feed-in Tariff Program (FiT) along with RPS promote and facilitate growth of RETs on the utility side of generation.

The customer side generation has programs such as Emerging Renewable Program (ERP), Self-Generation Incentive Program (SGIP), Net Energy Metering (NEM) and Go Solar California aiding the growth of RETs.

The solar energy related portion of the emerging renewable program (ERP), which is the integral part of the Renewable Energy Program by CEC, was revamped in 2007 into new categories namely, California Energy Commission's New Solar Homes Partnership (NSHP), California Public Utilities Commission's California Solar Initiative (CSI) and Publicly Owned Utilities' (POUs) various programs. Collectively this effort is known as the Go Solar California (GSC), with a statewide goal of 3000 MW of solar generation capacity and a budget of $3.35 billion until 2016. (CEC, 2011). Further, the CSI also took the SGIP under its purview, while the ERP is temporarily suspended.

NSHP provides incentives to encourage new solar based energy efficient homes that reduce the house owner's electricity bills and at the same time is environmentally friendly.

CSI within its umbrella has many sub programs which provides incentives for solar system installations to customers of the state's three investor-owned utilities (IOUs): Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E).

- CSI General Market Program (GM CSI) - Offers rebates to solar technologies for customers' existing homes, existing or new commercial, agricultural, government and non-profit buildings.
- CSI Thermal Program- Funds for solar hot water (solar thermal systems) on homes and businesses.
- Single-family Affordable Solar Homes (SASH) - Offers rebate for low income single housing customers.
- Multi-family Affordable Solar Homes (MASH) - Offers rebates for multi housing customers.
- CSI R&D Program- grants for research, development, demonstration and deployment of solar technologies.

The CSI program extends support to Governor Schwarzenegger's "Million Solar Roofs" program. It has a budget of $2.167 billion over 10 years, aiming to reachinstalled solar capacity of 1,940 MW by 2016. The set goal includes 1,750 MW of capacity from the general market program and 190 MW of capacity from the low income programs.(CPUC, 2011)(CEC & CPUC, 2011)

So a general residential customer within the IOUs territories, who wants to invest in solar PV technology falls under the CSI general market program and is also eligible for economic incentives from the NEM policy. An added bonus is the Federal Investment Tax Credit (FITC) for any residential solar system owner, which is 30% of the total system cost after rebate value, has been deducted. (California Energy Commission, 2011)(Black, 2009).

A simple diagrammatic view of the various policy instruments that support the policy for solar power dissemination in California is represented below:

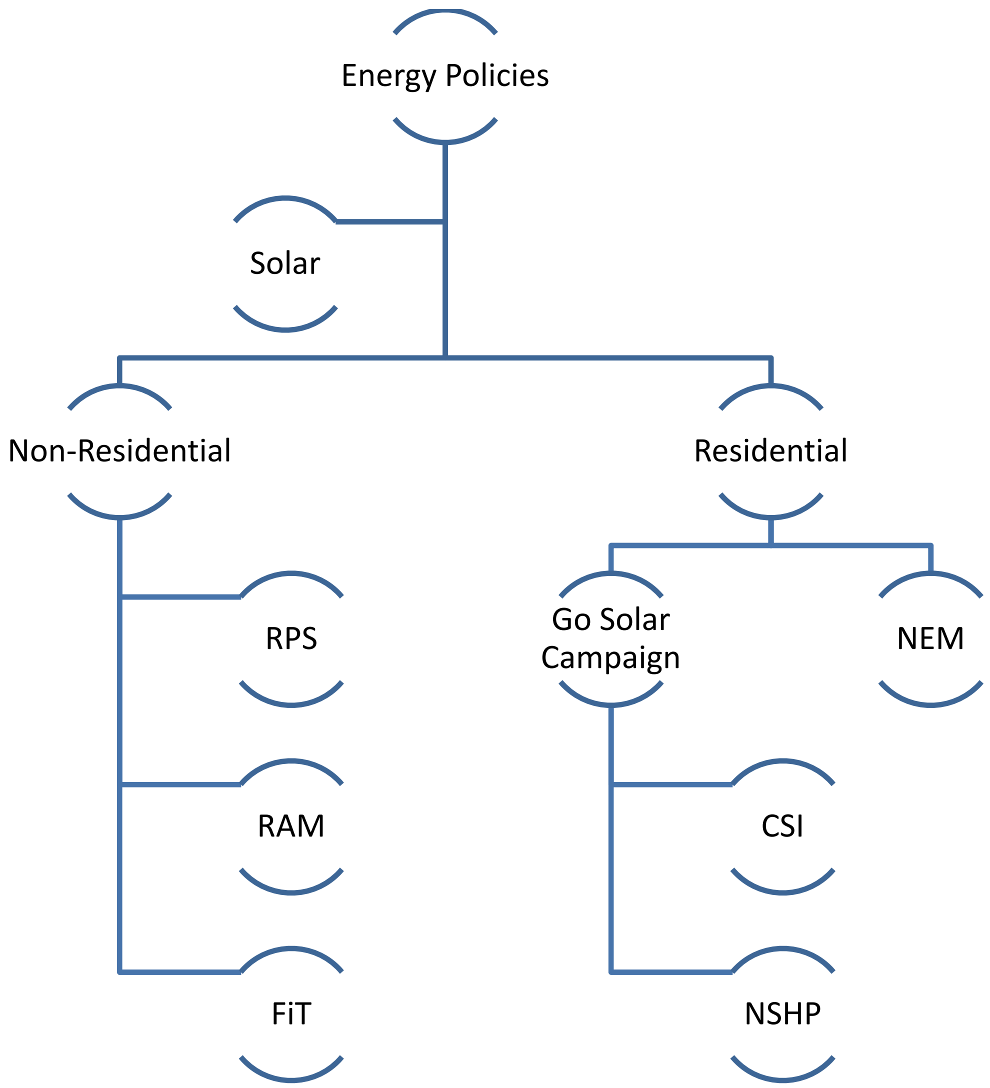


Figure 2-4California's Solar Energy Policies(Author, 2012)

2.1.5 Policy for Solar PV

As discussed in the previous section, the programs that aid residential solar PV investments are the GM CSI and NEM. A detailed explanation of these two programs is given in this section.

2.1.5.1 California Solar Initiative General Market Program (GM CSI)

The CSI general market program has a budget of $1,950 million to install 1,750 MW of solar capacity between the years f 2007 - 2016. The CSI initiative overseen by California Public Utilities Commission (CPUC) provides incentives for solar system installations. The incentive provided is an upfront incentive to customers in the PG&E, SCE and SDG&E territory for installations on existing residential homes, existing and new commercial buildings, industrial, government, non-profit, and agricultural properties. (CPUC, 2011).

The three IOUs- PG&E, SCE and SDG&E cater to about 68% of California's electric load. PG&E and SCE act as program administrators (PA) in their respective territories and for SDG&E the PA is the California Center for Sustainable Energy (CCSE). (CPUC, 2011)

A breakup of the individual budget allotment for the IOUs under GM CSI is given in the table below:

Program Administrator	% of Total Budget	Budget (in millions)
PG&E	43.7%	$946
SCE	46.0%	$996
CCSE/SDG&E	10.3%	$223
Total	100%	$2,165

Table 2-4Program Administrators budget under GM CSI(CPUC, 2011)

Based on the customer class the percentage breakup under GM CSI is as below:

Customer Class	MW	Percentage
Residential	578	33%
Non- Residential	1,173	67%
Total	1,750	100%

Table 2-5GM CSI MW breakup based on customer class (CPUC, 2011)

Customer class is broken into two sub-classes, residential and non-residential. The non-residential sub-class consists of the commercial, governmental, industrial, agriculture and non-profit segments. The residential sub-class consists of the housing segment. As emphasized earlier, residential class is considered for the purpose of this study.

The incentive available under GM CSI is divided into ten steps and is designed to respond to the economics of scale of the California solar market; i.e. as the solar market grows the expected system costs will drop, leading to decline of the incentive. CPUC further divided the overall MW goal and the incentive amount for each step of the program, for each IOUs territory and for each customer class. (CPUC, 2011). The GM CSI MW Targets by Program Administrator and Customer Class is given in appendix A1.

There are two types of incentives offered for the solar system installations based on the system size. For smaller systems an upfront incentive is given while for larger systems it is given over the course of five years. The upfront capacity based incentive which is based on expected performance of the smaller system is termed as Expected Performance-Based Buy-down (EPBB) and the one for larger systems the incentive is based on actual performance which is called Performance Based Incentive (PBI).The residential solar PV systems generally fall under EPBB incentive, but the customer can also opt for the PBI incentive. (CPUC, 2011). In this study the EPBB has been considered because a residential system is smaller in size. The table below summarizes these two incentive types:

Incentive Type	Details
Expected Performance-Based Buy-down (EPBB) **Paid In ($/watt)**	• For Residential and small business customers • System size less than 50 kW • Incentive paid based on expected performance of the system factoring the CEC-AC rating, location, orientation and shading of the system • One time upfront payment
Performance Based Incentive (PBI) **Paid in (cents/kWh)**	• For large customers, government and non-profit customers • Mandatory for system size greater than 50 kW and optional for system size less than 50 kW • Monthly payments over 5 years

Table 2-6GM CSI MW Incentive Types (CPUC, 2011)

A detailed breakup of payment received for each customer class in each step of the two incentive types is given in appendix A2.

The CSI program will last until the target MW installations for each IOU is met or until the allotted budget has been spent.

A comparative overview chart for GM CSI is shown below:

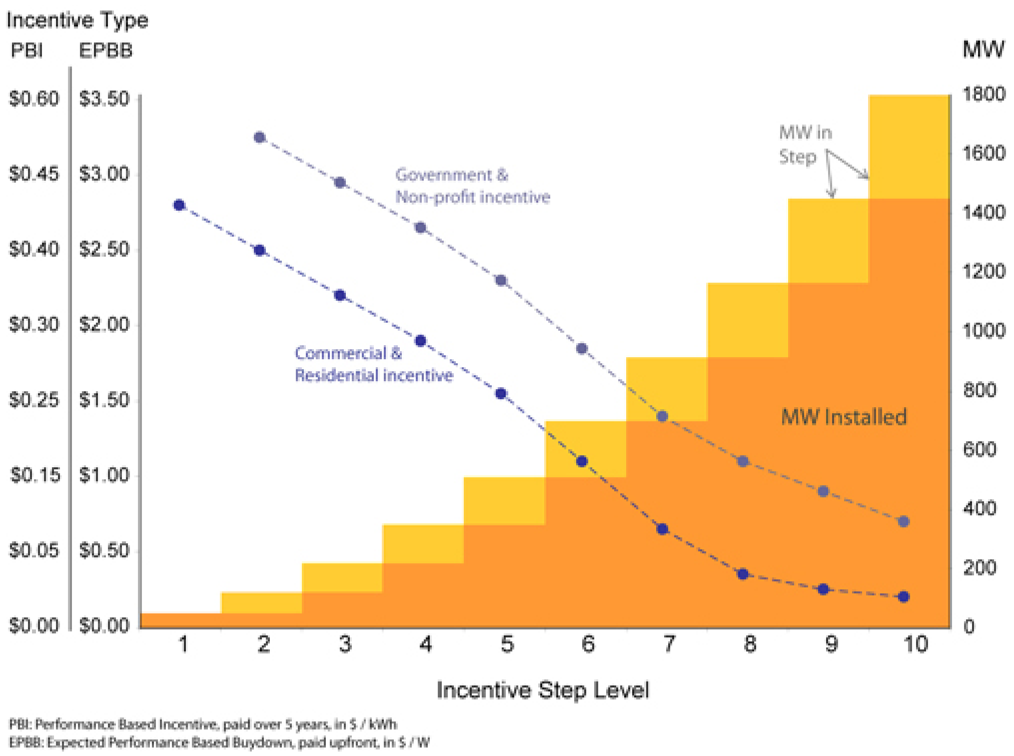


Figure 2-5CSI Overview (CPUC, 2011)

2.1.5.2 Net Energy Metering

Unlike the GM CSI policy which is an upfront rebate policy, the NEM policy acts as an added economic incentive for the customers who install a renewable energy system.

NEM is a simple billing arrangement that allows a residential or commercial customer to receive incentives for the amount of electric load that can be offset by the installation of a renewable energy system. That is NEM allows a customer to receive incentive for the amount of power generated on site and which is fed into the utility grid, the credits gained can be used to offset the customers electricity bills. Thus NEM acts as a policy instrument which supports direct customer investments into grid tied distributed renewable systems. (CPUC, 2007)

In California the utilities calculate the bill credits for an NEM customer on a hourly basis, by taking the difference in amount of electricity used on site and amount of electricity generated by the system. The bill credits are calculated using the retail electricity price for each hour and the benefits of NEM is available for the lifetime of the system. Importantly for an NEM customer, the rate which the customer will be paying for consuming electricity is the same rate the customer gets for sending electricity to the utility. Added advantage for a NEM customer is that, one can roll over the excess credits of each month and use it within the 12 month cycle or roll over the credits indefinitely or receive payment for the bill credit at an 12 month average rate spot market price for the hours of 7 am to 5 pm for the year in which the surplus power was generated. (DSIRE, 2012) (CPUC, 2007)

For a solar PV customer the NEM policy is a best fit in the Californian case as the solar PV system generation and the customers load compensate each other well. As the utility grid acts more or less like a storage unit, which allows the sizing of the system to be done based on annual load instead of the peak demand. (CPUC, 2007)

To understand the economics of NEM one needs to understand how the solar system works on site through the course of the day. The DG system basically works in three states and at any given point of the day the customer will be under one of these three states. (R.Thomas Beach, 2012)

The Three States are the following:

Retail Customer State: This is when there is no solar resource available, i.e. when the sun is down and there is no PV production. Here the customer has a net flow of electricity from the utility grid, thus behaving like regular utility customer.

Energy Efficiency State: There is limited availability of solar resource, which means that there is not enough solar resource to meet the customer's electricity loads. Here the customer uses electricity from the solar PV system and also imports electricity from the utility grid. Thus the DG system is reducing the customers load on the utility grid, which in turn acts as an energy efficiency measure.

Power Export State: The solar resource availability is high and there is excess production from the PV system. Here the customer not only meets the load requirements but also provides electricity to the utility grid. Thus, making the customer a net exporter of electricity. The amount of electricity that is exported is used to calculate the bill credits for the customer.

A typical profile of the customers load and solar PV system output illustrating these three states is shown below:

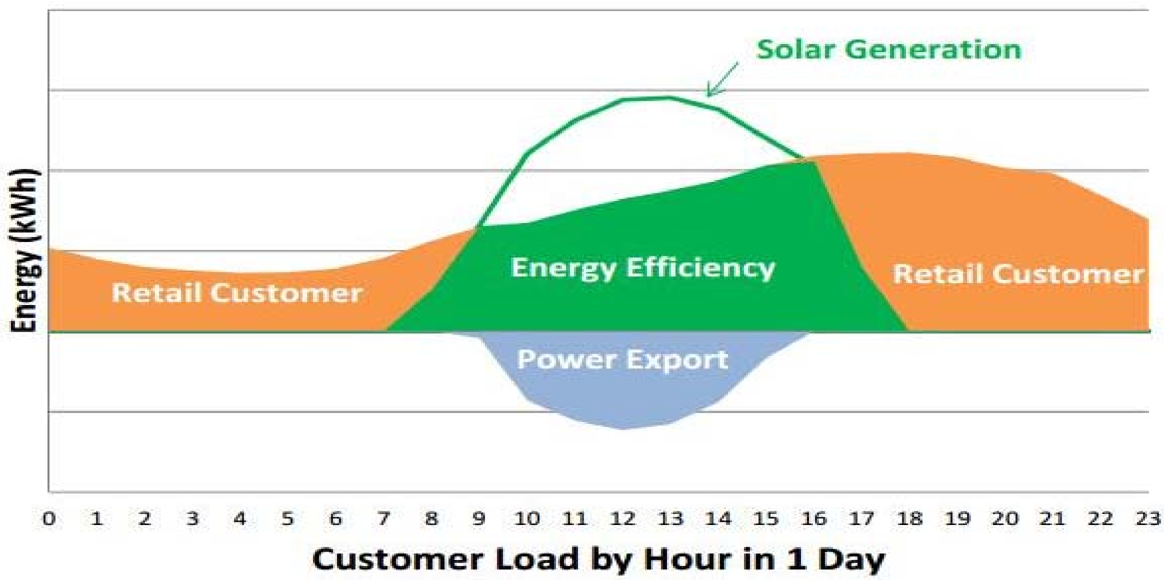


Figure 2-6Three States of NEM (R.Thomas Beach, 2012)

2.1.6 California Data for Policy Analysis

2.1.6.1 Area under consideration

As mentioned earlier, the targeted customers for this study are the residential class. It can also be noted that the policies for solar PV dissemination are eligible only in the territories of PG&E, SCE and SDG&E. The table below gives you the percentage of renewable energy in the energy mix for each territory:

Utility	% of renewable in energy mix (2010)
PG&E	15.9
SCE	18
SDG&E	11

Table 2-7IOUs renewables (%) in energy mix for 2010 (CEC, 2012)

The map presented in appendix A3 will give us an idea of the area covered under the various IOUs territories, from which we see that PG&E holds a large share.

Also, PG&E has the highest number of customers under its service area, totaling to 5,212,605 in the year 2010. (CEC, 2012)

Therefore for the purpose of this study, the PG&E territory has been selected. In the year 2010 PG&E was in Step 7 of the GM CSI steps and for residential NEM customers it makes use of E6- Time of Use (TOU) electricity schedule. (CSI, 2012) (PG&E, 2012)

2.1.6.2 PG&E Prices

Retail Electricity Price

The retail electricity rate structure for PG&E is based on a 5 Tier system for each of the territories within PG&E.A detailed map is presented in appendix A4 which gives you the territories within PG&E.

The territories are divided depending on the climatic condition of that region which intern reflects the energy consumption needs. Each territory has a baseline limit which is set for the winter and summer season and is considered tier 1 category. Any consumption above these baseline limits will place the customer in higher tiers such as 2, 3, 4 and 5. (PG&E, 2012)

The table below gives you the 5Tier rate structure of PG&E:

Tier	Description
Tier 1	Up to the Baseline amount
Tier 2	Electricity usage from 101% to 130% of Baseline
Tier 3	Electricity usage from 131% to 200% of Baseline
Tier 4	Electricity usage from 201% to 300% of Baseline
Tier 5	Electricity usage in excess of 300% of Baseline

Table 2-8PG&E 5Tier Electricity Rate Structure (PG&E, 2012)

The utilities follow a standard code while setting baselines, in summer, baseline quantities are set at 50 percent and in winter it is set to 60 percent of average use for all-electric needs of the customer. This code is referred to as Code H. A detailed table with the baseline quantities for each of the territories of PG&E is presented in appendix A5 (PG&E, 2012).

Coming to the NEM pricing which uses the E6 –Residential Time of Use (TOU) electric schedule, the schedule prices were changed three times in 2010. The average E6-TOU pricing for PG&E in the year 2010 was $ 0.187 /kWh. (PG&E, 2012). A detailed E6-TOU price schedule and the time of the day at which these rates apply are given in appendix A6 &A7.

In the case of calculating net bill value of the customer under normal condition i.e without a PV system we use the E1 rate, which are specified in the table below:

Tier	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Rate in $/kWh	$0,11877	$0.13502	$0.27572	$0.40577	$0.47393

Table 2-9PG&E E1 Rates (PG&E, 2012)

Thus NEM benefits can be calculated for the customer, making use of the PG&E E6 and E1 rate schedules.

Solar Price

For the PG&E territory the 'cost per watt-peak' of solar PV in 2010 is given below, using which system costs can be calculated. The costs projected in the table are for system sizes below 10kW for the residential sector.

Quarter (2010)	System Price ($/Wp) - AC
Quarter 1	8.84
Quarter 2	8.23
Quarter 3	8.11
Quarter 4	8.07

Table 2-10PG&E Territory Solar PV Pricing for 2010(CEC &CPUC, 2012)

2.1.6.3 Solar Data

The average gross solar insolation on a flat plate PV system ranges from 5 to 7.5 kWh/m^2/day and is highest during summer. (George Simons, 2005)

Based on the insolation data, two locations have been shortlisted for analyzing the residential solar PV policy in California. Locations were selected from regions with low insolation and medium insolation. The map presented in appendix A will give you the technical potential of solar insolation on a flat plate collector for California.

The table below gives the locations and their insolation values:

Location	Insolation Level	Average Solar Insolation (kWh/ m^2/day)
Eureka	Low	4.31
San Francisco	Medium	5.26

Table 2-11 Locations selected in the PG&E Territory based on Insolation

2.2 Germany – Energy Profile

This section provides information about Germany and its energy scenario. This section begins with the background of Germany leading into a discussion on the energy matrix of Germany. The section lays out the various energy policies of Germany and its stakeholders. It further focuses on the solar PV residential policies in detail and corresponding data required for analyzing these policies.

2.2.1 Germany

Germany has a population of approximately 82 million spread over an area of 357,022 km². The population density is 235 persons per km², with per capita personal income of $43,330.Germany was the world's fourth-largest economy in 2010, with a Gross Domestic Product (GDP) per capita of $40,116.(CIA, 2012)(World Bank, 2012). The average person per households is 2.1 and the household electricity consumption in 2010 is 2,326 kWh.(Eurostat, 2012).

2.2.2 Energy Matrix

Being an industrialized country, Germany is heavily dependent on large amounts of cheap energy. Germany has reserves of natural gas and coal. It imports close to 98% of its oil requirements. The energy mix of Germany is diversified in term of the resources being used. In the past few years there has been a decline in the use of fossil fuel recourses in most cases except for natural gas. Therein turn there is a rise in renewable energy sources instead. Since Germany is dependent on energy imports, the need to shift to renewables is essential for the purpose of energy security. (DERA, 2012)

The primary sources of electricity generation in Germany for the year 2010 were nuclear, lignite, hard coal, natural gas, renewables, heating oil and hydro. (AGEB, 2012). The figure below gives you the percentage contribution of each fuel type:

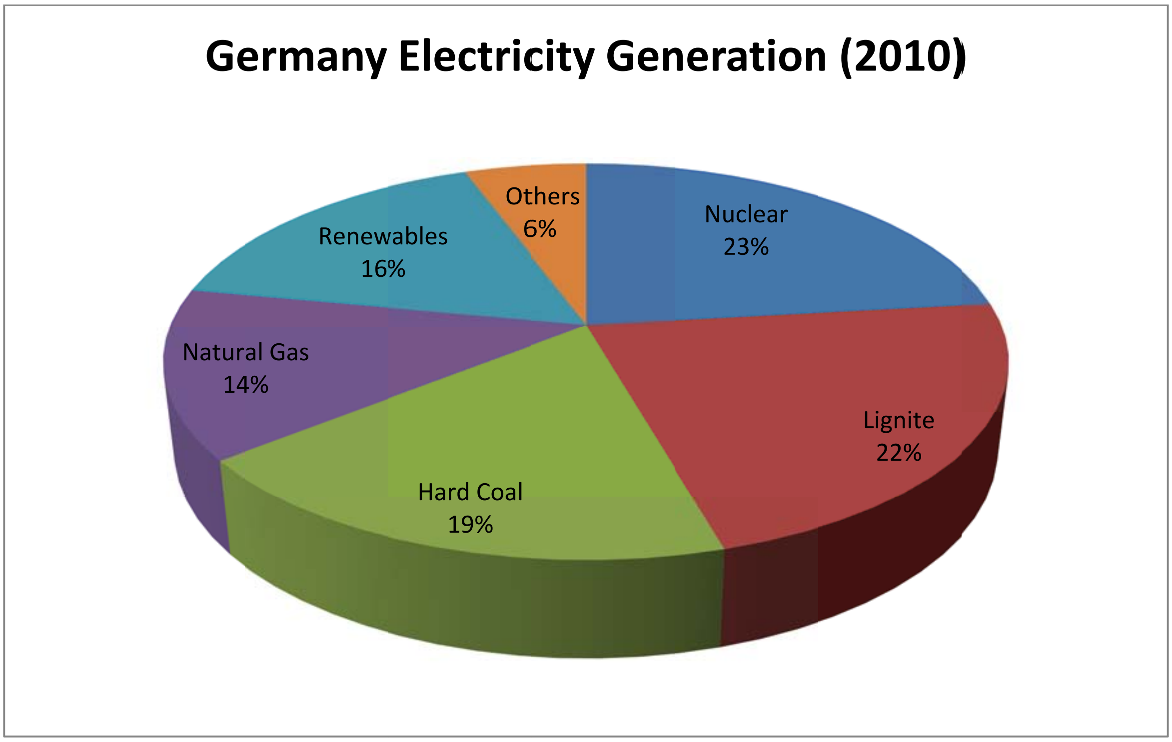


Figure 2-7Germany Electricity Generation in 2010 (AGEB, 2012)

The total net electricity generation of Germany in 2010 was 628,100GWh, of which 102,800 GWh was the electricity generation from renewable energy resources.

Germany generates electricity making use of the renewable energy resources such as wind, solar PV, biomass (solid, liquid, landfill and biogenic), municipal solid waste (MSW), geothermal and hydro (small hydro and storage). Germany is also the world leader in solar power installations. The table below gives details of the total net renewable installed capacity for the year 2010 in Germany.

Type	Capacity Value(MW)
Total	55,578
Hydro	4,395
Wind	27,191
Biomass	5,014
MSW	1,650
Solar PV	17,320
Geothermal	7.5

Table 2-12Germany's Net RenewableInstalled Capacity in 2010 (BMU, 2012)

The table below gives the breakup of electricity generation from the various renewable energy resources for the year 2010 in Germany.

Type	Generation Value(GWh)	Percentage of Country Total
Total	102,800	16.4
Hydro	21,000	3.3
Wind	37,800	7.2
Biomass	27,600	5.2
MSW	4,800	0.8
Solar PV	11,700	3.1
Geothermal	<100	0.09

Table 2-13Germany's Net Renewable Electricity Generation in 2010 (AGEB, 2012)

2.2.3 Stakeholders

There are various organizations, institutions, research facilities and interest groups that influence and direct PV dissemination in Germany. Each of their roles and responsibilities are laid out in the tables below.

Organization	Key Functions	Type
Bundesnetzagentur (Federal Network Agency)	• Regulates and liberalizes development of electricity, gas, telecommunication and postal and railways markets. • Root certification authority	Federal Network Agency
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment , Nature	• Energy policy issues • International cooperation • Awareness on environmental issues	Energy Information and Administration

Conservation and Nuclear Safety)	• Climate protection • Air Quality control	
Bündnis 90/ die Grünen (The Alliance'90/ The Greens)	• Political Party among that fights for environmental protection	Green Party
European Energy Exchange AG (EEX)	• Leading market in European energy trading	Electricity Stock Market
Bundesverband Solarwirtschaft e.V (BSW Solar) (German Solar Energy Industry Association)	• Supports widespread adaptation of solar technologies • Works alongside the American Solar Energy Society (ASES) and the Solar Electric Power Association (SEPA)	Industrial Association
Electricity Service Providers (POUs, IOUs and others)	• Distribution & Transmission operators for the grid	Electricity Transmission & Distribution Operators
IntersolarEurope	• Solar Exhibitions • Development of business opportunities	Exhibition
Fraunhofer Association, Wuppertal Institute, Max Planck Society and others	• Facilitate research and development	Research Facilities

Table 2-14Organizations that support solar PV dissemination in Germany(Schindele, 2011)

2.2.4 Policy Instruments

Germany's interest in promotion of renewable energy technologies began in 1970s and 1980s among key policy makers and finally came to light in 1990s. A series of policies initiated from 1990s promoting renewable energy technologies has increased the growth of this industry rapidly and is looked upon as a successful model all over the world today. The policies implemented centered on environment, economics and energy security considerations. The policies promoted research and development along with encouraging adaptation of technologies via market incentives. With strong backing from opposition parties over the years, each trying to promote different renewable energy technologies, Germany has overall seen tremendous growth in this sector. (Runci, 2005)

In 1991, the Federal Electricity Feed Law (StrEG) was adopted, which obligated the utilities to buy power from renewable energy resources on a yearly basis, based on their average revenue per kWh sold. The renewable energy producers received remuneration for their production anywhere from 65%-90% of the retail electricity price. This law also heavily subsidized commercial wind generation and also state owned banks provided cheap loans, which saw the wind energy industry growing more rapidly than others. (Volkmar Lauber, 2004).

The Ecological Tax Reform (ETR) policy launched in 1999 that levied an electricity tax across all sectors and also increased taxes on fossil fuels such as motor fuels, fuel oils, and natural gas. Aiding the growth of solar PV technology growth was the 100,000 Solar Roofs Program (HTDP) in 1999. The program subsidized solar PV system sized 3kWp or higher, with a grant of 510 million euros. (Runci, 2005)

In 2000 came the Renewable Energy Law (EEG), which aimed at increasing the share of renewable energy technologies in the total energy mix at a more rapid rate. The EEG unlike the StrEG, provided a fixed length regressive feed in tariff (FiT). (Volkmar Lauber, 2004)

The EEG facilitates the operator of renewable energy technology to receive payment from the grid operator for the electricity sold to the grid. The EEG also started the market premium and flexibility premium tariffs that let the renewable energy system operator to sell directly to a third party via an agreement or sell at the energy stock market. (BMU, 2012)

The technologies eligible under the EEG are wind, solar, geothermal, hydro, biogas and biomass. The tariff rates have been set for various system size categories such as less than 30kW, between 30kW to 100kW, 100kW to 1MW and lastly above 1MW. The tariff rate is set and defined by law and degression rate is set taking into account the economics of scale. The tariff rate differs for each technology and depends on the costs of constructing and operation i.e. investment costs, operational costs, the costs of measurement and the cost of capital. A special tariff is also provided in case the customer for using percentage of the electricity generated for own use (partial self-consumption). This self-consumption tariff acted as a double bonus, as the customer received a tariff for sending electricity to the grid as well as for partially self-consuming. The self-consumption tariff aimed to facilitate the use of storage systems in order to increase the self-consumption ratio and also to reduce the burden created on the grid. (BMU, 2012).

In 2003 the Market Incentive Program (MIP) was launched that aimed at commercialization and deployment of renewable energy systems with a grant amount of 203 million euros.

2.2.5 Policy for Solar PV

The EEG law is the policy that aids solar PV technology dissemination in Germany. So a residential customer will fall under the 30kW category as either a total exporter to the grid or a partial exporter to the grid with partial self-consumption. The table below gives you the tariff rate for solar PV under EEG 2010:

System Size	**Feed in Tariff (EEG 2010) in $-Ct/kWh**					
	From 01.01.2010		01.07.2010		01.10.2010	
Roof Top Installation						
Up to 30kWp	51.79		45.05		43.70	
30 kWp to 100 kWp	49.26		42.85		41.57	
100 kWp to 1MWp	46.61		40.55		39.33	
1 MWp and above	38.86		33.80		32.80	
Open Space Installation						
Regardless of size	37.61		33.10		32.10	
Self-Consumption						
	< 30%	> 30%	< 30%	> 30%	< 30%	> 30%
Up to 30kWp	30.11		23.38	29.17	22.01	27.82
30 kWp to 100 kWp	-		21.18	26.98	19.90	25.69
100 kWp to 500 kWp	-		18.88	24.67	17.66	23.46

Table 2-15Feed in Tariff (EEG 2010) in Germany (Bundesnetzagentur, 2010)

2.2.6 Germany Data for Policy Analysis

2.2.6.1 Prices

Retail Electricity Price

The average electricity rate for the year 2010 in Germany is $ 0.32/kWh[1]. (AEE, 2012).

Solar Prices

For Germany the 'cost per watt-peak' of solar PV in 2010 is given below, using these values the system costs can be calculated. The costs projected in the table are for system sizes up to 100kW for the residential sector.

Quarter (2010)	System Price ($/Wp)-AC
Quarter 1	3.78
Quarter 2	3.85
Quarter 3	3.74
Quarter 4	3.59

Table 2-16 Germany Solar PV Prices for 2010(BSW-Solar, 2011)

2.2.6.2 Solar Data

The average gross solar insolation on a flat plate PV system ranges from 2.6 to 3.5 kWh/m^2/day and is highest during summer. (DWD, 2011)

Based on the insolation data from the map in appendix B 1, two locations have been shortlisted for analyzing the residential solar PV policy in California. Locations were selected from regions with low insolation and high insolation as the range is small.

The table below gives the locations and their insolation values:

Location	Insolation Level	Solar Insolation (kWh/ m^2/day)
Berlin	Low	2.95
Munich	High	3.39

Table 2-17 Locations selected in Germany based on Insolation

[1] The euro values have been converted to dollars making use of the 2010 dollar conversion rate of 1USD= 0.7557 EUR.

2.3 Comparison: California Vs Germany

This section compares and discusses the various indicators which were listed in the previous two sections with regards to California and Germany.

California and Germany are the largest economies in their respective regions namely the USA and the EU. They also have the largest population in their respective regions, but the population of Germany is almost twice that of California. The difference in population clearly reflects in the energy requirements as well, with California generating 204,126GWh and Germany generating 628,100 GWh. It is also important to note that the household electricity consumption of California is approximately three times that of Germany.

Both California and Germany are dependent on interconnected electricity imports from neighbors, leading to the concerns about energy security. Both California and Germany are promoting renewable technologies via various policies initiated over the past few decades to facilitate the growth of the renewable energy sector which will in turn will provide energy self-sufficiency in the coming years as well as provide employment, research, development and innovation opportunities.

Although both regions have implemented vastly different policy initiatives, they have been able to facilitate a rapid growth of the renewable energy industry. The policies of California are centered around energy efficiency and energy conservation in order to lower the per capita electricity consumption, thus promoting distributed generation on a large scale. Whereas in Germany the main aim of the policies is to generate and provide clean electricity. Thus, the policies provide incentives for anyone who feeds clean electricity into the grid and is not centered on per capita consumption until new self-consumption policy came to light.

The solar PV policy for California -GM CSI is designed to lower the upfront cost to the customer while installing the solar system. As an added incentive the NEM policy guarantees long term remuneration for an investor, making NEM policy a self-regulating system. In Germany as the policy is aimed at stimulating the market, the FiT acts as an incentive tariff for the solar PV system operator.

The costs borne by the IOUs to pay customers under the NEM and FiT policy is distributed evenly in the electricity bills of the non-participating customers, thus making the retail price of a customer higher than usual, whereby encouraging participation.

In California the additional costs associated with NEM is far less than that with FiT. In NEM the grid operator charges only for operation and maintenance cost, as the customer in most cases is self-sufficient using electricity generated by the solar system. But in FiT the grid operator has to pay for most of the electricity generated by the customer as very less percentage is self-consumed and in most cases it is nil.

Coming to the solar insolation, California has almost double that of Germany, technically giving California an edge over Germany in terms of potential.

The installed capacity of solar PV systems in Germany is very large when compared to California. Hence the cost to install a solar PV system is also less in Germany than California owing to its market size. The prices in Germany range from 3.5-3.7$/Wp and in California 8-9 $/Wp.

The table below summaries the various key indicators used to compare California and Germany:

Variable	California	Germany	Units
Population	37	82	Million
GDP per capita	51,470	40,116	$
Per capita personal Income	42,514	43,330	$
Average persons per household	2.89	2.1	-
Total net renewable electricity generation	29,891	102,800	GWh
% share of renewables in total energy mix	14.6	16.4	%
Yearly residential load	6,714	2,326	kWh
Average gross solar potential on a flat plate PV system	5 - 7.5	2.6 - 3.5	kwh/m^2/day
PV Price Index	8.31	3.74	($/Wp) - AC
Retail electricity price (Base year 2010)	0.18	0.32	$/kWh

Table 2-18 Comparison of California and Germany Key Indicators(Author, 2012)

But the real question is to analyze which policy instrument is more beneficial to the residential investor. Thus, this study will compare the two very different policies structures; hence the methodology used for comparison would be to analyze the most different policy cases and check how they reach similar outcome. Also to check which policy instrument is more beneficial to the residential customer.

3. Theory

The first part of the chapter deals with the main concepts used to define the research questions of this study. A thorough knowledge of the basic theoretical concepts used in this study isrequired and thus the later part of this chapter elaborates these concepts, which need to be understood in order to analyze and compare the two very different policies of solar PV dissemination in California and Germany.

3.1 Discounting Grid Parity

The cost of manufacturing solar PV cells has been declining at a fast rate from $100/watt at inception up to $1/watt up until now; this dramatic decline leads one to believe that solar PV systems will soon be locking horns with conventional modes of power generation. This very notion leads to the concept of ***Grid Parity***. There is confusion and uncertainty over the concept of Grid Parity as there is no single definitive understanding of the concept. Yet, it is often looked upon as the corner stone for PV technology. (Morgan Baziliana, 2012) (Yang, 2010)

A crude outline of the definition of Grid Parity would be when cost of solar energy becomes competitive with conventional grid supplied electricity (Yang, 2010). In this report the definition of grid parity is outlined based as follows:

'Grid parity is defined as the point when the total cost to customer of PV electricity equals the retail grid electricity price.'(Stavy, 2002).

In order to determine when Grid Parity will be reached, we need to determine the cost to customer of PV electricity. There are many ways in which one can determine the cost associated with a solar PV system, but the most widely usedtool is the ***Levelized Cost of Electricity*** (LCOE). Nowadays, LCOE has replaced "cost per watt" as the new metric for comparing PV systems. (Morgan Baziliana, 2012) (Gerlach, 2011)

Therefore when the LCOE for the solar PV system equals the retail electricity price we can determine the point at which Grid Parity is reached in California and Germany. A graphical representation of the above explanation is as follows:

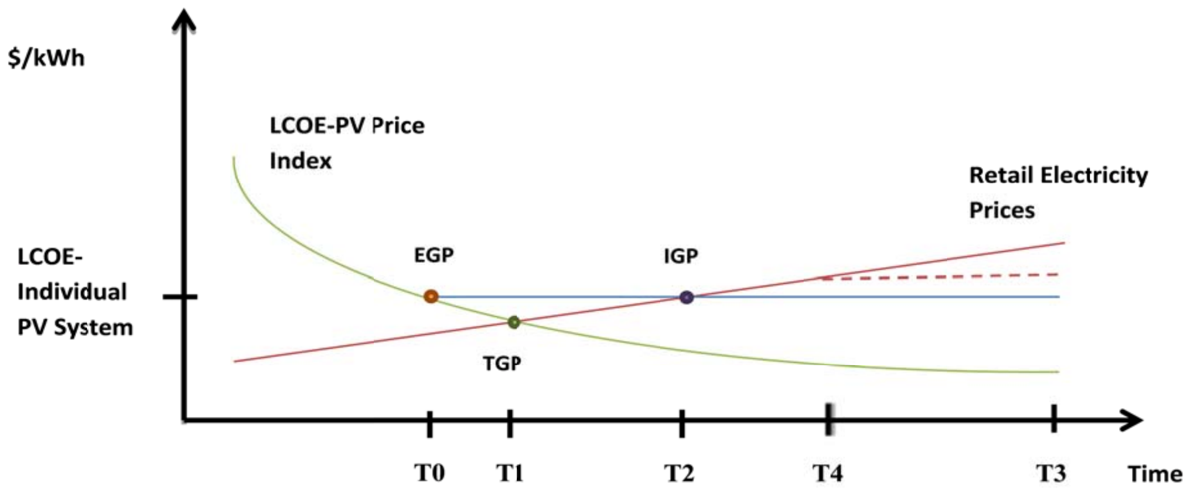


Figure 3-1 Grid Parity(Author, 2012)

From the graph we see that the green line represents the LCOE fitted to the economics of scale varying with time, the red line representing the retail electricity price increasing over time and the blue line referring to the individual solar PV system LCOE line. The point where the individual solar PV system achieves grid parity is referred to as Individual grid Parity (IGP). The point at which all solar PV installations reach Grid Parity would be when the cost per watt of solar PV equals the retail electricity price. This point can be referred to as Total Grid Parity (TGP) and is observed at T1.

A techno - economic analysis is done to find out when IGP is reached for a solar PV system installed at time T0 (2010) and operating until time T3 (2035). This analysis is done by determining the LCOE for each solar system under consideration for the locations shortlisted in section 2.1.6. The time at which IGP is reached is denoted as T2.

From the above graphical representation, we can see that after attaining IGP the investor makes a net benefit from the solar PV system as compared to the net costs before IGP. In a special scenario represented by the red dotted lines, where the retail electricity price is assumed to increase for ten years (T4) and later become constant, we observe that the benefits made in this case will be lower when compared to the continuous price increment in retail electricity price scenario. In the case where the LCOE of a given PV system is below the TGP point, then we see that there are only benefits observed for the PV system. One should also note that the grid parity model is a dynamic process and changes with time depending on various independent variables contributing towards the model.

By performing a cost- benefit analysis (CBA), which in turn is conducted in this study by calculate the savings made by the investor under the influence of a given energy policy. In the case of California and Germany, this analysis will be dictated by their respective policy structures that support solar PV dissemination. In order to know which of these cases is better than the other, the concept of discounting is being used which compares the systems at present value. (Walter Short, 1995). Thus we will be essentially ***'Discounting Grid Parity'*** (DGP) to check if the solar PV system is having an Early Grid Parity (EGP) effect by making use of the ***Discounted Savings Model*** (DSM). That is if a solar PV system has a net saving when discounted over its lifetime, we can say EGP is observed.

The ***'Discounted Savings Model'*** (DSM) designed in this study will help us determine the net savings made by the solar PV system and also help compare various the policy instruments. Thus DSM helps check the attractiveness of the policy and if the system is economically viable from the residential customer's point of view.

Therefore the techno- economic analysis will help analysis and answer our research questions:

'If there a discounted savings effect for a residential solar PV system installed in California and Germany for the time period 2010-2035?'

If a discounted savings effect is observed then the further research questions are:

'To find out how the independent variables contribute towards the discounted savings effect' and

'To find out which energy policy instrument is having the highest discounted savings effect'

3.2 Discounted Savings Model

The Discounted Savings Model (DSM), points out the net bill savings made by the customer for every kWh of annual electricity consumption made once a solar PV system has been installed. Since the policies of California and Germany are very distinctive in nature, DSM appears to be the best method for comparing them on a common ground. DSM inter relates the retail electricity prices and the benefits made from the energy policy in its model.

The savings per kWh consumption is calculated for each year of the solar PV system lifetime and when discounted, we get the saving per kWh at present value. This is nothing but the Net Present Value (NPV) of the savings per kWh. From the concept of NPV, if the value of NPV is positive then the system is making a benefit. Hence the system with higher NPV savings per kWh is the best system. Clearly, this model will help analyze the research questions effectively. Performing a sensitivity analysis, we can compare different systems within the same policy and also check the effect of the independent variables used in this model.

Evidently, DSM is simplistic in nature and can be used to compare and analyze policies. Making use of the single value obtained from this model, an investor can compare, making it an effective application.

The following section illustrates a general formula using which we can calculate the savings per kWh in each case.

$$NPVofSavings\left(\frac{\$}{kWh}\right) = \sum_{t=0}^{N}\left(\frac{\left\{\frac{(\text{Net Bill without PV system} - \text{Net Bill with PV system})}{\text{Annual Household Electricity Consumption}}\right\}}{(1+\text{dn})^{\text{t}}}\right)$$

- (1)

Denoting using variables

$$NPV\ Savings\left(\frac{\$}{kWh}\right) = \sum_{t=0}^{N}\left(\frac{\left\{\frac{(\text{A}-\text{B})}{C}\right\}}{(1+\text{dn})^{\text{t}}}\right)$$

- (2)

Where,

A=Net Bill without PV system = Annual Electricity Consumption per household * Retail Electricity Price
B=Net Bill with PV system = Net Cost of Buying Electricity from the Grid (BB) – Net Cost of Selling Electricity to the Grid (BS)
dn= Nominal Discount Factor (%)
N= Lifetime of the solar system
C= Annual Household Electricity Consumption

The Net Bill with PV system varies in the case of each policy. A detailed breakup of the calculation for each policy is given in section 4.2.6

3.3 Fundamental Concepts

The concepts discussed in this section aid in better computing of the financial analysis. The objective of such analysis is to determine which solar PV system is a better option. Each of the variables used affect the end results and it is imperative they are used with thorough understanding of the theory behind these concepts.

3.3.1 Cash Flows

The cash flows (CF's) integrate the money associated with the various activities of the project such as operating, investing and financing. Depending on the nature of the analysis, respective cash streams can be given emphasis. (Walter Short, 1995).Cash Flow is an integral part of the financial analysis. But, the various components which are considered as part of it are not explicitly defined and are often dictated by the type and extent of analysis that is required.

3.3.2 Inflation

Inflation can be defined as 'the ongoing rise in general level of prices for goods and services quoted in the units of money; subsequently lowering the purchasing power of the monetary unit' (White, 2008).

3.3.3 Discount Factor

The value of money decreases over time i.e. the value of one dollar is more today than what it is tomorrow. Conversely, one dollar is worth less tomorrow than it is today as it has lost out on the opportunity to earn interest. Discount factor (DF) acts as a measure of this time value which centers the calculation to the present value. (Walter Short, 1995).

Since, calculations based on DF provide the present value of the future cash flows, DF can either include the effects of inflation, making it nominal discount factor (NDF) or exclude the effect of inflation, making it real discount factor (RDF). It is important to note here that the choice of DF should be consistent for all cash flows. (Walter Short, 1995).

The following relationship exists between NDF and RDF:

$$(1 + dn) = (1 + dr)(1 + R)$$

- (3)

Where,

dn= Nominal Discount factor
dr= Real Discount Factor
R= Inflation Rate

DF is often equated to the Cost of Capital, but the system costs in our case involve various capital cost components, when all these costs are proportionately weighted we arrive at the weighted average cost of capital (WACC). Thus the overall WACC is not just based on the cost of capital but also on how this capital is distributed. (Walter Short, 1995).

WACC is now the rate at which we discount the cash flows to arrive at the present value (Fernandez, 2011).

The formula for WACC is given as:

$$WACC = \frac{E}{V} * Ke + \frac{D}{V} * Kd * (1 - Tc)$$

- (4)

Where,

WACC= Weighted Average Cost of Capital (%)
Ke = Cost of Equity
Kd= Cost of Debt
E= Market Value of the Equity
D= Market Value of the Debt
V= E+D
E/V= Percentage of financing that is Equity
D/V= Percentage of financing that is Debt
Tc= Tax Rate

Using this WACC formula, RDF can be determined and further, depending on whether inflation is accounted in the calculations, the NDF can also be calculated. Another case would be, if the Ke and Kd values already account for inflation, in which case the WACC obtained using equation 2 will be the nominal discount factor. In this study the NDF has been considered.

The value of Ke and Kd are to be determined/ assumed appropriately as the WACC will vary with change in these inputs. The Kd value is generally the rate of interest one pays for securing the amount of capital that is proportioned for debt, in other words the bank interest rate. The Ke value is determined making use of the Capital Asset Pricing Model (CAPM). It is a general equilibrium theory that results in a single risk factor namely the return on the overall stock market, which quantifies the trade-off between risk and expected return. The equation representing this relation is as below:

$$E(Ri) = Rf + \beta\ [E(Rm) - Rf]$$

- (5)

Where,
E(Ri)= Expected Return on Stocks
Rf= Nominal Yield on Risk Free Asset
E(Rm)= Expected Return on Market Portfolio
β= Riskiness of the Stock relative to Market

The values considered in this study to calculate WACCare in close approximation to the values obtained from literature survey of (Alan Goodrich, 2011)(King, 2009)(KfW, 2004)(Bankrate, 2012)(CA GOV, 2010)(BSIRN, 2012)(Schröder, 2012).

3.4 Economic Measure - Tools

Investment decisions can be determined by making use of capital budgeting techniques such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period and Accounting Rate of Return.But of these the tools that received most attention was the IRR and NPV as both make use of discounted cash flows, which takes the time value of money into considerations. While the IRR method determines the rate at which one should discount the cash flows in order to equalize the cash inflows and outflows, the NPV on the other hand determines the difference in the cash inflows and outflows, using a discount factor determined based on how the cost of capital is financed. In the case of a solar

PV system, the LCOE tool is commonly used to analyze cost distribution over the lifetime of the project to determine the generation cost of the system. In this study NPV and LCOE are the decision making tools which are used. A detailed explanation is given in the following sections. (Goosen, 2008) (John Herbohn, 2002).

3.4.1 Net Present Value

The NPV of a project is one way of examining costs (cash outflows) and revenues (cash inflows) together. (Walter Short, 1995).Thus NPV is the sum of the discounted cash flows (DCF); discounted using the discount factor. In a cost-benefit analysis, NPV is a critical parameter for analysis.

Suppose a Project has a sequence of annual cash flows say 'Ct' for the project duration of 'N' years. (Joan Pasqual Rocabert, 2005). Then NPV can be given as:

$$NPV = \sum_{t=0}^{N} \frac{\mathrm{Ct}}{(1+\mathrm{d})^{\mathrm{t}}}$$

- (6)

Where,

NPV= Net Present Value
Ct= Annual Cash Flow in year t
d= annual discount factor (%)
N= Lifetime of the project

As NPV is a DCF method, for a project it can further be broken down into discounted benefits and discounted costs. Thus we can write Equation 3 as follows:

$$NPV = Discounted\ Revenues - Discounted\ Costs$$

$$NPV = \sum_{t=1}^{N} \frac{\mathrm{Revenues}}{(1+\mathrm{d})^{\mathrm{t}}} - \sum_{t=1}^{N} \frac{\mathrm{Costs}}{(1+\mathrm{d})^{\mathrm{t}}}$$

- (7)

Where,

NPV= Net Present Value
d= Annual discount factor (%)
N= Lifetime of the project

A positive value of NPV indicates that the project is economically viable. The advantage of using NPV as a tool is that it allows direct comparison between projects with differing cost structures while taking into account the time value of money. In the case of solar PV technologies, NPV helps derive an accurate value for the irregular cash flows of the solar PV system over its lifetime. (Walter Short, 1995) (Goosen, 2008).

3.4.2 Levelized Cost of Electricity:

LCOE is a tool which can be used to compare a wide range of technologies and also different systems within the same technology range. LCOE unlike the simple 'cost per watt' calculations includes accurate costs distributed over the lifetime of the system. (Cambell, 2008).

The very basic representation of LCOE is:

$$LCOE = \frac{Total\ Life\ Cycle\ Cost}{Total\ Lifetime\ Energy\ Production}$$

- (8)

LCOE is metric that describes the cost of every unit of energy of the system and is given in $/kWh which is used as a normal benchmark. Also one should remember that LCOE is an evaluation of the Levelized life cycle energy costs over the lifetime of the system and can be expressed in variable ways depending on the parameters than have been considered. (Walter Short, 1995).

The equation 8 can be mathematically defined as:

$$TLCC = \sum_{t=0}^{N} \frac{\mathrm{Ct}}{(1+\mathrm{d})^{\mathrm{t}}}$$

- (9)

$$LCOE * TLEP = \sum_{t=0}^{N} \frac{\mathrm{LCOE} * \mathrm{Qt}}{(1+\mathrm{d})^{\mathrm{t}}}$$

- (10)

Thus rearranging the above two equations:

$$LCOE = \frac{\sum_{t=0}^{N} \frac{\mathrm{Ct}}{(1+\mathrm{d})^{\mathrm{t}}}}{\sum_{t=0}^{N} \frac{\mathrm{Qt}}{(1+\mathrm{d})^{\mathrm{t}}}}$$

- (11)

Where,

TLCC= Total Life Cycle Cost
TLEP= Total Lifetime Energy Production
LCOE= Levelized Cost of Electricity
Ct= Annual Cash Flow in year t
Qt= Energy generated by the system in kWh in year t
d= Annual discount factor (%)
N= Lifetime of the project

From Equation 8, it can be understood that each year's cash flow and energy is being discounted and it is for this very reason that LCOE is assumed to have a constant value over time. (Walter Short, 1995).

Depending on the nature of the project, the LCOE equation can be further expanded appropriately by incorporating the different costs such as initial capital cost, operating costs (O&M, system financing, & replacement) and incentive revenue in the numerator and in the denominator by including system degradation along with energy production.

We have the new equation as:

$$LCOE = \frac{I + \sum_{t=0}^{N} \frac{\mathrm{Ot}}{(1+\mathrm{d})^{\mathrm{t}}} - \sum_{t=0}^{N} \frac{\mathrm{Rt}}{(1+\mathrm{d})^{\mathrm{t}}}}{\sum_{t=0}^{N} \frac{\mathrm{Qt}*(1-\mathrm{deg})}{(1+\mathrm{d})^{\mathrm{t}}}}$$

- (12)

Where,

LCOE= Levelized Cost of Electricity
I= Initial capital cost
Ot= Operating Cost in year t
Rt= Incentive Revenue in year t
d= Annual discount factor (%)
N= Lifetime of the project
deg= Annual degradation rate of the system (%)

In the upcoming chapters, a sensitivity analysis would be conducted to observe the effects of the independent variables on the outcome.

4. Data Background

This chapter focuses on the data background and calculation procedures used in the study. It specifies where and how the data collected is being used in the study and which variables are applied in the sensitivity analysis.

4.1Data Background

While analyzing different solar PV systems from California and Germany, it is important to ensure that the input data used for the calculation is well defined and the appropriate set of values are considered in order to analyze and compare the respective policies from California and Germany. Since the emphasis of the entire study is centered on the customer from the residential sector who is setting up a solar PV system, the various input variables are deliberated accordingly.

The following sections will define each step of the evaluation method in detail and discuss how the input variables were derived for California and Germany respectively. The evaluation of a solar PV system in California and Germany differ in each step but the most important difference is in the LCOE and DSM calculations as they depend on the structure of the policy. The method explained in these sections is for a general solar PV system in the respective regions, the next chapter will deal with results for specific systems in California and Germany.

4.1.1 Load Profile

Load Profile (LP) enables an electricity supplier to estimate the average electricity demand or consumption of a customer over a period of time. (Eurelectric, 2000).The customer in our study is the residential sector and thus a consumption load profile for this segment is determined. The time period for the load profile is split into two types, firstly the hourly load profile (HLP) which gives the consumption pattern of the household throughout the day and secondly the monthly load profile (MLP) which gives the consumption pattern over the entire year.

The load profiles for California and Germany are required in order to determine the amount of load than can be sufficed by the solar PV system and also aid in calculation of the associated monetary benefits.

Californian Residential Electricity Load Profile

The average hourly residential electricity load and monthly load values calculated for the Southern California Edison (SCE) territory for the year 2000 (NABH, 2001) was available in literature. Based on this data, the annual residential consumption for California was calculated. Consequently the annual residential electricity consumption for the year 2010 was available for California (EIA, 2012)and the average residential electricity hourly load and monthly load data was estimated making use of the proportions inferred from 2000 SCE data. Cross referencing with Pacific Gas and Electric Company (PG&E) Residential Use per Household value for the year 2010 (California Energy Commission, 2011); we see that the data is consistent.

Germany Residential Electricity Load Profile

The hourly residential electricity load data was obtained internally (ISE, 2012) for the year 2010, from which the monthly residential electricity load profile and the yearly residential electricity consumption were determined. Since a specific territory was not considered for Germany, the load profiles used in this study are average values for the residential sector of Germany.

4.1.2 System Sizing

The sizing of the system in this study is dictated by the policy structure. Hence the size of the system varies considerably between California and Germany. It is important to note that the system size influences calculation steps associated with system costs and energy production.

The system size can be specified in both AC (kW) or DC (kW). The AC specification is used in calculating the cost of the system as the cost per watt prices are generally mentioned for AC. The DC specification is used for calculating the production of a solar PV system, as the online tools make use of DC specification. We can convert the AC specification to DC specification using the overall DC-AC derate factor of 0.77. (NREL, 2011)

System Sizing for California

The net metering policy of California limits the size of the system to offset the electricity need of the household. (CPUC, 2011) In other words the system size should be designed such that the monthly load of the household is taken care from the production of the solar PV system.

Steps to Calculate the System Size:

1. Estimate the average monthly kWh used by the household from the load profile.
2. Convert KWh/month to Wh/month.
3. Calculate average daily Wh of electricity utilized by dividing Wh/month by 30.
4. Multiply the result of step 3 with the percentage of the home to be powered by the PV system.
5. Divide result in step 4 by the average solar insolation (kWh/sqm/day) to get the total watts.[2]
6. Multiply the result of step 5 with a factor of 1.2 to cover for system inefficiencies. The result obtained is the AC specification value.
7. Divide the result from step 6 with the DC-AC derate factor to get the DC specification value.

With the knowledge of the monthly average load of a household and the solar insolation at the place, the system size of any solar PV system can be determined. The calculation procedure used above follows standard guidelines. (NREL, 2002).

System Sizing for Germany

The German energy policy sets no specific eligibility criterion for the size of the system, but average system size in Germany falls under the category of less than 30kWp. A customer in the residential sector generally installs a solar PV system ranging anywhere from 1kW to 30 kW. A specific system size was required for the purpose of this study. Thus the average residential solar PV system size that was installed in Germany was obtained by studying the data of all the solar PV installations that took place in the year 2010.

From the database of installations that took place in the year 2010 in Germany the average solar PV system size installed was obtained as 8.5 kW-DC or 6.6 kW-AC. (Deutsche Gesellschaft für Sonnenenergie e.V., 2012).

[2] The units of numbers obtained from the Web site for solar insolation are kWh/m2/day, but the value of solar insolation used to rate the panel of 1 kW/ m2 is included in the calculation resulting in watts.

4.1.3 PV System Production

In order to determine the energy production from a PV system the online tool by NREL called PV WATTS Grid Data calculator was utilized in this study. PV WATTS is available in two versions, one catering to locations within USA and the other to specific location from across the world. The PV WATTS calculator makes use of typical meteorological data for the location specified and generates hour by hour performance of the system as well as monthly and yearly performance.

For California the PV WATTS Version 2 was used and in the case of Germany Version 1. By feeding in the DC system size into the calculator, the system's production can be obtained. The array tilt of the solar PV system is set to the default latitude and array azimuth to equator facing. (NREL, 2012).

The data obtained from this calculator is used to compare and analyze the ability of the PV system to suffice the household electricity load on an hourly and as well as monthly basis.

4.1.4 Levelized Cost of Electricity

The definition of LCOE has been explained in the previous chapter. This section explains development of the LCOE equations for both California as well as Germany.

Firstly, the cash flow for the PV system needed in each case is identified. Further, using the NPV tool, future cash flows are discounted to the present value. Apart from the cash flows the yearly PV production of the system also needs to be discounted.

California LCOE

From the understanding of the structure of the energy policy in California from Chapter 2, we can further build up on the basic concept of LCOE.

The typical costs that need to be accounted for in the LCOE calculation are the initial capital cost and the operation costs. The operational costs can further be broken into operation and maintenance costs (O&M) and replacement costs.

The upfront incentive offered by California's CSI rebate program (EPBB) is also accounted for along federal tax credits as per the policy support received for solar PV system.

Thusa customer inCalifornia has in the LCOE calculation the costs (operating costs) and the revenue (CSI Rebate and Tax Credits) earned accounted for individually, which will influence the LCOE value.

Combining equation 8 and 12 from section 3.4.2 we have the new modified LCOE equation for California as:

$$LCOE = \frac{I + \left(\sum_{t=0}^{N} \frac{\text{Costs}}{(1+\text{dn})^{t}} - \sum_{t=0}^{N} \frac{\text{Revenue}}{(1+\text{dn})^{t}} \right)}{\sum_{t=0}^{N} \frac{\text{Qt}*(1-\text{deg})}{(1+\text{dn})^{t}}}$$

- (13)

Where,

LCOE= Levelized Cost of Electricity

I= Initial Capital Cost
Revenues =CSI Rebate+ Federal Tax Credit
Costs= O&M costs+ Replacement Costs
dn= Annual Nominal Discount Factor (%)
Qt= Energy generated by the system in kWh in year t
N= Lifetime of the solar system
deg= Annual Degradation Rate of the System (%)

Initial Capital Cost:

It is calculated by multiplying the system size in (W) with the cost per watt ($/W) for the year 2010.

CSI Rebate Value

It is calculated by multiplying the system size in (W) with the incentive rate ($/W) under the Expected Performance Based Buydown (EPBB) category of the California Solar Initiative Rebate program.

Federal Tax Credits

The Federal Investment Tax Credit for the residential solar system owner is 30% of the total system cost after rebate value has been deducted. (California Energy Commission, 2011)(Black, 2009).

System Lifetime

The lifetime of a solar PV system is assumed to be 25 years, which is the average value used in most studies.

System Financing

Is used to calculate the WACC value based on percentage of initial capital cost being used for secure a loan and percentage of Initial capital cost used to self-finance.

Operating costs

The O&M cost annually is assumed to be (0.25) % of the total system cost adjusted for inflation and the replacement costs are is considered to be $ 1500 for the year 8 and 16 of the system lifetime.

Discount Factor

The DF used in this study is adjusted for inflation and hence it is the nominal discount factor 'dn' that is used. Equation 2 and 1 from Chapter 5 are used to calculate the value of dn.

PV Production

Yearly PV production values obtained from PV WATTS online calculator for the given solar PV system is used. Multiplying with the degradation rate we get the PV production values for each year of the system lifetime.

Degradation Rate

The annual degradation rate for a solar system is generally below 1% (NREL, 2011); in this study the value used is 0.5%.

Substituting all the values in equation 10 we can calculate the LCOE of a solar PV system in California.

Germany LCOE

Unlike California, in Germany there is not upfront incentive given to the customer investing in solar PV system. Rather the FiT is a rate paid to the customer for the electricity supplied to the grid from the solar PV system installed. Thus the FiT rate is designed to be in close proximity to the LCOE value of a solar PV system.

Thus in the German case the LCOE calculation is basic, which considers only the initial capital costs and operation costs.

Modifying equation 12 from section 0 we have the new LCOE equation for Germany as:

$$LCOE = \frac{I + \left(\sum_{t=0}^{N} \frac{\text{Operating Costs}}{(1+\text{dn})^{t}}\right)}{\sum_{t=0}^{N} \frac{\text{Qt}*(1-\text{deg})}{(1+\text{dn})^{t}}}$$

- (14)

Where,

LCOE= Levelized Cost of Electricity
I= Initial Capital Cost
Operating Costs= O&M costs+ Replacement Costs
dn= Annual Nominal Discount Factor (%)
Qt= Energy generated by the system in kWh in year t
N= Lifetime of the solar system
deg= Annual Degradation Rate of the System (%)

The LCOE parameters for Germany are calculated in the same way as mentioned in the California LCOE section. The two main parameters that might affect the results are the cost/W value for the solar PV system and the WACC. Thus sensitivity analysis is conducted for varying values of these two variables. Additionally in the case of Germany, a new LCOE is calculated taking into account the battery storage capital cost.

4.1.5 Economic Benefits

The economic benefits are provided by the policy in place at California and Germany. These economic benefits act as an incentive for lower the burden on the residential customer for investing into solar PV system. Each country has a different method of providing this incentive to the customer; how this incentive helps the customer is discussed below.

California -Net Metering

Thus in the case of California, NEM offsets the residential customers electricity bill. The calculation of net metering is multipart.One need to do an hourly calculation for the amount of electricity bought and sold to the grid. The following steps were followed to calculate the new electricity bill after incorporating NEM. Obtain the hourly load values for the household for each month as these values vary with seasons.

1. Obtain the hourly PV production values for each month of the year.
2. Calculate the difference between the load value and PV system production value and obtain the amount of electricity sold to the grid and bought from the grid on an hourly basis.
3. Now multiply the values obtained in Step 3 with the corresponding rates from the residential time of use rate schedule E6, with this we ascertain the price at which the electricity was bought or sold to the grid.[3] The values obtained are hourly prices from which the total price of electricity bought and sold to the grid per day can be calculated.
4. Now the monthly price of electricity bought and sold to the grid can be calculated by multiplying values from Step 4 with the number of days in the month.
5. The difference of the monthly price of electricity bought and sold from the grid will give us the net bill per month after PV system installation. Summation of all the individual monthly bills will give us the annual bill after PV system installation.

In the case of net metering one should remember that the customer is both the producer and consumer and that the solar PV system is sized such that it offsets the residential customer's complete load. Thus the cost of generation applies in the case of generating and consuming as the utility is just acting as a battery system. Hence while calculating the net electricity bill, the cost of generating is not included as it is the same while producing and consuming, making the time of use rates as the only applicable value needed to be considered for billing and benefit calculations.

Germany – FiT

In the case of Germany calculation of benefits is directly done using the feed in tariff value given in the two cases i.e. when the residential customer in a total exporter and when one is partly self-consuming. The FiT rate is used to offset the cost of generating solar power using a solar PV system. The lower the cost of generation the more benefit is made.

4.1.6 Discounted Savings Model

The Net Bill with PV system varies in the case of each policy. A detailed breakup of the calculation for each policy is given below and modified versions of equation 2 from section 3.2 in each case are listed below.

DSM Parameters for California Net Metering Policy

In the case of California, the net bill with PV system is nothing but the bill to customer after implementation of net metering policy. From Section0 we have the value net bill with PV system from Step 5.

So Equation 2 parameters for California are:

B = Annual Net Bill using Net Metering

[3] Based on the value obtained from step 3, check for deviation from the baseline scenario and apply corresponding tier rates for calculation.

A= Net Bill without PV system = (Annual Electricity Consumption per household * Retail Electricity Price[4])

C= Total Household Electricity Consumption in California

DSM parameters for German FiT Policy

In Germany FiT policy, the Net Bill with PV system is calculated as follows:

BB=Net Cost of Buying Electricity from the Grid = (Annual Electricity Consumption per household * Retail Electricity Price)

BS=Net Cost of Selling Electricity to the Grid = (Annual PV system Production * (FiT rate-LCOE))

In the FiT policy the value of A happens to be the same as BB.

So equation 2 parameters for German FiT are:

A=Net Bill without PV system = (Annual Electricity Consumption per household * Retail Electricity Price)

B= (BB-BS)

C= Total Household Electricity Consumption in Germany

DSM parameters for German FiT Policy with Self Consumption

In Germany FiT policy with self-consumption, the Net Bill with PV system is calculated as follows:

BB=Net Cost of Buying Electricity from the Grid = (Annual Electricity Consumption per household * Retail Electricity Price)

BS=Net Cost of Selling Electricity to the Grid = (Percentage of Annual PV system Production * (FiT rate-LCOE))

We have an additional parameter in this case

BQ =Net Cost of Buying Electricity from the Grid under FiT Self Consumption = (Percentage of Annual Electricity Consumption per household * (FiT rate for self-consumption-LCOE))

So equation 2 parameters for German FiT with Self Consumption are:

A=Net Bill without PV system = (Annual Electricity Consumption per household * Retail Electricity Price)

B= (BB+BQ-BS)

C= Total Household Electricity Consumption in Germany

The percentage of self-consumption can be increased by using a storage system. A battery system has been considered and with new LCOE for a system with battery, an additional result will be

[4] Use the PG&E E1 schedule rates for calculating the bill value

analyzed to check if inclusion of battery system has variation in DSM in the case of Germany FiT policy with self-consumption.

The main parameter than might influence the outcome of the results in this section is the retail electricity price. A sensitivity analysis is conducted for varying retail electricity price increase over the lifetime of the solar PV system. Also the other most important variable considered for sensitivity analysis is the WACC.

5 . Results

5.1 Results- California

This section presents the results for the theory and methodology discussed in the previous chapter pertaining to the techno-economic analysis of a solar PV system in California. The first few parts of the section will layout the LCOE calculations for California for solar PV systems in Eureka and San Francisco and the next part will use the LCOE to check when individual grid parity is reached for the solar PV systems for both the locations. Lastly the DSM values will be presented.

5.1.1 Load Profile

The load profile will help us determine the optimal size of the solar PV system which intern will help calculate the NEM benefits.

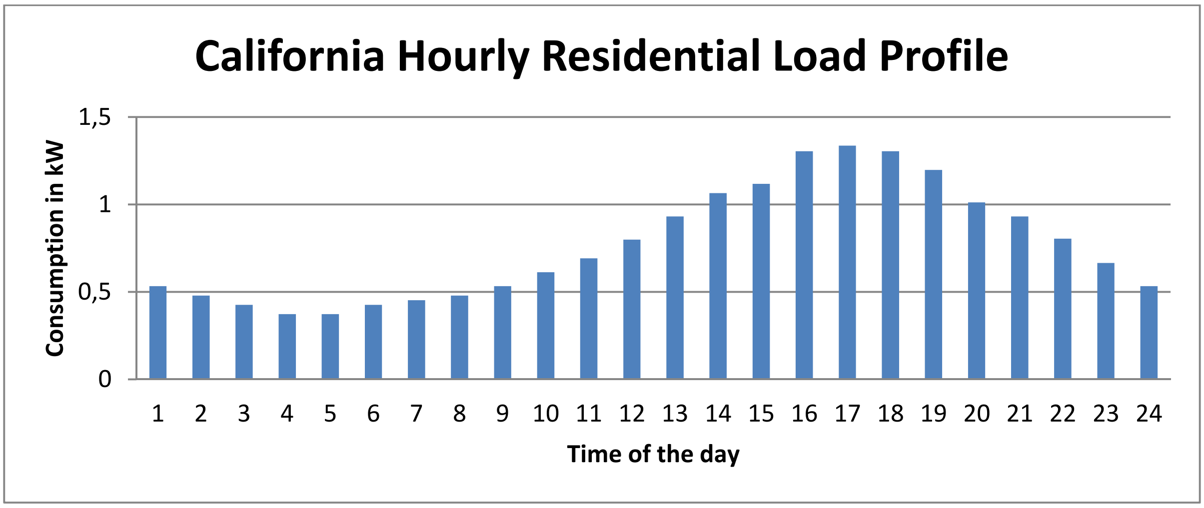


Figure 5-1 California's Hourly Residential Electricity Load Profile

We observe that the peak hour in California is from 16.00 – 18.00 which is due to the overlapping of work and home activities. The main reason for the higher demand is the use of air conditioning in both the above mentioned activities, which accounts for the largest chunk of the load during the peak hours. (Black, 2009)

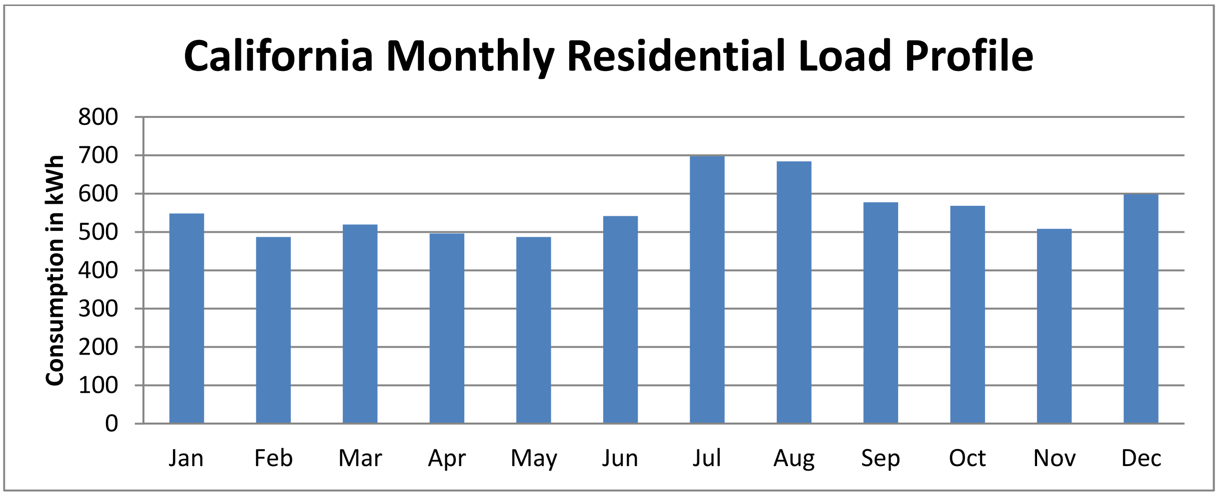


Figure 5-2California's Monthly Residential Electricity Load Profile

The monthly residential electricity load profile is close to a flat line thought out the year, indicating a temperate climate zone that creates warm winters and cool summers, which leads to similar air conditioning requirement through all the months. (NABH, 2001)

The average yearly residential electricity consumption for the year 2010 in California is 6,714 kWh/year (California Energy Commission, 2011), making the average monthly residential electricity consumption close to 560 kWh/year.

The load profile determined will be used as the standard base for all the locations chosen under this study from California.

5.1.2 System Size

The solar PV system size for the two locations chosen in California is determined using the steps mentioned in section0. The table below gives you the optimal size of the system for Eureka and SanFrancisco to suffice the average residential load in California.

Location	Average Solar Insolation (kWh/ m^2/day)	System Size –AC (kW)	System Size –DC (kW)
Eureka	4.31	4.7	6.1
San Francisco	5.26	4.0	5.2

Table 5-1 Solar PV System Size for Eureka and SanFrancisco

Based on the insolation levels we see that with increase in insolation the system size decreases.

5.1.3 PV Production

The PV production determined using PV WATTS for Eureka and SanFrancisco for their corresponding system sizes and solar insolation ranges from 6,882 kWh/year to 7,336 kWh/year. The graphs below represent the hourly and monthly production.

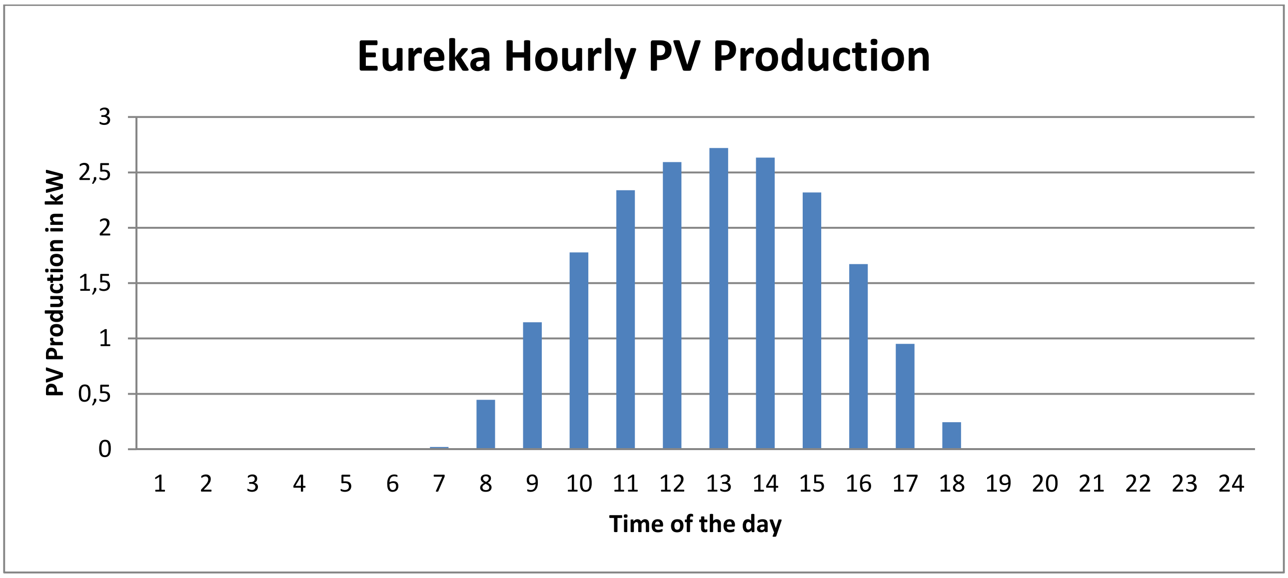


Figure 5-3Eureka Hourly PV Production for System Size- 4.7 kW-AC

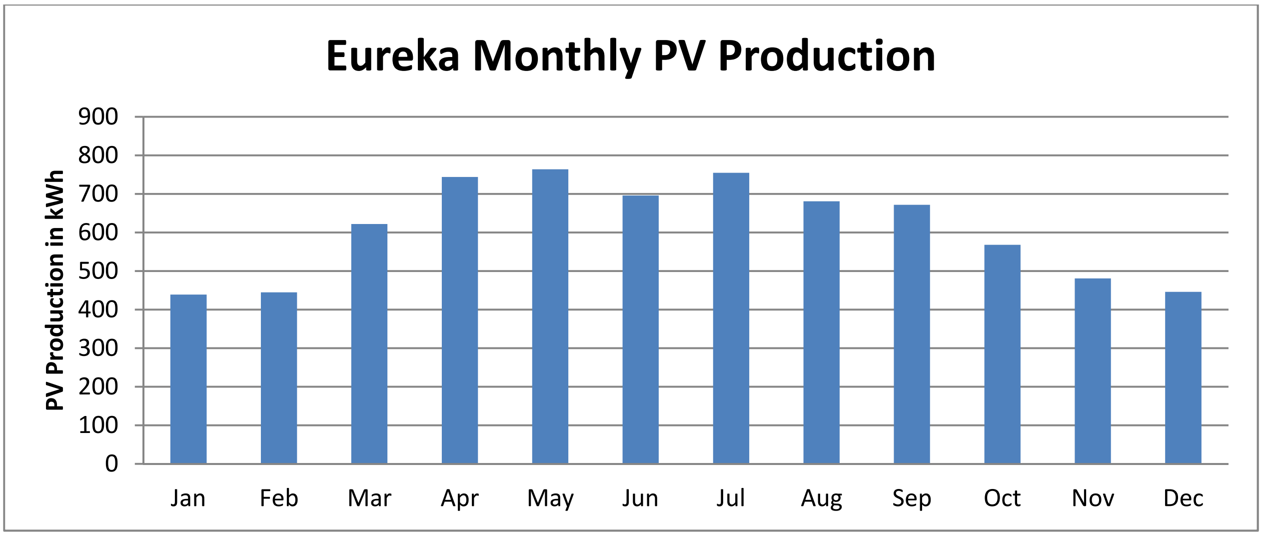


Figure 5-4Eureka Monthly PV Production for System Size- 4.7 kW-AC

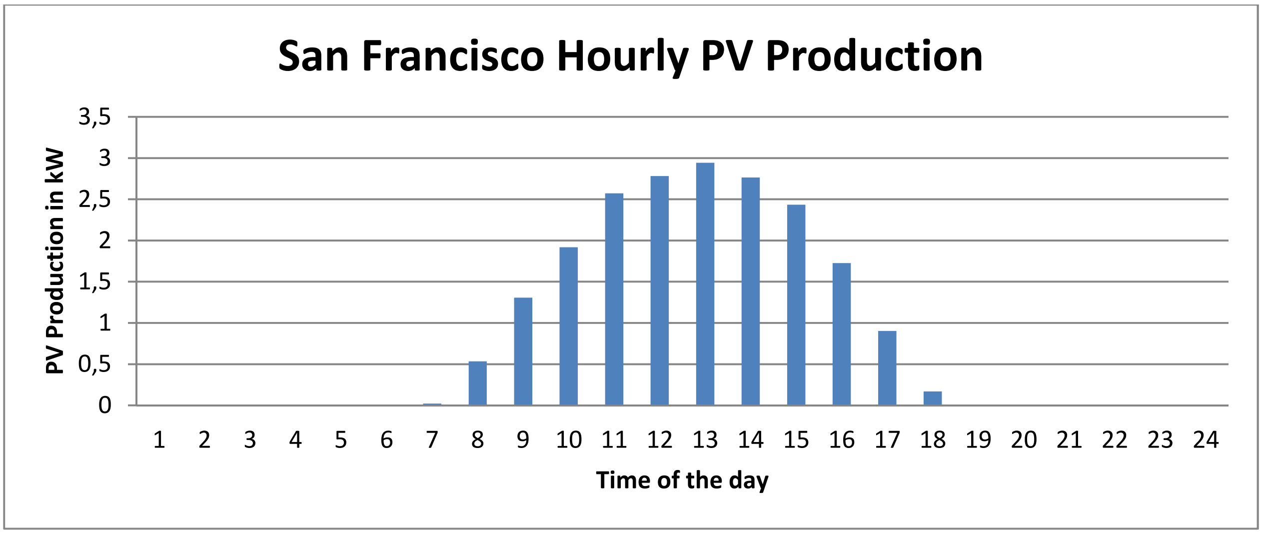


Figure 5-5SanFrancisco Hourly PV Production for System Size- 4 kW-AC

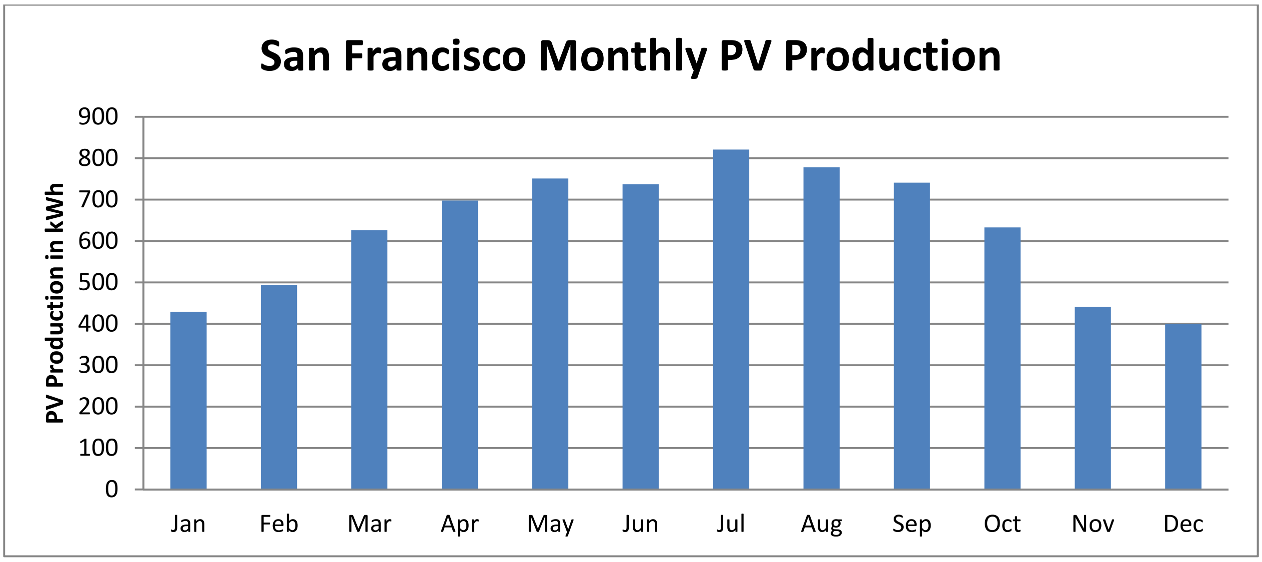


Figure 5-6SanFrancisco Monthly PV Production for System Size- 4 kW-AC

5.1.4 Net Energy Metering (NEM) Benefits

As we know NEM facilitates the residential customer to design the system to offset maximum amount of the annual residential load.

Load vs PV Production

The graph below gives you the PV system output and corresponding load for each hour of the day for Eureka and SanFrancisco.

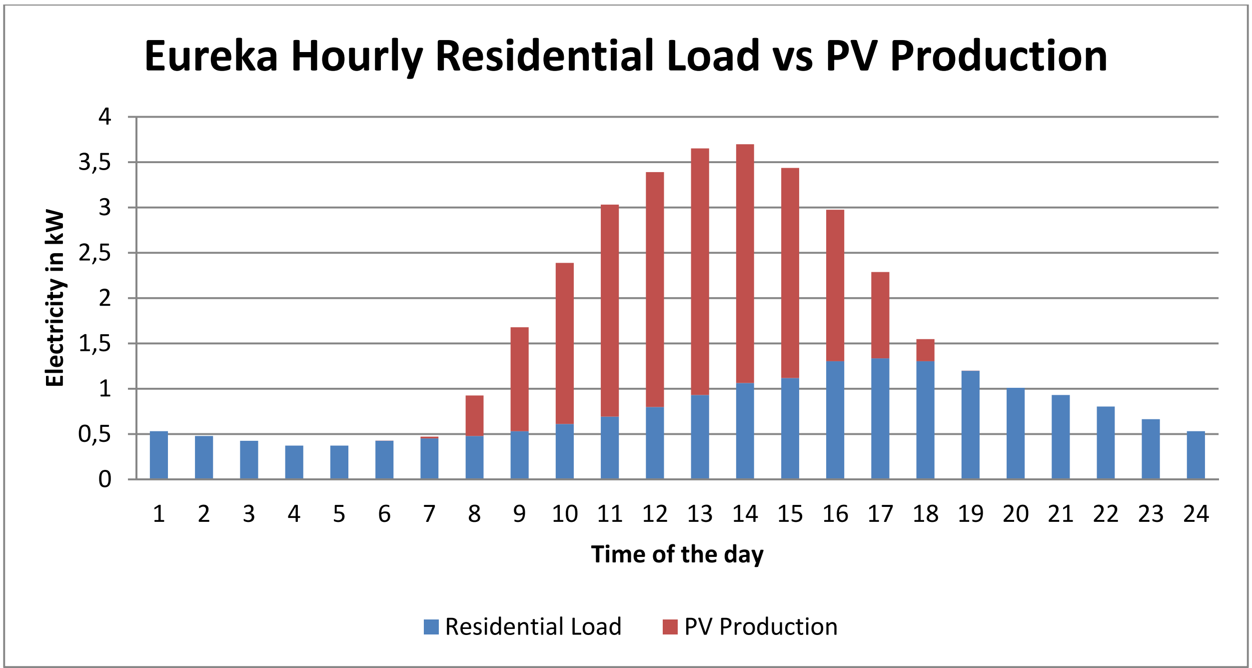


Figure 5-7Eureka Hourly Residential Load vs PV Production

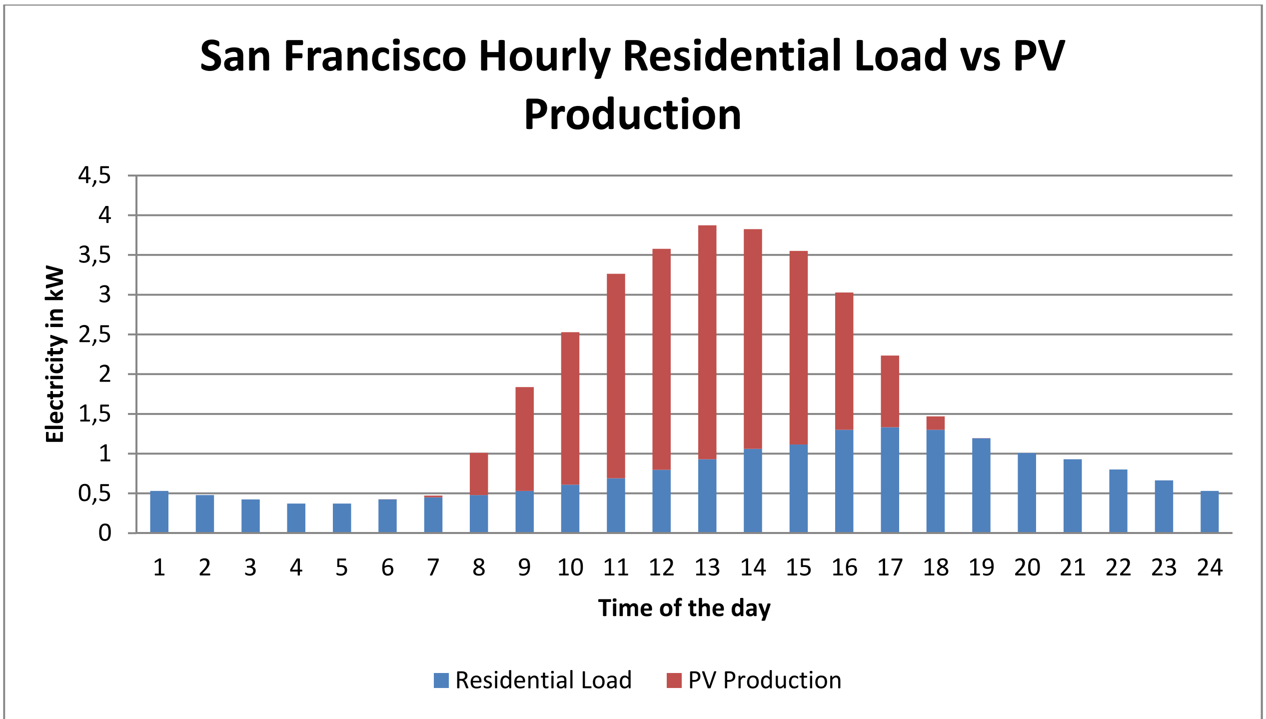
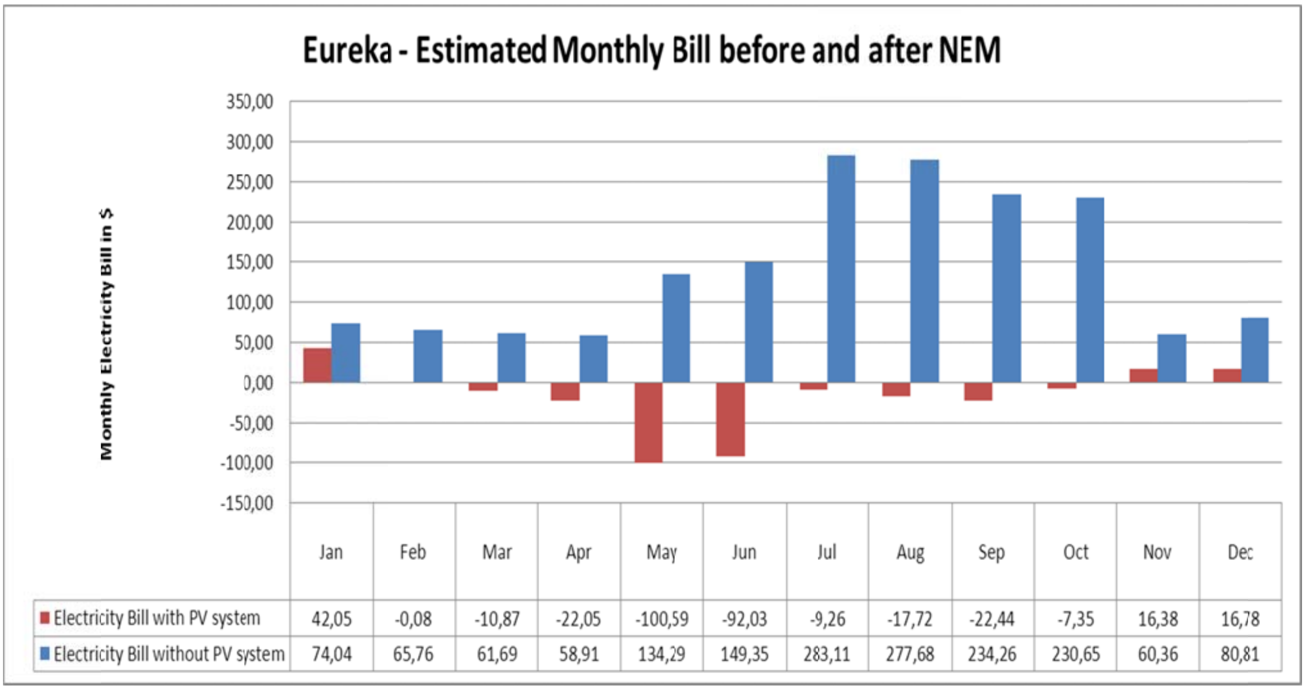


Figure 5-8SanFrancisco Hourly Residential Load vs PV Production

NEM Benefits

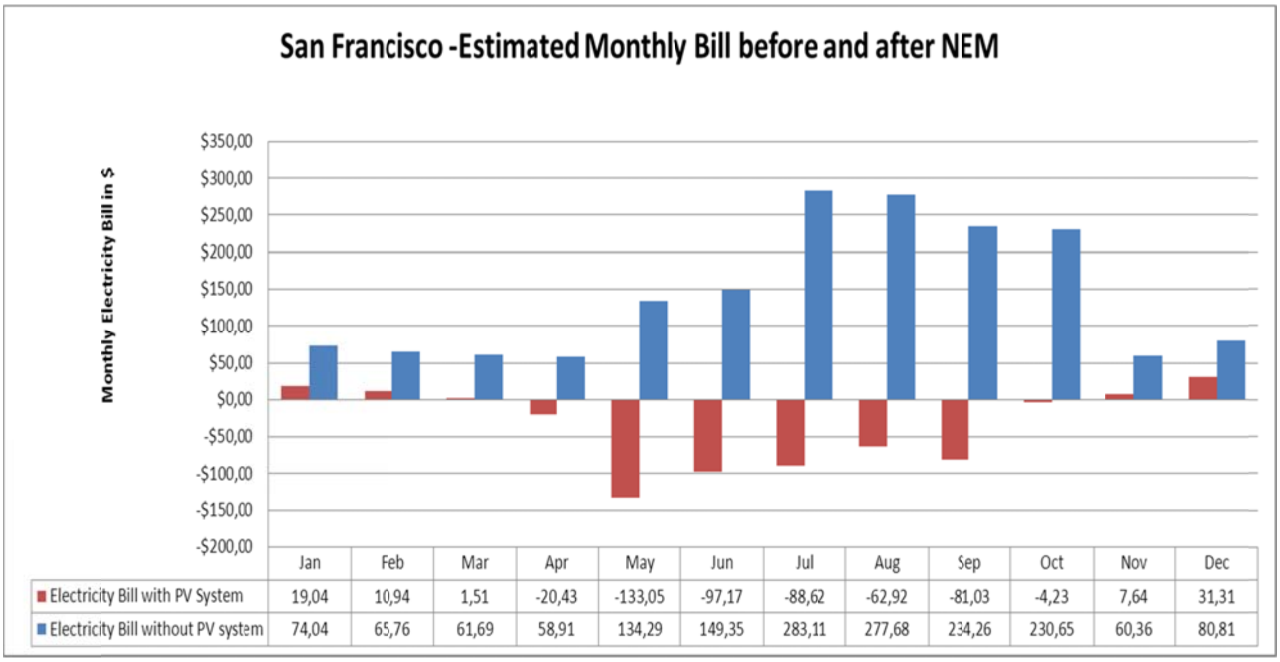
Using the calculation steps mentioned in section0, we get the NEM benefits as follows:



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity Bill with PV system	42,05	-0,08	-10,87	-22,05	-100,59	-92,03	-9,26	-17,72	-22,44	-7,35	16,38	16,78
Electricity Bill without PV system	74,04	65,76	61,69	58,91	134,29	149,35	283,11	277,68	234,26	230,65	60,36	80,81

Figure 5-9 Eureka Estimated Monthly Bill before and after NEM

From the graph we see that the net bill savings made for a year for Eureka is $ 1,918 and the annual electricity bill after installing a PV system is - $ 207.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Electricity Bill with PV System	19,04	10,94	1,51	-20,43	-133,05	-97,17	-88,62	-62,92	-81,03	-4,23	7,64	31,31
Electricity Bill without PV system	74,04	65,76	61,69	58,91	134,29	149,35	283,11	277,68	234,26	230,65	60,36	80,81

Figure 5-10SanFrancisco Estimated Monthly Bill before and after NEM

From the graph we see that the net bill savings made for a year for San Francisco is $ 2,127 and the annual electricity bill after installing a PV system is - $ 417.

5.1.5 Levelized Cost of Electricity

In order to calculate the LCOE for California, the following input variables were calculated making use of values and assumptions made in section 0and steps from section0 and 0.

Eureka and SanFrancisco Input Data for LCOE

Input Variable	Eureka	SanFrancisco
Cost of the System (Without Rebates and Tax Credit)	$ 39,039.15	$33,444.72
CSI Rebate Value	$ 3,060.97	$ 2,622.32
Federal Tax Credit	$ 10,793.45	$ 9,246.72
Net System Cost (Including Rebate and Tax Credit)	$ 25,184.72	$ 21,575.68
System Financing	70% debt ; 30% Equity	70% debt ; 30% Equity
Cost of Debt (Nominal)	6.4%	6.4%
Tax Rate	34.3%	34.3%
Cost of Equity (Nominal)	7.2%	7.2%
WACC (Nominal)	5.10%	5.10%
Cost/Watt (2010)	$ 8.29	$ 8.29
Lifetime	25 years	25 years

Table 5-2Input Data for LCOE calculations for Eureka and SanFrancisco

On calculation, we have the Levelized cost of electricity for the systems under consideration at Eureka and SanFrancisco as follows

LCOE	$/kWh
Eureka	0.30
SanFrancisco	0.24

Table 5-3LCOE for Eureka and SanFrancisco

5.1.6 Grid Parity

As discussed in chapter 3, grid parity is achieved when the LCOE of a given system reaches retail electricity price (REP) value. From section 0we have the REP value for the year 2010 for PG&E territory. Historic trends show PG&E has a 4% increase in REP each year. Against these assumptions and values we see when GP is reached for the individual systems installed in 2010 in Eureka and SanFrancisco.

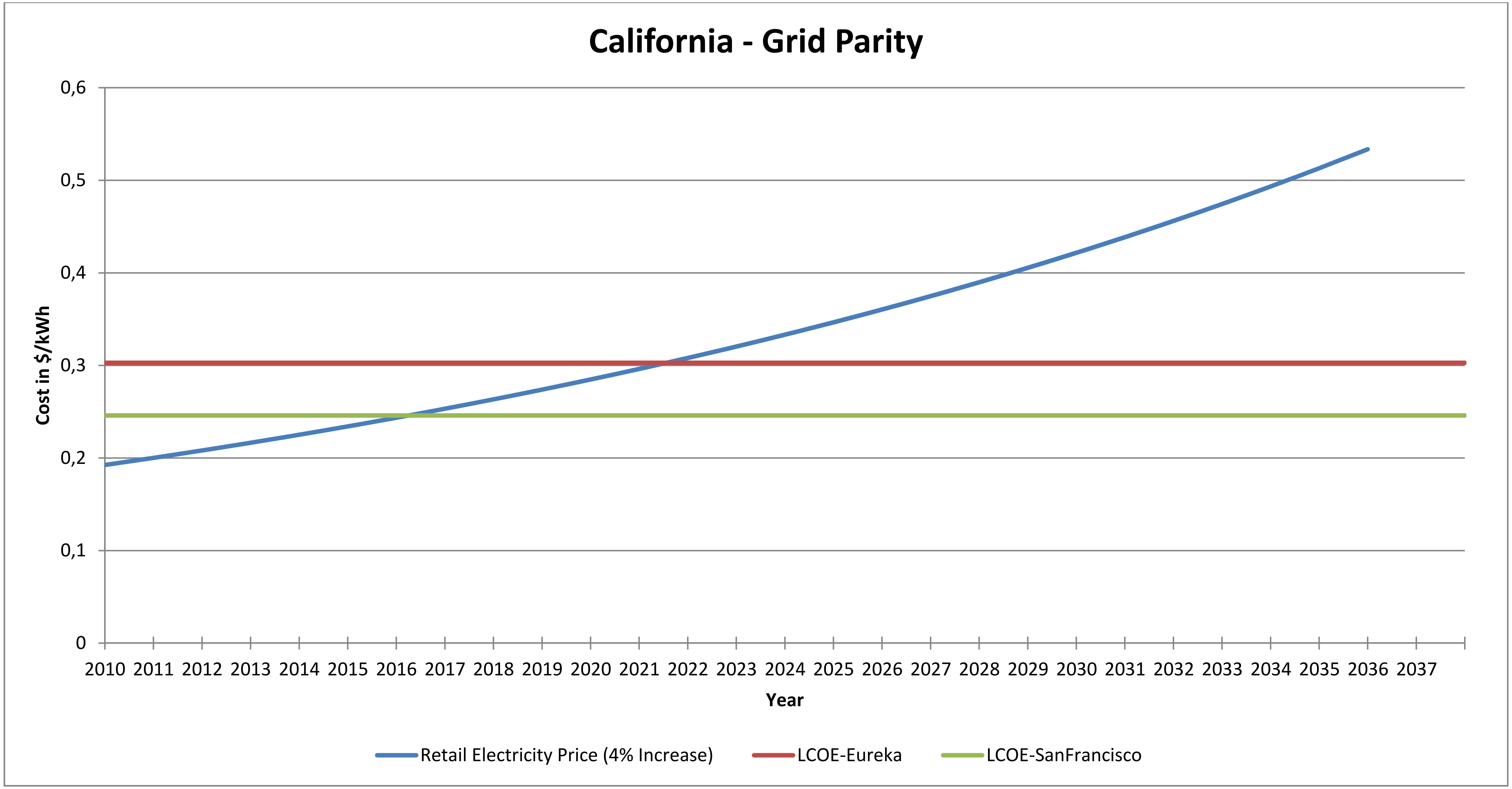


Figure 5-11IGP for Solar PV systems in Eureka and SanFrancisco

From the graph we can point put that IGP is reached for Eureka between the years (2021-2022) and for San Francisco between the years (2016-2017).

5.1.7 Discounted Savings Model

The discounted savings yielded from DSM for the two systems under consideration making use of the formula specified in section 0 and specifications from 0 is as below:

Retail Electricity Price Increment		**4%**
Discounted Savings ($/kWh)	Eureka (WACC=5.10%)	6.01
	SanFrancisco (WACC=5.10%)	7.97

Table 5-4California Discounted Savings for Solar PV installation considered in the Study under NEM

We see from this table that a net positive discounted savings is observed for the two systems considered in California under NEM policy instrument.

Total net discounted savings made by the residential investor for the two locations is given below:

Net Discounted Savings ($)	**Eureka**	**40,351**
	SanFrancisco	**53,510**

Table 5-5 California Net Discounted Savings for Solar PV installation considered in the Study under NEM

The net discounted savings in obtained by multiplying the discounted savings ($/kWh) with the annual electricity consumption value for California which is 6,714 kWh. Thus the value obtained in table 7-5 is the savings made over the lifetime of the system which is 25 years.

5.2 Results – Germany

This section presents the results for the theory and methodology discussed in the previous chapter pertaining to the techno-economic analysis of a solar PV system in Germany. The first few parts of the section will layout the LCOE calculations for Germany for solar PV systems in Berlin and Munich and the next part will use the LCOE to check when individual grid parity is reached for the solar PV systems for both the locations. Lastly the DSM values will be presented.

5.2.1 Load Profile

The load profile will help us determine how much of the PV system production can be self-consumed with and without battery system.

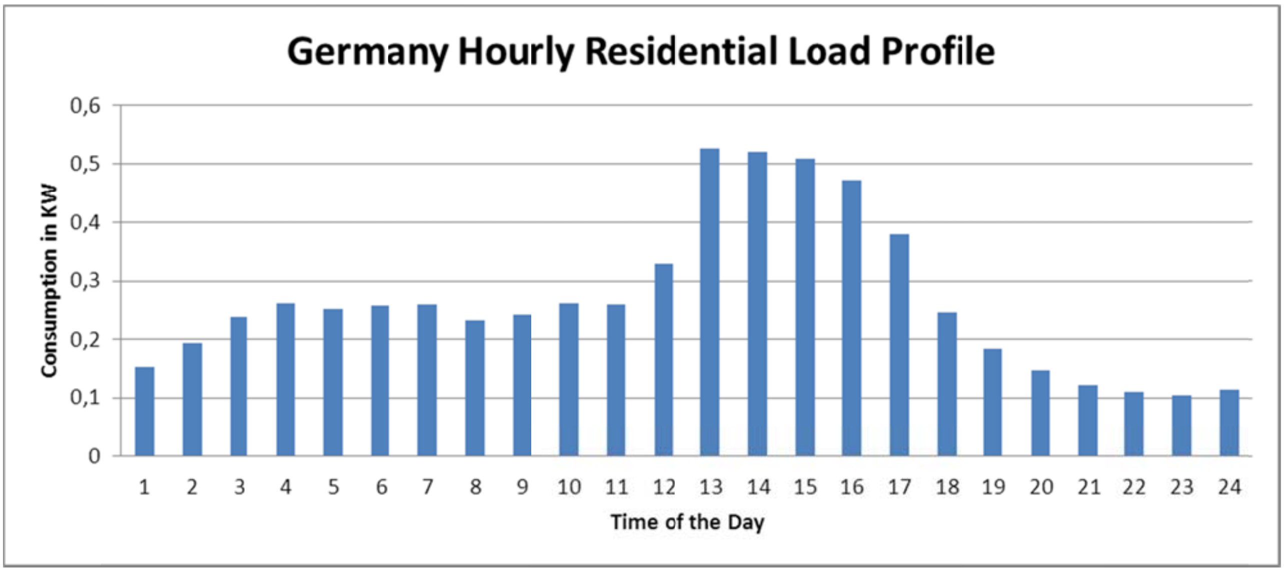


Figure 5-12Germany's Hourly Residential Electricity Load Profile

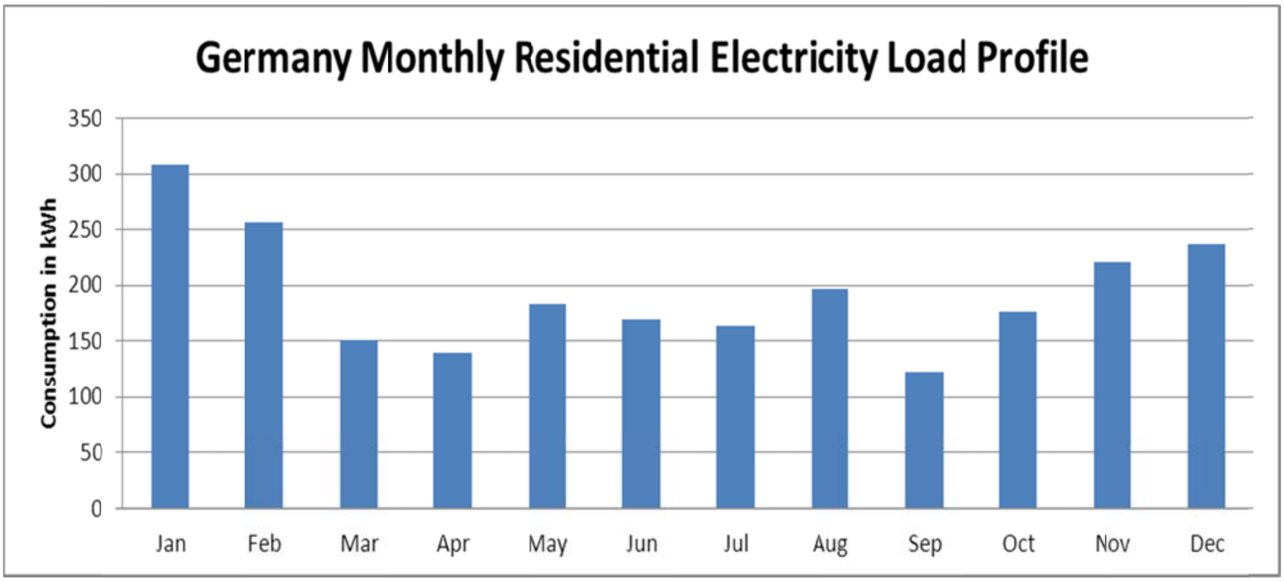


Figure 5-13Germany's Monthly Residential Electricity Load Profile

The average yearly residential electricity consumption for the year 2010 in Germany is 2,326 kWh/year, making the average monthly residential electricity consumption approximately 195 kWh/year. (ISE, 2012).

The load profile determined will be used as the standard base for all the locations chosen under this study from Germany.

5.2.2 System Size

The solar PV system size for the two locations chosen in Germany is determined using the steps mentioned in section0. The table below gives you the average size of the system for Berlin and Munich.

Location	Average Solar Insolation ($kWh/m^2/day$)	System Size –AC (kW)	System Size –DC (kW)
Berlin	2.95	6.6	8.5
Munich	3.39	6.6	8.5

Table 5-6Solar PV System Size for Berlin and Munich

5.2.3 PV Production

The PV production determined using PV WATTS for Berlin and Munich for their corresponding system sizes and solar insolation ranges from 6,411 kWh/year to 7,555 kWh/year. The graphs below represent the hourly and monthly production.

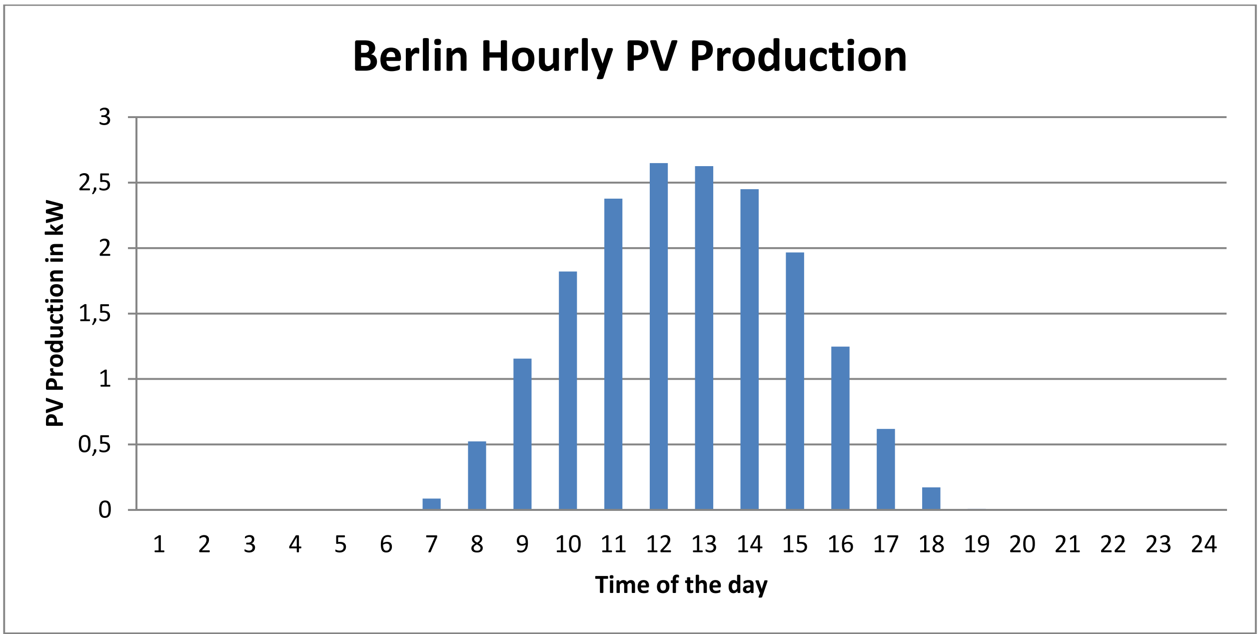


Figure 5-14Berlin Hourly PV Production for System Size- 6.6 kW-AC

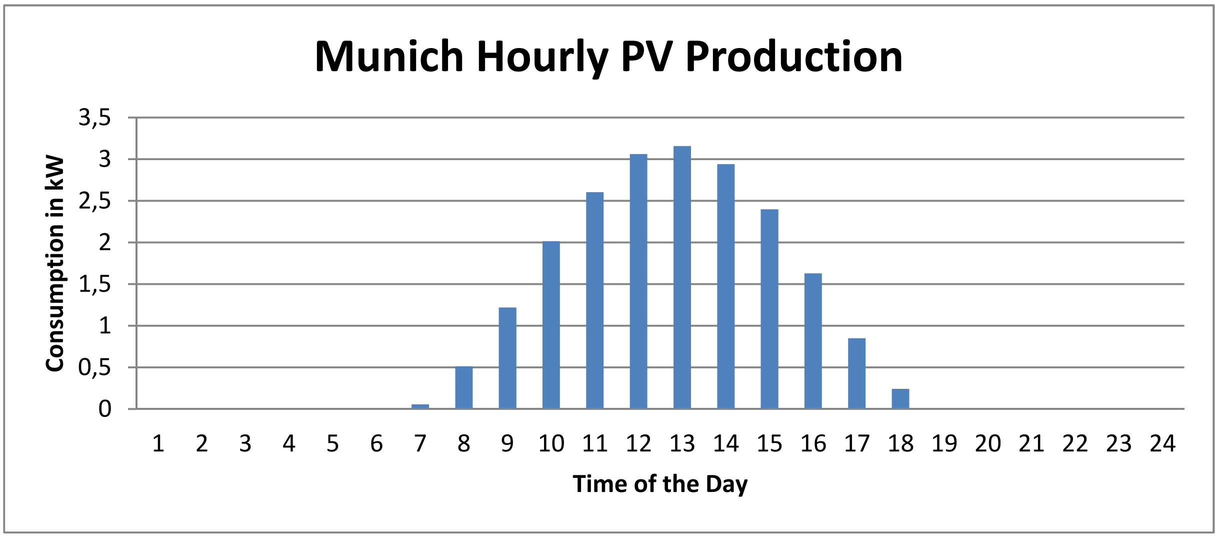


Figure 5-15 Munich Hourly PV Production for System Size- 6.6 kW-AC

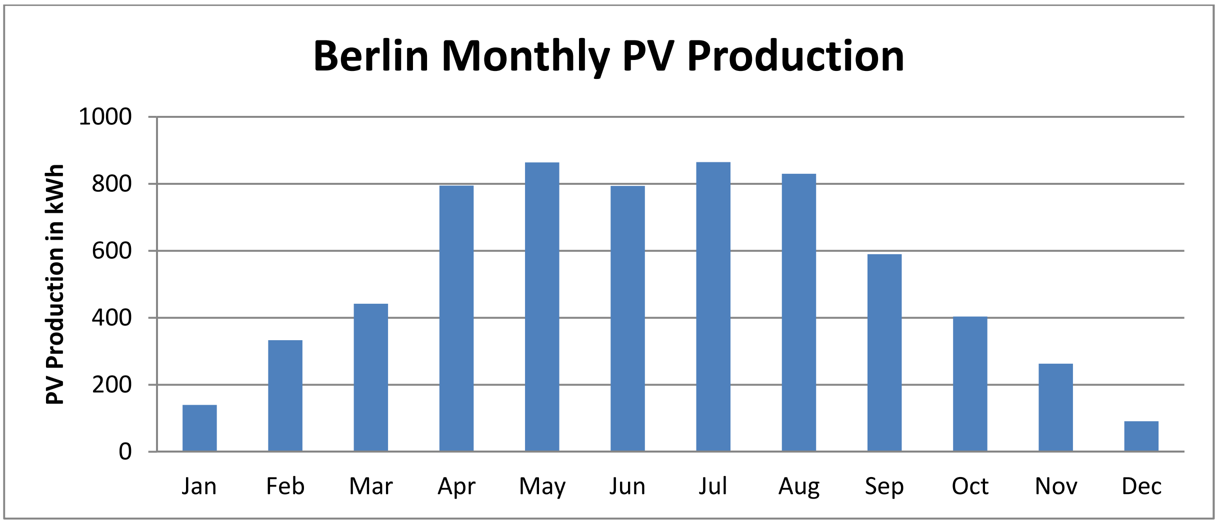


Figure 5-16Berlin Monthly PV Production for System Size- 6.6 kW-AC

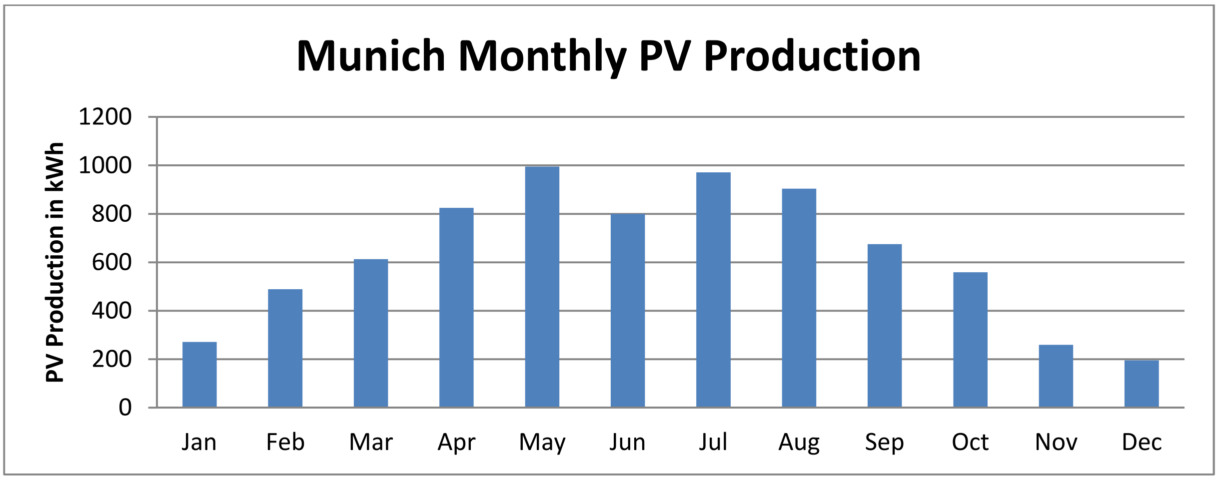


Figure 5-17Munich Monthly PV Production for System Size- 6.6 kW-AC

5.2.4 Levelized Cost of Electricity

In order to calculate the LCOE for Germany, the following input variables were calculated making use of values and assumptions made in section 20 and steps from section 0 and 0.

Berlinand Munich Input Data for LCOE

Input Variable	Berlin	Munich
Cost of the System	$ 24716	$24716
System Financing	70% debt ; 30% Equity	70% debt ; 30% Equity
Cost of Debt (Nominal)	4%	4%
Tax Rate	34.3%	34.3%
Cost of Equity (Nominal)	10%	10%
WACC (Nominal)	4.17%	4.17%
Cost/Watt (2010)	$ 3.74	$ 3.74
Lifetime	25 years	25 years

Table 5-7Input Data for LCOE calculations for Berlin and Munich

On calculation, we have the Levelized cost of electricity for the systems under consideration at Berlin and Munich as follows

LCOE	$/kWh
Berlin	0.29
Munich	0.24

Table 5-8LCOE for Berlin and Munich

5.2.5 Grid Parity

As discussed in chapter 3, grid parity is achieved when the LCOE of a given system reaches retail electricity price (REP) value. From section 2.2.6.1we have the REP value for the year 2010 for Germany. Assuming a 3% increase in REP each year we check when Grid Parity is reached for the individual systems in Berlin and Munich.

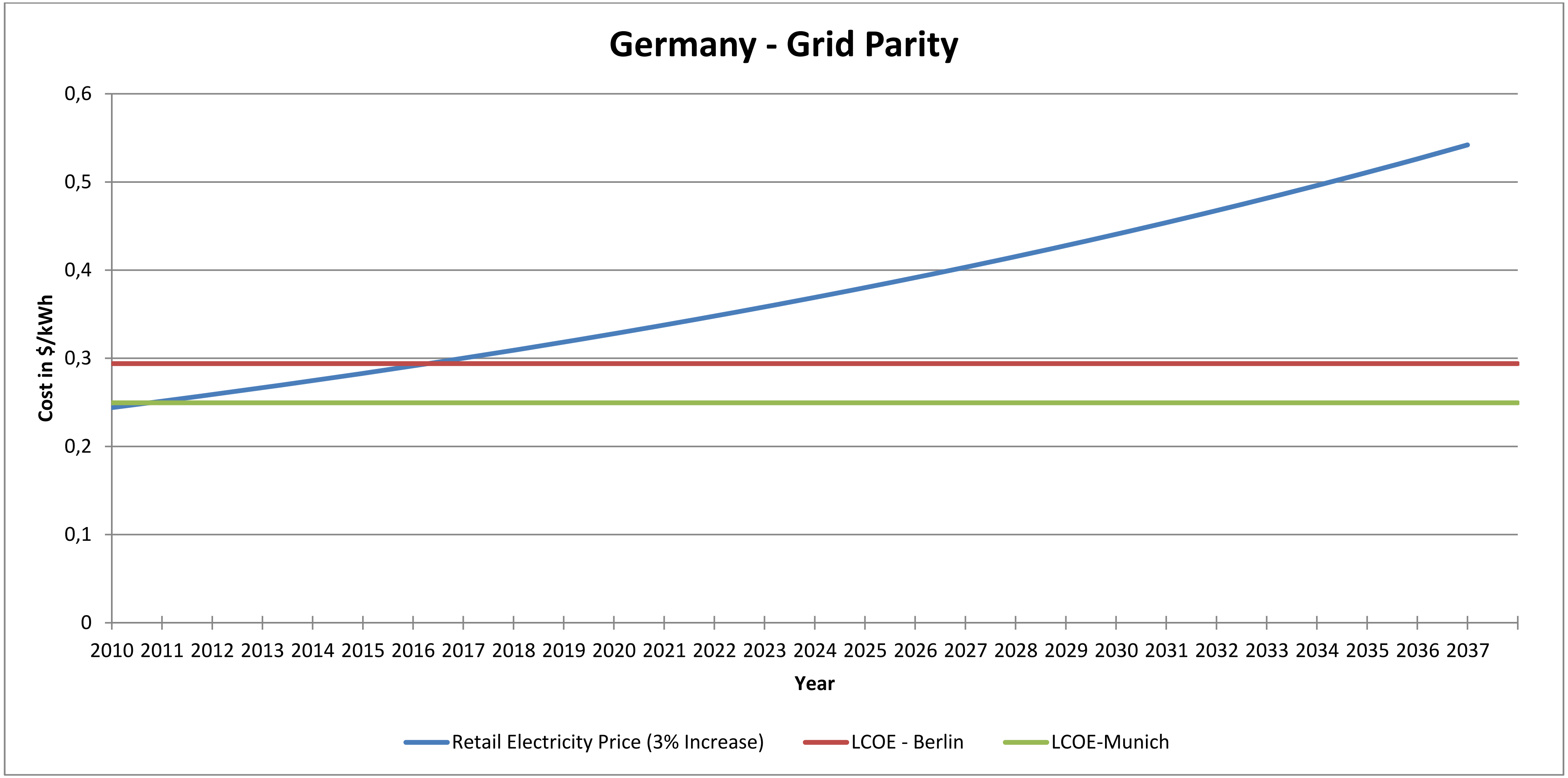


Figure 5-18IGP for Solar PV systems in Berlin and Munich

From the graph we can point put that IGP is reached for Berlin between the years (2016-2017) and for Munich between the years (2010-2011).

5.2.6 Discounted Savings Model

The discounted savings yielded from DSM for the two systems under consideration making use of the formula specified in section 0 and specifications from 0 is as below:

Germany FiT

Retail Electricity Price Increment		3%
Discounted Savings ($/kWh)	Berlin (WACC=4.17%)	1.92
	Munich (WACC=4.17%)	5.06

Table 5-9 Germany Discounted Savings for Solar PV installation considered in the Study under FiT

We see from this table that a net positive discounted savings is observed for the two systems considered in Germany under the FiT policy instrument.

Total net discounted savings made by the residential investor for the two locations is given below:

Net Discounted Savings ($)	Berlin	4,465
	Munich	11,769

Table 5-10 Germany Net Discounted Savings for Solar PV installation considered in the Study under FiT

Germany – FiT Self Consumption without battery system (FiT-Self)

Retail Electricity Price Increment		3%
Discounted Savings ($/kWh)	Berlin (WACC=4.17%)	2.77
	Munich (WACC=4.17%)	5.65

Table 5-11 Germany Discounted Savings for Solar PV installation considered in the Study under FiT-Self

We see from this table that a net positive discounted savings is observed for the two systems considered in Germany under the FiT-Self policy instrument.

Total net discounted savings made by the residential investor for the two locations is given below:

Net Discounted Savings ($)	Berlin	6,443
	Munich	13,141

Table 5-12 Germany Net Discounted Savings for Solar PV installation considered in the Study under FiT-Self

The net discounted savings in obtained by multiplying the discounted savings ($/kWh) with the annual electricity consumption value for Germany which is 2,326 kWh. Thus the value obtained in table 8-5 and 8-7 is the savings made over the lifetime of the system which is 25 years.

5.3 Results -California vs. Germany

This sectionpresents the results of the sensitivity analysis performed on the techno-economic analysis of California and Germany. The first parts of this section will compare the sensitivity results for the LCOE calculations for California and the second part will present the results of the sensitivity analysis of discounted savings model for California and Germany. From the sensitivity analysis we can compare the solar PV systems for these two regions based on the various independent variables.

5.3.1 LCOE –Sensitivity Analysis

A sensitivity analysis is performed to calculate the LCOE with varying cost/W pricing of the solar system and with varying WACC values. As both these parameters have the highest influence on the LCOE, they have been chosen for the sensitivity analysis.

5.3.1.1 California LCOE-Sensitivity

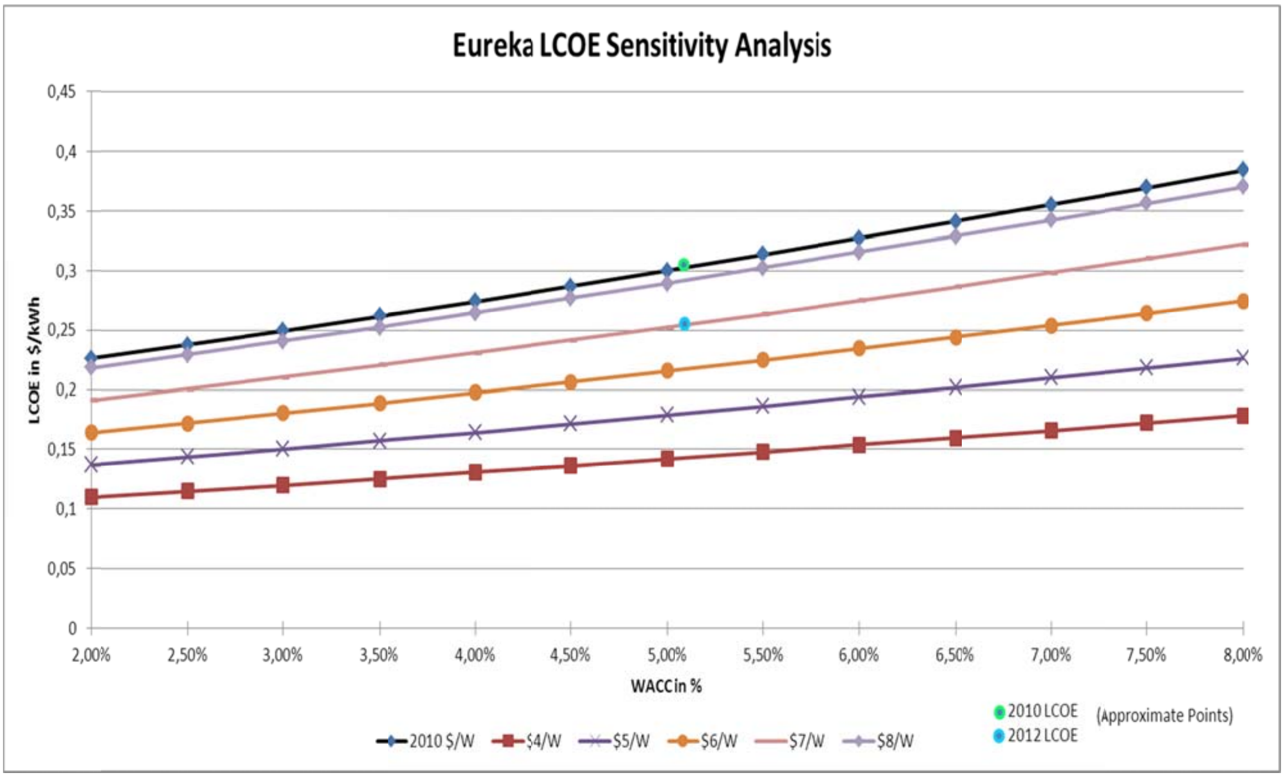


Figure 5-19Eureka LCOE Sensitivity Analysis

The graph shows a comparative variation of LCOE along with varying system pricing and WACC values. Two points have been highlighted in the graph, which indicates the approximate LCOE for the solar PV systems considered for the year 2010 and 2012. The points have been approximated for the same WACC value for both the years, thus giving the reader a direct comparative analysis.

In the similar manner, the forthcoming sensitivity analysis graphs are presented for the locations that have been chosen in the study.

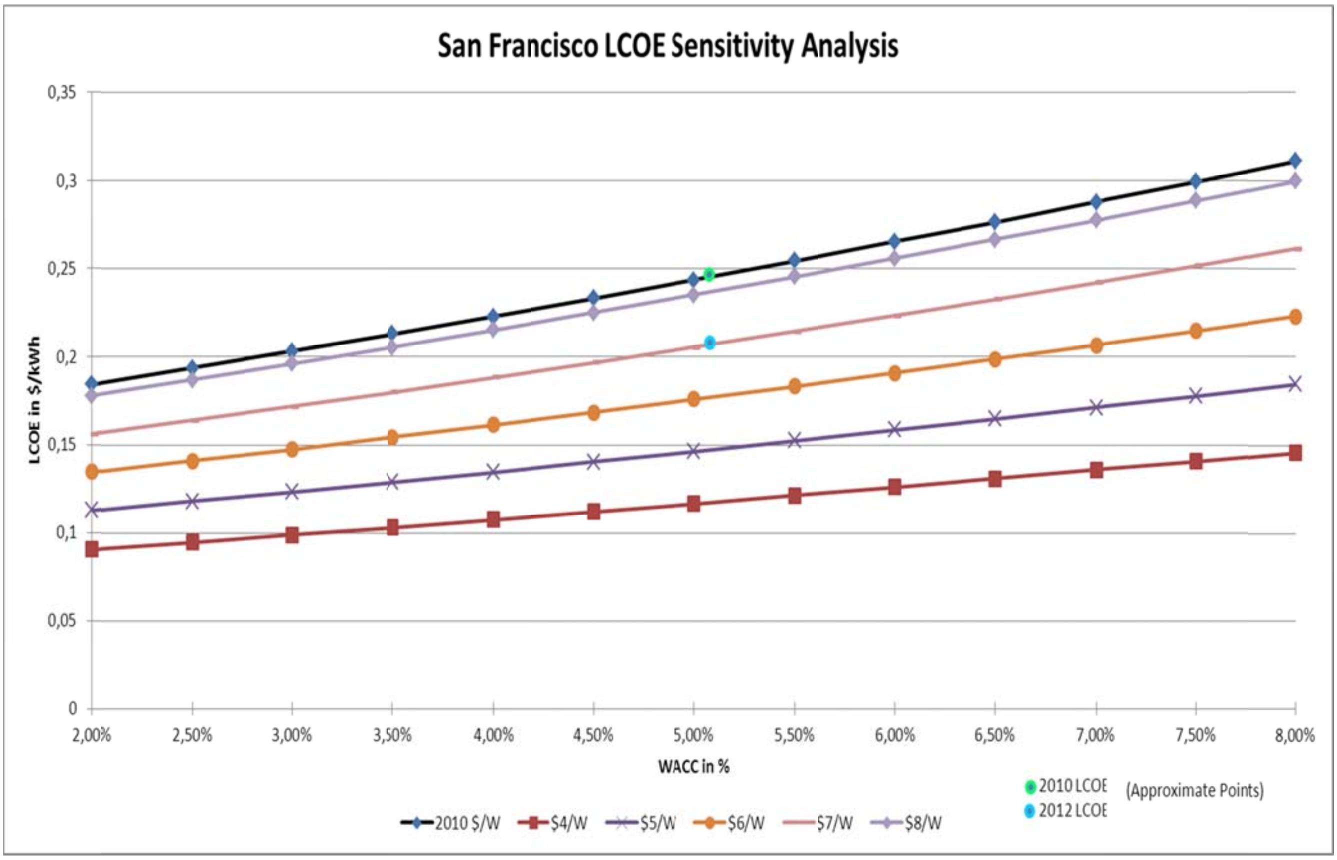


Figure 5-20SanFrancisco LCOE Sensitivity Analysis

5.3.1.2 Germany LCOE-Sensitivity

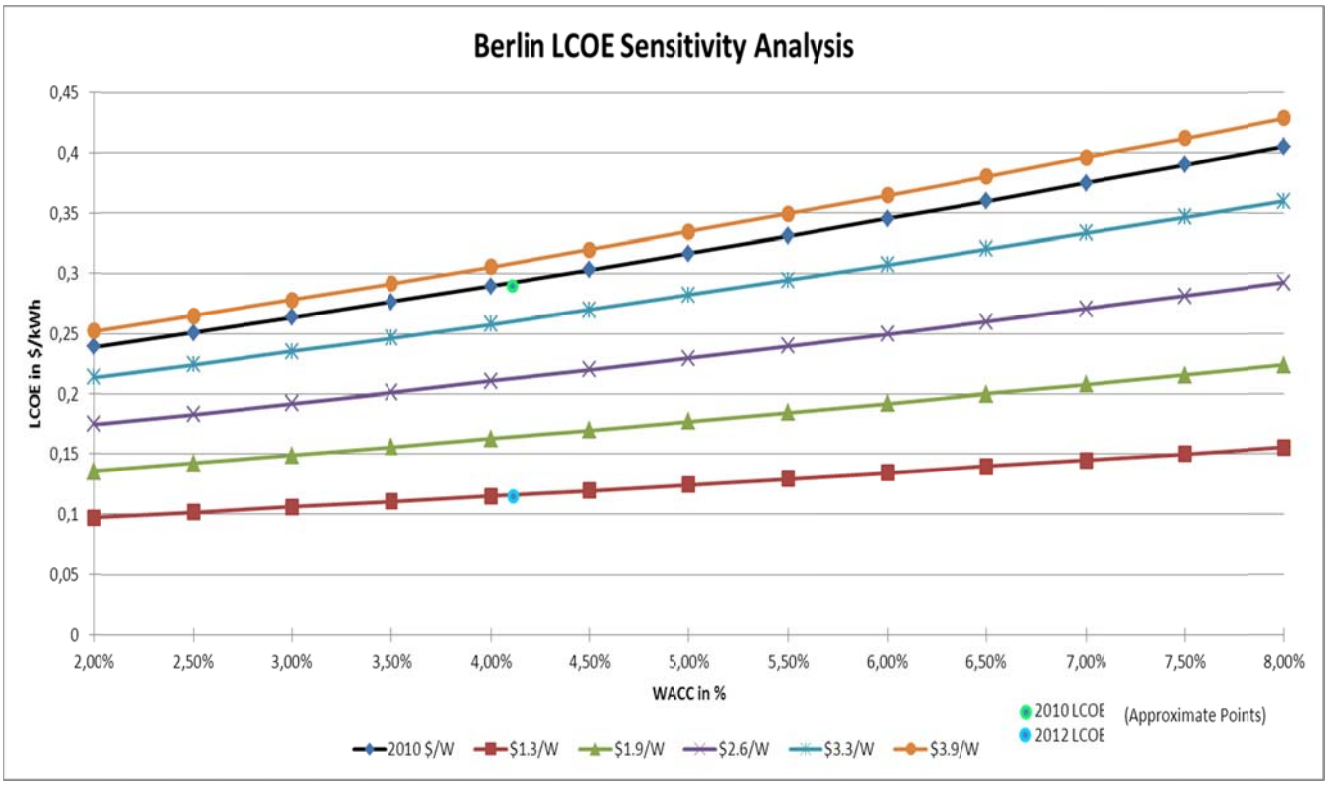


Figure 5-21Berlin LCOE Sensitivity Analysis

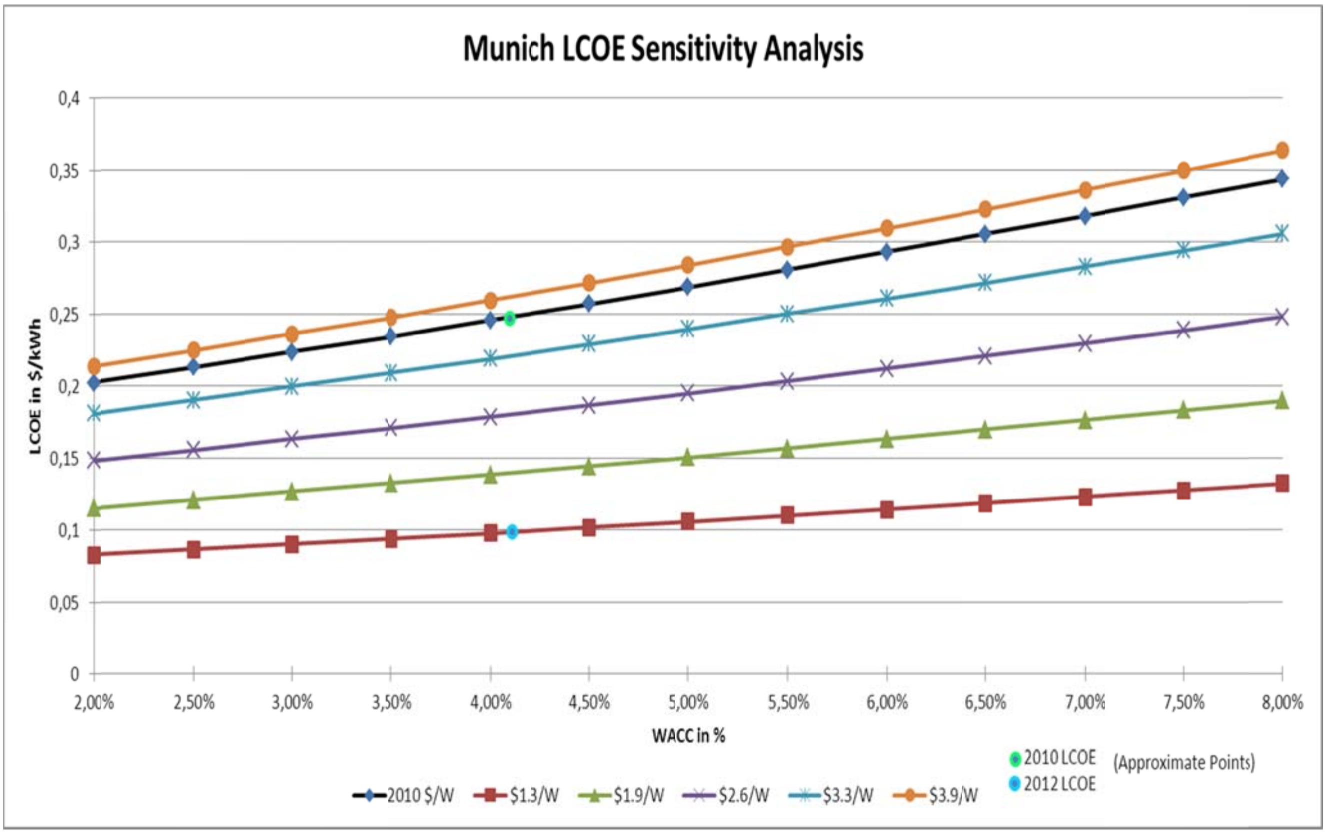


Figure 5-22Munich LCOE Sensitivity Analysis

The additional sensitivity analysis performed in the case of Germany as mentioned before in section 0is to calculate a new LCOE for the solar PV system installations in Germany and to use it to check variation in discounted savings made. A study at hand has been used in order to check the benefits made by the customer, if the self-consumption percentage is increased making use of a battery system. Under the assumption that a lithium ion battery costs $400/kWh, 11 kWh battery size the LCOE value is :(Sabo, 2011)

LCOE – With Battery	**$/kWh**
Berlin (WACC=4.17%)	0.35
Munich (WACC=4.17%)	0.29

Table 5-13 LCOE with Battery for Berlin and Munich

5.3.2 DSM –Sensitivity Analysis

The sensitivity analysis is conducted to check for variation in discounted savings made by the solar PV system considered in this study for varying WACC values and retail electricity price increment.

5.3.2.1 California

Retail Electricity Price Increment in %		**2%**	**2.5%**	**3%**	**3.5%**	**4%**	**3% increase for first 10 years and later constant**
Discounted Savings ($/kWh)	Eureka (WACC=5.10%)	4.86	5.11	5.39	5.69	6.01	4.82
	Eureka (WACC – 2% to 8%)	(7-3.62)	(7.43-3.79)	(7.89-3.97)	(8.39-4.16)	(8.93-4.36)	(6.85-3.63

	San Francisco (WACC=5.10%)	6.44	6.78	7.15	7.55	7.97	6.40
	San Francisco (WACC – 2% to 8%)	(9.29-4.80)	(9.86-5.03)	(10.47-5.26)	(11.13-5.52)	(11.84-5.79)	(9.09-4.82)

Table 5-14California Discounted Savings Sensitivity Analysis for Solar PV installation considered in the Study under NEM

5.3.2.2 Germany

5.3.2.2.1 Germany-FiT

Discounted Savings	($/kWh)
Berlin (WACC=4.17%)	1.92
Munich (WACC=4.17%)	5.06

Table 5-15Germany Discounted Savings Sensitivity Analysis for Solar PV installation considered in the Study under FiT

The retail electricity does not have influence in this calculation as the customer is selling all the generated power to the grid. Thus we see in the graph below the variation in discounted savings made for different WACC values. [5]

5.3.2.2.2 Germany- FiT Self Consumption

Germany – FiT Self Consumption without battery system (FiT-Self):

Retail Electricity Price Increment in %		2%	2.5%	3%	3.5%	4%	3% increase for first 10 years and later constant
Discounted Savings ($/kWh)	Berlin (WACC=4.17%)	2.67	2.72	2.77	2.82	2.88	2.66
	Berlin (WACC – 2% to 8%)	(3.42-1.84)	(3.49-1.86)	(3.56-1.89)	(3.63-1.92)	(3.72-1.95)	(3.30-1.34)
	Munich (WACC=4.17%)	5.57	5.61	5.65	5.70	5.75	5.56
	Munich (WACC – 2% to 8%)	(7.11-3.86)	(7.16-3.88)	(7.23-3.90)	(7.29-3.93)	(7.37-3.96)	(6.87-2.76)

Table 5-16Germany Discounted Savings Sensitivity Analysis for Solar PV installation considered in the Study under FiT-Self

When self-consumption option is factored in the net savings made per kWh of electricity consumed by the solar PV customer has increased, when compared to the situation where the customer is only a total exporter of electricity.

Germany – FiT Self Consumption with battery system (FiT-Self+ B)

Based on the new LCOE values presented in section 5.3.1.2 we have the discounted savings with inclusion of a battery system under the assumption 80% of the PV production being self-consumed and 20% being sent to the grid, as follows.

[5] The values obtained are approximate values making an assumption on the amount of PV generation used for self-consumption for the considered battery size.

Retail Electricity Price Increment in %		2%	2.5%	3%	3.5%	4%	3 % increase for first 10 years and later constant
Discounted Savings ($/kWh)	Berlin (WACC=4.17%)	5.82	6.20	6.60	7.03	7.50	5.75
	Berlin (WACC – 2% to 8%)	(7.59-3.89)	(8.13-4.10)	(8.71-4.32)	(9.33-4.56)	(10.01-4.82)	(7.26-3.26)
	Munich (WACC=4.17%)	8.36	8.76	9.13	9.56	10.01	8.29
	Munich (WACC – 2% to 8%)	(10.82-5.66)	(11.35-5.87)	(11.92-6.09)	(12.54-6.32)	(13.20-6.58)	(10.39-4.31)

Table 5-17Germany Discounted Savings Sensitivity Analysis for Solar PV installation considered in the Study-under FiT-Self+ B

With increase in self-consumption rate, the savings made also increase despite the fact that the LCOE for a solar PV system with battery is higher than a solar PV system without battery.

6. Discussions, Conclusion and Policy Advice

This chapter will discuss the observations made from the results of California and Germany and further discuss the effect of the important parameters in determining the end results. The conclusions made from this study will be presented and necessary policy advice for California and Germany will be provided. Lastly the scope for further research is indicated.

6.1 Discussions

The study at hand conducted a comparative case study between California and Germany to evaluate the techno-economic parameters associated for a solar PV system installed in 2010 over a lifetime of 25 years. It is found that the installed capacity of solar power technologies is clearly larger in the case of Germany when compared to California, which when fitted to economics of scale results in a lower pricing of solar PV panels in Germany than California. The pricing of cost/Wp in the case of California is approximately twice as much of Germany. The results of the techno-economic analysis state that despite this price variation in cost/Wp, the LCOE for both the regions are in close proximity. This is observed due to certain policy instruments in the case of California, such as the GM CSI rebates and FTC, which lower the upfront cost of the solar PV system. Further when LCOE was used to determine when grid parity will be reached by the individual solar PV system i.e IGP, we see that the systems in Germany reach grid parity before the system in California, owing to the variation in retail electricity pricing in the respective regions. The time difference noted between the IGP for the two regions is close to six years.

Interestingly when the study compared the benefits made by the solar PV systems in California and Germany, the Californian systems presented more benefits than Germany despite the fact that the system size of California was smaller and more expensive. The discounted savings made by installations in lower insolation regions of California where nine times higher than the ones made in Germany, in the case where the German systems have no self-consumption. Subsequently regions of higher insolation presented a difference close to four times. The discounted savings made by installation when self-consumption was factored in for the German systems, presently California is still making a higher savings which is six times as that of Germany for lower insolation regions and four times in case of higher insolation. A further check on the discounted savings made with a solar PV system in Germany along with a battery storage system, presented Californian savings to be twice as much of Germany for lower insolation regions and thrice in case of higher insolation.

Inclusion of a storage unit facilitates higher benefits for the solar PV investor in Germany. With larger storage units, the savings made in the German case can reach the levels of California and beyond, provided the storage units are economically viable.

The policy instrument of Germany to disseminate solar PV technology in the residential has no set cap on the system size, so logically a customer can install system based on availability of area and with generate savings with or without a storage unit. In the case of California as the system size is locked in relation to the electricity consumption levels, the benefits a solar PV system can make is in a fixed range.

Based on the discussion so far, we see that the main research objective of the study*'Is there a discounted savings effect for a residential solar PV systems installed in California and Germany for the time period 2010-2035?'*has been achieved and that we observe a discounted savings effect for all the solar PV system considered in this study. The secondary objective *'To find out which energy policy instrument is having the highest discounted savings effect'* shows that the Californian solar PV system is most beneficial. This means that the NEM policy instrument leads to more benefits for the residential customer than the FiT with and without self-consumption.

The forthcoming part will discuss the effect of independent variables on these savings.

We observe that with varying cost/Wp and WACC the LCOE values is lower for smaller WACC values. In the year 2010 and 2012 LCOE value for the systems under consideration in California differ by a smaller range while in Germany the range is larger as the cost/Wp reduces at a faster rate for each quarter of the year owing to the market size of the solar PV technology. In the case of DSM, with varying retail electricity prices and WACC, we see that in California and Germany for lower WACC values we observe higher savings and with higher increment in retail electricity prices also we observe higher savings. But in the case of Germany's FiT without self-consumption, retail electricity price increments have not effect. From the discussion on the sensitivity analysis conducted, we see the correlation of the independent variables on the discounted savings model, thus another secondary objective *'To find out how the independent variables contribute towards the discounted savings effect'* of this study was achieved.

Despite California reaping higher benefits to the residential customer, in terms of market growth it is considerably slower and smaller when compared to Germany. Also the official procedure involved in procuring the permissions to apply the policy instruments in the case of the residential customer is more cumbersome for California than Germany. In Germany as only one law dictates the solar PV sector, it is rather simplistic in nature of interconnections involved with procurements. But in the case of California as we have studied, more than one policy instruments can be applied by the residential customer, which makes the task of the customer to follows all the interconnections difficult and time consuming. Further there is no guarantee that the applications filed by the customer will be approved, as few policy instruments are budget oriented which requires more scrutiny by the authorities. With the administrative system in California letting done the chances for a faster acceptance of solar PV, the benefits one can make using a solar PV system is sidelined which intern reflects on the market segment of the solar PV technology.

Moving on to the very core concept that has been considered in this study –Grid Parity, the results obtained in this study show that the solar PV systems make a net discounted benefit over their lifetime. This discounted savings proves that the system is making benefits from day one of installation rather than after reaching grid parity. This leads one to question about the concept of Grid Parity in itself. And in this study the discounted benefits being positive indicate early grid parity. There is a need for a new metric to quantify the benefits of a solar PV system, which needs to emphasize on the benefit of renewable energy technologies over time, rather than a particular point in time. A recent comparative study published, discusses a set of research papers which deal with concepts such as grid parity and LCOE and highlights the fact that grid parity is used as a tool by the promoters of other technologies against solar PV. This is because the concept of grid parity indicates that solar PV is beneficial at a later point in time, but on the contrary it is beneficial from the very beginning, as seen from results obtained in this study.

6.2 Conclusion

With California and Germany determined to promote solar PV technologies the results obtained from this study will help decision makers in the science - policy interface to decide if the technology is competitive with other technologies and that if it is economically viable. Also policy makers will be able to use the results to evaluate the effectiveness of the current policy instruments being used in the case of California and Germany. In the case of regions which want to implement new policy instruments to deploy solar PV technology, the results can be used to decide the most optimally fit policy instrument.

The findings of this study conclude that the solar PV systems, independent of which policy instrument is being applied are economically viable to the investors of residential sector and that the systems installed make a net discounted benefit over its lifetime. This indicates that a solar PV system is competitive from its time of installation and not necessarily dependent on when Grid Parity is reached.

The cost of generating electricity- LCOE, from solar PV is in close proximity for California and Germany despite a large difference in the cost per watt peak pricing.

Amongst the various policy instruments which were reviewed, the Net Energy Metering policy turned out to be the most beneficial to a residential solar PV investor, followed by the Feed in Tariff policy aiding self- consumption and lastly the normal Feed in Tariff.

6.3 Policy Advice

In the case of California, the solar PV systems are heavily subsidized which create a burden on the government in case of investment tax credits and on the IOUs in the case of CSI rebates and NEM's grid maintenance costs. This burden needs to be proportioned and few modifications need to be done in the approach towards the dissemination of solar PV technology. As mentioned earlier the interconnections involved in procurement of permissions for the application of policy instruments for the residential sector is tedious, time consuming and has no guarantee of being accepted. Moreover a customer needs to bear additional consultancy costs as the process involved with interconnection is difficult to understand for a common man. All these put together reduce the chances of a faster growth of the solar PV market leading to the fact that the cost of solar systems is not becoming competitive and thus dependent on heavy subsidization to gain acceptance.

A few modifications than can be done are:

a. Simplify the process involved with interconnection and procurement of the various policy instruments for the residential customer by housing a single authority or agency that unifies all the applications under a single roof.
b. Increase the acceptance of the technology amongst the residential sector customers by speeding up the processes and by providing some assurance that the applications filled properly will come through.
c. Proportion the costs associated with grid maintenance in the case of NEM amongst the user who benefit from NEM, as earnings made are large under this policy. This can ensure a long term existence of this policy.
d. Improve research and development in general and specifically in grid interconnection, to counter technical constraints that may arise due to integration of grid tied solar PV systems.

e. Promote solar PV technology by bringing to light the true benefits that can be made by the customer, such as those found in this study.

In the case of Germany although predominantly a single policy dictates the dissemination of solar PV systems, we see that in the case of Feed in Tariff with incorporation of storage systems the policy reaps more benefits. New concepts such as the merit order effect indicates that the utilities who gain from selling electricity on the spot market due to injection of solar PV generation into the grid at peak hours is not reflected in the incentives being given to customer investing in solar PV technologies. (Frank Sensfuss, 2007). The recommendations provided focuses on how the current policy can enhance the growth of the solar PV market with a few add- ons.

(1) Provide more funding to improve research and development in the field of energy storage systems.
(2) Create a market for storage systems, which will reduce the cost of storage systems over time and help the residential customers to invest in storage systems. This will increase the self-consumption rate and reduce the burden on the grid due to solar PV integration.
(3) Try and club the NEM policy instrument alongside Time of Use payments, to encourage higher self-consumption rate.
(4) Alternatively proportion the benefits made by the merit order effect by the utilities to the end customer which will yield in higher benefits to the investor.

6.4 Future Research Scope

Given the limitations of this thesis, there are few avenues which can be enhanced. The areas which can have continuing research are:

Comparative Analysis:

- More locations can be considered to get a precise picture of how the benefits varying with change in location.
- Different load pattern can be used to check how benefits vary accordingly.
- Detailed analysis on the PV Production vs Load Profile correlation.
- Detailed study on how storage systems can vary the behavior of the residential customer.
- Analysis on the most cost effective storage systems options available for a residential customer.
- Based on different PV technologies available check how benefits change.

Financial Considerations:

- Making use of different financing options to check for variation in benefits made by the investor.
- Also to calculate more accurately the input variables associated with the independent variables.

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Appendices

A. SupportingCalifornia Data

(1) The GM CSI MW Targets by Program Administrator and Customer Class is given in the table below: (CPUC, 2011)

		PG&E (MW)		SCE (MW)		SDG&E (MW)	
Step	MW in Step	Residential	Non-Residential	Residential	Non-Residential	Residential	Non-Residential
1	50	-	-	-	-	-	-
2	70	10.1	20.5	10.6	21.6	2.4	4.8
3	100	14.4	29.3	15.2	30.8	3.4	6.9
4	130	18.7	38.1	19.7	40.1	4.4	9.0
5	160	23.1	46.8	24.3	49.3	5.4	11.0
6	190	27.4	55.6	28.8	58.9	6.5	13.1
7	215	31.0	62.9	32.6	66.3	7.3	14.8
8	250	36.1	73.2	38.0	77.1	8.5	17.3
9	285	41.1	83.4	43.3	87.8	9.7	19.7
10	350	50.5	102.5	53.1	107.9	11.9	24.2
Total	1,750	252.2	512.3	265.6	539.5	59.5	120.8
Total by Utility		764.8		805.0		180.3	
Percentage		43.7%		46.0%		10.3%	

GM CSI MW targets by PA and customer class

(2) A detailed breakup of payment received for each customer class in each step of the two incentive types is given in the table below: (a) Refers to the original rate and (b) refers to the revised rates. (CPUC, 2011)

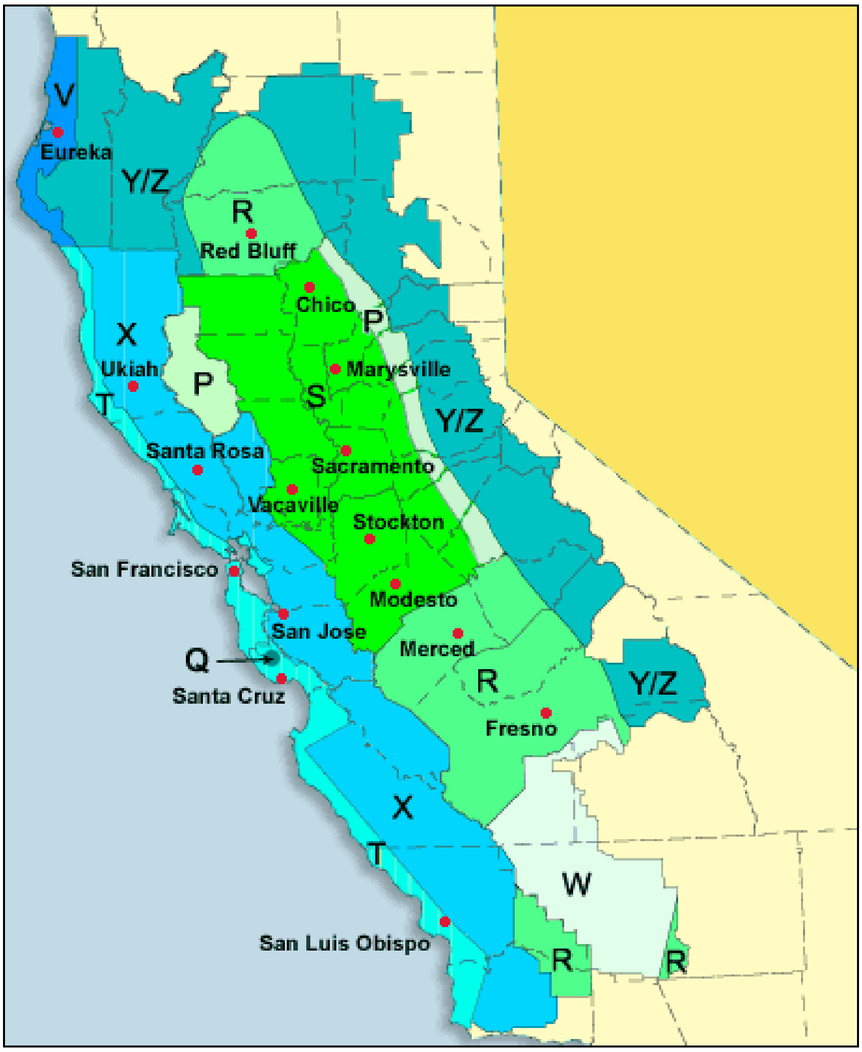
		EPBB Payments (per Watt)			PBI Payments (per kWh)		
Step	**MW in Step**	**Residential**	**Non-Residential**		**Residential**	**Non-Residential**	
			Commercial	**Government / Non-Profit**		**Commercial**	**Government / Non-Profit**
1	50	n/a	n/a	n/a	n/a	n/a	n/a
2	70	$2.50	$2.50	$3.25	$0.39	$0.39	$0.50
3	100	$2.20	$2.20	$2.95	$0.34	$0.34	$0.46
4	130	$1.90	$1.90	$2.65	$0.26	$0.26	$0.37
5	160	$1.55	$1.55	$2.30	$0.22	$0.22	$0.32
6	190	$1.10	$1.10	$1.85	$0.15	$0.15	$0.26
7	215	$0.65	$0.65	$1.40	$0.09	$0.09	$0.19
8	250	$0.35	$0.35	$1.10	$0.05 (a)/$0.044 (b)	$0.05 (a)/$0.044 (b)	$0.15 (a)/$0.139 (b)
9	285	$0.25	$0.25	$0.90	$0.03 (a)/$0.032 (b)	$0.03 (a)/$0.032 (b)	$0.12 (a)/$0.114 (b)
10	350	$0.20	$0.20	$0.70	$0.025	$0.025	$0.088

GM CSI MW incentive based on type and customer class

(3) The map below will give us an idea of the area covered under the various IOUs territories, from which we see that PG&E holds a large share. (CEC, 2012)

California IOUs Territories

(4) A detailed map is given below which gives you the territories within PG&E. (PG&E, 2012)



PG&E Territory

(5) The table below gives you the baseline quantities for all electric appliances termed as (Code H) for each territory of PG&E: (PG&E, 2012)

BASELINE QUANTITIES (kWh per DAY)		
Code H - All-Electric Quantities		
Baseline Territory	Summer Tier 1	Winter Tier 1
P	18.0	33.9
Q	9.1	19.3
R	20.9	30.2
S	18.0	28.6
T	9.1	16.8
V	19.4	33.4
W	23.5	22.8
X	10.3	19.3
Y	14.1	30.7
Z	11.2	22.5

PG&E Baseline Quantities for each Territory

(6) The table below gives you the E6 price schedule for the year 2010: (PG&E, 2012)

Season	Time-of-Use Period	Energy Charge($/kWh) for 2010					Average Rate (per kWh)
		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	
Prices for (JAN-FEB)							
Summer	Peak	$0.30142	$0.31765	$0.45818	$0.58808	$0.65614	$0.18675
	Part-Peak	$0.14865	$0.16488	$0.30541	$0.43531	$0.50337	
	Off-Peak	$0.08700	$0.10324	$0.24376	$0.37366	$0.44173	
Winter	Part-Peak	$0.10319	$0.11942	$0.25994	$0.38984	$0.45791	
	Off-Peak	$0.09112	$0.10736	$0.24788	$0.37778	$0.44585	
Prices for (MAR-MAY)							
Summer	Peak	$0.30142	$0.31765	$0.46807	$0.60711	$0.67996	$0.19122
	Part-Peak	$0.14865	$0.16488	$0.31530	$0.45434	$0.52719	
	Off-Peak	$0.08700	$0.10324	$0.25365	$0.39269	$0.46555	
Winter	Part-Peak	$0.10319	$0.11942	$0.26983	$0.40887	$0.48173	
	Off-Peak	$0.09112	$0.10736	$0.25777	$0.39681	$0.46967	
Prices for (JUN-DEC)							
Summer	Peak	$0.30142	$0.31765	$0.47307	$0.58292	$0.58292	$0.18420
	Part-Peak	$0.14865	$0.16488	$0.32030	$0.43015	$0.43015	
	Off-Peak	$0.08700	$0.10324	$0.25866	$0.36851	$0.36851	
Winter	Part-Peak	$0.10319	$0.11942	$0.27484	$0.38469	$0.38469	
	Off-Peak	$0.09112	$0.10736	$0.26278	$0.37263	$0.37263	

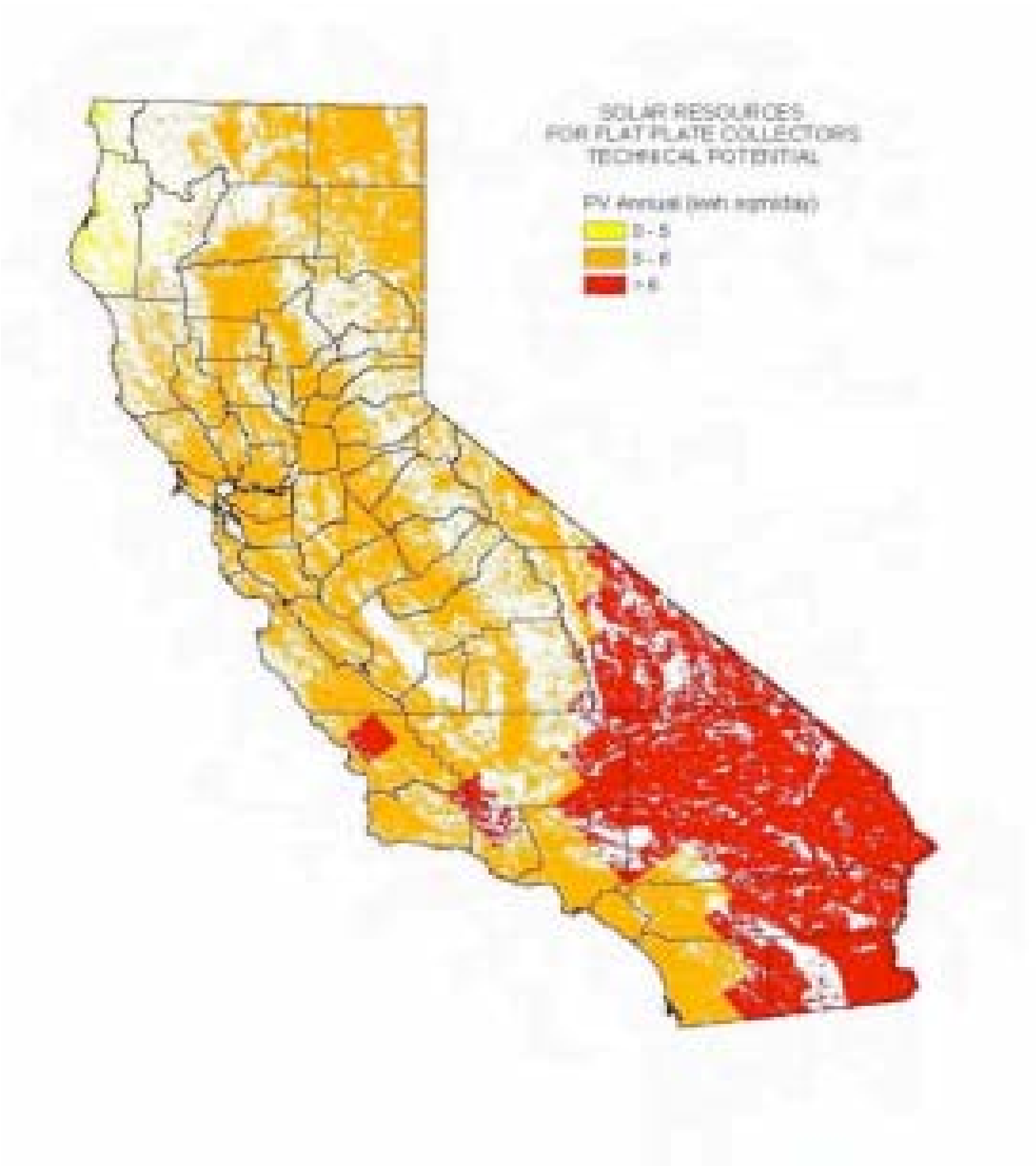
PG&E E6 Electric Rate Schedule for 2010

(7) The time of the day at which these rates apply for E6 is give in the table below: (PG&E, 2012)

E6 Time-of-Use Periods		
Summer (May-October)		
Peak:	1:00 pm to 7:00 pm	Monday through Friday
Partial-Peak:	10:00 am to 1:00 pm	Monday through Friday
	7:00 pm to 9:00 pm	Monday through Friday
	5:00 pm to 8:00 pm	Saturday and Sunday
Off-Peak:	All Other Hours	Including Holidays
Winter (November-April)		
Partial Peak:	5:00 pm to 8:00 pm	Monday through Friday
Off-Peak:	All Other Hours	Including Holidays

PG&E E6 TOU Periods

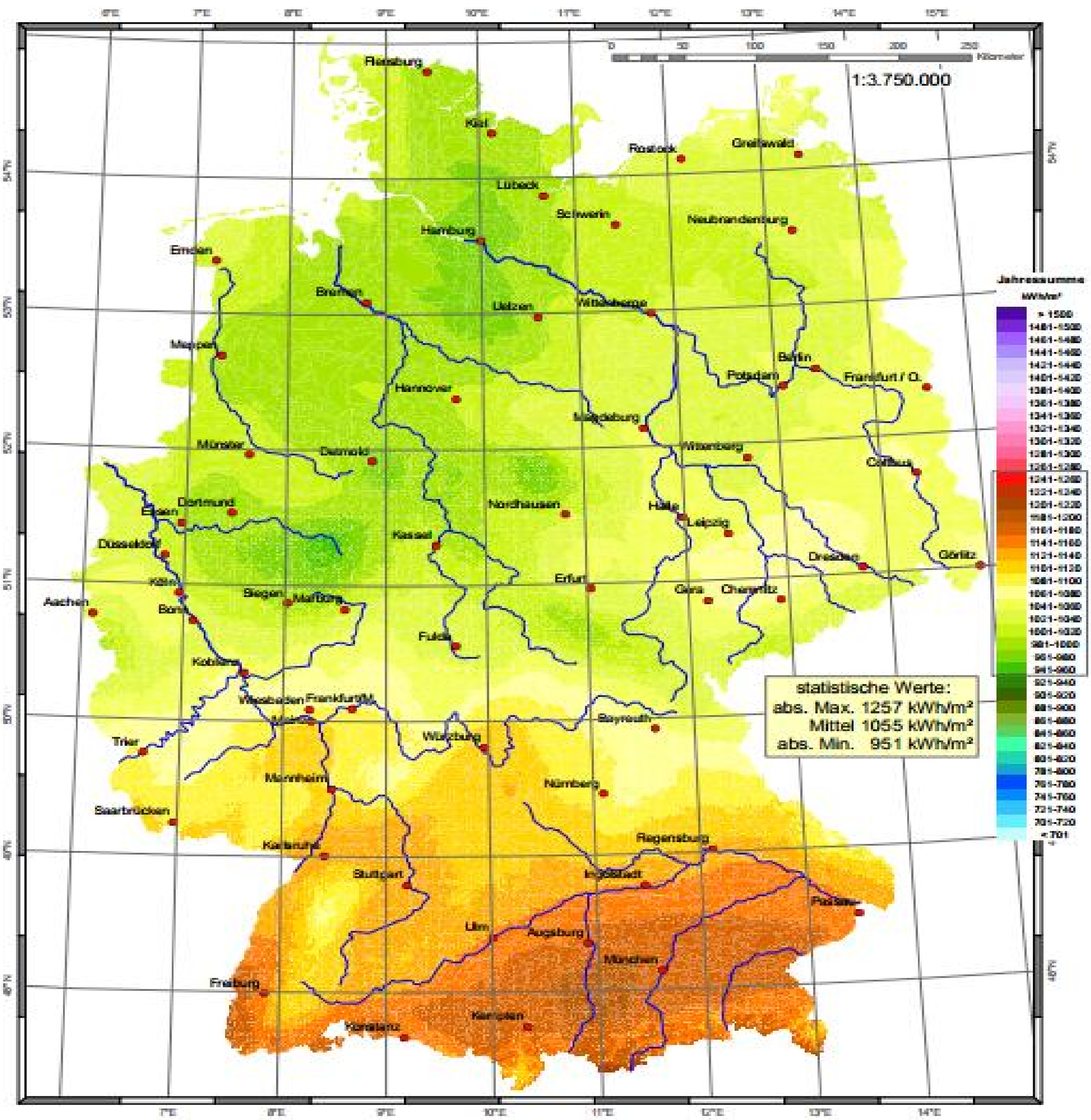
(8) The map presented below will give you the technical potential of solar insolation on a flat plate collector for California.



California Solar Insolation

B. Supporting Germany Data

(1)



Germany Solar Insolation

Statement of Authorship

I, Swetha Ravi Kumar, hereby certify that this Master Thesis project is original work, unless otherwise acknowledged in the text. All references have been properly quoted and all sources of information have been specifically and clearly acknowledged.

Signature:

Name: Swetha Ravi Kumar

Place and Date: Freiburg, 31st July 2012.