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ECONOMIC AND POLICY ANALYSIS FOR SOLAR PV SYSTEMS IN INDIANA

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ECONOMIC AND POLICY ANALYSIS FOR SOLAR PV SYSTEMS IN INDIANA

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ABSTRACT

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In recent years, the energy market in the US and globally is expanding the production of renewable energy. With other energy sources, solar energy for electricity is also expanding in the US. Indiana is one of the states expanding solar energy with solar PV systems. However, the economics of solar PV systems in Indiana have not been analyzed and electricity customers in Indiana are not informed enough about the economics of solar PV systems. Therefore, we conduct benefit cost analysis with several uncertain input variables to determine the economics of adopting solar PV systems in Indiana based on policy instruments that could increase adoption of solar PV systems. The specific objectives of this study are analyses of the cost distribution of solar PV systems compared with grid electricity in homes and on the probability that solar can be less than current electricity from grids under different combinations of policies.

We first do the analysis under current policy options and then do the analysis under potential policy options for a variety of scenarios. With the information addressed in our study, customers can be informed how beneficial or not it would be to adopt solar PV systems in their homes. Also, government can be informed how effective policies can be and how to manage policy options for encouraging solar PV systems.

The results show that the current policies are important in reducing the cost of solar PV systems. However, with current policies, there is only 50-50 chance of solar being cheaper than electricity from grids. However, if potential policies are implemented, solar PV systems can be more economical than electricity from the grids. Thus, it is arguable that government still should implement other policies to encourage people to adopt solar PV systems in Indiana.

CHAPTER 1. INTRODUCTION

1.1. Motivation

1.1.1. Environmental Issue related to Fossil Fuels

Historically, energy production and consumption per capita has been increasing. Most energy has been produced from fossil fuels such as coal, oil, and natural gas. Through the industrial revolution in the past 20th century, the consumption and production of energy rose substantially and, as a result, so did the use of fossil fuels, which are the major energy sources. In addition to the depletion of fossil fuels, fossil fuels are emitting substances such as CO_2 or nitrous oxides which are harmful to the environment (Maslin, 2009). The noxious substances emitted from using fossil fuels attributed to air pollutions and an adverse impact on human health. For air pollution, CO_2 emissions per capita have increased with the rise in use of fossil fuels. According to IPCC (2007), the average surface temperature is predicted to rise by 3 degrees Celsius as the concentration of CO_2 in the atmosphere doubles. This rise in temperature could have disastrous effects on the agricultural and industrial sectors. For human health, air pollution can cause bronchial diseases such as asthma. The pollutants related to the respiratory diseases are NO_2, SO_2, and other particular matter, and these are by-products of burning fossil fuels.

There are many studies that state the positive relationship between the rate of occurrence of respiratory diseases and the levels of pollutants in the atmosphere (Bernstein et al., 2004), (Dockery et al., 1993), (Pope et al., 2009).

Thus, there appears to be a need to switch to sources of energy other than fossil fuels. Alternative energy sources should be clean, in other words, not emitting harmful substances, and sustainable or renewable so that they will not be depleted. Solar, wind, geothermal, and biomass are the major renewable energy sources considered.

1.2. Background

1.2.1. Renewable Energy in the US and Globally

Renewable energy is defined a category of energy sources. Renewable energy usually comes from sources which can be replenished such as sunlight, wind, tides, or geothermal heat. Renewable Energy Policy Network for the 21st Century (REN21) reported that total capacity of renewable energy in the world increased by 8.5% from 2011 to 2012 and exceeded 1,470GW. This accounts for around 26% of global generating capacity and supplies around 21.7% of global electricity at the end of 2012, with 16.5% of electricity provided by hydropower (REN21).

Energy production in the US is categorized by EIA into fossil fuels, nuclear energy, and renewables. In 2011, 11.8% of total energy came from renewable energy sources, 77.6% from fossil fuels, and 10.6% from nuclear. Renewable energy still occupies a small part of total energy. When we look at the growth, however, renewable energy is growing impressively. From 2010 to 2011, renewable energy production increased by 13.5%, while fossil fuels increased only 4.1% and nuclear even decreased by 2.1%. From the beginning of 2000, except 2001 and 2007, renewable energy has continued to increase by 6% on average while both fossil fuels and nuclear energy increased by less than 2% on average. This shows that renewables are increasing faster than fossil fuels and nuclear.

Traditionally, the largest share of renewable energy comes from hydro and biomass. EIA data shows that, in 2011, 34.4% and 48.9% of renewable energy come from hydro and biomass, respectively. On the other hand, solar PV and wind account only for 1.7% and 12.7% of total renewable energy production, respectively. However, when we look at growth from 2010 to 2011 of each renewable energy source, solar PV and wind show 26% and 27% growth rates, respectively. These are two highest growths among renewable energy sources. Biomass shows only 4% increase over the same period. With the advancement of technology for making use of renewable energy sources, it becomes more attractive to adopt renewable energy equipment such as wind or solar PV systems than ever before. Thus, we are going to examine wind and solar PV energy sources in the US in detail.

1.2.1.1. Penetration of Wind (Global and US)

Wind power is expanding fast to new markets in the world. REN21 reports that, during 2012, almost 45GW of wind power came into operation bringing global wind capacity to 283GW. The increase in wind capacity is more than any other renewable energy source, and the total global wind power capacity at 2012 year-end is enough to meet 2.6-3% of global electricity consumption. For several countries in Europe, wind power capacity is higher; for example, Denmark (30% in 2012), Portugal (20% in 2012), Spain (16.3%, 2012) (REN21). China and the US together account for 60% of the global market in 2012, followed by Germany, Spain, and India. The United Kingdom, Italy, France, and Canada are also in the largest markets of wind power. Even if more than 85% of global wind capacity was accounted for by 10 leading countries, the wind market is broadening with smaller scale turbines. The average annual growth of global wind power capacity from 2007 and 2012 is 25%, and this has been led by the US.

The United States is yet the second largest wind power market with 60GW operating at 2012 year-end following China with 75GW, but its growth in 2012 is the strongest. The United States installed 13.1GW in 2012 which is almost double compared to 2011. REN21 also states that this strong expansion of wind power in the US can be attributed to several factors; for example, technology improvement which brings higher efficiency and a reduction in price. In the US, wind power represents 3.5% of total electricity generation in 2012, and this can meet more than 10% of electricity consumption in 9 states. In particular, wind power capacity covers 25% in Iowa and 24% in South Dakota.

1.2.1.2. Penetration of Solar PV (Global and US)

Led by European countries and Asia, solar PV shows high growth in 2012 and reached 100GW of total global operating capacity (REN21). The EU added 16.9GW in 2012 bringing the level to 70GW. Beyond Europe, around 12.5GW of solar PV capacity was added in 2012. Asia added 7GW, and Northern America added 3.5GW in 2012.

Solar PV is expanding rapidly in Asian countries such as China and Japan. EU accounts for 70% of the global market of solar PV. Germany has 32GW capacity and Italy has 18GW. These two countries account for almost half the total global solar PV capacity. China (3.5GW), the United States (3.3GW), and Japan (1.7GW) show largest total capacity of solar PV following the EU.

In the United States, the capacity increased 85% in 2012 to 7.2GW, 35% of which comes from California. Sherwood (2012) reported that, in the US, the PV capacity installed in 2011 is double compared to 2010 bringing the cumulative grid-connected capacity to 4 GW_{DC}. Particularly in the residential sector, photovoltaic (PV) cells are usually used to generate electricity. According to Sherwood (2012), residential capacity grew by 24% compared with 2010. This rise in PV installation in the US is attributed to several factors including the following:

- Renewable Portfolio Standards (RPS)
- A drop in the price of solar panels, called module cost (Wiser, 2006)
- A drop in installation and labor cost, called non-module cost (Wiser, 2006)
- Incentive-related policies such as federal tax credits, state-level financial incentives, and utility incentives

As Wiser (2006) says, the non-module costs such as installation and labor costs can be subject to the influence of local policies, while the module costs is determined by a worldwide market and therefore affected by factors out of control of local policy. In this sense, policies such as incentives help people to reduce the total costs because the upfront cost of installing solar PV systems in house is still very high. In other words, the upfront cost of installing solar PV is high and needs to be reduced for solar to achieve higher penetration rates (Heal, 2009). Other than the policy approaches, technological advantages of solar PV systems also contribute to the diffusion of solar PV systems.

1.2.2. Introduction of Solar Energy and Solar PV systems

1.2.2.1. What is Solar Energy?

Solar Energy is a renewable energy source. It is clean in the sense that it is free from carbon and other emissions associated with electricity generation from burning fossil fuels. It is also inexhaustible because the sun does not deplete any natural resources. It is usually provided in the form of light and heat from the sun, and the solar energy can also be converted into various forms of energy such as electricity or thermal energy for heating water of space through solar related technologies. Usually, the solar technology is divided into two main categories: active and passive technologies (EPA). Active solar technology produces electricity using solar Photovoltaic (PV) and hot water using solar thermal technology. Passive solar technology absorbs heat or light for structures.

1.2.2.2. What is Solar Technology?

Our interest in this study is solar PV technology. Solar PV technology uses the light energy of the sun to generate electricity. It uses the properties of semi-conductors to produce electricity. The semi-conductors are made in the form of cells, and these cells are assembled into a panel. The panels can again be assembled into big arrays to produce a larger amount of electricity. Since several panels are assembled into larger groups and each panel is independent, the solar PV system can still be working even after one or several panels are broken. All that is needed is to replace the broken panels. Also, it is easily installed to produce electricity.

However, even if solar energy has lots of benefits, solar energy is an intermittent energy source because solar energy depends on the availability of sunlight. Therefore, it needs technology to store the energy produced, or any excess energy produced must be sold to the grid.

From the consumer's perspective, it is not clear whether it is economical to adopt solar PV technology or to remain as consumers of current electricity grid since consumers are not yet sure about the technology and its operation and maintenance (O&M) costs. Solar PV technology still has room for technological advancement.

Usually, there are different sizes in solar PV systems. Large-scale PV systems are connected to grid and able to provide electricity for multiple customers. Sometimes, large scale systems can store electricity it generates. There are also small PV systems, and this is what we are interested in this study. Small PV systems usually supply electricity for a single home or building. Small PV systems for a single home are usually installed at rooftop or ground to generate electricity. In this study, we consider the small PV systems connected to the grid, which is typically the public electricity grid. The grid-connected PV systems have lots of advantages. By generating electricity at the site of use with solar PV systems, transmission costs from power plants that are located remotely from customers can be reduced. Also, grid-connected solar PV systems do not require storage facilities in the sense that grid can be used as a huge storage facility. These characteristics of the systems could drive the solar market to grow in the future.

1.2.2.3. Cost Trends

The costs for solar PV systems consist of capital cost including panels, inverter, installation cost, labor cost, and O&M cost. According to SunShot Initiative report (2012), the PV system price has been decreasing roughly by 5-7% per year on average since 1998.

Figure 1-1 presents the median installed price of all residential and commercial projects from 1998 to 2011 (SunShot, 2012)

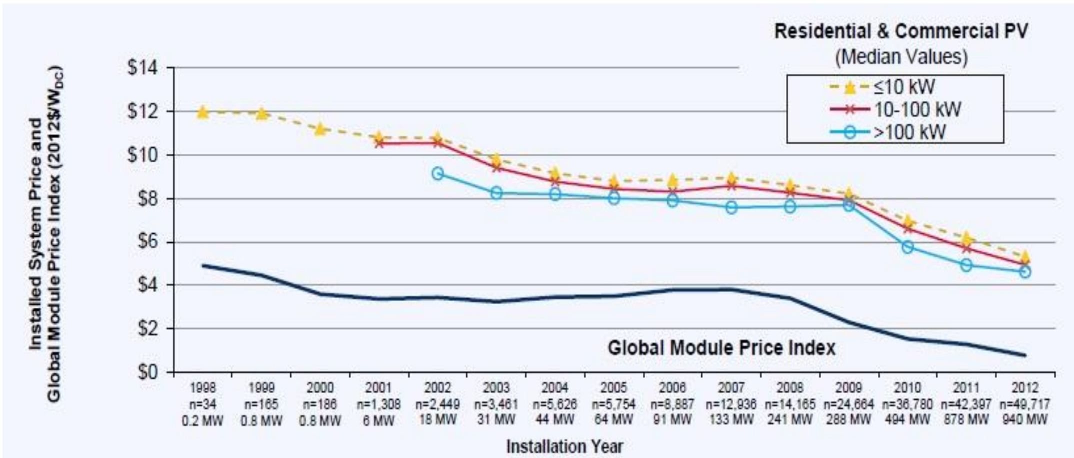

Figure 1-1: Installed System Price of Residential and Commercial PV systems over Time

In particular, the price for the systems with capacity of less than 10kW fell by \$0.88/W (14%) from 2011 and 2012. This fall in price of solar PV systems has contributed to a rise in installation of solar PV systems.

Figure 1-1 also presents the global module price index over time. This seems quite similar to installed system price, but not the same. Since module costs have declined faster than non-module costs, now the module costs represents around 21% of the total PV system costs (SunShot, 2012).

1.2.3. Expansion of Renewables in Indiana

Indiana is a state which has incentives to expand the installation of solar PV systems in houses. In Indiana, 95% of electricity is generated from coal. Coal supplies about half the demand in the state. The other half of the coal that Indiana uses is imported from states such as Wyoming, West Virginia, and Illinois (EIA). Besides, the fact that the electricity generation in Indiana is concentrated in coal means that there is adverse effect of burning coal on the environment in the state. Therefore, it may be reasonable to expand renewable energy sources, especially solar energy, to generate electricity in Indiana in order to improve its environment.

1.3. Research Goal

From the customers' perspective, cost of solar electricity compared to the retail electricity price from the grid is one of the most important factors to consider. From the policy makers' perspective, the effectiveness of each policy in reducing the cost of installing solar PV systems is important. In this study, we evaluate the economics of solar based electricity compared to the grid electricity. The specific aims of this study are as follows:

- Calculating a breakeven electricity cost of installing solar PV system in Indiana
- Doing scenario analysis on policy options
- Stochastic analysis for key uncertain variables
- Calculating a probability that solar PV systems can be less than the electricity from the grid
- Analysis on stochastic domination between the cost of solar PV system and the annualized electricity price
- Sensitivity analysis

Through calculating the breakeven cost of installing solar PV systems in Indiana under current incentive policies, customers of electricity can be informed if it is better to adopt solar PV systems than to continue as users of current electricity from the grid. With scenario analysis of policy options, it can be explained how each current incentive works to compensate cost of installing solar PV systems. Also, we introduce possible policy options to see how they affect the economics of solar PV systems. Since there is uncertainty in key variables considered in this study, we also do a stochastic analysis for the uncertain variables. With this, we get a probability that solar PV systems can be less expensive pathway than current electricity from the grid. With scenario analysis on policy options, sensitivity tests for other variables are also studied.

1.4. Organization of the Thesis

This study progresses as follows. In section 2, we do the literature review for the background of solar PV system and policies related to encouraging people to install solar PV system. We also examine the status of renewable energy and policies for solar PV system in Indiana in section 2. In section 3, we describe the methods and data used in an analysis. In section 4, results and conclusions of the analysis are presented. Finally, suggestions for the future work are discussed in section 5.

CHAPTER 2. LITERATURE REVIEW

2.1. Economics of Solar PV Systems

Many papers have examined the economics of installing solar PV systems. Most of the papers present a levelized cost of the solar PV system. According to Borenstein (2007), in California, the levelized cost of solar PV system per kWh is $0.322 with 2 kW system capacity, 5% real interest rate, and time-of-use net metering considered. Thus, it can be asserted that the solar PV system is not economical to install yet, compared to the residential retail price of electricity in 2007 in California, $0.152 per kWh (Pacific Gas and Electric, PG&E) and $0.148 (Southern California Edison, SCE), (California Public Utilities Commission). Makhyoun (2012) also estimates that the levelized cost of solar PV systems in North Carolina is higher than $0.15 per kWh in 2012. It is also illustrated that, for the system capacity less than 10kW, the levelized cost of solar PV system is expected to be reduced to $0.11 per kWh in 2020. Thus, with the 1.3% growth rate of residential retail electricity price from Duke Energy utility in North Carolina, Makhyoun (2012) also says that solar PV systems will be cost competitive with retail electricity price in 2020 in North Carolina. This means that the solar PV system deserves to be invested even if it is not beneficial yet since the levelized cost of solar PV system decreases while the retail electricity price is expected to increase in the future (Cai et al.

2013, Makhyoun 2012). Furthermore, Makhyoun (2012) mentions that the levelized cost in 2020 is estimated to be $0.17 per kWh without federal tax credits, which is higher than the one with federal tax credits. This shows that the federal tax credit is an important policy to increase the value of solar PV system for households.

However, while many papers have studied the economics of southwestern or southern areas in the US where most of the electricity from solar energy is generated, little has been done for mid-western areas such as Indiana or Illinois. However, Indiana is also expanding its electricity production from renewables including wind and solar energy. Wind energy has recently been increasing substantially in Indiana (Figure 2-2), while solar energy has not been used to generate electricity so far. Therefore, in order to see if it is efficient for residents to adopt solar PV systems and to provide people with information related to economics of solar PV systems in Indiana, it is necessary to analyze its economics in Indiana. It can be helpful for customers' decision making. In addition, the effectiveness of policies in reducing the cost of solar PV systems should be examined so that policy makers can be informed how effective policies are.

2.2. Policies for Promoting Solar PV Systems in Indiana

There are many policies to promote adoption of renewable energy technologies. The policies are mainly related to the monetary benefits in installing solar PV system in houses, and this is meaningful because customers are interested in how much can be saved by adopting solar PV systems (Cai et al., 2013). In solar PV system installation in Indiana as other states, the policies are broken down into two categories: federal policy and state level policy. For federal policy, the federal tax credit is the most important instrument. The federal tax credit, established by *The Energy Policy Act of 2005*, is applied to renewable energy generation property in residential units. Thirty percent of the installation cost including purchase, installation, and labor cost is available for qualified consumers. There was a limit of $2,000, but it was removed in 2009 for solar PV systems installed after 2008.

In addition to the federal incentives, in general, there are several state-level incentives such as property tax exemption, net-metering, or feed-in tariff as a utility incentive in Indiana. In our analysis for Indiana, we take net-metering which is still available through Northern Indiana Public Service Company (NIPSCO) for the base model. Under the net-metering program, the utility company is required to purchase its customer's excess generation at the retail electricity price.

2.2.1. Net Metering

2.2.1.1. Policy Introduction

Net metering is a policy that forces companies to buy from solar or wind owners any excess electricity they may generate. That is, the utility buys any electricity produced that consumers do not need at that instance. For example, if a consumer with a solar PV system on rooftop and connected to the grid for net metering generates more electricity than they use during daytime, the electricity meter will run backwards to provide credits. The consumer is then billed only net electricity usage each month. With net-metering which connects households with a major grid so that excess electricity can be exported to the grid, customers do not have to install a storage systems in their houses. Therefore, net metering is a great option for spreading the adoption of solar PV systems in houses.

Net metering is different from other incentives in that it places the financial burden of promoting solar energy on private utilities and ultimately on other utility customers rather than governments. Thus, net metering is attractive because governments can avoid the cost of other incentives and move the cost to the utility companies (Stoutenborough and Beverlin, 2008). In addition, Stoutenborogh and Beverlin (2008) state that the power of net metering lies in the fact that it removes a negative feeling that utility companies are taking advantage of its customers. Net metering with which energy credits are given to customers if they generate more electricity with solar PV than they need is helpful for customers to reduce their electricity bills each month (Rose et al, 2009). Thus, state governments may adopt net metering in order to encourage people to install solar PV systems in their houses.

A primary obstacle in adopting solar PV systems is the incongruity between timing of generating electricity from solar PV systems and peak demand hours. Commonly, the highest system electricity demand is in the middle of the day when the solar radiance reaches at its highest (O'Rear et al). On the contrary, households' peak demand for electricity usually occurs in the evening after people come back from work. In this sense, we need to look at different forms of net metering related to this obstacle.

2.2.1.2. Different Forms of Net Metering

There are three major forms of net metering policy.

- One is net metering with fixed retail rate regardless of the timing of generation and consumption

- Another is market rate net metering
- The other one is usually called time of day net metering.

Fixed rate net metering provides credits independent of the timing of generation and consumption, consumers get credits at exactly the same retail rate when they generate excess amount of energy regardless of timing that they produce electricity. For example, in Indiana, the retail electricity price is about $0.1137 per kWh (EIA, July 2013). So if a consumer produces excess electricity using solar or wind energy, they get paid at $0.1137 per kWh of excess electricity.

In market rate net metering, the utilities pay customers back for the excess electricity based on wholesale electricity price, not on the retail electricity rate as in the fixed rate net metering. Since the wholesale electricity price is usually lower that the retail electricity rate, it is not as profitable to customers as fixed rate net metering with the retail rate.

With the time of day net metering, the rate at which consumers can get credits for the excess electricity changes based on the electricity value during each time period. In other words, the value of electricity is assessed based on the time that electricity is used. Since the solar PV system produces electricity during the daytime, which is the peak-load period, consumers with the solar PV system can take advantage of the timing of peak production hours and peak demand hours if their utility company has time of day net metering. For example, Pacific Gas & Electric in California has time of day net metering that charges as much as $0.32 per kWh from noon to 6PM weekdays from May to October and as low as $0.09 at other times (Sunlight Electric). This time of day net metering is very appealing to consumers because the peak generation hours match the peak price hours. This means that consumers can sell their excess electricity to the utility at a higher price, and this raises the value of solar PV systems.

2.2.2. Tax Treatment of Solar Investments

2.2.2.1. Federal and State Subsidies

There is a federal incentive for residential renewable energy. Taxpayers can claim a 30% federal tax credit for installation cost of renewable technologies such as solar water heat, photovoltaic, wind, fuel cells, geothermal heat pumps, other kinds of solar-electric technologies, and fuel cells using renewable fuels (DSIRE, 2012). In order for taxpayers to claim the tax credits for solar PV systems, the systems must be placed in service on or after January 1st, 2006 and on or before December 31st, 2016 and provide electricity for a residence. It must be owned by taxpayers. However, homes served by solar PV systems do not have to be the taxpayers' principal residence. If a household leases the solar PV system from the leasing company, the leasing company can claim the credits. Installation costs eligible for federal tax credits include labor cost for on-site preparation, assembly or original system installation, and for piping or wiring to connect a system to the home (DSIRE, 2012).

2.2.2.2. Depreciation Benefits

Internal Revenue Service (IRS) defines, in its publication 946 (2013), that depreciation is an annual income tax deduction for people to recover the cost of certain property while they use the property. Any tangible and intangible property can be depreciated for tax deduction, such as buildings, machinery, or vehicles as a tangible property and patents, copyrights, or computer software as an intangible property. Basically, for a property to be qualified for claiming tax deduction from depreciation, it should be owned by taxpayers, used in business or income-producing activity, have a determinable useful life, and be expected to last more than one year. Because the home installation is not used in a business, residential property including the solar PV system interested in this study cannot be claimed for the tax deduction from depreciation. Property that meets the requirements for depreciation and is put in service after 1986 is depreciated by the Modified Accelerating Cost Recovery System (MACRS), which is the current tax depreciating system in the US. MACRS consists of two systems, the General Depreciation System (GDS) and the Alternative Depreciation System (ADS). Depending on which system a property is used, different methods and recovery periods are used to depreciate the property for tax deduction. We will examine this in greater detail later.

2.2.2.3. Tax Deduction from Interest of Home Equity Loan

There is another benefit related to interest of a home equity loan. If people take out home equity loan in order to consolidate debts, improve their houses, or purchase homes, the interest on most of the home equity loans is tax deductible. If the loan is used to buy, build, or significantly improve homes, it is called home acquisition debt. On the other hand, if the loan is not used to buy or build homes, it is called home equity debt (IRS Publication 936). Since installing solar PV systems in homes can be regarded as a home improvement, we can take home equity loan, specifically home acquisition debt, as a way of financing for adopting solar PV systems in houses. If the amount of mortgage is more than the sum of housing cost and the cost of any home improvement, only the part of the mortgage that is not more than the sum qualifies the home acquisition debt (IRS Publication 936, 2012). However, the interest deduction from the home equity debt is not unlimited. The total amount of debt cannot be more than $1 million ($500,000 if married filing separately) for the home acquisition debt for the main and second home. (IRS Publication 936, 2012). In this study, we assume that the debt from financing is 80% of the total installation cost, which is not greater than $1 million. Therefore, it is possible to deduct all of the solar installation debt interest.

2.3. Energy Production in Indiana

2.3.1. Renewable Energy in Indiana

Although it is noted that Renewable Portfolio Standards (RPS) play an important role in increasing PV system installation in the US, Indiana does not have a RPS. However, Indiana does have a voluntary clean energy portfolio standard which is called Comprehensive Hoosier Option to Incentivize Clean Energy (CHOICE). The CHOICE program started on January 1st 2012, and it is voluntary, while RPS is mandatory. In other words, the CHOICE program does not require any utility to join and does not penalize utilities for not joining the program. At the same time, the Indiana General Assembly designed the program to be voluntary in order to keep the impact on utility rates low (Indiana Office of Energy Development (OED)). Specifically, utilities joining the CHOICE program participants cannot increase the electricity rate that they charge customers more than the rate that would exist if they were not part of the program (OED). The program target is 4% renewable of total electricity by 2018, 7% by 2024, and 10%

by 2025. There are 21 clean energy sources included in the CHOICE program under Indiana's Clean Energy Law. These 21 sources include wind, solar, crops grown for energy production, biomass, geothermal, nuclear, etc. The CHOICE program provides incentives called "Clean Energy Credits" for participating utilities in order to increase electricity generated by renewable energy sources (OED). Utilities use the credits as part of the CHOICE program. Also, if utilities take part in the CHOICE program and achieve each goal, utilities may be allowed to increase Return on Equity by as much as 50 basis points over the rate of return that is currently approved.

2.3.2. Electricity Production from Renewables

Figure 2-1 illustrates net electricity generation by source in Indiana in July 2013. As shown, fossil fuel sources including natural gas and coal account for around 98% of the total electricity generated in Indiana. Renewables including hydroelectric account for only 2% of the net electricity generated. Figure 2-2 shows the share of electricity production in Indiana from 2006 to 2010 (EIA). With the CHOICE program, the share of the renewable energy sources could increase in the future.

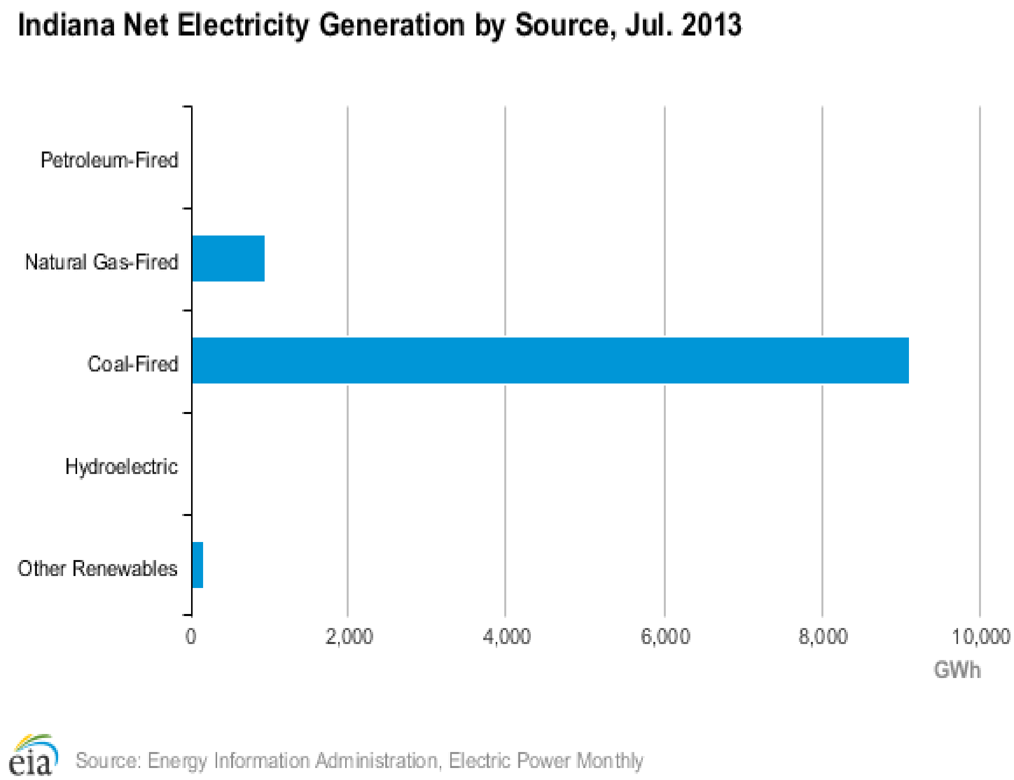

Figure 2-1: Indiana Net Electricity Generation by Source, July 2013 (EIA, 2013)

Figure 2-2 shows share of each renewable energy source out of total renewable energy production in Indiana from 2006 to 2010 (EIA). Among renewable energy sources used in Indiana, wind has been increasing substantially and amounts to 80% in 2010, while the hydro and biogenic/landfill gas shares have been decreasing. There is almost no electricity generated by solar energy.

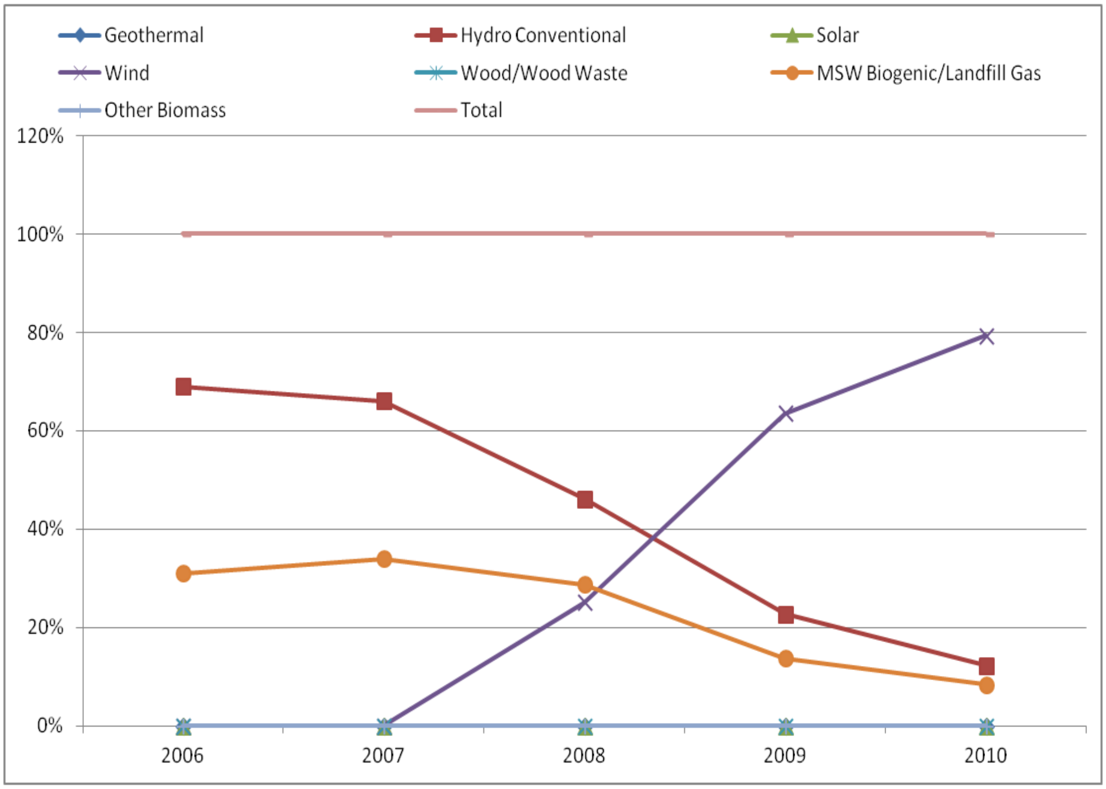

Figure 2-2: Share of each Renewable Source out of Total Renewable Electricity Production (EIA, 2006-2010)

2.4. Social Cost of Carbon Information

One of the most important issues in using fossil fuels is climate change such as global warming and its effect on agricultural productivity, human health, coastal inundation, etc. Global warming derives mostly from CO_2 emissions since CO_2 is one of several heat-trapping greenhouse gases (GHGs). According to the EPA annual report (2013), CO_2 accounts for 84% of the greenhouse gases emitted a year. In this sense, the Kyoto Protocol was adopted by 192 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and enacted in 2005 (UNFCCC, 2012). The Kyoto

Protocol is an international treaty which sets binding obligations on industrialized countries to reduce emission of GHGs.

There are several policy instruments for abatement of CO_2 emission. We have 4 major categories of the policy instruments according to Dinica (2002).

- Direct regulations (Command and Control instrument)
- Information and communication policy instruments
- Voluntary agreements
- Economic instruments

Direct regulations, also known as command and control instruments, include licenses, standards, and bans. These regulations have been the most often implemented to reduce the GHG emission and to induce the use of environment friendly technologies (Dinica, 2002).

Information and communication policy instruments aims at inspiring changes in behavior of energy consumers. For example, media campaigns, new education curricula with energy information, training of managers in industries, or labeling of energy efficiency on vehicles or appliances may result in increased awareness on environment or energy reduction of consumers. This may also bring about voluntary reductions in energy consumption (Dinica, 2002).

Voluntary agreements represent a new type of policy instrument. In voluntary agreements, emission level targets are discussed and agreed between firms and public authorities. Alternatively, industrial actors declare targets set by firms unilaterally (Dinica, 2002).

Economic instruments include taxes, subsidies, tradable emission permits, and deposit refund systems (OECD environment policy) (Dinica, 2002). In this study, we focus on taxes as an economic instrument. Since climate change caused by the CO_2 emission is considered to be a negative externality, a Pigovian tax can play a role in reflecting a social cost of CO_2. We call it carbon tax. To impose a carbon tax, the social cost of CO_2 should be estimated because the carbon tax imposed on a negative externality is called a Pigovian tax and should be equal to the marginal damage loss. Yohe *et al.* (2007) defines Social Cost of Carbon (SCC) as an estimate of the economic value of the marginal impact caused by the emission of one extra tone of carbon at any point in time. EPA (2013) also defines SCC to be a comprehensive estimate of climate change damages. The climate change damages include changes in agricultural productivity, human health, and property damages from increased flood risk (EPA, 2013). EPA estimates SCC $37/ton in 2013 (EPA, 2010). Even if SCC does not include all the possible impacts of climate changes and it underestimates the damages because of a lack of information on nature of damages (IPCC, 2007), it is a useful measure to assess the negative impacts of CO_2 emissions (EPA 2013). Thus, if the carbon tax for SCC is imposed on industrial, commercial, or transport sectors emitting CO_2, it is expected that the use of fossil fuel declines so that CO_2 emission also reduces.

In most cases, firms or industries with carbon tax imposed will pass the burden of a carbon price onto consumers, which, in turn, induces consumers to consume less electricity. For example, plants generating electricity with fossil fuels will raise an electricity price with a carbon tax included. According to National Association of Manufacturers (NAM), the residential electricity rate is expected to increase 11% in

Indiana on average in 2013 if a carbon tax of $20/ton were applied, which is even less than the estimate of SCC ($37/ton) by EPA (2013). In our study, we create the case with the assumption that the carbon tax for SCC is imposed on current grids in Indiana because 98% of total electricity produced in Indiana comes from fossil fuels (Figure 2-1) and fossil fuel combustion is the primary anthropogenic source of CO_2 emission. Then, we will examine the effect of imposition of carbon tax and its distributional impacts on the cost of solar PV systems.

2.5. Solar Radiation Information

Indiana does not have as much solar radiation as in the southwestern region. It can be seen in Figure 2-3 that solar resources are concentrated in the southwestern region in the US.

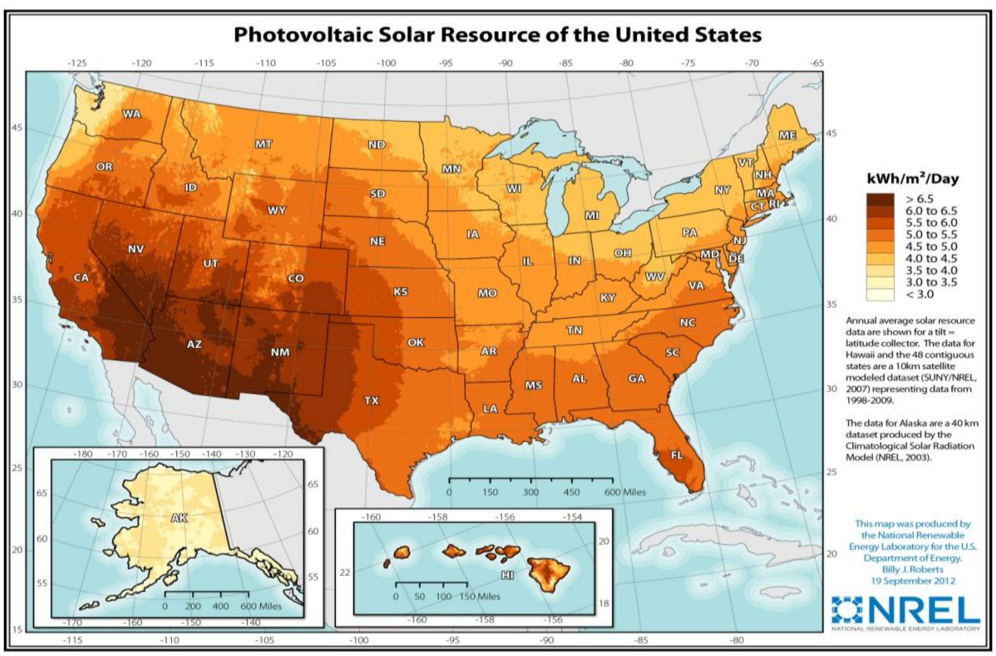

Figure 2-3: National Solar Resource Potential (January, 2012)

However, the amount of the solar resource is not the only critical factor in solar PV technology. As Skoplaki and Palyvos (2008) assert, the electrical performance of solar PV modules are negatively related to its operating temperature. The speed at which electrons move is changed by temperature, and how electricity flows through an electrical circuit is affected. This is due to an increase in resistance of the circuit that results from an increase in temperature (www.teachingengineering.org). For example, even if there is more solar irradiance in Arizona than in North Dakota, the PV system in Arizona have a maximum system voltage that is lower than the same system in North Dakota due to higher temperature in Arizona. Specifically, Waco (2011) represents that efficiency of a solar PV panel decreases with temperature in ambient temperature greater than 25 degrees C (77 degrees F) which is the Standard Test Condition (STC). In other words, heat reduces the solar output around 10 – 25% depending on its location installed. For example, Sharp Solar Panel NU-U230F3 shows that its maximum power decreases by 0.485% with an increase in 1 degrees C above 25 degrees C (77 degrees F) (Waco, 2011). In order to tackle this negative temperature dependence of solar PV system, engineers may set up a cooling system with the solar PV system. For example, the solar PV system has fans to blow air over the solar systems or equipment to pump water below the solar PV panels to absorb the heat.

The solar PV module's operating temperature is also dependent on weather variables such as ambient temperature and the local wind speed (Skoplaki and Palyvos, 2008). In particular, wind can be helpful to lower the system's temperature so that the output efficiency of solar PV module can be higher. In this sense, mid-western areas might also be considered as good places to adopt solar PV systems in spite of the lower amount of solar resources.

In addition, supporting the potential possibility of solar PV system in Indiana, an experiment that New Holland Rochester, Inc. performed in Rochester, IN, over 2012 shows that monthly electricity generation by solar PV system with 5.88 kW and 7.84 kW of capacity is slightly below the average monthly residential demand of Indiana for electricity per household (Figures 5 and 6). Considering various factors, it can be said that expanding solar energy in Indiana may be possible.

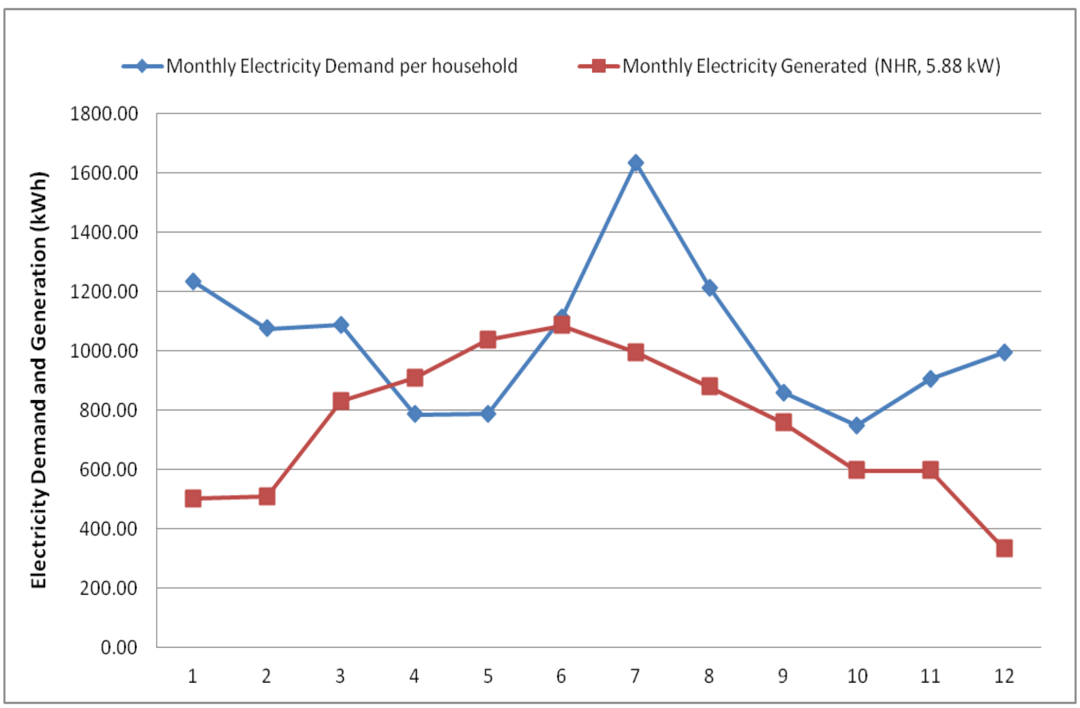

Figure 2-4: Monthly Electricity Demand per Household and Monthly Electricity generated by New Holland Rochester PV system with the 5.88 kW of capacity

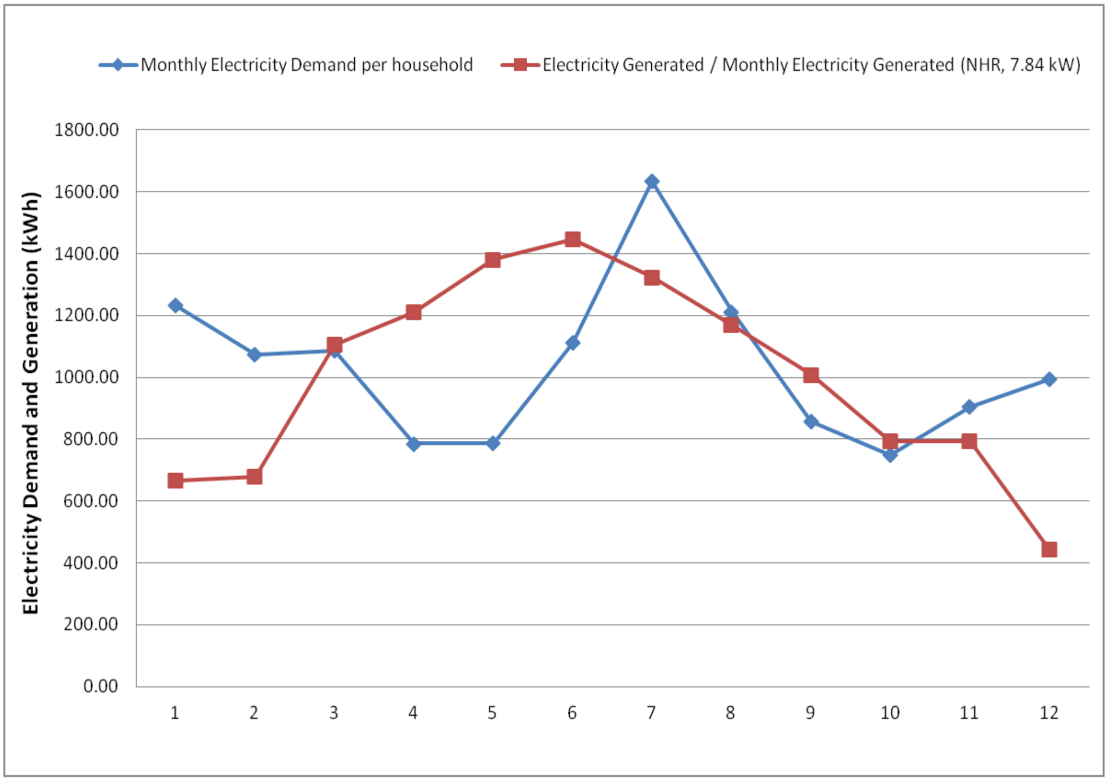

Figure 2-5: Monthly Electricity Demand per Household and Monthly Electricity generated by New Holland Rochester PV system with the 7.84 kW of capacity

CHAPTER 3. METHOD AND DATA

3.1. Benefit-Cost Analysis

Benefit-Cost analysis is used to evaluate the economics of solar PV systems under operating conditions in Indiana. A key indicator of economic viability is the comparison of breakeven cost of electricity of a solar PV system installed in a household with the expected annualized cost of electricity supplied from the grid. In the base case, we define the breakeven cost of electricity as the annualized cost of electricity ($/kWh) at the time of installing the solar PV systems which is the beginning of the period considered in this study. With this definition, we can compare the breakeven electricity cost of the solar PV systems with the expected annualized price of electricity from the grid. For the calculation of the breakeven cost of solar PV systems and the comparison of it with the cost of electricity from the grid, it is necessary to consider both real and nominal values. Since we have 20 years of future period and the breakeven cost of solar systems should be calculated for a present value which is for the beginning of the period so that it is possible to compare the breakeven cost of solar systems with the a nnualized electricity price, inflation should be removed.

While either real or nominal values could be used for the comparison so long as each was used consistently, we have chosen to do the comparison in real terms. How to convert nominal values into real values and vice versa will be discussed later in this chapter.

The breakeven electricity cost per kWh can be estimated from the ratio of annualized cost to the household's annual demand for electricity according to the following reduced equation.

$$Breakeven\ Electricity\ Cost\ (kWh) = \frac{Annualized\ Cost}{Household's\ Annual\ Demand\ for\ Electricity} \tag{1}$$

The annualized cost of installing solar PV system is calculated by the following equation.

$$Annualized\ Cost = NPV \times CRF \tag{2}$$

NPV for annualized cost in equation (2) represents the net present value (NPV) of all costs and benefits involved in installing solar PV panel in a household. The NPV is the cumulative cost of a solar PV system, which is equal to the sum of the discounted cost in each year:

$$NPV = \sum_{j=1} \frac{AC_j}{(1 + discount\ rate)^j} + IIC$$

(3)

- IIC is initial installation cost. This is the cost spent purchasing solar PV system in the beginning of the first year including solar panels, inverters, stands, labor, and installation costs.
- AC_j is annual cost in year j. The annual cost in year j can be calculated by equation (4) followed.

$$AC_j = EC_j + LP_j + O\&M_j + RC_j - B_j$$

(4)

- EC_j represents cost of electricity not produced from solar and purchased in year j after solar PV system is installed. Since the solar PV system considered in this study does not always produce more electricity than consumer needs, consumers still need to buy electricity from the grid. Net-metering is taken into account when calculating EC_j if needed. An annual increase of the retail price of electricity is also reflected, and an increased retail price of electricity in each year is calculated into present value through equation (3).
- LP_j is annual loan payment from financing in year j.
- $O\&M_j$ is operation and maintenance cost in year j. An annual increase of the O&M cost is reflected every year.
- RC_j presents cost for repairing if the system has any failure in year j.

- B_j represents benefits for installing solar PV systems in year j. The possible benefits in this study are federal tax credits, depreciation tax deduction, home equity loan tax deduction, and salvage value.

Different elements of benefits and costs are taken into account for getting NPV depending on what elements each corresponding scenario considers; for example, since the baseline case does not consider depreciation benefits, we do not include depreciation benefits in the baseline case to calculate NPV.

In equation (2), CRF represents Capital Recovery Factor as is shown below in equation (5).

$$CRF = \frac{i \times (1+i)^n}{(1+i)^n - 1} \tag{5}$$

i is the discount rate and n is the number of year in the annuity, which is a solar PV panel life for our analysis.

3.1.1. Conversion of Nominal Value into Real Values

In our study, we use real values for assumptions and the breakeven cost for the analysis. However, from the data sources, we have both nominal values and real values. Values given in real terms can be used without any conversion because they are already in real terms, while values given in nominal values must be converted into real values. For example, growth rate of electricity price from grids is assumed as 1.08% in real terms

(State Utility Forecasting Group, 2011), and this can be directly used. Since we consider 20 year period and the electricity price increases year by year with 1.08% growth rate, we can't use the base electricity price ($0.1137 per kWh in July 2013) for comparison. Rather, we need to calculate the expected annualized electricity cost. The expected annualized electricity cost means the NPV of 1kWh of electricity converted to annuity. Annualized electricity cost can be calculated from NPV of the 1kWh electricity cost using equation (2) above. I put it here again.

$$Annualized\ Cost = NPV \times CRF \tag{2}$$

CRF is the Capital Recovery Factor and NPV in equation (2) for retail electricity prices can be calculated in equation (6) below:

$$NPV\ of\ electricity = \sum_{j=1} \frac{EP_j}{(1 + discount\ rate)^j} \tag{6}$$

EP_j represents the electricity price in year j.

The growth rate of O&M cost is assumed to be 3% in nominal values (New Holland Rochester, Inc.), and this should be converted into real values. In order to get a real value of the benefits and costs in each year, we divide the nominal value of benefits and costs by the inflation factor in that year. The equation below can be used to get the real value of benefits and costs.

$$\text{Real Value} = \frac{\text{Nominal Value}}{(1 + \text{Inflation Rate})^y} \tag{7}$$

y is the number of year that inflation is applied.

3.2. Stochastic Analysis for Key Uncertain Variables

We look at the breakeven cost of electricity per kWh and annualized cost of each case option for comparison in real terms. However, since there is uncertainty in several variables, and the uncertainty for key input variables plays an important role in estimating the breakeven cost, we calculate stochastic values of electricity price per kWh and annualized cost of solar system rather than using just deterministic values. The stochastic values provide more complete projection of the breakeven cost than simply calculating the breakeven cost with deterministic input variables. We have three uncertain input variables to consider.

- Residential electricity price and its projection
- Degradation rate of power generated from the solar PV system
- Failure rate for system panels

We conduct Monte Carlo simulation of the three variables using @Risk, the Palisade risk and decision analysis software embedded into the Excel Spreadsheet, to estimate the stochastic breakeven costs. We can create distributions for the uncertain variables using @Risk based on data from NHR, Inc. and literature.

3.2.1. Uncertainty of Electricity Price

In this study, we need to project the residential electricity price for 20 years after the solar PV system is first installed. For the first year of installation, \$0.1137 of the residential electricity price is reported by EIA based on July, 2013. In order to forecast the residential electricity for the next 20 years, which is the lifetime of the solar PV system, 1.08% average growth rate of residential electricity price (3.61% in nominal value with 2.50% of inflation rate) for residential electricity price 2010 through 2029 is reported from Indiana State Utility Forecasting Group (SUFG) (2011).

To do the stochastic simulation of electricity price, we needed to determine what distribution would be appropriate to assume for electricity price change. We tested the normality for the change of electricity price based on the historical data from 1960 to 2012 (EIA) using the Shapiro-Wilk test. It shows that the electricity price change is normally distributed with a p-value of 0.1929, which is greater than 0.05. Therefore, we use the normal distribution for the change of electricity price.

For price projection with uncertainty introduced, we take the price for the first year as the base price and make the price for subsequent years dependent on the lagged price, a trend value, and a random component. We add random component with 0 for mean and 10% of the previous year's price for standard of deviation.

$$EP_k = EP_{k-1} * (1 + EGR) + RiskNormal(mean, standard\ deviation) \tag{8}$$

This is the function we actually use for @Risk.

- EP_k is the residential electricity price in year k
- EP_{k-1} is the residential electricity price in year $k-1$

- EGR is the growth rate of the residential electricity price
- $RiskNormal(mean, standard\ deviation)$ is the part for random component with its mean and standard deviation. We assume normal distribution with 0 for mean and $0.1 * EP_{k-1}$ for standard deviation. Sometimes, Monte Carlo simulation with a lag structure can result in a bi-modal price distribution towards the end of time period. In that case, it may need to be corrected with mean-reversion since a bi-modal distribution is not realistic. However, since the price distribution in our study shows normal distribution throughout the time period, we do not need to use the mean-reversion process.

After getting electricity price each year, we calculate an annualized electricity price for later use of the comparison with breakeven cost of installing solar PV systems. With the stochastic analysis, both the prices each year and the annualized electricity price are actually distributions. Thus, we will compare the distribution of annualized electricity price with the distribution of breakeven solar electricity cost.

3.2.2. Uncertainty of Degradation Rate

Performance of the solar PV system over the lifetime is highly dependent on assumed degradation rate of the panels. Degradation occurs due to chemical processes such as weathering, oxidation, corrosion, or thermal stress (Skoczek et al., 2009, Realini, 2003). Due to the degradation, electricity generated from the solar PV system decreases gradually year by year. This also means that the amount of electricity that consumers need to purchase from the current grid increases each year. There are lots of studies illustrating the annual degradation rate of the solar PV system. Most of studies show

0.3% through 3% for the degradation rate (Skoczek et al., 2009, Realini, 2003, Branker et al. 2011), and the rate is expected to rise during its weathering period. Weathering period means the later period of the system's lifetime during which degradation rates usually rise. The most likely value (mode) of the degradation rate for years 1-18 is assumed to be 0.5% with a min of 0.3% and a max of 1%. For years 19 and 20, we assume a mode value of 0.75% and min and max values of 0.3 and 3% respectively. (Skoczek et al. 2009, Vazquez and Rey-Stolle, 2008). The function for calculating the amount of electricity generated from the solar PV system with degradation considered in excel is shown in equation (9):

$$Elec_t = Elec_{t-1} * (1 - Degradation\ Rate_t)$$

(9)

$Elec_t$ and $Elec_{t-1}$ represent the amount of electricity generated from the solar PV system in year t and $t-1$, respectivley. Common distributions used for degradation rate are Pert and Triangular distribution. Both distributions have as parameters the min, mode, and max values. The difference between the two is that Pert distribution has more of the probability density closer to the mean while Triangular distribution has more towards the max and min values. Since Pert has more density towards the mean, it is chosen for this study. Since we have min, mode, and max values for the degradation rate, we can find mean values for both distributions. We can calculate the Pert mean value using equation (10):

$$Pert\ Mean = \frac{Min + 4 * Mode + Max}{6}$$

(10)

Values of the degradation rate for Pert distribution are shown in Table 3-1.

Table 3-1: Values of the Degradation Rate for the Pert Distributions

(Source: Skoczek et al. 2009, Vazquez and Rey-Stolle, 2008)

Variable Name	Distribution	Period	Min (%)	Mode (%)	Max (%)	Mean (%)
Degradation Rate	Pert	1-18	0.3	0.5	1	0.550
		19-20	0.3	0.75	3	1.050

3.2.3. Uncertainty of Failure Rate

We also consider failure rate of the solar PV system. The failure rate represents the rate of physical failure of the system panels; for example, defects caused by extreme weather such as hail, thunderstorm, or rocks. Based on a real experiment of NHR, Inc. over the year 2012, there is no array of the system broken. Furthermore, since there is no real experiment for failure rate over 20 years, we assume the average failure rate of the system is 0.5% a year for each single array and it remains the same over 20 years as suggested by NHR, Inc.

The solar PV system usually consists of multiple arrays which are independent of each other. In other words, even if a single array is broken, other arrays are still working. Hence, all we need to do is to replace the broken single array.

For calculating how many arrays fail annually with 0.5% failure rate, we introduce the Bernoulli trials since the outcome of each array is classified in but one of two mutually exclusive ways, non-defective or defective, and the possibility of each array's failing is independent. Thus, we let X a random variable associated with the Bernoulli trial be defined as follows.

$$X(non-defective) = 0$$

$$X(defective) = 1$$

In addition, we also define that p is the probability of failure for each array and n is the number of arrays, 24 arrays and 32 arrays in this study, so we can say that the random variable X is $binomial(n, p)$. If the random variable X is $binomial(n, p)$, the expected value can be calculated in equation (11).

$$E(X) = \mu = n * p \tag{11}$$

Thus, we assume that the failure rate follows Binomial distribution with its failure rate of 0.5%, and the number of trials of 24 and 32 arrays. In @Risk, in other words, X follows $binomial(24, 0.005)$ for 24 arrays of the system and $binomial(32 ,0.005)$ for 32 arrays of the system. Thus, the expected values of the number of arrays broken a year are 0.12 arrays for the 24 array system and 0.16 arrays for the 32 array system. We assume that there is no correlation from year to year, so a separate Risk Binomial variable is included for each year. Then, if we multiply the price of a single array of the system, cost for broken array can be estimated.

In addition to the cost of array, customers need to pay labor cost for replacing a broken array. We assume that the labor cost is $75 including driving to and back from the location and repairing, and its annual growth rate in nominal terms is 1% based on NHR, Inc and converted into real value for this analysis.

The arrays often come with a warranty. In this case, the warranty covers replacement cost in years 1-10, and 50% of the cost after the 10th year. Values of the failure rate for binomial distribution are summarized in Table 3-2.

Table 3-2: Values of the Failure Rate for Binomial Distribution for the 5.88kW and the 7.84kW System Capacities

Variable Name		Distribution	Min	Mode	Max	Mean
Failure Rate	5.88kW	Binomial	0.00	0.00	24	0.12
	7.84kW	Binomial	0.00	0.00	32	0.16

3.3. Stochastic Dominance

Since we do the stochastic analysis for uncertain variables, we also do analysis on stochastic dominance as well as on probability that solar can be less expensive than electricity from the grid. Stochastic dominance is a fundamental concept in decision theory and is a form of stochastic ordering. It is used to determine the conditions under which one outcome may be preferred to another outcome; for example, for lottery or gambling. There are two kinds of stochastic dominance we consider in our study;

- First-order stochastic dominance
- Second-order stochastic dominance

We use cumulative distribution function (CDF) for stochastic dominance. The first-order stochastic dominance is the simplest form. If a CDF of 'A' lies entirely below to the right of another CDF of 'B', 'A' dominates 'B' in first-order sense. This means

$$F_A(a) \leq F_B(a)$$

(12)

Second-order stochastic dominance is based on the area under the CDF. In other words, A is second-order stochastically dominant over B if and only if the area under CDF of A from minus infinity to a is less than or equal to that under CDF of B from minus infinity to a for all real numbers a, with strict inequality at some a; that is, equation (13) should be met for A to stochastically dominates B.

$$\int_{-\infty}^{a} [F_B(t) - F_A(t)]dt \geq 0$$

(13)

Last but not least, the stochastic dominance we use for our analysis should be reversed. Stochastic dominance as described above is for lottery or gambling. In other words, it is usually used for the cases in which the higher or the more outcomes are, the better the results are. However, on the other hand, our analysis is focus on the cost. This means that our results are cases in which the lower the outcomes are, the better the results are. Thus, stochastic dominance for our study should be working in the opposite way. For first-order stochastic dominance, if a CDF of ‘A’ lies entirely above to the right of another CDF of ‘B’, ‘A’ dominates ‘B’ in first-order sense. This means

$$F_A(a) \geq F_B(a)$$

(14)

For second-order stochastic dominance, A is second-order stochastically dominant over B if and only if the area under CDF of A from minus infinity to a is more than or equal to that under CDF of B from minus infinity to a for all real numbers a, with strict inequality at some a; that is, equation (15) should be met for A to stochastically dominate B.

$$\int_{-\infty}^{a} [F_B(t) - F_A(t)]dt \leq 0$$

(15)

3.4. Economic Analysis

First, we look at an economic analysis which contains only the real resource benefits and costs of a solar system without including any government incentives or financing. Thus, this analysis considers cost of the systems including panels, inverters, labor, and installation, cost of electricity purchased after the installation of the solar PV systems, O&M cost, repairing cost, and salvage value. We do not introduce financing, tax benefits, or net metering in the economic analysis. This analysis can be reflected in equation (4). This means that LP_j and all benefits but salvage value in B_j are not considered, and EC_j should be calculated with net-metering excluded. The economics analysis is also known as asset based analysis.

In addition, we also take a look at two other economic analyses. One is only with federal subsidy, which is the federal tax credit, and the other is with net metering, financing, depreciation and carbon tax. Net metering and financing are current policies while depreciation and carbon tax are potential policy options. With this, we examine how carbon tax and potential policy correct failures in the system with net metering and financing.

3.5. Financial Analysis (The Baseline Case)

After we examine the flow of resources in the economic analysis, we add financing, net-metering, and tax benefits into the economic analysis to do a financial analysis. This financial analysis will be the baseline case since the baseline case is composed of incentives which are available in Indiana at present. In other words, the base case can be set up by introducing the incentives into the economic analysis. Those incentives are net metering, financing with tax deduction from home equity loan interest, and federal tax credits. With the base case, we can find the breakeven cost of electricity from solar PV systems, and compare it to an annualized retail price of electricity from the grid.

3.6. Scenarios considered

In this study, we analyze several cases to get the breakeven cost for each case and compare it with the expected annualized electricity price to get the distributions of the difference between the cost of solar PV systems and annualized electricity price in each scenario case. With this, we can get the probability that the cost of solar PV systems can be less than the annualized electricity price and determine stochastic dominance. We also figure out the relative importance in reducing the cost of installing PV systems in houses with the distributions. Since incentive-related policy is usually composed of a mixture of several incentives, this comparison can be meaningful to show how effective each incentive is in reducing the cost of the solar PV systems. There will be three individual cases to compare plus four cases that represent different combinations of the one change at a time cases.

- A case without net-metering
- A case without financing
- A case without federal tax credit
- A case with depreciation
- A case with carbon tax
- A case with depreciation and carbon tax
- A case with depreciation and carbon tax and no federal tax credit

The detailed combination of policies for each case is described in Table 3-3. For simplicity, we use abbreviations for policy options:

- NM for Net Metering
- F for Financing
- FTC for Federal Tax Credits
- D for Depreciation
- CT for Carbon Tax

Table 3-3: Combinations of Policies for Each Case

Policy Options / Cases	NM	F	FTC	D	CT
Baseline Case (Financial Analysis)	O	O	O	X	X
The Case Without Net Metering	X	O	O	X	X
The Case Without Financing	O	X	O	X	X
The Case Without Federal Tax Credits	O	O	X	X	X
The Case With Depreciation	O	O	O	O	X
The Case With Carbon Tax	O	O	O	X	O
The Case With Depreciation and Carbon Tax	O	O	O	O	O
The Case With Depreciation and Carbon Tax and No Federal Tax Credit	O	O	X	O	O

Therefore, this study aims at calculating the annualized cost of solar PV systems and the breakeven cost of electricity per kWh generated from solar PV system in each case and to evaluate the effect of each policy or combination of policies in reducing the cost of solar PV systems.

3.6.1. The Case without Net Metering

The first scenario compares the cost of solar PV systems with the annualized cost between the baseline case with net metering and the case without net metering. The most important thing in determining the effect of the net metering is how much excess electricity can be generated from the solar PV system. Tables 3-4 and 3-5 show how much electricity is generated from solar PV systems based on the results of an experiment of New Holland Rochester, Inc. Although both the solar PV systems generate enough electricity to compensate the household's demand for electricity in annual total amounts, its monthly amount of electricity generation is not necessarily high enough in every month to produce excess electricity for consumers to sell back to the utilities. In other words, since the net metering is based on monthly net amount of electricity between generation and consumption, it is necessary to focus on whether there is excess amount of electricity in each month.

For comparing the larger system with the smaller system, the larger the capacity of the system is, the more electricity is generated. As is noted in Tables 3-4 and 3-5, the electricity generated from the solar PV system with 5.88 kW of capacity is more than is consumed during only two months, April and May. When it comes to the solar PV system with 7.84 kW of capacity, excess electricity is generated during 6 months, March through June and September through October. Thus, this analysis also presents comparison in an effectiveness of net metering between the two systems with different system size.

Table 3-4: Monthly Demand and Generation of Electricity by Solar PV System with the 5.88 kW of Capacity in the 1st year (Source: experiment of New Holland Rochester, Inc.)

Note: * denotes months when excess electricity is generated from solar PV system

Month	Electricity Demand (kWh)	Electricity Generated (kWh)	Excess Electricity (kWh)
1	1232.37	500.00	-732.3715
2	1073.97	509.40	-564.5653
3	1086.32	829.40	-256.9180
4	785.49	908.30	122.8085*
5	787.31	1035.90	248.5919*
6	1111.54	1084.90	-26.6449
7	1633.49	992.80	-640.6940
8	1212.78	877.50	-335.2823
9	857.11	756.50	-100.6086
10	748.28	595.50	-152.7786
11	904.30	596.00	-308.2972
12	995.21	332.00	-663.2127
Total	12428.17	9018.20	-3409.9727

Table 3-5: Monthly Demand and Generation of Electricity by Solar PV System with the 7.84 kW of Capacity in the 1st year (Source: experiment of New Holland Rochester, Inc.)

Note: * denotes months when excess electricity is generated from solar PV system

Month	Electricity Demand (kWh)	Electricity Generated (kWh)	Excess Electricity (kWh)
1	1232.37	666.67	-565.7048
2	1073.97	679.20	-394.7653
3	1086.32	1105.87	19.5486*
4	785.49	1211.07	425.5752*
5	787.31	1381.20	593.8919*
6	1111.54	1446.53	334.9884*
7	1633.49	1323.73	-309.7607
8	1212.78	1170.00	-42.7823
9	857.11	1008.67	151.5581*
10	748.28	794.00	45.7214*
11	904.30	794.67	-109.6305
12	995.21	442.67	-552.5461
Total	12428.17	12024.27	-403.9060

3.6.2. The Case without Financing

It is assumed that financing solar PV systems can be done through a home equity loan in this analysis. To be more specific, this study assumes that households can finance the solar PV systems using a home equity loan with a 10-year period. When it comes to loan options, it is assumed that a bank finances at most 80% of the initial installation cost and the financing is at 7.5% of nominal interest rate. Since we assume that the debt from financing is 80% of the total installation cost, 20% of the total installation cost will be a down-payment in the year of installing solar PV systems. It is worth considering the effectiveness of a financing option in reducing the upfront cost of installing solar PV systems because there is a tax deduction based on interest paid on a home equity loan which is for financing for the solar PV systems. Thus, we will calculate a breakeven cost of electricity from solar PV system without the financing option and compare it with the annualized electricity price so that we can figure out how effective the financing option is.

3.6.3. The Case without Federal Tax Credits

Federal tax credits accounts for the largest reduction of total installed cost of solar PV systems. Thirty percent of the total installation cost can be fully applied to federal tax credits. Thus, we are going to see how much higher the breakeven cost will be without the federal tax credit and this can explain how important the federal tax credit is in reducing the upfront cost of solar PV system.

3.6.4. The Case with Depreciation

In the US, households are not able to claim tax deduction from depreciating their solar PV system. This means that households cannot have benefits of tax deduction from depreciation at present. At the same time, however, this also means that there is room for improvement in reducing the cost of installing solar PV system by introducing tax deduction from depreciation. Thus, in this study, the baseline case without depreciation is compared to another case with depreciation so that the effectiveness of tax deduction of depreciation can be explained. That is, the difference between the breakeven cost of electricity from solar PV systems and the annualized electricity price is expected to show how much more beneficial the introduction of tax deduction from depreciation will be for households to reduce the upfront cost of solar PV systems.

The IRS classifies certain geothermal, solar, wind energy property with a 5-year class life under GDS. In order for taxpayers to figure how much deduction they can earn, the IRS has established percentage tables to depreciate properties. Table 3-6 shows the MACRS percentages used in this paper. As we can see below, there is one extra year depreciated. This is attributed to the time that a property is purchased. For example, if a person buys an asset in January while another buys the same asset in December, they should claim different tax deduction from depreciation depending on when they place the asset in service. IRS considers this and uses mid-quarter convention for solar PV systems. No matter when the property is purchased and put in service during a first quarter, one who purchases the asset can claim a mid-quarter's depreciation for the first year, 35%. This results in another depreciation over one extra year which is 6 year for a 5-year depreciation period. IRS has four different MACRS percentage plans for each different quarter. In this study, I assume that the solar PV panel is place in service on the first day of the first year which is the first quarter so that our analysis can be conducted in the entire period from the first year. The corresponding depreciation schedule used is in table 3-6.

Table 3-6: Applicable MACRS Depreciation Percentages for Mid-quarter Convention placed in service in the first quarter

Recovery Year	Depreciation Rate (%)
1	35.00
2	26.00
3	15.60
4	11.01
5	11.01
6	1.38

3.6.5. The Case with Carbon Tax

In our study, carbon tax can be imposed on the current grids emitting CO_2 in Indiana. We assume that most of the electricity in Indiana is produced from coal plants because 98% of total electricity in Indiana is generated from fossil fuel combustion (Figure 2-1). Thus, we examine the effect of carbon tax on the breakeven cost of electricity from solar PV systems. If carbon tax is introduced in Indiana, it might be passed onto electricity consumers by increasing electricity price. For our analysis, we assume that the Social Cost of Carbon (SCC) is complete and market is perfect for simplicity even if the SCC estimate is not complete and market is not perfect in reality. And since a carbon tax is Pigovian tax which is imposed in a negative externality, a carbon tax should be equal to the marginal damage cost which is \$37/ton in 2013 (EPA, 2010). Also, according to EPA (2010), the SCC is expected to increase over the time because future emission might produce larger damages as economic system gets more stressed in response to greater climate changes and more countries industrialized. EPA (2010) also provides the growth rate for the SCC estimate between 2010 and 2050. The growth rate is 1.7% for the period of 2010 through 2020, 1.8% for the period of 2020 through 2030, and 1.6% for the period of 2030 through 2040. So we use each value for given period since the period considered in this study is 2013 through 2032.

Since we consider the distribution of carbon tax on electricity price, we first need to calculate the effect of carbon tax in a unit of electricity price (\$/kWh). We use the CO_2 conversion factor of $7.055 * 10^{-4}$ tons per kWh. Thus SCC can be converted using equation (16):

$$\left(\$37/_{ton}\right) * \left(7.055 * 10^{-4} tons/_{kWh}\right) = \$0.0261/kWh \tag{16}$$

Then, we can add this to electricity price for the first year. Since there is a growth in carbon tax rate, we need to calculate carbon tax each year using equation (17).

$$CTR_k = CTR_{k-1} * (1 + CTGR) \tag{17}$$

This is the function we actually use for @Risk.

- CTR_k is the carbon tax rate in year k

- CTR_{k-1} is the carbon tax rate in year $k-1$
- $CTGR$ is the growth rate of the carbon tax rate

  For $CTGR$, we use different growth rate depending on the period.

  - 1.7% for the period from 2010 to 2020
  - 1.8% for the period from 2020 to 2030
  - 1,6% for the period from 2030 to 2040

After calculating carbon tax each year, we add it to the electricity price in that year and we get the new electricity price inclusive of the carbon tax. In cases which include carbon tax, we should use new electricity price which is the sum of electricity price from the grid and carbon tax imposed instead of the base electricity price.

$$NEP_k = EP_k + CTR_k \tag{18}$$

We also calculated new annualized electricity price distribution for comparison using equation (2) and (6). Thus, in cases which include carbon tax, the annualized electricity price for comparison increases.

3.6.6. The Case with Depreciation and Carbon Tax

We also consider both depreciation and carbon tax. Depreciation and carbon tax are potential policy options to take. Thus, we can examine how much they correct failure of the current policy scheme.

3.6.7. The Case with Depreciation and Carbon Tax but No Federal Tax Credits

We remove the federal tax credits in this part and this case is a kind of economic analysis. With this case, we level the playing field for depreciation providing homeowners the same tax benefit as the grid, and the carbon tax correct the market failure due to the GHG externality.

3.7. Data and assumptions

The assumptions of the benefit cost analysis are listed in table 3-7.

Table 3-7: Benefit Cost Analysis Assumptions

Assumption for analysis of solar PV system in Indiana			
Parameter	Value	Units	Source
PV Panel Capacity (smaller size)	5.880	kW	New Holland Rochester, Inc.
PV Panel Capacity (larger size)	7.840	kW	New Holland Rochester, Inc.
Installation Cost of PV Panel	2.857	$/W	New Holland Rochester, Inc.
Annual Electricity Generated by PV Panel (5.88kW)	9,018.20	kWh/year	New Holland Rochester, Inc.
Annual Electricity Generated by PV Panel (7.84kW)	12,024.27	kWh/year	New Holland Rochester, Inc.

Table 3-7 Continued

O&M Cost	0.005	$/kWh	New Holland Rochester, Inc.
O&M Cost Growth Rate (Nominal)	3	%	New Holland Rochester, Inc.
O&M Cost Growth Rate (Real)	0.49	%	Author's Calculation
Wire Cost	6.00	%	New Holland Rochester, Inc.
Failure Rate of Panel	0.5	%	New Holland Rochester, Inc.
Labor Cost of Repair	75	$	New Holland Rochester, Inc.
Growth Rate of Labor Cost (Nominal)	1	%	New Holland Rochester, Inc.
Degradation Rate of Electricity Generated from PV system (Mode, 1st through 18th year)	0.55	%	Skoczek et al., 2009, Vazquez and Rey-Stolle, 2008
Degradation Rate of Electricity Generated from PV system (Mode, 19th through 20th year)	1.05	%	Skoczek et al., 2009, Vazquez and Rey-Stolle, 2008
Solar PV Panel Life	20	years	New Holland Rochester, Inc.

Table 3-7 Continued

Inflation Rate	2.50	%	Author's assumption
Current Retail Electricity Price	0.1137	$/kWh	EIA
Annualized Electricity Price	0.1206	$/kWh	Author's assumption
Current Electricity Price Growth Rate (Real)	1.08	%	State Utility Forecasting Group, 2011
Discount Rate (Real)	6.00	%	Author's assumption
EPAct 2005 Federal Tax Credit	30.00	%	DSIRE
Loan Amount	80.00	%	Author's assumption
Loan Interest Rate (Nominal)	7.50	%	Average estimation around Lafayette, IN
Loan Financing Period	10	years	Author's assumption
Salvage Value Rate	15.00	%	Author's assumption
Household's Annual Demand for Electricity	12,428.17	kWh/year	EIA

3.7.1. Data Assumptions on the Solar PV System

In this study, we use information for the solar PV system based on the New Holland Rochester, Inc. (NHR, Inc.), the retailer of the solar PV system in Rochester, IN. NHR, Inc. provides two capacities of the solar PV systems, 5.88 kW and 7.84 kW. Thus, we use these two capacities as reference sizes for our analysis. Specific descriptions for assumptions for the system in Table 3-7 are followed below.

- Installation cost of PV panel that NHR, Inc. offers includes costs of solar panels (capital cost), inverters, stands, labor, and installation.

- O&M cost and its growth rate are also provided by NHR, Inc. O&M cost is proportionate to the amount of electricity generated so its unit is denoted on the bases of $ per kWh.

- The annual electricity generated is based on the real experiment conducted by NHR, Inc (Table 3-4 and 3-5).

- Wire cost is for connecting the electricity from the systems to inverters or other components. It is also given by NHR, Inc. that 6.00% of the total installation cost should be added for wiring cost.

- Usually, inverter is replaced around every 10 years. However, in our study, cost of replacing inverter is not accounted because NHR, Inc. offers 25 year warranty for the inverter. This means that, once solar PV systems are set up, there will not be any extra cost for customers to pay for purchasing and changing inverter during the lifetime of solar PV system, 20 years assumed in this study; therefore, it does not need to be included in our assumption.

- Furthermore, as the solar PV systems are connected to the grid, there is no cost for battery or storage facility considered as well.

- For salvage value, we assume that 15% of property will be left after 20 years of installing solar PV system in houses.

3.7.2. General Data Assumptions

There are other assumptions not related to the solar PV system itself. Those assumptions are economic assumptions for analysis.

- Current electricity price comes from the state energy profile data of U.S Energy Information Administration (EIA) for Indiana on July 2013 and its growth rate for projecting price of electricity is from State Utility Forecasting Group (2011).
- For inflation rate, although it is estimated 2.90% for the past 30 years according to the U.S. consumer price index (Bureau of Labor Statistics, 2013), we assume that it is 2.50% for each year.
- We also assume that discount rate is 6.00% in real terms.
- Loan interest rate is the average of the interest for home equity loan in Lafayette, Indiana based on Sep, 2013 and its financing period is assumed to be 10 years with the loan interest rate assumed. For equity fraction for initial capital investment, we assume that banks will finance at most 80% of the initial capital cost.
- Annual household demand for electricity comes from the state energy profile data of U.S EIA for Indiana and is estimated for 2013 based on the average from 2009 and 2012.

3.7.3. Sensitivity Analysis

We also do the sensitivity analysis on several variables which may have effect on the results of the analysis. The variables we consider in this study are;

- Financing period

- Standard Deviation of electricity price from the grid
- Salvage value rate
- Growth Rate of O&M Cost
- Discount rate

For financing, we assume that 10 years of period as a base. For the sensitivity test, we also do the sensitivity analysis over 15 years of financing period. We have used $0.1 * EP_{k-1}$ as a standard deviation of electricity price. As will be seen below, that results in a fairly wide distribution for annualized electricity price, so we do sensitivity using 0.05 as well to determine if the standard deviation has a significant impact on results. With the change of salvage value rate, the results may not change much since it is 20 years in the future, but it is still important to do the analysis. We change the salvage value rate by +/-50% and see the percentage change on the results. The base salvage rate is 15%, so we change it to 22.5% (+50%) and 7.5% (-50%). Since customers are concerned O&M cost in the future may be higher than forecast, we also increase O&M cost growth rate by 50%, which becomes 4.5%, and see how much the results will change. O&M cost for the base year should be fixed because it is based on the current data from NHR, Inc. Finally, we do sensitivity on the real discount rate using values of 3 (-50%) and 9 (+50%) percent in addition to the 6 percent in the base case.

CHAPTER 4. RESULTS

In chapter 3, methodology for benefit cost analysis, specific cases, and scenarios are described. In this chapter, we present and summarize the results of the analysis which is for the difference between the breakeven cost of solar PV systems and the annualized electricity price. Then, in chapter 5, we draw conclusions from the results.

4.1. Results from the Scenarios considered

4.1.1. Annualized Electricity Price

Now, we take a deeper look at the comparison of a breakeven cost for each case with the annualize electricity price from the grid. We have two annualized electricity prices for comparison.

- Annualized electricity price for cases that do NOT include carbon tax
- Annualized electricity price for cases that include carbon tax

The annualized real electricity price distribution for cases without carbon tax is shown in Table 4-1 and Figure 4-1. It has a mean of 0.1206 and a standard deviation of 0.0259. There is a 90% probability that the price will be between 0.0835 and 0.1672. The other annualized real electricity price distribution for cases with carbon tax has a mean of 0.1447 and a standard deviation of 0.0257.

There is a 90% probability that the price will be between 0.1081 and 0.1904. For comparisons, we use the electricity price with or without the carbon tax to be consistent with the assumption applied for the solar system. This electricity price distribution will be compared with the distribution of annualized solar costs in each of the cases to be presented below. For comparison, we calculate differences between the distribution of solar cost of each case and the annualized electricity price by subtracting the annualized electricity price from the breakeven cost of the solar PV system. Thus, if the mean value for a difference is positive, it means that solar is more expensive. On the other hand, if the mean value for a difference if negative, solar is less expensive. Also, we get the distributions for the difference as well to determine the probability that the cost of solar systems will be less than the annualized electricity price. In addition to the probability that solar can be less expensive than electricity from grids, we get the stochastic dominance for each case. With this probability information, we have an estimate of how likely the solar PV systems will be less expensive in each case.

Table 4-1: Annualized Electricity Price without and with Carbon Tax

	Mean	Standard Deviation
	$/kWh	$/kWh
Annualized Electricity Price without Carbon Tax	0.1206	0.0259
Annualized Electricity Price with Carbon Tax	0.1447	0.0257

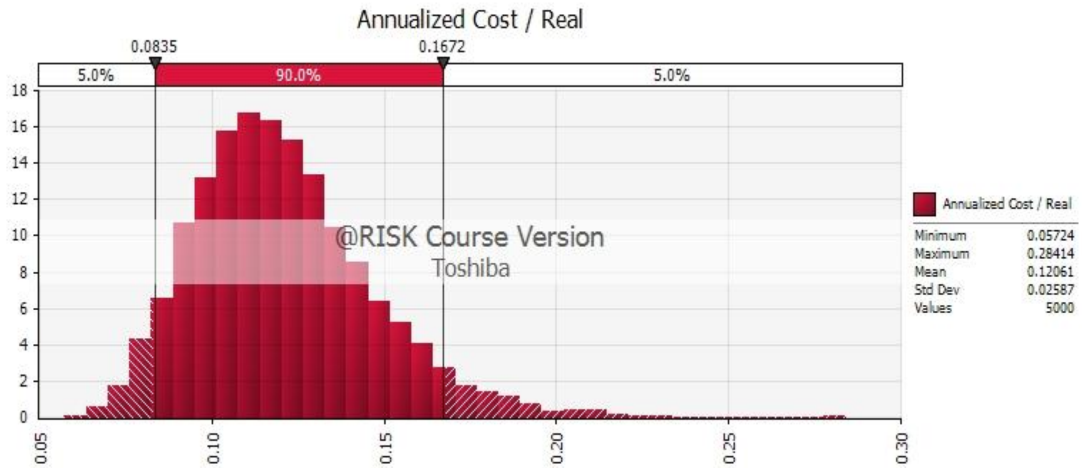

Figure 4-1: Annualized Electricity Price for cases that do NOT include Carbon Tax

4.1.2. The Economic Analysis

4.1.2.1. <u>Without Federal Tax Credits</u>

The result for the difference is shown in Table 4-2. As we can see in Table 4-2, the mean value for the difference is positive. This means that it is more expensive for consumers to adopt solar PV systems without any incentives. The probability that the solar PV system can be a less expensive path is shown in Table 4-2. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of 0.0475 and a standard deviation of 0.0169. There is a 90% probability that the difference will be between 0.0170 and 0.0718. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of 0.0735 and a standard deviation of 0.0203. There is a 90% probability that the difference will be between 0.0366 and 0.1025. The probabilities that the solar systems can be less expensive than the electricity price are 1.1% and 0.2% for the 5.88kW and the 7.84kW system capacities, respectively. In other words, it is highly unlikely that either solar system will be economical under these assumptions.

Table 4-2: Breakeven Cost of Solar PV System in Economic Analysis without Federal Tax Credits and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1682	0.0475	1.1
	Standard Deviation	0.0090	0.0169	
7.84kW	Mean	0.1942	0.0735	0.2
	Standard Deviation	0.0057	0.0203	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.1.2.2. With Federal Tax Credits

Since we introduce the federal subsidy here, it can be expected that the actual cost of solar will be reduced with federal tax credits removed. As illustrated in Table 4-3, the difference between the cost of solar system without federal subsidy and the annualized electricity price is expected to be positive. Thus, it is still not profitable to adopt solar PV systems. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of 0.0122 and a standard deviation of 0.0170. There is a 90%

probability that the difference will be between -0.0189 and 0.0361. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of 0.0264 and a standard deviation of 0.0204. There is a 90% probability that the difference will be between -0.0108 and 0.0554. The probability that the solar systems can be less expensive than the electricity price becomes greater than the economic analysis without federal tax credits. In other words, there is a 21.2% probability that the solar PV system with the 5.88kW capacity can be less expensive than the electricity from the grid with federal tax credits introduced in economic analysis. For the 7.84kW system, there is a 10.4% probability solar will be less expensive. Since federal tax benefits are introduced, the probability is expected to be larger than the economic analysis without federal tax credits.

Table 4-3: The Difference between the Breakeven Cost of Solar PV System in Economic Analysis with Federal Tax Credits and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1328	0.0122	21.2
	Standard Deviation	0.0091	0.0170	
7.84kW	Mean	0.1470	0.0264	10.4
	Standard Deviation	0.0057	0.0204	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.2. Scenarios Considered

4.2.1. The Financial Analysis (The Baseline Case)

Since it is not always profitable to adopt solar PV systems without any incentive as shown in the economic analysis, it is necessary to consider incentives to reduce the cost of solar PV systems. The result shows that the cost of solar PV systems decreases with net-metering, financing, and federal tax credits (Table 4-4). Now we look at the difference between the cost of solar systems in financial analysis and the annualized electricity price. Table 4-4 presents the results for the difference distribution. As presented in Table 4-4, the mean values for the difference are negative. Thus, we can say that solar PV systems can be less expensive on average with financing. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of -0.0016 and a standard deviation of 0.0174. There is a 90% probability that the difference will be between -0.0330 and 0.0232. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of -0.0024 and a standard deviation of 0.0232. There is a 90% probability that the difference will be between -0.0446 and 0.0308. There is a 48.5% probability for the 5.88kW system and a 50.0% probability for the 7.84kW system of solar being less expensive. With the incentives introduced for financial analysis, the probability increases substantially especially for the 7.84kW system. Net metering plays an important role in inducing the greater effect on the larger system. Since the larger system produces more electricity and there is more electricity to sell back with net metering, the probability solar is less expensive for the larger system increases more than for the small system. Thus, even if it is not always less expensive to adopt solar PV systems with the current incentives, solar PV systems can be considered as a good option for customers, since there is a 50-50 chance of the solar system being breakeven for both system sizes.

Table 4-4: The Difference between the Breakeven Cost of Solar PV Systems in Financial Analysis and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1189	-0.0016	48.5
	Standard Deviation	0.0081	0.0174	
7.84kW	Mean	0.1181	-0.0024	50.0
	Standard Deviation	0.0025	0.0232	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.2.2. The Baseline Case and the Case without Net-Metering

The breakeven cost increases if net-metering is removed. Table 4-5 represents the results of the actual cost and the difference between the cost of solar systems without net-metering and the annualized electricity price. Compared to the baseline case, the mean value for the difference distribution becomes higher than the annualized electricity price. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of 0.0021 and a standard deviation of 0.0165. There is a 90% probability that the difference will be between -0.0275 and 0.0256. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of 0.0127 and a standard deviation of 0.0205. There is a 90% probability that the difference will be between -0.0239 and 0.0414. Besides, net metering is more effective in the larger system capacity, 7.84kW, in the sense that the difference becomes greater in the 7.84kW than in the 5.88kW system capacity without net metering. Also, the probability that solar PV system without net metering can be less expensive than the electricity price becomes less than the baseline case. The probability is 41.4% and 24.0% for the 5.88kW system and the 7.84kW system, respectively. We can say that net metering plays an important role in reducing the cost of solar PV systems.

Table 4-5: The Difference between the Breakeven Cost of Solar PV Systems in the Case without Net Metering and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1225	0.0021	41.4
	Standard Deviation	0.0087	0.0165	
7.84kW	Mean	0.1334	0.0127	24.0
	Standard Deviation	0.0057	0.0205	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.2.3. The Baseline Case and the Case without Financing

Were it not for financing, the breakeven cost is expected to rise, and it does as we can see in the Table 4-6. Table 4-6 presents the results of the difference between the cost of solar systems without financing and electricity price. As expected, the cost of solar PV systems is higher than the annualized electricity price ($0.1206/kWh). We also have the distribution of the difference between the cost of solar systems without financing and the annualized electricity price. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of 0.0086 and a standard deviation of 0.0176. There is a 90% probability that the difference will be between -0.0234 and 0.0335. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of 0.0112 and a standard deviation of 0.0234. There is a 90% probability that the difference will be between -0.0314 and 0.0439. Even if the mean value for the cost of solar PV system is higher than the annualized electricity price, there is a probability that solar PV systems can be a less expensive pathway. The probability is 27.0% and 27.8 % for the 5.88kW and the 7.84kW system, respectively. However, the probabilities decrease from the baseline case. In this sense, financing also seems to play an important role in reducing the cost of solar PV systems. This is because our assumed nominal loan interest rate (7.5%) is less than the 6% real discount rate (8.65% nominal).

Table 4-6: The Difference between the Breakeven Cost of Solar PV Systems in the Case without Financing and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1292	0.0086	27.0
	Standard Deviation	0.0082	0.0176	
7.84kW	Mean	0.1318	0.0112	27.8
	Standard Deviation	0.0025	0.0234	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.2.4. The Baseline Case and the Case without Federal Tax Credits

Federal tax credit plays the most important role in reducing the cost of adopting the solar PV systems as seen in Table 4-7. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of 0.0288 and a standard deviation of 0.0172. There is a 90% probability that the difference will be between -0.0026 and 0.0536. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of 0.0380 and a standard deviation of 0.0232. There is a 90% probability that the difference will be between -0.0045 and 0.0716. The probabilities that the cost of solar PV systems is less than the annualized electricity prices are 6.2% for the 5.88kW system and 6.3% for the 7.84kW system. Since the federal tax credits takes the largest part in reducing the cost of solar systems, the substantial decrease in probability is as expected.

Table 4-7: The Difference between the Breakeven Cost of Solar PV Systems in the Case without Federal Tax Credits and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1492	0.0288	6.2
	Standard Deviation	0.0080	0.0172	
7.84kW	Mean	0.1586	0.0380	6.3
	Standard Deviation	0.0025	0.0232	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

4.2.5. The Baseline Case and the Case with Depreciation

What if tax deduction from depreciation is introduced? As we have seen in Table 4-8, the breakeven cost with depreciation decreases because tax deduction from depreciation is another benefit that consumers can obtain. Table 4-8 represents the result for the difference between the cost of the solar PV systems with tax deduction from depreciation and the electricity price. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of -0.0223 and a standard deviation of 0.0174. There is a

90% probability that the difference will be between -0.0537 and 0.0027. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of -0.0300 and a standard deviation of 0.0235. There is a 90% probability that the difference will be between -0.0725 and 0.0035. The mean values for both system capacities show negative values so the solar systems can be much less expensive with the depreciation tax deduction. Figure 4-2 illustrates the distribution of the difference and the probability that the solar systems can be less expensive to adopt than to remain purchasing electricity from the grid. As seen in Figure 4-2, the probabilities that solar is less expensive for both systems are very high, 92.1% for the 5.88kW and 92.3% for the 7.84kW. This means that the solar PV system can be a lot less expensive way with tax deduction from depreciation introduced.

Table 4-8: The Difference between the Breakeven Cost of Solar PV Systems in the Case with Depreciation and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.0983	-0.0223	92.1
	Standard Deviation	0.0081	0.0174	
7.84kW	Mean	0.0906	-0.0300	92.3
	Standard Deviation	0.0025	0.0235	

* Annualized Electricity Price Mean: $0.1206 (without Carbon Tax)

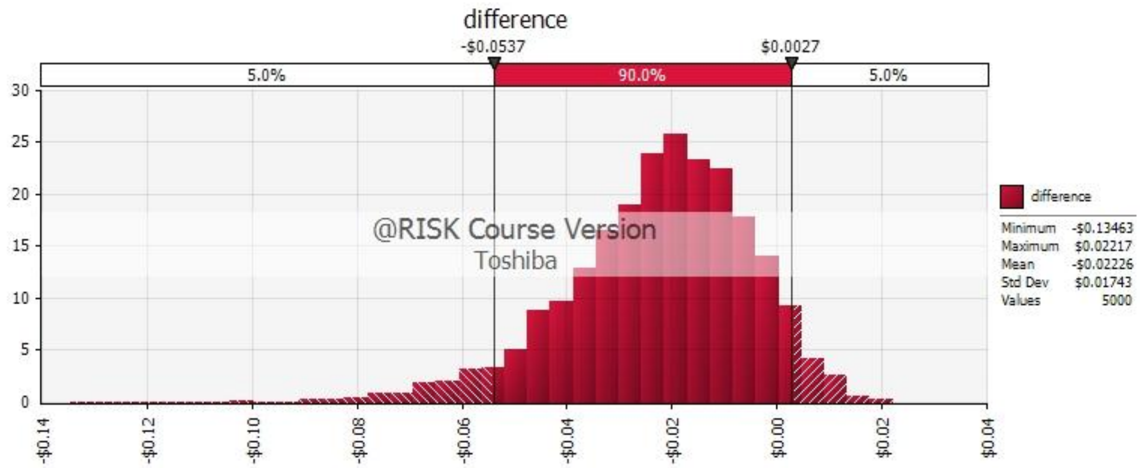

Figure 4-2: Distribution of the Difference between the Breakeven Cost of Solar PV Systems with Depreciation and the Annualized Electricity Price for the 5.88kWh system

4.2.6. The Baseline Case and the Case with Carbon Tax

If carbon tax is imposed on the grid generating electricity with fossil fuels, the burden may be passed onto customers. This means that we need to use the new electricity price which is the sum of electricity price from the grid and carbon tax rate. Thus, the annualized electricity price for the analysis increases. Also, there will be an increase in cost of solar since the electricity cost that customers need to pay increases by the amount of carbon tax. Table 4-9 shows the results of the difference between the cost of solar PV systems when carbon tax is introduced and the annualized electricity price. In this case, the differences become negative for both system capacities. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of -0.0184 and a standard deviation of 0.0177. There is a 90% probability that the difference will be between -0.0503 and 0.0063. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of -0.0248 and a standard deviation of 0.0231. There is a 90% probability that the difference will be between -0.0676 and 0.0083. The difference is greater for the 7.84kW system capacity than for the 5.88kW system capacity. This may be associated with how much more electricity consumers still need to purchase even after installing solar PV systems. The smaller the solar system is and the less electricity it generates, the larger amount of electricity the consumers need to buy from the grid. The amount of electricity from solar systems is smaller for the 5.88kW system, so the result that the solar system annualized cost is less expensive for larger system seems to be reasonable. Figure 4-3 illustrates the distribution of the difference and the probability the cost of solar systems will be less than the electricity cost if carbon tax is enacted. For the 5.88kW system capacity, there is a 86.2% probability while there is a 86.8% probability for the 7.84kW system capacity. As is expected, the probability solar is less expensive is higher for the larger system than for the smaller system.

Table 4-9: The Difference between the Breakeven Cost of Solar PV Systems in the Case with Carbon Tax and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1263	-0.0184	86.2
	Standard Deviation	0.0082	0.0177	
7.84kW	Mean	0.1198	-0.0248	86.8
	Standard Deviation	0.0025	0.0231	

* Annualized Electricity Price Mean: $0.1447 (with Carbon Tax)

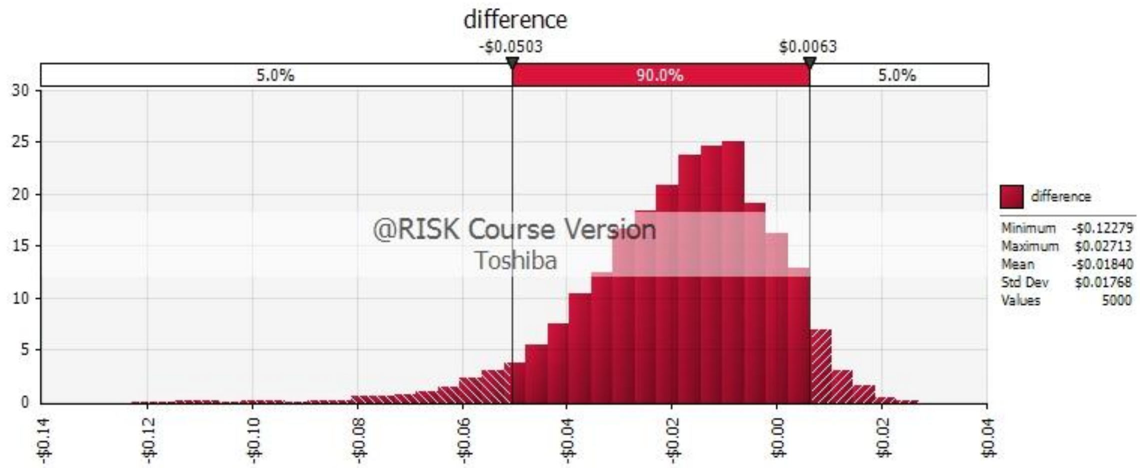

Figure 4-3: Distribution of the Difference between the Breakeven Cost of Solar PV Systems with Carbon Tax and the Annualized Electricity Price for the 5.88kWh system

4.2.7. The Baseline Case and the Case with Depreciation and Carbon Tax

Table 4-10 represents the result for the difference distribution of the case with depreciation and carbon tax. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of -0.0391 and a standard deviation of 0.0177. There is a 90% probability that the difference will be between -0.0713 and -0.0141. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of -0.0524 and a standard deviation of 0.0236. There is a 90% probability that the difference will be between -0.0951 and -0.0191. Although the results show a slight difference between the two system capacities, the probability solar is less expensive is 99.9% for both systems. For smaller system, the probability increases from the case only with carbon tax with the effect of depreciation benefits. Figure 4-4 illustrates the distribution of difference between the cost of solar PV system and the annualized electricity price.

Table 4-10: The Difference between the Breakeven Cost of Solar PV Systems in the Case with Depreciation and Carbon Tax and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1056	-0.0391	99.9
	Standard Deviation	0.0083	0.0177	
7.84kW	Mean	0.0923	-0.0524	99.9
	Standard Deviation	0.0025	0.0236	

* Annualized Electricity Price Mean: $0.1447 (with Carbon Tax)

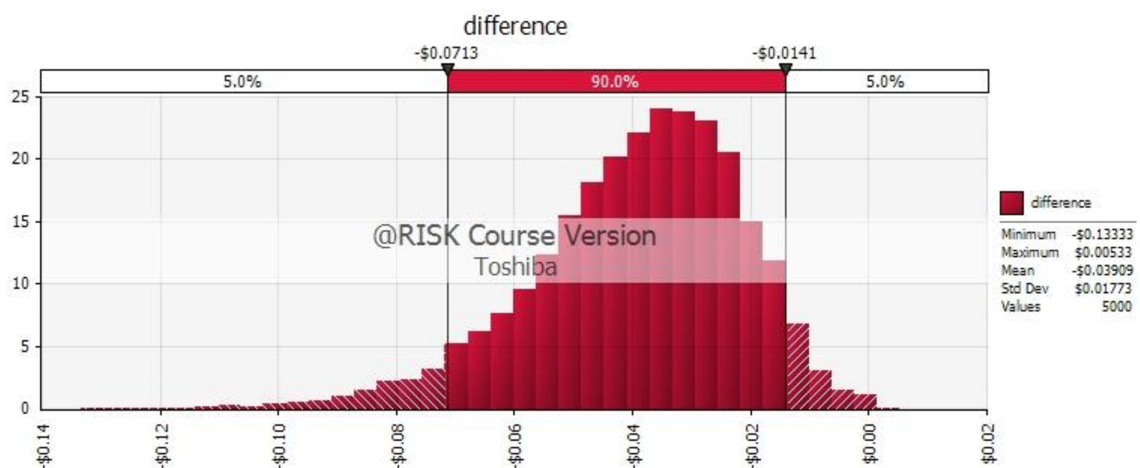

Figure 4-4: Distribution of the Difference between the Breakeven Cost of Solar PV Systems with Depreciation and Carbon Tax and the Annualized Electricity Price for the 5.88kWh system

4.2.8. The Case with Depreciation and Carbon Tax but No Federal Tax Credits

Here, we take a look at another economic analysis with net metering, financing, depreciation, and carbon tax, but without federal tax credits. Table 4-11 presents the results for the difference distribution. For the 5.88kW system, the distribution of the difference in the economic analysis has a mean of -0.0169 and a standard deviation of 0.0176. There is a 90% probability that the difference will be between -0.0483 and 0.0083. For the 7.84kW system, the distribution of the difference in the economic analysis has a mean of -0.0121 and a standard deviation of 0.0239. There is a 90% probability that the difference will be between -0.0557 and 0.0214. Figure 4-5 illustrates the distribution of difference between the annualized electricity cost and the solar cost. The probabilities that the solar systems can be less expensive than the electricity price are 83.7% and 66.0% for the 5.88kW and the 7.84kW system capacities, respectively. Compared to the case with all the policy options considered in this study, the probability decreases since federal tax credits which is the most important policy is removed in this case. However, the solar systems have an 84 and 66% chance of being less costly than electricity from the grid. This is significant because this case in a sense represents an economic case with no subsidies – just a level playing field for depreciation and a carbon tax to correct the GHG externality.

Table 4-11: The Difference between the Breakeven Cost of Solar PV System in Economic Analysis with Net Metering, Financing, Depreciation, and Carbon Tax and the Annualized Electricity Price

System Capacities	Results	Solar System Annualized Cost	Difference between Solar and Grid	Probability Solar is Less Expensive
		$/kWh	$/kWh	%
5.88kW	Mean	0.1278	-0.0169	83.7
	Standard Deviation	0.0082	0.0176	
7.84kW	Mean	0.1327	-0.0121	66.0
	Standard Deviation	0.0025	0.0239	

* Annualized Electricity Price Mean: $0.1447 (with Carbon Tax)

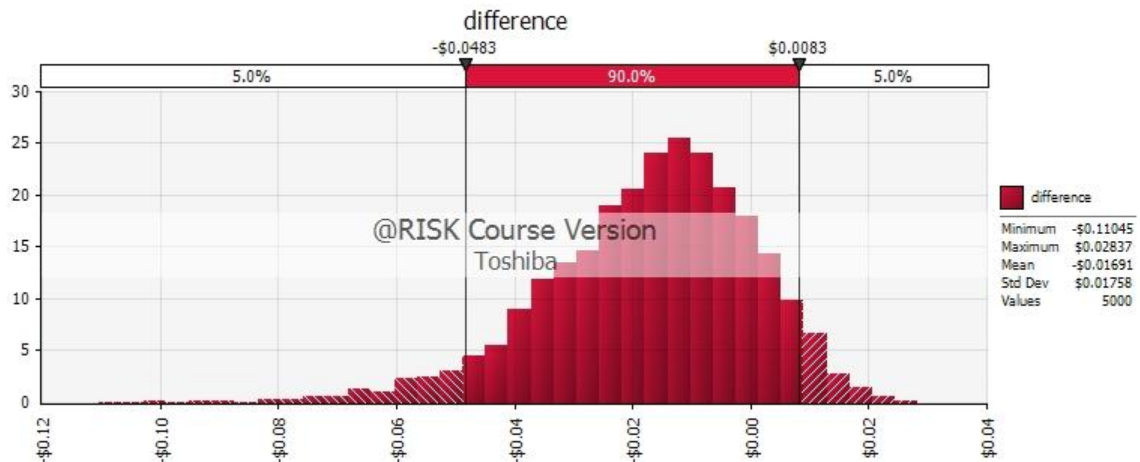

Figure 4-5: Distribution of the Difference between the Breakeven Cost of Solar PV Systems with Depreciation and Carbon Tax but NO Federal Tax Credits and the Annualized Electricity Price for the 5.88kWh system

4.3. Sensitivity Analysis

In sensitivity analysis, we see the effect of the change in input variables in the results. Variables we consider are financing period, standard deviation of electricity price from the grid, salvage value rate and growth rate of O&M cost.

4.3.1. Financing Period

We do the sensitivity test for longer period of financing, 15 years instead of 10 years. For most cases, the probability that solar is less expensive increases. But the increases are by 5% at most. This means that the change of financing period does not impact on the probability solar is less expensive by much.

4.3.2. Standard Deviation of Electricity Price from the Grid

We use a smaller standard of deviation for the electricity price. We use 0.05 instead of 0.1 for the factor multiplied by the previous year's price for the standard deviation. The results are shown in Table 4-12. We report mean solar costs and the probability solar is less expensive for each case with both the base standard deviation multiplication factor (0.1) and the other multiplication (0.05) for comparison. The mean solar costs are almost the same for all cases. Probability does not seem to change much. However, the probabilities show a little difference. It shows higher probabilities for several cases and lower probabilities for other cases. One particular observation we can make here is that there appear lower probabilities in cases removing any policy. On the other hand, in cases adding any policy, the probabilities get higher. The last case with depreciation and carbon tax but no federal subsidy shows a higher probability of solar being economic with the lower standard deviation on electricity price.

Table 4-12: Sensitivity Analysis for the Standard Deviation of Electricity Price

Case	Multiplied Factor for Standard Deviation	5.88kW		7.84kW	
		Mean Solar Cost	Probability Solar is Less Expensive	Mean Solar Cost	Probability Solar is Less Expensive
		$/kWh	%	$/kWh	%
Base Case	0.1	0.1189	48.5	0.1181	50.0
	0.05	0.1190	55.9	0.1181	56.2
Case without Net Metering	0.1	0.1225	41.4	0.1334	24.0
	0.05	0.1226	39.3	0.1334	10.8
Case without Financing	0.1	0.1292	27.0	0.1318	27.8
	0.05	0.1292	15.9	0.1385	16.6
Case without Federal Tax Credits	0.1	0.1492	6.2	0.1586	6.3
	0.05	0.1493	0.2	0.1586	0.3
Case with Depreciation	0.1	0.0983	92.1	0.0906	92.3
	0.05	0.0983	95.0	0.0906	99.9
Case with Carbon Tax	0.1	0.1263	86.2	0.1198	86.8
	0.05	0.1263	95.0	0.1198	95.0
Case with Depreciation and Carbon Tax	0.1	0.1056	99.9	0.0923	99.0
	0.05	0.1056	100.0	0.0923	100.0
Case with Depreciation and Carbon Tax and No Federal Tax Credits	0.1	0.1278	83.7	0.1327	66.0
	0.05	0.1278	95.0	0.1327	85.4

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

4.3.3. Salvage Value Rate

We examine the sensitivity of salvage value rate. We take a look at how much the probability solar is less expensive is changed with the +/- 50% change of salvage value rate. The results of percentage change are shown in Table 4-13. As is seen, it shows a certain pattern. If salve value rate decreases, so does the probability solar is less expensive, vice versa. However, changes in the probability are not large. Thus, a change in salvage value rate does not impact on the probability that solar is less expensive much.

Table 4-13: Sensitivity Analysis for the Salvage Value Rate

Case	System Capacity	Probability solar is Less Expensive (%)		
		Base	-50%	+50%
Base Case	5.88kW	48.5	45.8	52.3
	7.84kW	50.0	46.2	52.9
Case without Net Metering	5.88kW	41.4	37.8	42.4
	7.84kW	24.0	21.7	26.1
Case without Financing	5.88kW	27.0	25.7	31.0
	7.84kW	27.8	25.9	30.0
Case without Federal Tax Credits	5.88kW	6.2	5.6	7.9
	7.84kW	6.3	6.0	7.6
Case with Depreciation	5.88kW	92.1	91.2	93.4
	7.84kW	92.3	90.7	94.0
Case with Carbon Tax	5.88kW	86.2	83.6	88.7
	7.84kW	86.8	85.0	88.9
Case with Depreciation and Carbon Tax	5.88kW	99.9	95.0	100.0
	7.84kW	99.9	95.0	99.9
Case with Depreciation and Carbon Tax and No Federal Tax Credits	5.88kW	83.7	79.8	87.3
	7.84kW	66.0	62.9	70.9

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

4.3.4. Growth Rate of O&M Cost

We take a look at how much the probability solar is less expensive is changed with the 50% increase of O&M cost growth rate. The results of percentage change are shown in Table 4-14. The result shows that the probability solar is less expensive decreases but it does not change much in most cases. This means that O&M cost growth rate does not affect the solar cost as much as customers concern, thus, customers do not need to worry about O&M cost when they consider solar PV systems.

Table 4-14: Sensitivity Analysis for the O&M Cost Growth Rate

Case	System Capacity	Probability Solar is Less Expensive (%)	
		Base	+50%
Base Case	5.88kW	48.5	47.7
	7.84kW	50.0	48.5
Case without Net Metering	5.88kW	41.4	39.5
	7.84kW	24.0	22.7
Case without Financing	5.88kW	27.0	27.0
	7.84kW	27.8	27.5
Case without Federal Tax Credits	5.88kW	6.2	6.0
	7.84kW	6.3	6.2
Case with Depreciation	5.88kW	92.1	91.2
	7.84kW	92.3	91.5
Case with Carbon Tax	5.88kW	86.2	86.2
	7.84kW	86.8	86.1
Case with Depreciation and Carbon Tax	5.88kW	99.9	95.0
	7.84kW	99.9	95.0
Case with Depreciation and Carbon Tax and No Federal Tax Credits	5.88kW	83.7	82.5
	7.84kW	66.0	66.1

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

4.3.5. Discount Rate

The discount rate, unlike other variables, would be expected to have a significant impact on results. Table 4-15 illustrates the result for the sensitivity analysis for the discount rate. Mostly, the probability solar is less expensive decreases with an increase in discount rate, while the probability increases with a decrease in discount rate. This change is due to the high capital intensity of solar systems. For solar, most of the 20 year cost is incurred at the beginning of year 1, so a high discount rate that reduces the value of future savings will make solar less attractive, while a lower discount rate that values future benefits higher will make solar more attractive.

Table 4-15: Sensitivity Analysis for the Discount Rate

Case	System Capacity	Probability solar is Less Expensive (%)		
		Base	-50%	+50%
Base Case	5.88kW	48.5	74.4	24.1
	7.84kW	50.0	75.7	24.8
Case without Net Metering	5.88kW	41.4	67.2	18.0
	7.84kW	24.0	50.0	7.9
Case without Financing	5.88kW	27.0	73.3	3.6
	7.84kW	27.8	73.0	4.0
Case without Federal Tax Credits	5.88kW	6.2	23.5	1.2
	7.84kW	6.3	23.5	1.2
Case with Depreciation	5.88kW	92.1	97.1	82.3
	7.84kW	92.3	95.0	82.8
Case with Carbon Tax	5.88kW	86.2	95.0	64.4
	7.84kW	86.8	97.4	64.8
Case with Depreciation and Carbon Tax	5.88kW	99.9	100.0	99.4
	7.84kW	99.9	100.0	95.0
Case with Depreciation and Carbon Tax and No Federal Tax Credits	5.88kW	83.7	95.9	62.3
	7.84kW	66.0	88.9	38.1

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

CHAPTER 5. CONCLUSIONS

5.1. Scenario Analysis

In this section, we summarize the results for all cases in Tables 5-1 and 5-2. Again, we use abbreviations for policy options included in each case. For both systems, the results normally show similar probability changes. Without net metering, financing, federal tax credits, the probabilities decrease for both systems. With the introduction of depreciation, the probabilities increase substantially for both systems, while they decrease with the introduction of carbon tax.

In economic analyses and case without net-metering for both system capacities, the larger system shows lower probability that solar can be less expensive even if the larger system generates more electricity. This may be associated with the fact that economic analysis does not include net-metering with which customer can take advantage of the larger system. Without net-metering, excess electricity should be discarded instead of being sold to the utility. Thus, the larger system shows lower probability solar can be less expensive for economic analyses and the case without net-metering.

Clearly, all the policy options have an impact on economic viability of solar systems. Under current policy, which is federal tax credit, financing, and net metering, solar has about a 50-50 chance of being breakeven. That probability falls if any of these policies or practices is not available. On the other hand, depreciation and carbon tax are not current policy. If either is added, the likelihood of solar being economic increases to around 90%. If both are added, solar has about a 100% chance of being preferable to grid electricity under the assumptions of this analysis. For the last case, we remove federal subsidy while keep net metering, financing, depreciation, and carbon tax. This case approximates a pure economic case as depreciation levels the playing field and the carbon tax prices the GHG externality. The probability of solar being economic more than doubles compared to the base case for the smaller system (to 84%), while the larger system increases to 66%. What this says is that the economically justifiable policy changes of leveling the field for depreciation and adding a carbon tax are more powerful in inducing investment in solar energy than the current federal tax credit.

However, there are differences in this change of probability between both system capacities. This difference in the change of probability is attributed to the system size. First, for the case without net metering, the 5.88kW system shows higher probability that solar is less expensive than the 7.84kW system. This may be because the amount of excessive electricity for customers to sell back to the grid is smaller for 5.88kW system than for 7.84kW system. Second, for the case with carbon tax, the 7.84kW system shows higher probability that solar is less expensive than the 5.88kW system. This may be because the amount of electricity for customers to buy even after installation of solar PV systems is smaller for 7.84kW system than for 5.88kW system. Last, for the case with depreciation and carbon tax, the probability that solar is less expensive is essentially the same (around 100%) for both sizes.

Table 5-1: Summary for Statistics of the 5.88kW System Capacity

Policy Set	Policy Options Included	Annualized Solar Expected Cost ($/kWh)	Standard Deviation	Probability Solar is Less Expensive (%)
The Base Case	NM, F, FTC	0.1189	0.0081	48.5
The Case without Net Metering	F, FTC	0.1225	0.0087	41.4
The Case without Financing	NM, FTC	0.1292	0.0082	27.0
The Case without Federal Tax Credits	NM, F	0.1492	0.0080	6.2
The Case with Depreciation	NM, F, FTC, D	0.0983	0.0081	92.1
The Case with Carbon Tax	NM, F, FTC, CT	0.1263	0.0082	86.2
The Case with Depreciation and Carbon Tax	NM, F, FTC, D, CT	0.1056	0.0083	99.9
Case with Depreciation and Carbon Tax and No Federal Tax Credits	NM, F, D, CT	0.1278	0.0082	83.7

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

Table 5-2: Summary for Statistics of the 7.84kW System Capacity

Policy Set	Policy Options Included	Annualized Solar Expected Cost ($/kWh)	Standard Deviation	Probability Solar is Less Expensive (%)
The Base Case	NM, F, FTC	0.1181	0.0025	50.0
The Case without Net Metering	F, FTC	0.1334	0.0057	24.0
The Case without Financing	NM, FTC	0.1318	0.0025	27.8
The Case without Federal Tax Credits	NM, F	0.1586	0.0025	6.3
The Case with Depreciation	NM, F, FTC, D	0.0906	0.0025	92.3
The Case with Carbon Tax	NM, F, FTC, CT	0.1198	0.0025	86.8
The Case with Depreciation and Carbon Tax	NM, F, FTC, D, CT	0.0923	0.0025	99.9
Case with Depreciation and Carbon Tax and No Federal Tax Credits	NM, F, D, CT	0.1327	0.0025	66.0

Mean electricity prices are 0.1206 without CT and 0.1447 with CT

5.2. Stochastic Dominance

Tables 5-3 and 5-4 represent the results of the stochastic dominance analysis. In these tables, a Y signifies that the case exhibits first or second degree stochastic dominance, and N signifies that it does not. A dash indicates that the test does not apply (case in which first degree stochastic dominance applies, so second degree is not relevant). In both system capacities, prices of electricity from grid is less expensive for economic analysis with and without federal tax credits, cases without net metering, financing, and federal tax credits. Cases for which the solar PV system can be less expensive are the base case, case with depreciation, carbon tax, depreciation and carbon tax, and case with depreciation, carbon tax, and no federal tax credits. For stochastic dominance, electricity from grid first-order stochastically dominates solar PV system in the economic case. Solar PV system first-order stochastically dominates electricity from the grid in the case with both depreciation and carbon tax. Other than these two cases, the one cost second-order dominates the other cost for each case as described in tables 5-3 and 5-4. Second order stochastic dominance is an important conclusion in this analysis and bears further research in the future.

Table 5-3: Results for Stochastic Dominance for 5.88kW System Capacity

Policy Set	Policy Options Included	Which is Less Expensive	1st-order Stochastic Dominance	2nd-order Stochastic Dominance
Economic Analysis*	None	Grid	Y	-
Economic Analysis with Federal Tax Credits*	FTC	Grid	N	Y

Table 5-3 Continued

The Base Case*	NM, F, FTC	Solar	N	Y
The Case without Net Metering*	F, FTC	Grid	N	Y
The Case without Financing*	NM, FTC	Grid	N	Y
The Case without Federal Tax Credits*	NM, F	Grid	N	Y
The Case with Depreciation*	NM, F, FTC, D	Solar	N	Y
The Case with Carbon Tax**	NM, F, FTC, CT	Solar	N	Y
The Case with Depreciation and Carbon Tax**	NM, F, FTC, D, CT	Solar	Y	-
Case with Depreciation and Carbon Tax and No Federal Tax Credits**	NM, F, D, CT	Solar	N	Y

* Cases with annualized electricity price of $0.1206

** Cases with annualized electricity price of $0.1447

Table 5-4: Results for Stochastic Dominance for 7.84kW System Capacity

Policy Set	Policy Options Included	Which is Less Expensive	1st-order Stochastic Dominance	2nd-order Stochastic Dominance
Economic Analysis*	None	Grid	Y	-
Economic Analysis with Federal Tax Credits*	FTC	Grid	N	Y
The Base Case*	NM, F, FTC	Solar	N	Y
The Case without Net Metering*	F, FTC	Grid	N	Y
The Case without Financing*	NM, FTC	Grid	N	Y
The Case without Federal Tax Credits*	NM, F	Grid	N	Y
The Case with Depreciation*	NM, F, FTC, D	Solar	N	Y
The Case with Carbon Tax**	NM, F, FTC, CT	Solar	N	Y

Table 5-4 Continued

The Case with Depreciation and Carbon Tax**	NM, F, FTC, D, CT	Solar	Y	-
Case with Depreciation and Carbon Tax and No Federal Tax Credits**	NM, F, D, CT	Solar	N	Y

* Cases with annualized electricity price of $0.1206

** Cases with annualized electricity price of $0.1447

5.3. Sensitivity Analysis

We do sensitivity analysis for four variables, a standard deviation of electricity price, salvage value rate, O&M cost growth rate, and discount rate. A standard deviation of electricity price, salvage value rate, and O&M cost growth rate do not change the results much. However, the discount rate changes the results significantly. This is because solar systems are so capital intensive with the costs being up front and the benefits downstream. Thus, we can say that the economics of solar PV systems is dependent on the discount rate.

5.4. Policy Implications

In this study, we check the effect of the current and potential policy incentives in reducing the cost of adopting the solar PV systems. The current policy incentives of net-metering, financing, and federal tax credits are effective in reducing the cost of solar PV systems. However, even with all the current incentives, there is a 50-50 chance that solar is less expensive. In order to lower the cost, we can consider other policy incentives. In our study, we introduce tax deduction from depreciation, and the breakeven cost decreases even below the electricity cost of the grid and the probability of solar being less expensive rises substantially. Hence, from a customer's perspective, it would be attractive to adopt the tax deduction from depreciation of the solar PV systems. From an economic perspective, that option may also be attractive because the effect is to level the playing field between tax treatment of solar and grid electricity. All the capital cost of grid electricity can be depreciated by the utility. Allowing depreciation for solar simply gives home solar the same tax treatment.

5.5. Suggestions for Future Research

It is unconvincing to input a single deterministic value for uncertain variables and calculate a deterministic value for the breakeven cost because there is uncertainty in several key variables. Rather, it is more convincing to consider and employ distributions based on the best data. Therefore, in our study, there are key uncertain variables from the assumptions for uncertain variables, which are electricity price, failure rate, and degradation rate. Thus, we use the Monte Carlo simulation to get distributions for the breakeven cost with data and assumptions for key uncertain variables. However, since there has been no experiment as long as 20 years for failure rate and degradation rate, values we use in this study are based on assumptions from previous studies or suggestion of NHR, Inc. Values for failure rate and degradation rate can be changed with time and with the advancement of solar PV technology. This means that we need to update the values for uncertain variables in the future as new data values are accumulated. With this, our analysis will be addressing more accurate results.

While stochastic dominance was not a major aspect of this research, the fact that all cases resulted in either first or second degree stochastic dominance merits more attention in future research.

Second, our study is based on customer's perspective. In other words, we focus only on reducing the cost of adopting solar PV systems. This is why we introduce tax deduction from depreciation. However, from government's perspective, there will be a drop in tax revenue if tax deduction from depreciation is actually applied. Therefore, we need to study and analyze further not only in customer's perspective, but also from government's perspective.

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