AN ECONOMIC ANALYSIS OF POTENTIAL PHOTOVOLTIAC SYSTEM

IN THE UNIVERSITY OF GEORGIA

by

SEUNG-TAEK LIM

(Under the Direction of Dr. Jeff Mullen)

ABSTRACT

Relative to a baseline of 2010, the University of Georgia (UGA) currently has a goal to reduce CO2 emissions by 20 percent using renewable energy sources. This report presents a cost-benefit analysis of a 10-acre, ground-installation solar energy project in the city of Athens, Georgia, and examines the ability of such a project to meet UGA's CO2 emissions reduction target. The analysis includes relevant incentive programs and technical details to evaluate nine possible system designs – three solar tracking devices for each of three photovoltaic solar panel types. Each of the nine system designs are evaluated under two end-use scenarios – either UGA uses the electricity generated by the PV system or the electricity is sold to Georgia Power and uploaded onto the electrical grid. Results shows that it would be more cost-effective for UGA to use their own created electricity rather than selling it back to Georgia Power (GP) company because scenario B (no transformer – for UGA) made more profit when compared to scenario A (requiring transformer – for UGA).

INDEX WORDS: Photovoltaic, Renewable Portfolio Standard, Electricity Price Forecasting, Net Present Value, Breakeven Year

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B.S., Purdue University, 2013

A Thesis Submitted to the Graduate Faculty of the University of Georgia in

Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2015

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August 2015

ACKNOWLEDGEMENTS

Foremost, I praised God, the almighty for providing me this opportunity and granting me the capability to proceed successfully. Then, the contributions of many different people, in their different talented ways, have made this work possible. I would like to extend my appreciation especially to the following.

It is a genuine pleasure to express my sincere gratitude to my advisor Professor Jeff Mullen. I have been amazingly fortunate to have an advisor who guided me step by step through the process of this exciting thesis. Besides my advisor, I would like to thank the rest of my thesis committee: Professor Gregory Colson and Professor Susana Ferreira who gave me encouragement, sagacious advice, and patient support in endless array of ways.

In addition, I would like to thank not only Kevein Kiersee from the Office of Sustainability for providing valuable information about UGA's 2020 strategic goals and electricity usage data, but also Lara Mathes from the office of University Architects for providing appropriate land for installing solar panels. Without their ideas, my thesis would not have been polished better.

Last but not the least, a special thanks goes to my family for their unconditional support: my parents Jong-Youn Lim and Shin Mi-Sook who supported me via both spiritually and physically throughout my life.

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CHAPTER 1

(INTRODUCTION)

1.1 Background

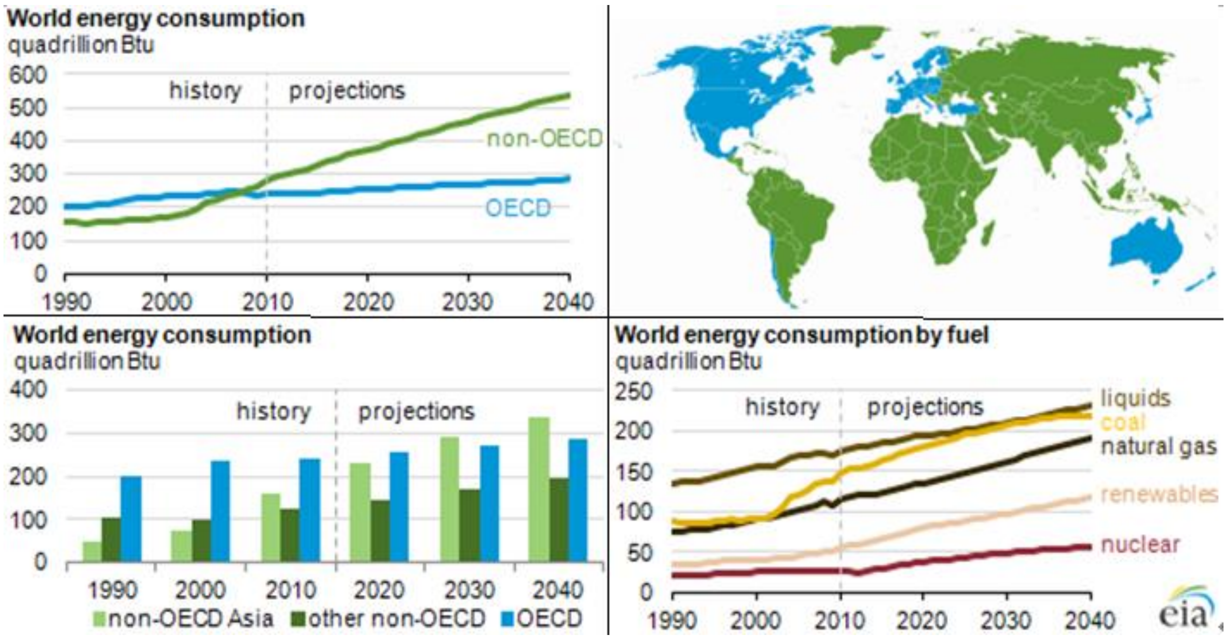
There are five major forms of fossil fuels: coal, petroleum, oil, liquefied petroleum gas (LPG), and natural gas (Methane). These underground resources formed over hundreds of millions of years as organic matter like plankton, plants, and other life forms were gradually buried by layers of sand, sediment and rock (Originenergy, 2014). Although fossil fuels are persistently being formed via natural development they are regarded as non-renewable resources because of the time scale; the existing reserves are used up much faster than new ones are created (U.S Energy Department, 2014).

The industrial revolution, which began in Britain in the 1700s, is one of the most celebrated watersheds in human history. The use of machinery and factories has had a profound effect on the economy worldwide by creating mass production. Vast quantities of fossil fuels have been used to fuel transportation, power electricity plants, heat and cool buildings, and to serve as inputs to the production of plastics, inks, tires, tables, pharmaceuticals, and other products.

The oil crises of the 1970s hastened the development of renewable energy - energy created from natural resources (sunlight, wind, rain, tides, and geothermal heat) that can replace conventional fuels and constantly be replenished - especially solar energy technologies such as photovoltaic systems (producing electricity directly from sunlight), solar hot water (heating water with solar energy), and passive solar heating (using solar energy to heat and light buildings). And yet, the adoption of photovoltaic systems, in particular, has been slow.

The first federal support for renewable energy began during the Carter Administration to reduce dependence on foreign oil and limit supply disruptions for the short term, and to develop renewable and essentially inexhaustible sources of energy for sustained economic growth for the long term. The Energy Tax Act (ETA) of 1978 provided tax credits for homeowners who invested in solar other technologies related to renewable energy (Nadel, 2012). In addition, the Public Utility Regulatory Policies Act (PURPA) was enacted in 1978 as part of President Carter's response to encourage energy companies to purchase power created by verified renewable power facilities and to stimulate regional economic development (U.S. Department of Energy). For example, the Act stimulated growth of medium-scale hydro plants to help meet the Nation's energy needs.

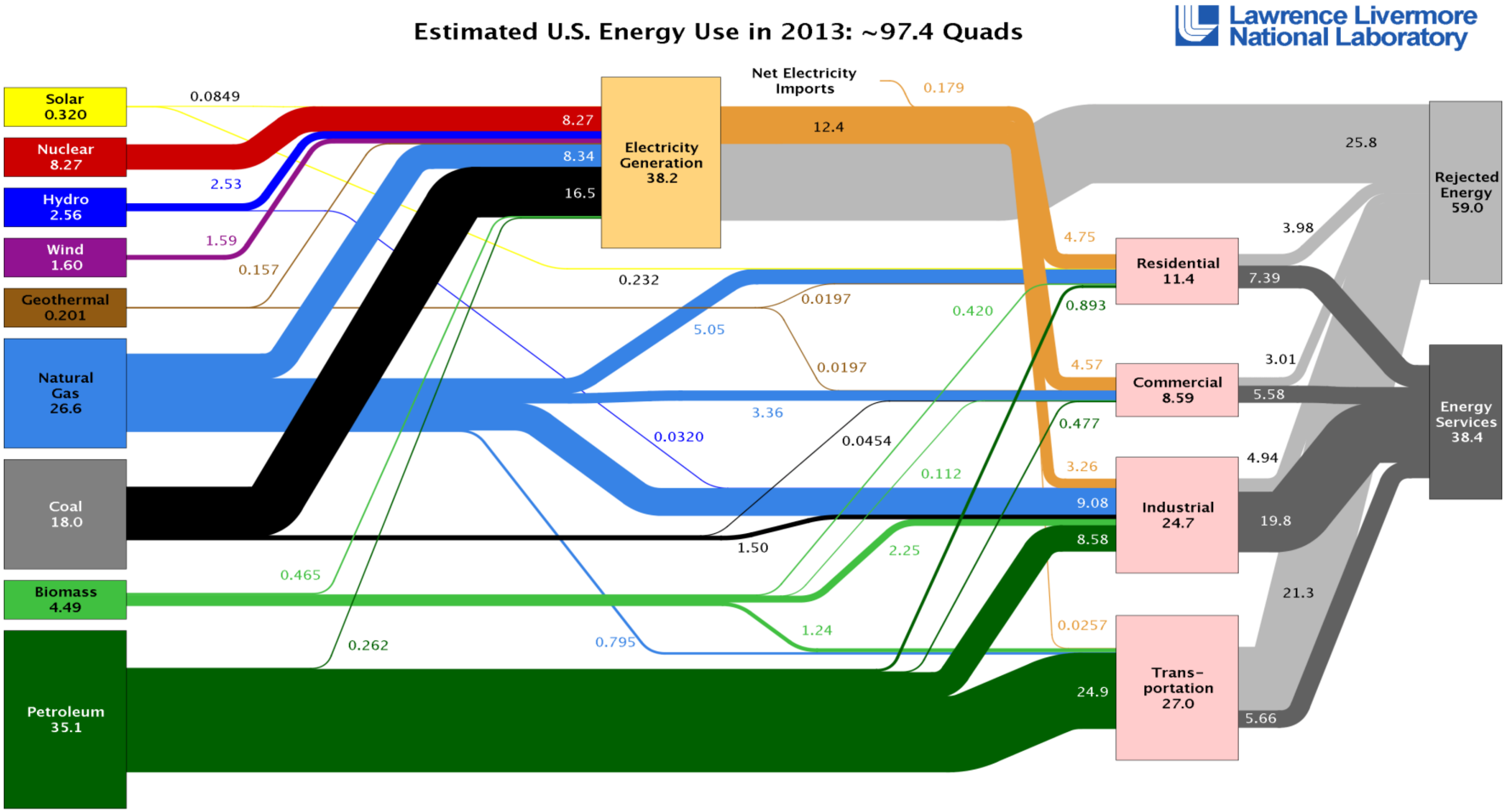
The U.S. Energy Information Administration (EIA) projects world energy consumption will grow by 56% between 2010 and 2040, from 524 quadrillion British thermal units (Btu) to 820 quadrillion Btu by the OECD (Organization for Economic Cooperation and Development) countries (Figure 1.1). Even though the OECD members (composed of 34 mostly developed countries) will steadily increase energy use, most of this increase will come from non-OECD countries, where demand is high due to strong economic growth and expanding populations



Source: EIA, 2013

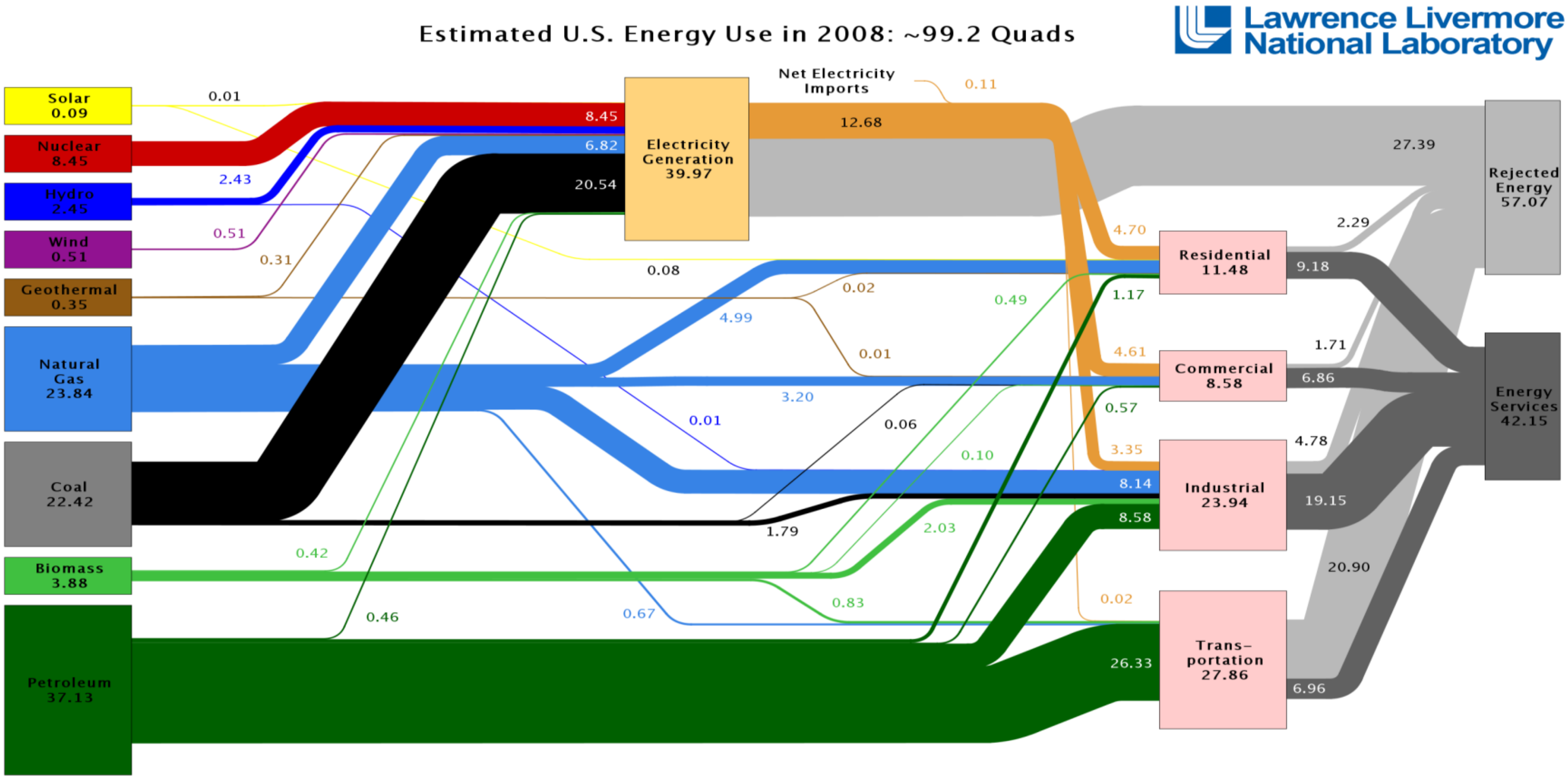
Figure 1.1 World Energy Consumption by Fuel (Quadrillion Btu)

The lower right quadrant of figure 1.1 illustrates that even though renewable energy and nuclear power are the world's fastest-growing energy sources (each increasing 2.5% per year), fossil fuels are expected to supply nearly 80% of world energy use through 2040. Figures 1.2 and 1.3 illustrate the share of energy generation by fuel source in the United States in 2013 and 2008, respectively. The major fossil fuels – petroleum, natural gas, and coal – represent more than 80% of the energy used in both years, but the share of solar power increased 350% in five years. In 2013, about 75% of the solar energy generation was used directly in residences, with the other 25% distributed over an electrical grid.



Source: Lawrence Livemore National Laboratory and EIA, 2014

Figure 1.2 Estimated U.S. Energy Use in 2013

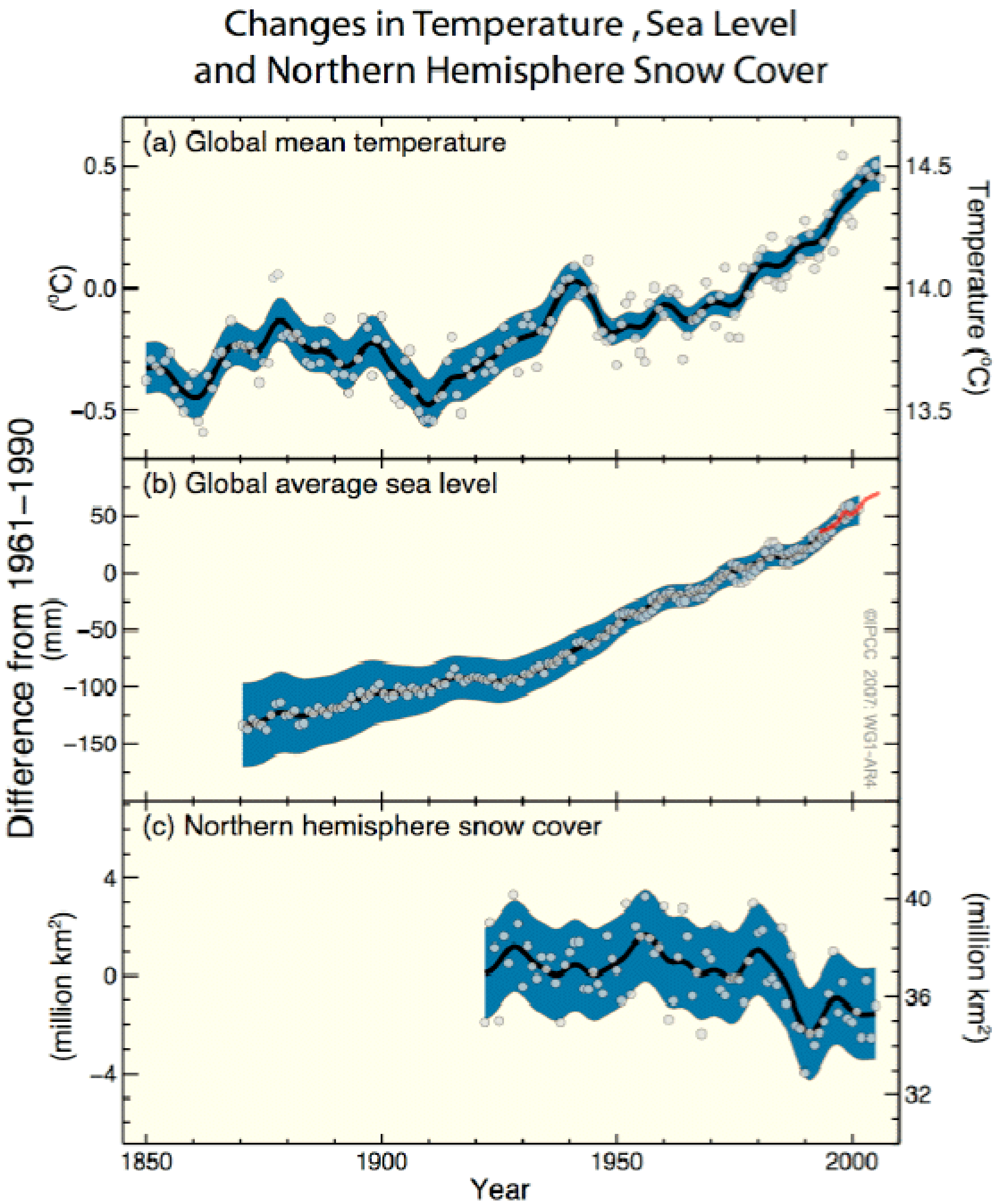


Source: Lawrence Livermore National Laboratory and EIA, 2014

Figure 1.3 Estimated U.S. Energy Use in 2008

Since its inception, the Earth’s natural climate has oscillated between warm periods and ice ages. Most often, the global climate has changed because of variations in the sun where the amount of solar energy reaching the Earth has alternately increased and decreased (Riebeek, 2010). Since 1990, the IPCC offered its strongest language yet that Earth's climate is warming and humans are largely responsible. According to Intergovernmental Panel on Climate Change (IPCC), climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

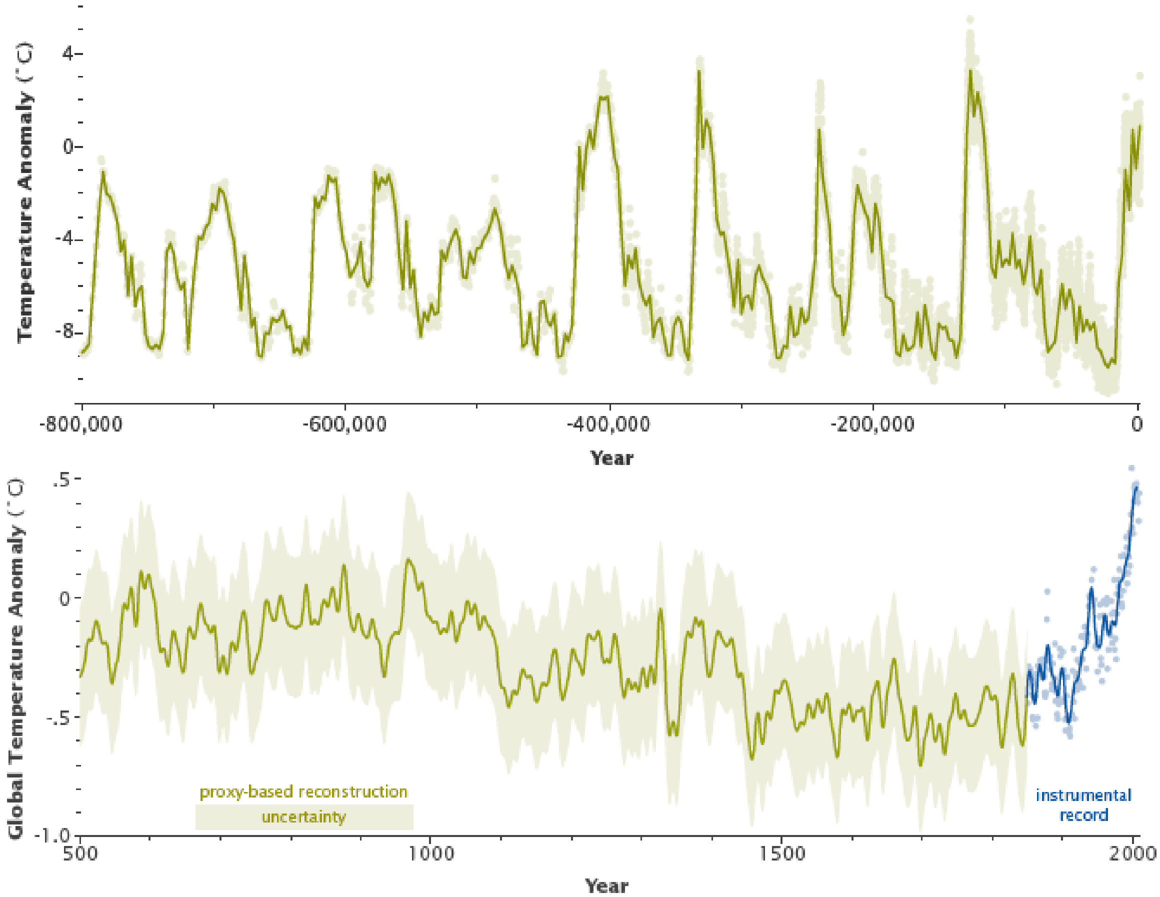
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure 1.4). Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). Temperatures are expected to continue to rise.



Source: IPCC 2007

Figure 1.4 Changes in Temperature, Sea Level, and Northern Hemisphere Snow Cover

Figure 1.5 shows the history of temperature stretching back more than 800,000 years. Earth has experienced climate change in the past without help from humanity. The mainstream climate science community has provided a theory (a record of Earth's past climates, or "paleoclimates.") through the ancient evidence left in tree rings, layers of ice in glaciers, ocean sediments, coral reefs, and layers of sedimentary rocks. Using this ancient evidence, the record depicts that the modern climatic warming is happening more quickly than past warming cases. According to NASA, as the Earth moved out of ice ages over the past million years, the global temperature rose a total of 4 to 7 degrees Celsius over about 5,000 years. However, in the past century alone, the temperature has climbed 0.7 degrees Celsius, roughly ten times faster than the average rate of ice-age-recovery warming.



Source: NASA 2010

Figure 1.5 World Paleoclimate Record

Importantly, Figure 1.5 shows that the earth experiences a natural climate cycle without any human interference. A warming trend accelerated and enhanced by greenhouse gas emissions from human activity is projected to add to the frequency and severity of extreme weather events such as the risk of dangerous floods, droughts, wildfires, hurricanes, and tornadoes (CCSP, 2008). Considerable disruptions of ecosystems and ecosystem services are also expected to occur (Schneider et al., 2007).

Food security is met when ‘all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life’ (FAO, 2008). Under various sets of assumptions, the International Panel on Climate Change (IPCC) has conducted numerous studies on impacts associated with global average temperature change for water, ecosystems, food and health (IPCC, 2007). For instance, rain- dependent agricultural production could be reduced globally by up to 50% where access to food in African countries depending on water, sun, and temperature is projected to adversely affect food security and exacerbate malnutrition. Also, the productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security as well (IPCC, 2007).

Unfortunately, continued reliance on conventional energy fuels will exacerbate global warming; there is an urgent need to embrace a new energy paradigm to change the trajectory of global temperatures. Countries around the world are looking for alternatives such as solar energy, wind, biomass & biogas energy, hydro power, geothermal energy, and off-shore wind, wave, and tidal energy. As UN Secretary General Ban Ki-Moon noted, “There is no plan B for climate action as there is no planet B.”

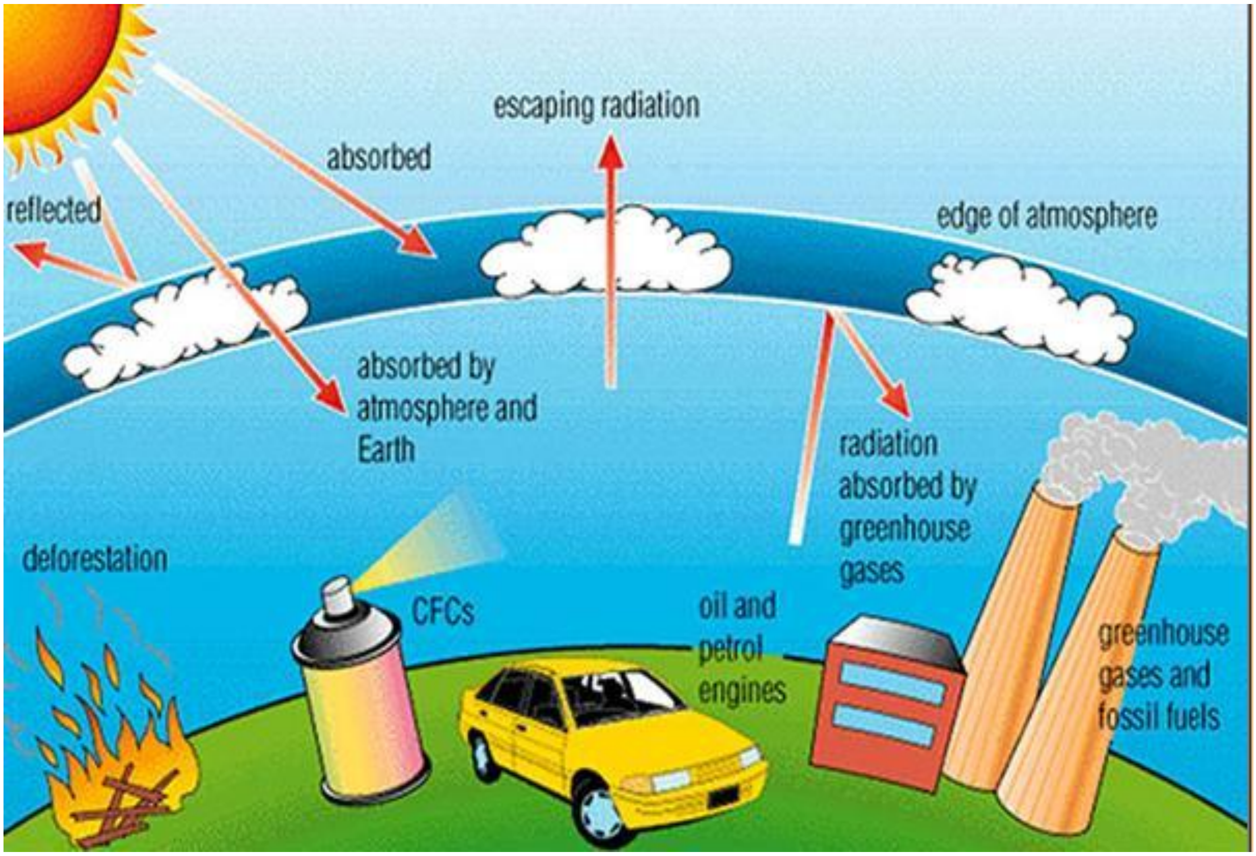
Every day humans generate greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrogen fluoride carbon (HFCs), phosphorus fluoride carbon (PFCs), sulfur hexafluoride (SF_6), and chlorofluorocarbon (CFCs) that trap heat in an earth's atmosphere. Table 1.1, shows how emissions levels of important pollutants vary across fossil fuels. In a more detail sense, figure 1.6 describes the greenhouse effect where some of the infrared radiation passes through the atmosphere, but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface.

Table 1.1

Fossil Fuel Emissions Levels

Pollutant	**Natural Gas**	**Oil**	**Coal**
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxide	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016
Unit: pounds per billion Btu of Energy Input			

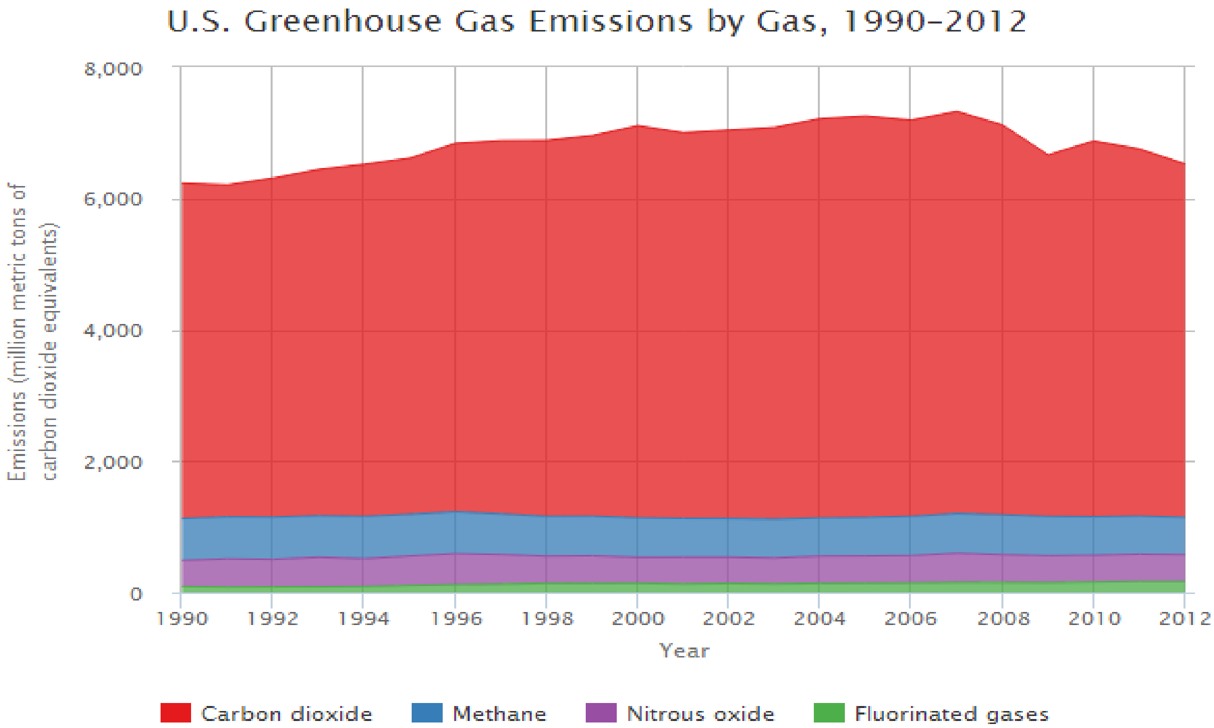
Source: EIA, 1998



Source: ENVIS, 2012

Figure 1.6 Greenhouse Effect & Global Warming

Figure 1.7 shows the trend of U.S greenhouse gas emissions by gas type between year 1990 and 2012. In 2012, U.S. greenhouse gas emissions totaled 6,526 million metric tons of carbon dioxide equivalents. Greenhouse gas emissions in 2012 were 10 percent below 2005 levels as well.



Source: EPA, 2013

Figure 1.7 U.S Greenhouse Gas Emissions by Gas, 1990-2012

Renewable sources often have a host of social, environmental, and economic benefits such as: (1) Most renewable energy sources produce little to no GHG emissions. (UCSUSA, 2013b). (2) Compared with fossil fuel technologies, which are typically mechanized and capital intensive, the renewable energy industry is more labor-intensive. This means that, on average, more jobs are created for each unit of electricity generated from renewable sources than from fossil fuels (UCSUSA, 2013a).

For example, in figure 1.8, the U.S. solar industry continues to grow at a faster pace than the overall economy, supporting 142,698 jobs as of November 2013. Between September 2012 and November 2013, the solar industry added 23,682 jobs – an increase of 19.9 percent over the Solar Foundation's 2012 findings – approximately 10 times the national average job growth rate of 1.9 percent (The Solar Foundation, 2011).

Also, according to Energy Future Coalition, the renewable energy technologies developed and built in the United States are exported out of the country, helping to reduce the U.S. trade deficit. Investments in energy efficiency upgrades to U.S. buildings could create 625,000 sustained jobs over the next decade. The American Council for an Energy-Efficient Economy believes that every $1 invested in energy efficiency generates $3 in return-good for businesses and consumers alike.

(3) Producing electricity from alternative energy rather than fossil fuels offers not only significant public health benefits, but also environmental quality improvements. The air and water pollution emitted by coal and natural gas plants is linked to breathing problems, neurological damage, heart attacks, and cancer (Machol, 2013). Replacing fossil fuels with renewable energy has been found to reduce premature mortality, lost workdays, and reduces overall healthcare costs.

Source: National Solar Foundation, 2012

Figure 1.8 National Solar Jobs Census, 2013

1.2 Objectives

The University of Georgia (UGA) has set a 2020 strategic priority plan to demonstrate a commitment to reducing fossil fuel use, thereby reducing the University's carbon emissions (University of Georgia, 2012). To take energy conservation one step further, the 2020 strategic goals are as follow:

(1) Reduce CO2 emissions by 20 percent relative to baseline of 2010; (2) Reduce University consumption of energy by 25 percent relative to base year of 2007; (3) Increase

purchase of energy from renewable sources by 10 percent with the baseline of 2010; (4) Increase the generation of energy from renewable sources to 10 percent relative to baseline of 2010; (5) build new construction on campus that targets a 20% reduction in energy consumption over standard code compliance; and (6) integrate sustainability into both the undergraduate and graduate student experience through curricular activities both in the classroom and beyond. Of the six goals listed, this paper will focus on goals (1) and (4).

The main objective in this paper is to evaluate the net present value of installing a photovoltaic (PV) system at the University of Georgia and to estimate the contribution such a system would make toward meeting UGA's CO2 emissions reduction target. While there are many different types of renewable energy available, this paper analyzes three distinct PV panels (mono-crystalline, poly-crystalline and thin-film) across three different solar tracking devices (fixed, single axis tracking, and double axis tracking) in a given size of 10 acre (UGA owned property). Both state and federal renewable energy programs are included in the analysis. Specific objectives of the study are to:

- Determine the degree to which a 10-acre, ground-installed PV system in Athens, GA, will help meet all the energy related criteria listed in the UGA 2020 Strategic plan.
- Identify key parameters and design features that determine whether the system has a positive net present value over its lifetime.
- Estimate the number of years it takes for the system to realize a positive net present value under different parameterizations.

- Determine whether it will be more cost-effective for UGA to use their own created electricity or create positive financial returns on PV investment by selling it back to Georgia Power.

1.3 Study Area

Sustainability is a growing area of interest for many universities across the United States where they are rapidly discovering that environmental and business performance can be intricately linked. Emerging climate change policies, volatile and upward trending energy prices, universal pressure on businesses to reduce costs, and increased public and investor awareness of environmental issues are all demanding prudent management of energy and materials use at the organizational level.

Under the fiscal year of July to June, both table 1.2 and figure 1.9 show the total energy usage at UGA (2006~2014). Also, table 1.3and figure 1.10 explain the total energy cost at UGA (2006~2014) as well. All of the natural gas, coal (bituminous) and Oil (Diesel) is used to only generate heat for the buildings. As none of them were used to generate electric power, all the electricity is bought from Georgia Power.

According to Georgia Power (2014), most of their electricity generation comes in the order of coal (41%), Gas and oil (35%), Nuclear (22%), and Hydro (2%). While the graph for the Energy Usage in UGA tends to be unstable due to the volatility of oil diesel price, the Energy cost has remained constant, roughly around $14,000,000, despite the few ups and downs. However, this paper will solely focus on the electricity usage and cost only.

Table 1.2 UGA Energy Usage

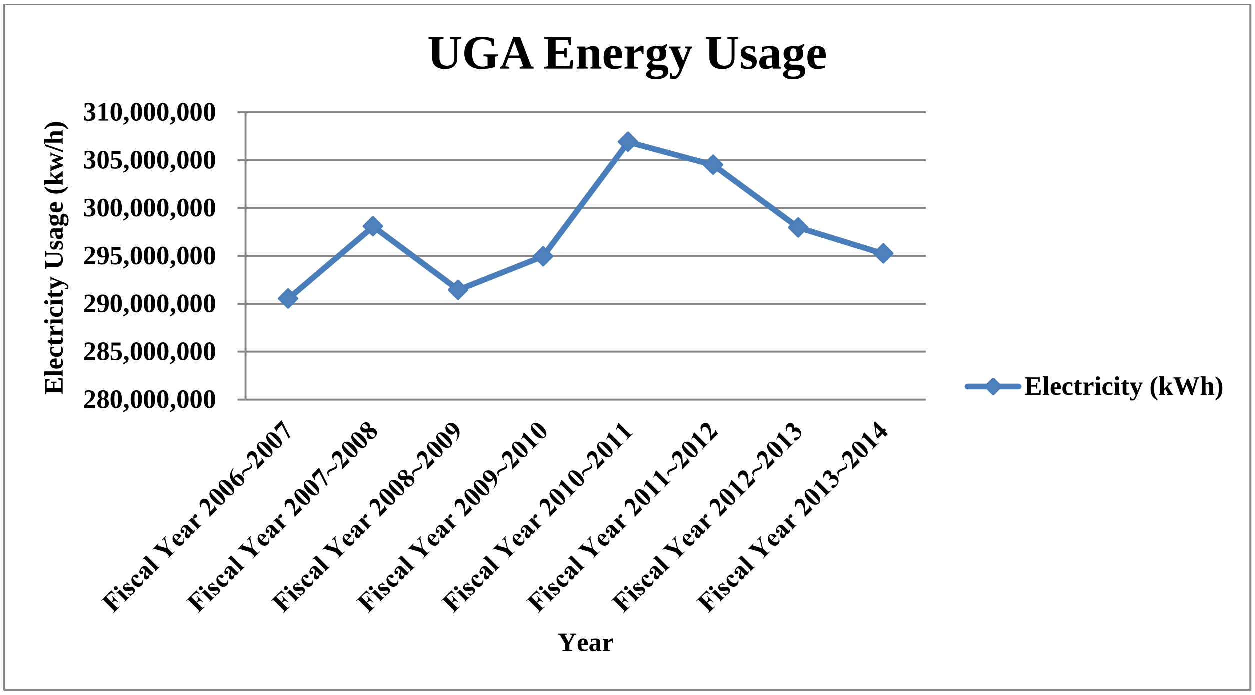
30 June ~ 01 July	Electricity (kw/h)	Gas (thm)	Coal (tons)	Oil/diesel (gallon)
Fiscal Year 2006~2007	290,536,670	2,217,173	11,239	19,349
Fiscal Year 2007~2008	298,084,625	1,977,239	16,869	151,907
Fiscal Year 2008~2009	291,446,606	2,585,973	11,055	39,805
Fiscal Year 2009~2010	294,960,641	2,406,538	9,259	143,421
Fiscal Year 2010~2011	306,900,225	2,363,320	7,096	203,660
Fiscal Year 2011~2012	297,964,581	2,467,023	6,869	689
Fiscal Year 2013~2014	295,240,278	2,506,524	3,697	256,988

Source: The University of Georgia, 2014

Table 1.3 UGA Energy Costs

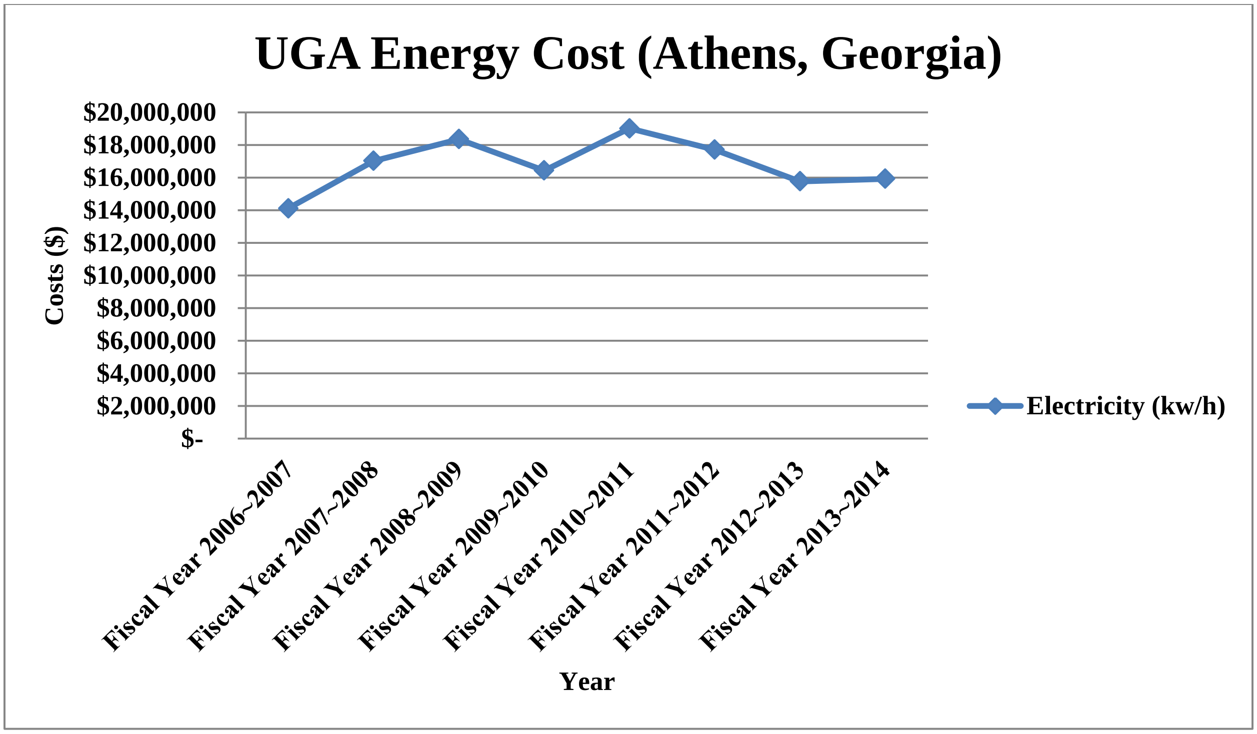
30 June ~ 01 July	Electricity ($)	Gas ($)	Coal ($)	Oil/diesel ($)
Fiscal Year 2006~2007	$14,115,693	$2,274,103	$1,348,680	$22,256
Fiscal Year 2007~2008	$17,027,655	$2,723,638	$2,078,340	$303,814
Fiscal Year 2008~2009	$18,359,859	$1,751,330	$1,157,375	$79,610
Fiscal Year 2009~2010	$19,013,367	$1,620,736	$1,192,128	$286,842
Fiscal Year 2010~2011	$17,718,539	$1,312,019	$1,151,136	$509,150
Fiscal Year 2011~2012	$15,772,013	$1,552,348	$1,112,778	$2,067
Fiscal Year 2013~2014	$15,932,969	$1,710,177	$607,894	$770,964

Source: The University of Georgia, 2014



Source: The University of Georgia, 2014

Figure 1.9 UGA Energy Usages

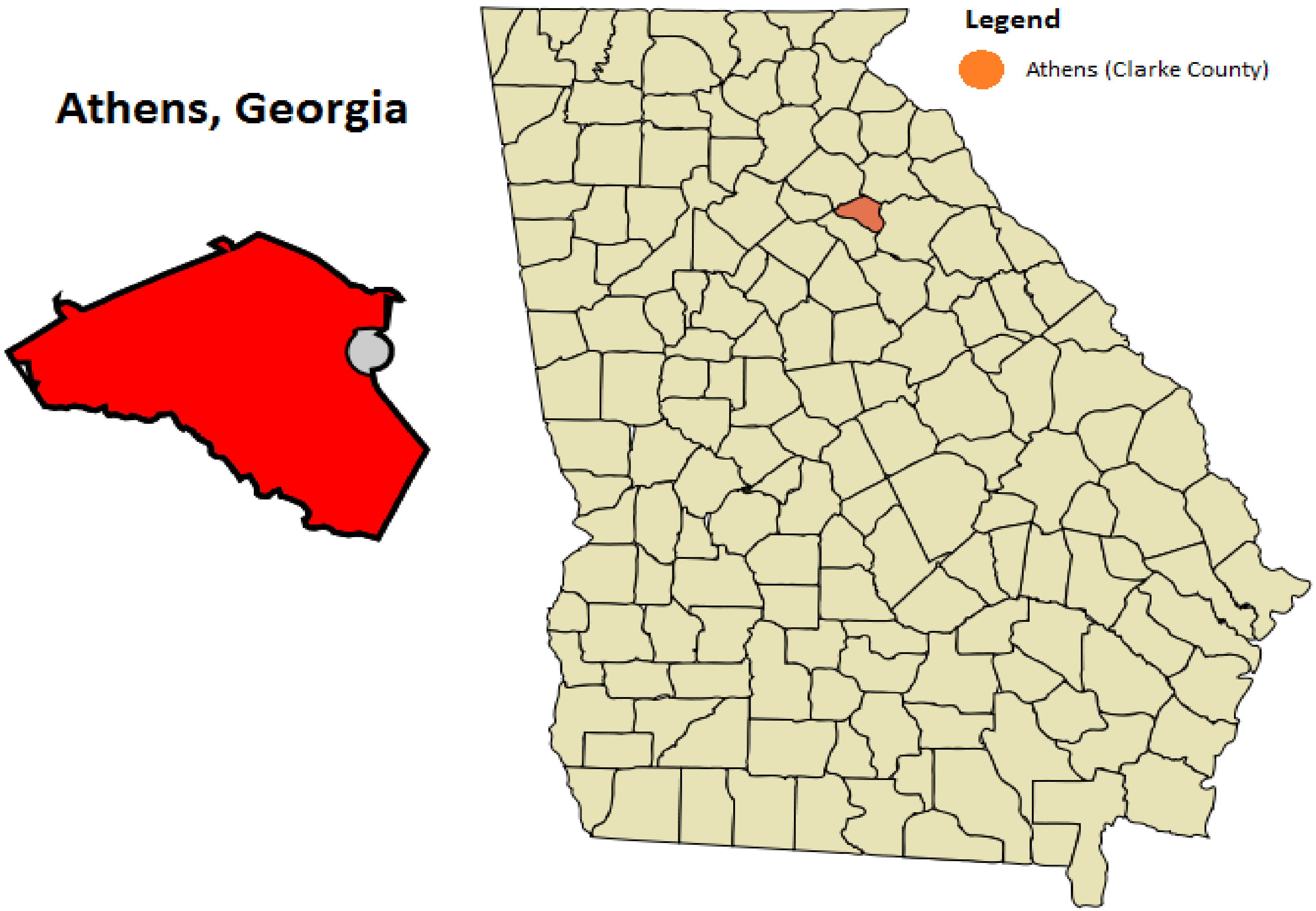


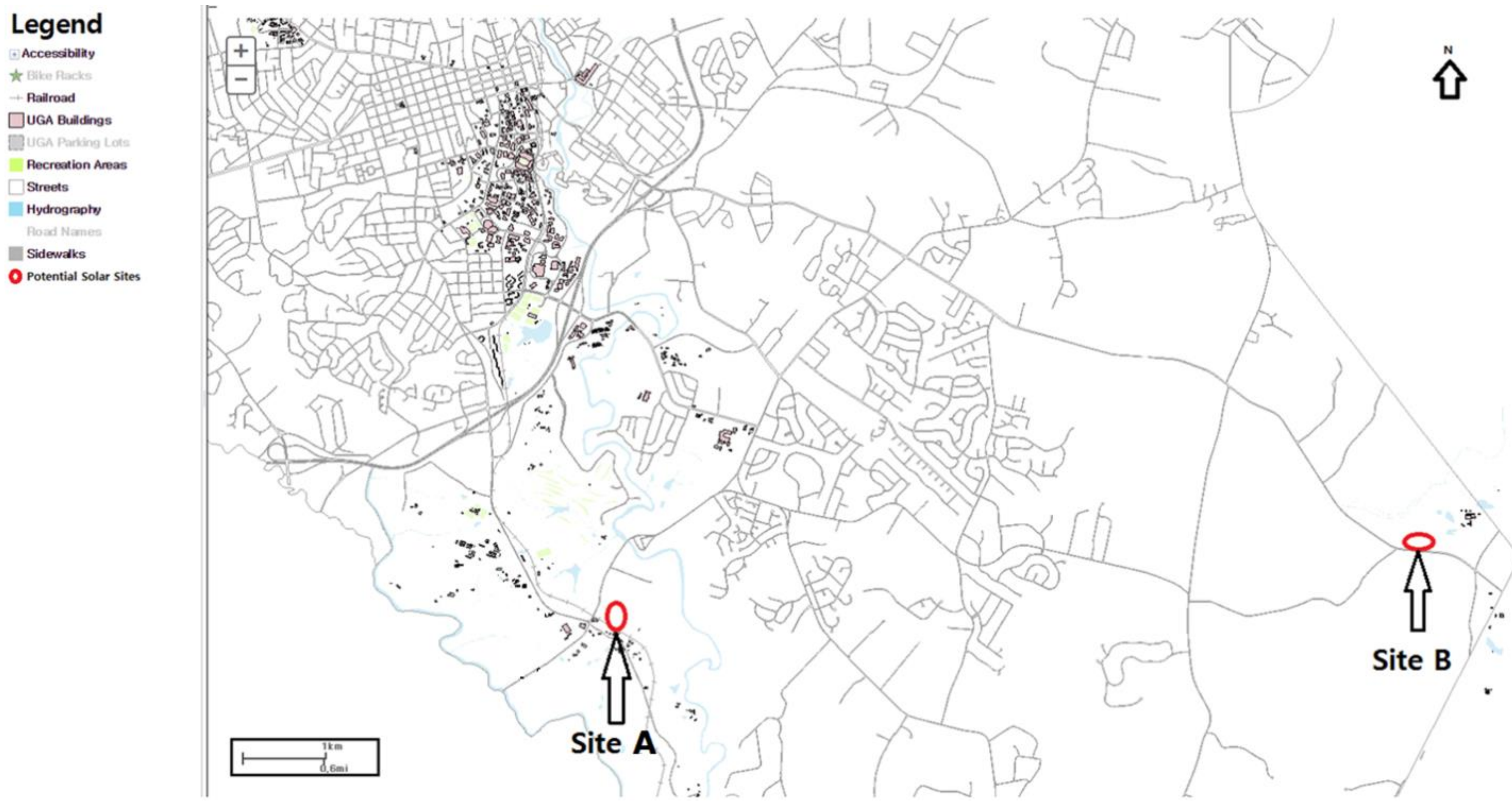
Source: The University of Georgia, 2014

Figure 1.10 UGA Energy Costs

Moreover, UGA's s Sustainability and Architects for Facilities Planning Committee commissioned a solar photovoltaic (PV) study to determine viable lands and buildings for the installation of solar PV arrays. PV arrays can be mounted on the ground, rooftops or any other suitable support structure. Figure 1.11 shows the map of Georgia highlighting Athens-Clarke county. There are currently two areas that are identified by the UGA architecture as a potential site for solar installations in terms of acreage and parcels. Those two areas are (1) Site A near the intersection of Whitehall road and Phoenix road located in the south of Athens, (2) Site B near the intersection of Lexington road and Old Lexington Road is located in the east of Athens.

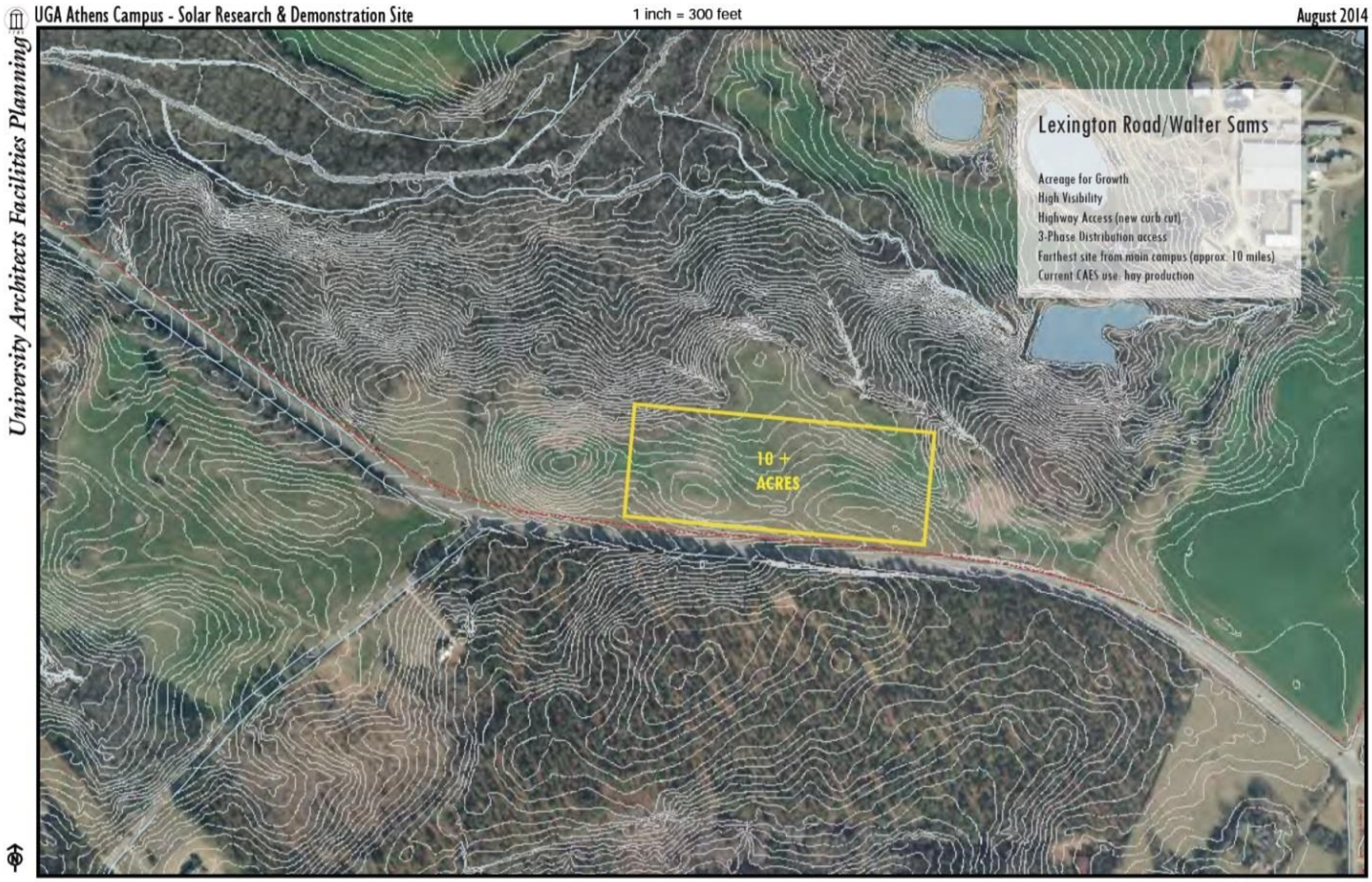
From a bigger picture to smaller case, figure 1.12 shows more detailed locations of Athens. Each parcel is 10 acres and they are as follow: Site A: 180 Hidden Hills Ln. Athens, GA 30605, and Site B: 6431-6463 Georgia 10. Winterville, GA 30683. They are currently owned by UGA and are approved for building solar panels. However, in this paper we will consider only site A because if the site is too far from the UGA campus, both the transmission loss and equipment will result in higher costs when installing PV systems (Discussed further in chapter 5.3.3.5). Considering the main parts of a typical transmission and distribution network, the overall losses between the generator and the consumers is about six percent (EIA, 2014).

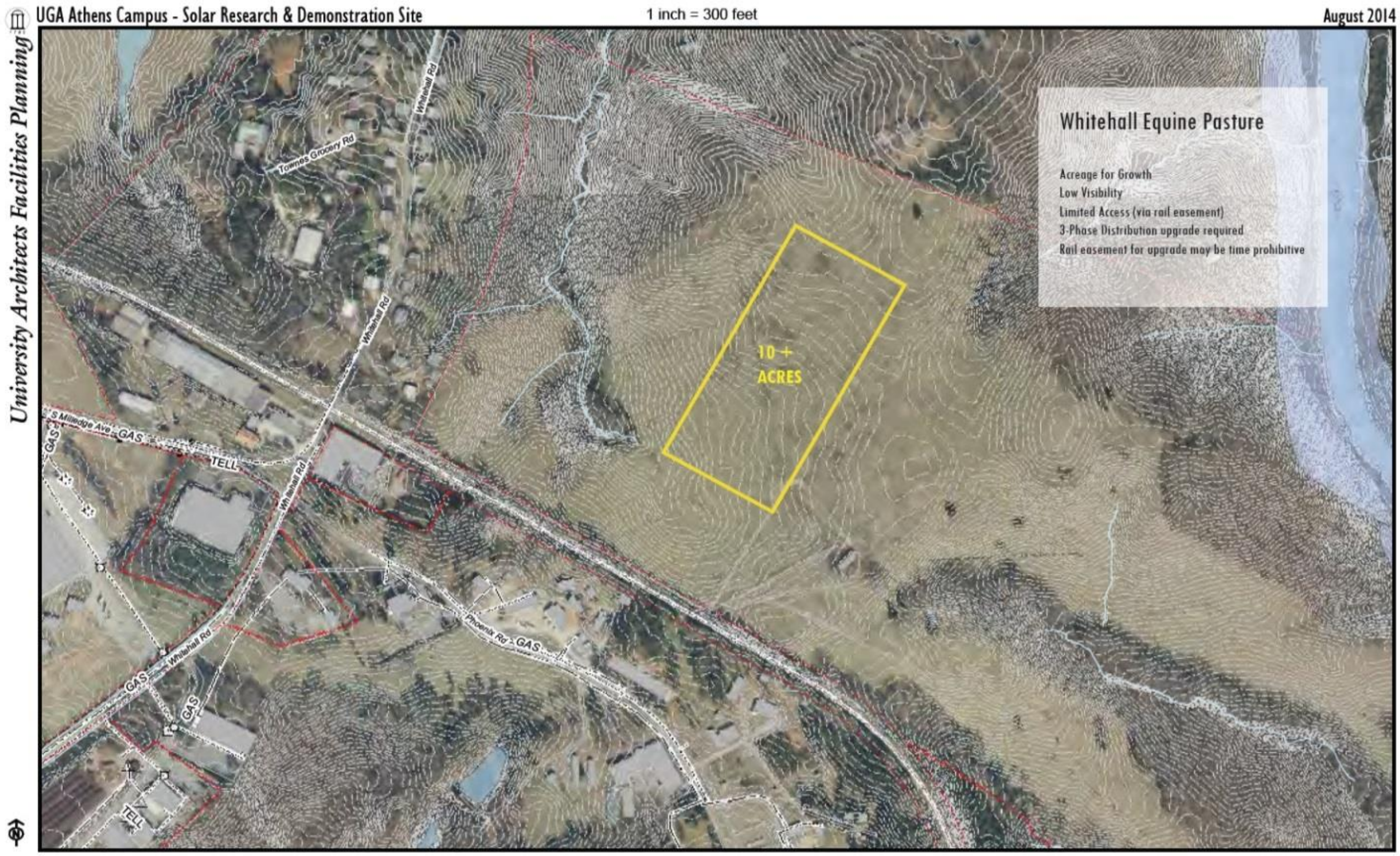

Athens, Georgia
Legend
Athens (Clarke County)



Source: Arc GIS

Figure 1.11 Map of Athens, Georgia


UGA Athens Campus - Solar Research & Demonstration Site
1 inch = 300 feet
August 2014
University Architects Facilities Planning
Lexington Road/Walter Sams
Acreage for Growth
High Visibility
Highway Access (new curb cut)
3-Phase Distribution access
Farthest site from main campus (approx. 10 miles)
Current CAES use: hay production
10 +
ACRES



Source: The University of Georgia

Figure 1.12 Capacity Potential for Installing Solar Panel at Site A and B

1.4 Organization

The rest of this paper is presented in the following order. The next three chapters are a review about photovoltaic, U.S renewable energy policies, and an overview of electricity price forecasting is discussed. Then, in the fifth and sixth chapter the feasibility of photovoltaic installations and financial models are used in estimation to get the result. And finally, conclusions have been presented.

CHAPTER 2

(ABOUT PHOTOVOLTAIC)

2.1 What is Photovoltaic System?

In 1839, a French physicist Alexandre E. Becquerel discovered that certain materials would produce small amounts of electric current when exposed to light, also known as the photovoltaic effect (Michael, 2008a). And it took more than a century before engineers would develop photovoltaic (PV) cells that could change solar energy into electricity to run electrical engines. Solar cells gained prominence in the 1970s when the energy crisis occurred to replace fossil fuels. However, the prohibitive prices that is nearly 30 times higher than the year 2013 price made solar applications impractical and indifferent (Solar Energy Industries Association, 2014).

Wind energy already offers 2% of the world's electricity, and their size is doubling every three years (Carr, 2012). If that growth rate is sustained, wind farms will surpass nuclear power plant impact to the world's energy in about a decade. But it is in the field of solar energy, currently only a quarter of a percent of the planet's electricity supply.

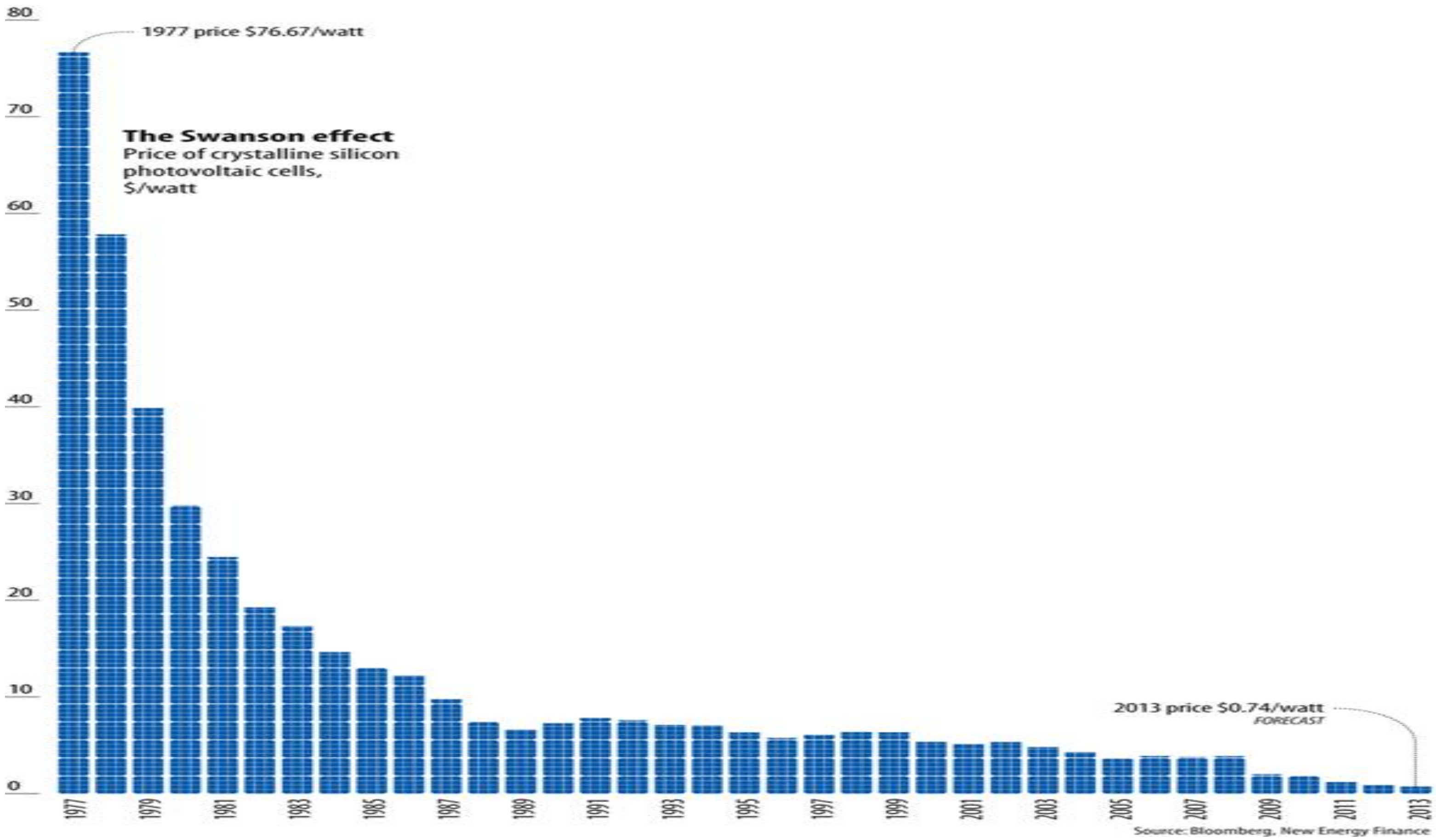
While the price of fossil fuels is becoming more expensive, the technology development in renewable energy has been getting cheaper over the past three decades. In figure 2.1, the average cost of crystalline silicon solar cell has decreased from $76.67/watt in 1977 to just $0.74/watt in 2013 and forecasted to decrease by $0.36/watt by 2017 (Rinaldi, 2013). The reason for the small increase between 2005 and 2008 was due to poly-silicon shortage. Since 1998, reported PV system prices have fallen by 6-8% per year on average, and the modules used to make solar-power plants now cost less than a dollar per watt of capacity.

The figure 2.2 also explains the median reported installed prices of residential and commercial PV Systems over time. All methodologies show a downward trend in PV system pricing. The reported pricing and modeled benchmarks historically had similar results as well in estimated pricing. On average, solar power has improved 14% per year in terms of energy production per dollar invested (Economists, 2013). In some regions, the cost of electricity from large-scale solar is now lower than the cost of retail electricity.

Figure 2.3 compares the price history of solar energy to oil and natural gas. While the electricity price from conventional energy remained flat in inflation adjusted terms, the cost of electricity from solar is dropping fast, and is likely to continue as technology and manufacturing processes improve (McConnell, 2013). The cost of solar is headed towards the wholesale cost of electricity from natural gas and this could get utility companies and power plant developers to switch to solar. This indicates that with careful financial planning for installing PV, residents can cut electricity costs by putting solar panels on the roofs. In addition, major companies like Walmart, IKEA, Google, Apple, Facebook, Costco, Kohl’s, Macy’s, Staples, and many others are turning their eyes to solar (Cost of Solar, 2013).

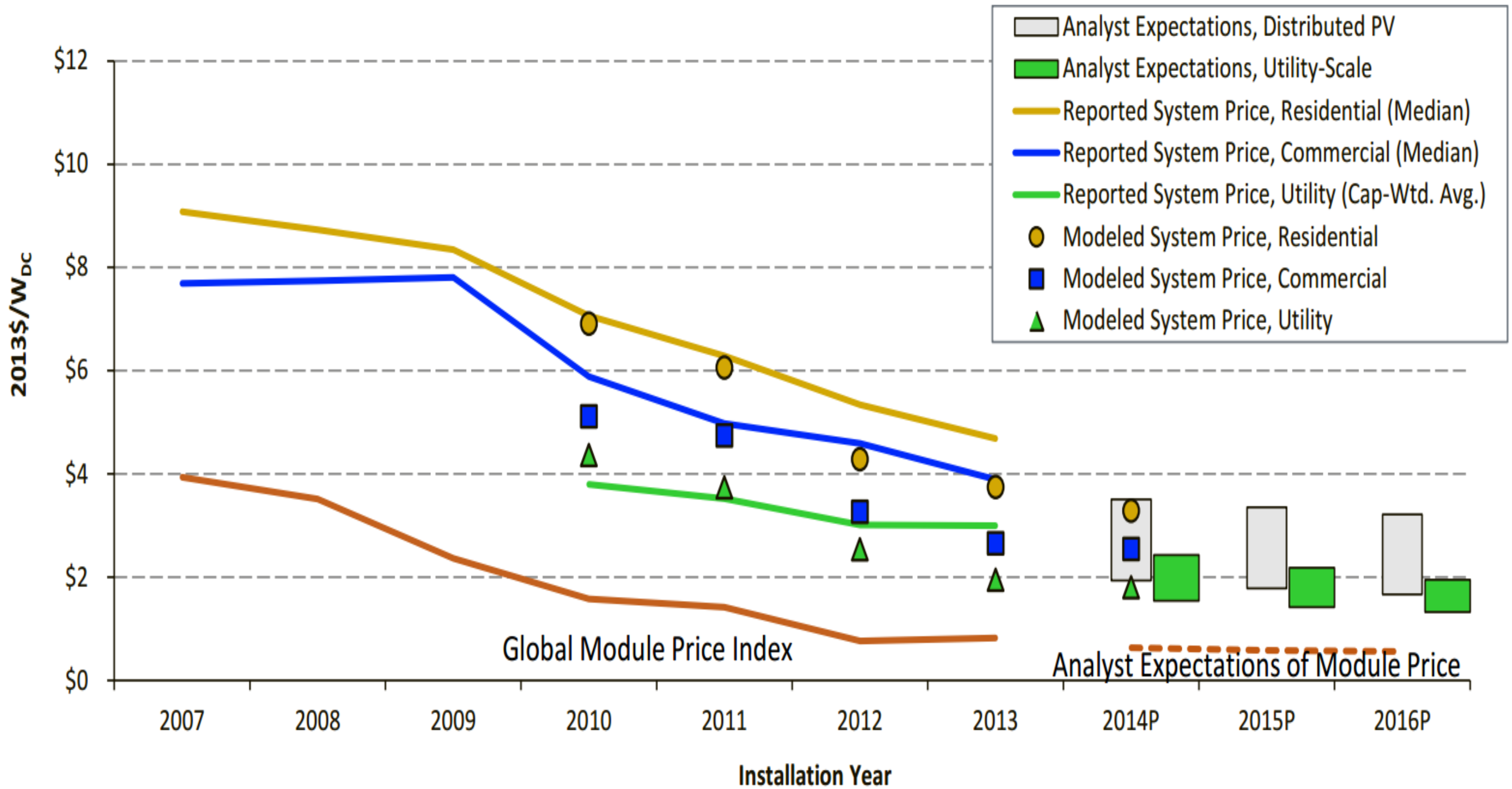
As indicated in Figure 2.4, solar cell efficiencies have increased at a steady rate over the last several decades. Efficiencies for advanced multi-junction technologies have approached 40% in laboratory settings at STC conditions. However, efficiencies for practical cells, such as crystalline and thin film technologies, are well below these levels in the field.

In figure 2.5, the energy analytics by Clean Power Research have used the results of 45,000 solar estimates created by real U.S. homeowners in 2011 and placed them into maps to show how much the solar system cost. And the maps are divided into four sections: (1) how much solar costs in each state, (2) how much could be saved every month, (3) how much could be saved over time, and (4) how long it will take to pay for itself after installing solar system.



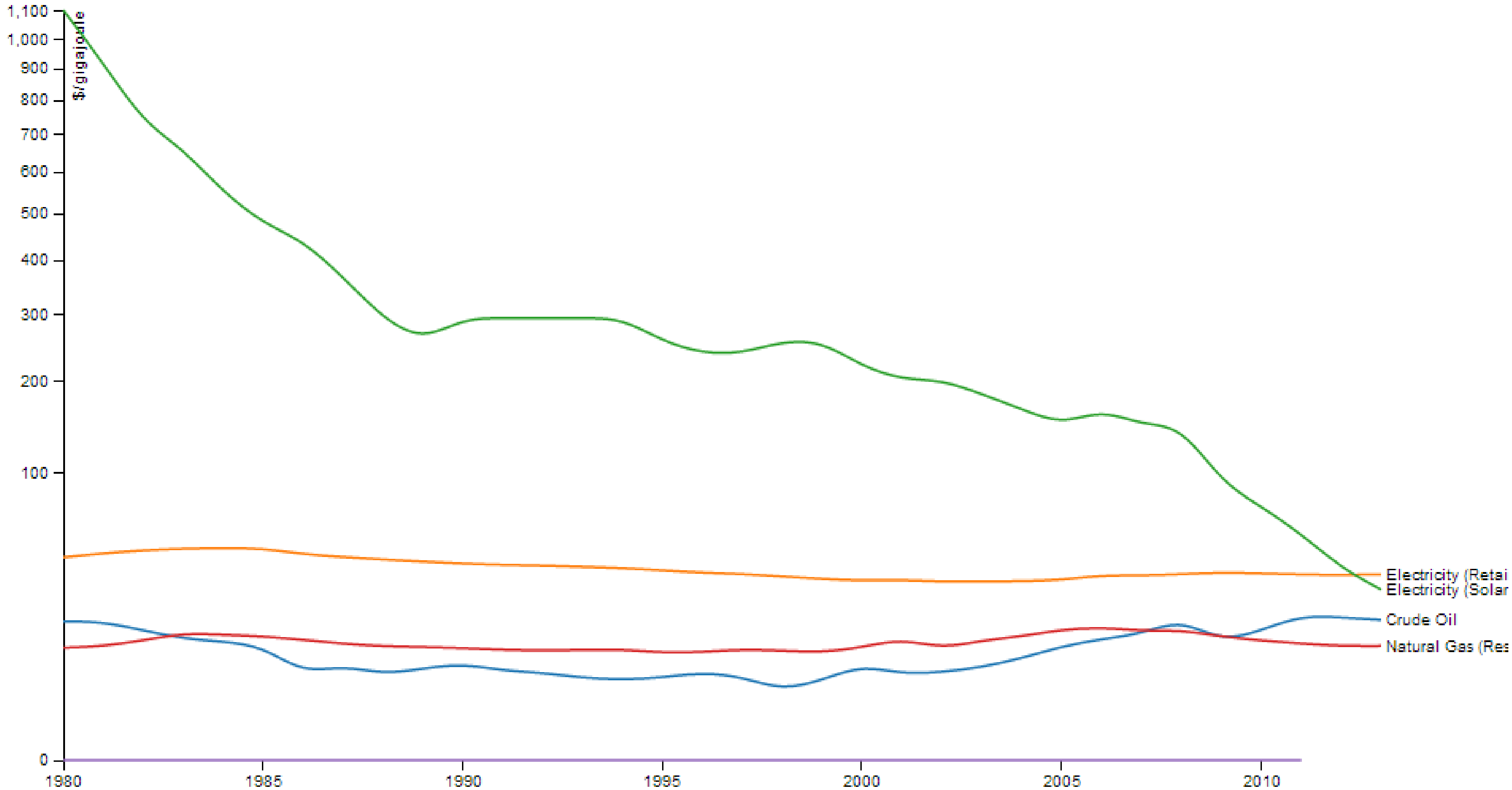
Source: Bloomberg New Energy Finance (BNEF)

Figure 2.1 Solar Panel Prices Over Time (1977~2013)



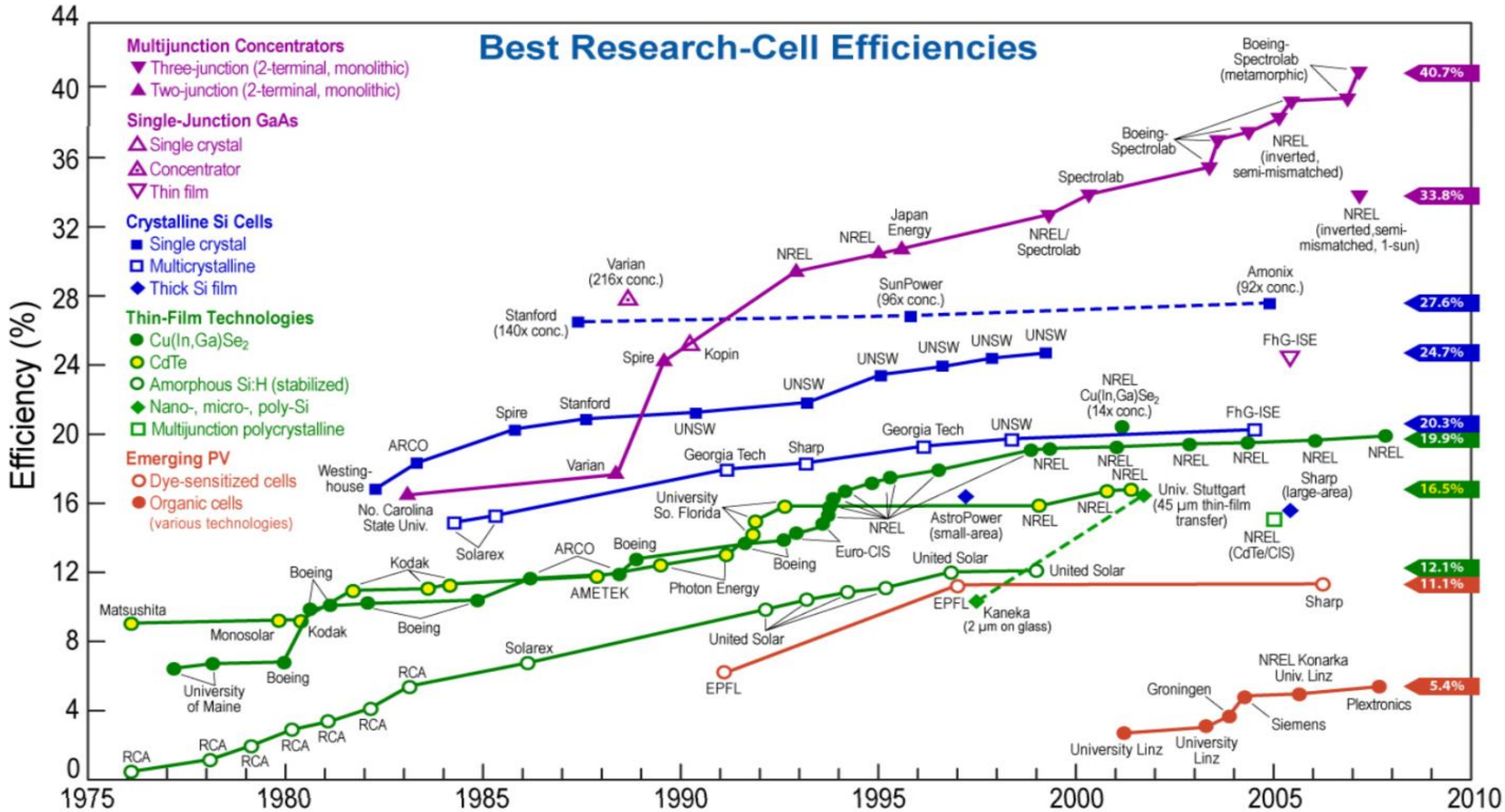
Source: U.S. Department of Energy, 2014

Figure 2.2 Median Reported Installed Prices of PV Systems over Time



Source: Brian McConnell, Resilience

Figure 2.3 History of Solar Energy to Oil & Natural Gas

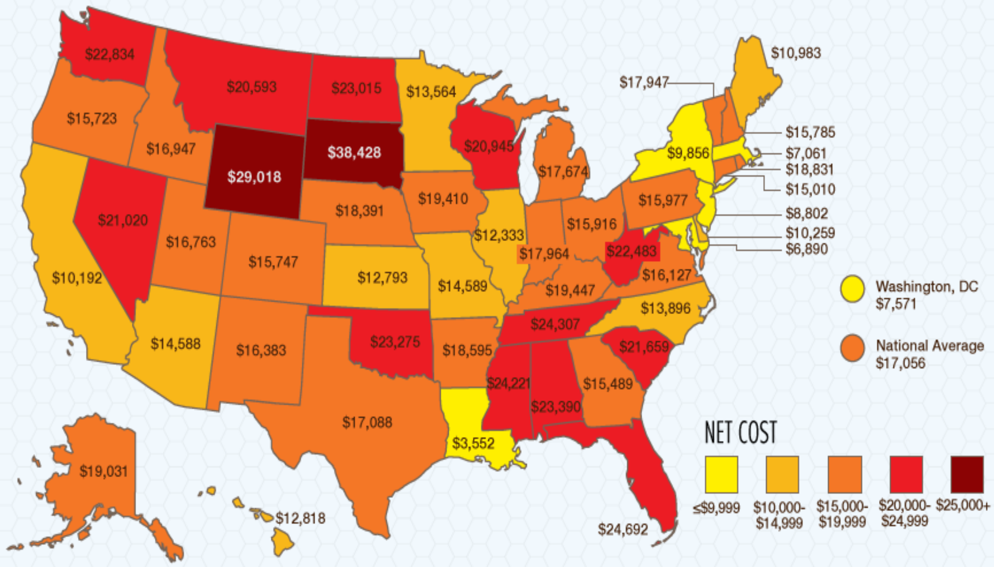


Source: NREL 2010

Figure 2.4 Historical Laboratory Cell Efficiencies – Best Research

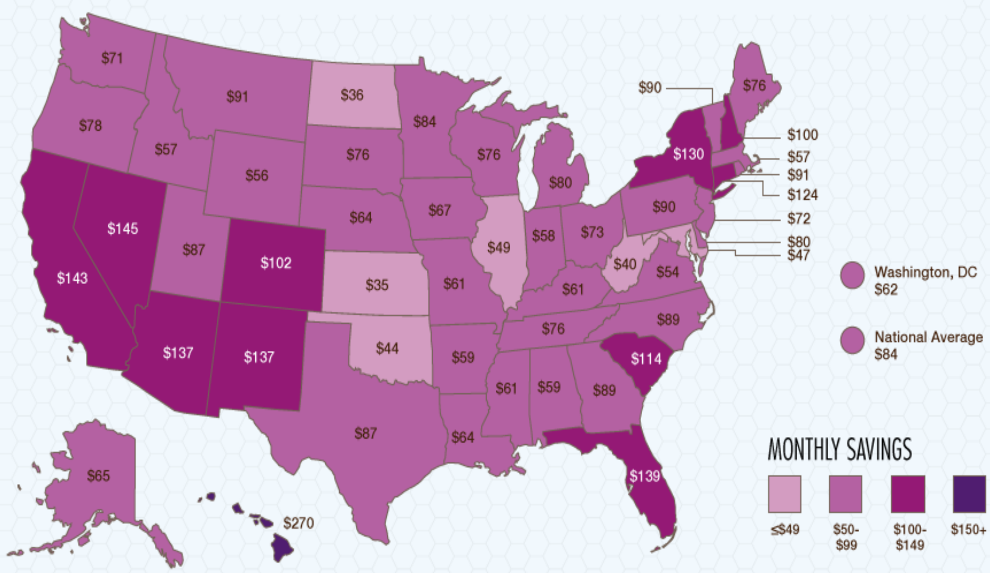
HOW MUCH SOLAR COSTS IN YOUR STATE

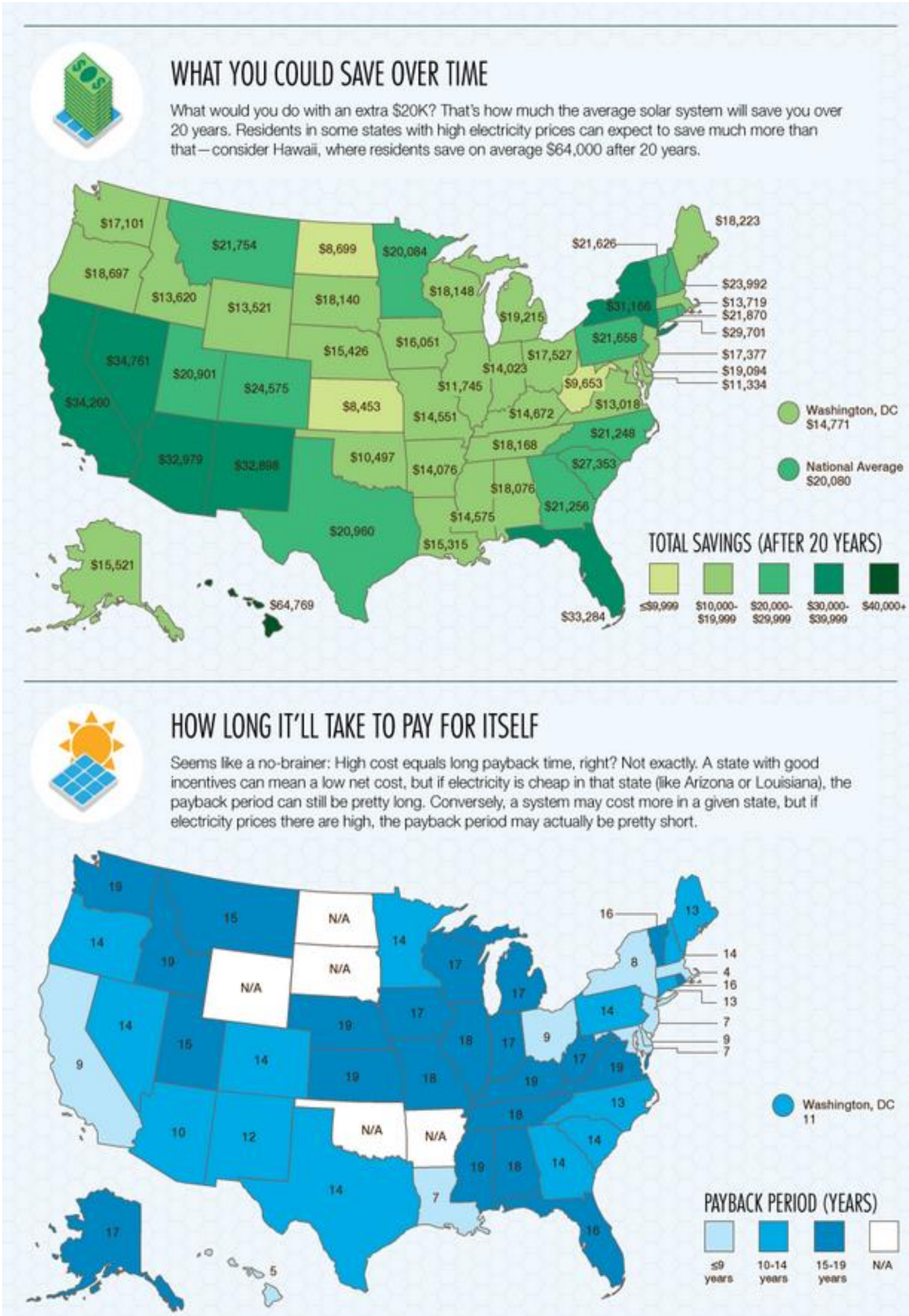
Think solar is out of reach? Think again. Real solar estimates show state, regional, and local incentives are helping bring the cost way down. In many states, you can go solar for less than $10,000. Here's a look at the average cost to go solar in each state.



WHAT YOU COULD SAVE EVERY MONTH

By going solar, people around the country are saving money each month that would have gone to utility companies. Just how much are they saving? In some places, over $100 each month.





Source: Clean Power Research, 2011

Figure 2.5 How Much Does Solar Cost?

2.2 Types of Solar Energy System

Before going into the different types of solar energy, the first way to look at solar energy is by how it is converted into a useful energy. Passive solar energy, facing the direction depending on hemisphere to provide natural lighting and heating, is the harnessing of the sun's energy without the use of mechanical devices. On the other hand, active solar energy, which includes space (crystalline, thin-film), water, and pool heating, uses mechanical devices in the collection, storage, and distribution of solar energy to required areas (Michael, 2008b).

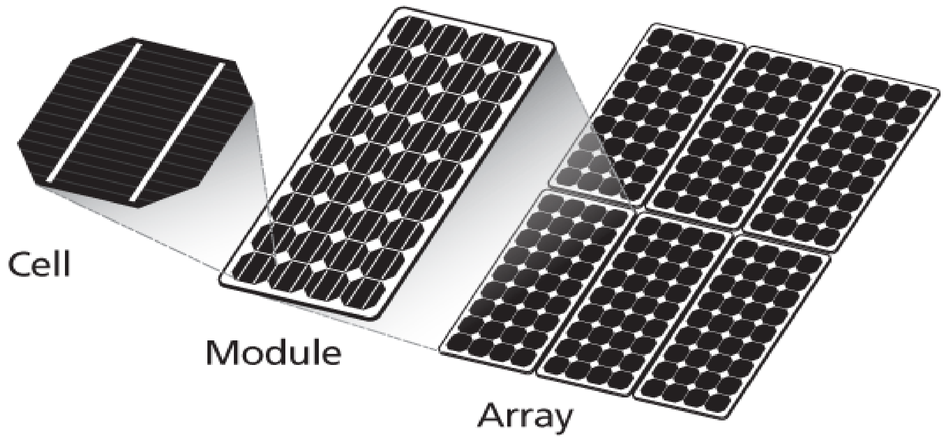
The second step is to look at the different types of solar energy. Solar thermal energy is the energy created by converting solar energy into heat that is put to practical use to heat water or space heating. Concentrating solar power is a type of solar thermal energy that is aimed at large-scale energy production that uses mirrors/lenses to concentrate sunlight to create high temperature to run steam turbines/engines that eventually turns into electricity (Solar Energy Industries Association, 2014). However, among the two major types of solar power systems, this paper will solely focus on PV energy.

The name PV comes from the process of converting light (photons) to electricity (voltage), which is known as PV effect (Engineering, 2013). PV cells can be divided into either crystalline silicon PV which accounts for roughly 80% of global PV production capacity or thin-film PV (a newer technology) which accounts for 20% of global installed PV capacity (Business Insights, 2011).

Instead of using a traditional polycrystalline silicon, which is also known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si), thin-film cells use thin layers of semiconductor materials like amorphous silicon (a-Si), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe) or organic photovoltaic cells (OPC).

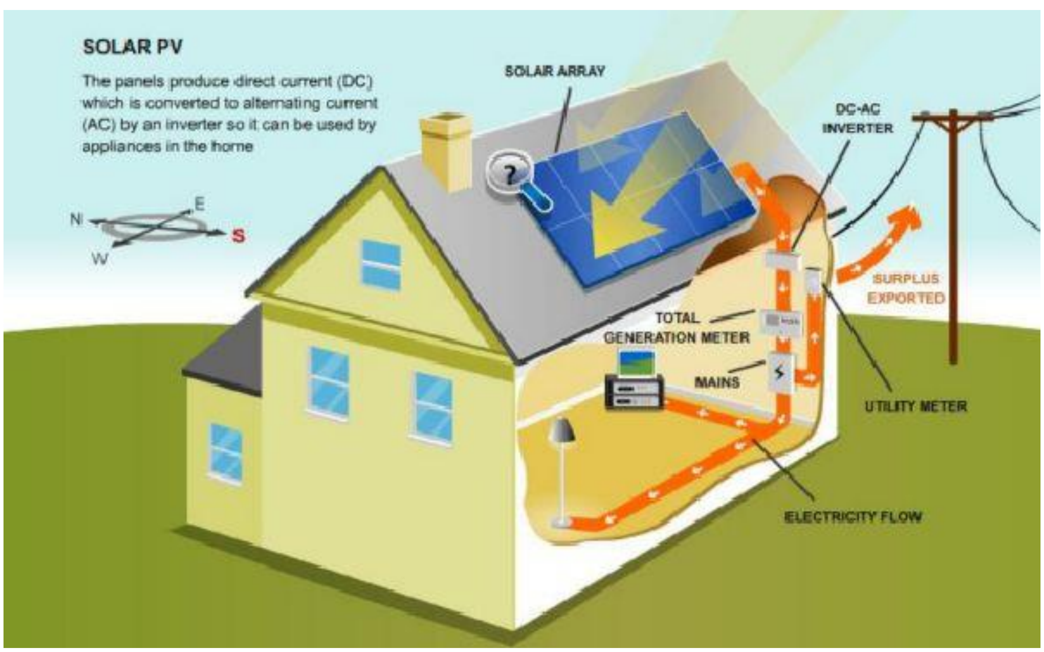
So far, thin-film solar panels tend to take more space compared to crystalline-based solar panels. On average, while thin-film cells convert 5~21% of incoming sunlight into electricity, crystalline silicon cells can bring efficiency of 11%~28% (NREL, 2012). However, there are still bright sides where thin-film can increase more efficiency than crystalline silicon.

As shown in figure 2.6 and figure 2.7, a number of solar cells (about 40 cells) are connected to each other and mounted in a support structure or frame to form a module. This PV module (panel) supports electricity at a certain voltage (commonly 12 volts system) which is again wired together to form an array (either in a fixed or tracking system) in both series and parallel electrical arrangements. A typical home will use about 10 to 20 solar arrays to produce direct-current (DC) electricity (NREL, 2014). And finally, both thin-film and crystalline silicon systems use a variety of other components, known as “balance-of-system (BOS)” components that include all mechanical or electrical equipment and hardware: conductors and wiring methods, raceways and conduits, junction and combiner boxes, disconnect switches, fuses and circuit breakers, terminals and connectors, grounding equipment, array mounting, battery (if needed), etc. Also in the United States, inverters are needed to convert the electricity from direct current (DC) to alternating current (AC).



Source: Samplexsolar

Figure 2.6 PV Cells, Modules, Panels and Arrays



Source: Blue Selenium Solar, LLC

Figure 2.7 Typical PV System

2.3 Why Use Solar Energy?

To date, many natural resources have been applied with technology to create and maximize a new market. Each year when summer arrive, the demand for a chunk of electricity and water increase among agriculture, households, industries, etc. For example, when constructing a hydroelectric dam, it stores lots of water behind it in the reservoir. Then the water falls to spin a turbine and create electricity to harness the energy potential.

As the sun's radiant energy reaches every part of Earth's surface, installing solar panels on rooftops of buildings can provide electricity to even the most remote locations. The potential of generating capacities vary from region to region based on varying levels of solar radiation. Generating electricity with photovoltaic and other renewable can reduce the amount of greenhouse gas emissions from fossil fuel energy sources (Faiman, Raviv, and Rosenstrich, 2007).

Before examining the positive side of the solar system, it is also important to take an honest look at the system's disadvantages (Conserve-energy-future, 2013). Some of the drawbacks are as follow: (1) The initial cost of purchasing and installing solar panels always become the first disadvantage when the subject is discussed. Even though subsidy programs, tax initiatives and rebate incentives are provided by the government to promote the use of solar panels, consumers are still hesitant to build PV system.

(2) The location of solar panels is important in the generation of electricity. Areas such as U.K. that is mostly cloudy and foggy during day will produce electricity at a reduced rate and may require more panels to generate enough electricity. Moreover, solar panels that are covered by trees, landscapes or other buildings are not appropriate to create electricity. (3) Most of the photovoltaic panels are made up of silicon and other toxic metals like mercury, lead and cadmium. Pollution in the environment can also degrade the quality and efficiency of photovoltaic cells. However, new innovative technologies can overcome the worst of these effects.

(4) Since not all the light from the sun is absorbed by the solar panels therefore depending on the type of solar panels, the average efficiency rate of 20% means that the rest of the 80% gets wasted and is not harnessed. However, the endless R&D is slowly increasing the rate of efficiency of solar panels. (5) Solar energy can only be harnessed when it is daytime and sunny. This means that unlike other renewable source which can also be operated during night, customers have to depend on the local utility grid to draw power in the night. The consumer may consider using solar batteries to store excess power, however, it is not recommended. (6) For home users, a large solar energy installation is not required for huge space. But for big firms, a large area is required for the system to be efficient in providing electricity.

Despite of all the negative reasons, there are more bright sides to use solar. Consumers can benefit from both an environmental and financial stand point. In-depth, the benefits of using solar energy can be understood as follows (Department of Energy). (1) Sun is a universal source of energy that is both free and infinitely renewable, which is accessible to everyone. (2) Solar energy can be used to heat, cool and light any dwelling areas at almost zero impact on the environment. By contrast, electricity generated by conventional resources produces emissions that pose serious threats to the world. (3) It will either completely eliminate or drastically reduce the electric bills via building a solar-energy system.

(4) A solar energy system helps to add value to commercial property and create a green image for homes and companies. (5) Solar panels aren’t an expense. They’re an investment that recompenses good returns that create revenue in ROIs of 20% or more (EnergySage, 2015). (6) Last but not least, under a good search, U.S. financial incentive programs (tax credits, grants) have been developed on the local, state, and federal level to encourage homeowners, businesses, and institutions. The Database of State Incentives for Renewables & Efficiency (DSIRE) is a good resource that helps to guide about current state, local, utility and federal incentives.

2.4 Life Cycle Assessment

Life Cycle Assessment (LCA), also known as cradle-to-grave, is a technique that studies the stages of raw material acquisition, materials manufacture, production, use/reuse/maintenance, and waste management. The system boundaries, assumptions, and conventions to be addressed in each stage are presented. LCA is used as a decision-making processes - support tool for both policy makers and industry in assessing the cradle-to-grave impacts of a product or process (EPA, 2014). The following figure 2.8 is a simple picture of LCA.

Source: The National Energy Technology Laboratory, 2014

Figure 2.8 LCA of Energy Technology and Pathways

Three forces are driving this evolution. First of all, the U.S. government is putting a regulation that a manufacturer is responsible not only for direction production impacts, but also for product inputs, use, transport, and disposal. Secondly, business is participating in voluntary initiatives which contain LCA and product stewardship components; for example, ISO to foster improvement through better environmental management systems. Lastly, environmental preferred has emerged as a criterion in both consumer markets and government guidelines.

For three decades, hundreds of life cycle assessments have been studied for residential and utility-scale solar systems. To further comprehend greenhouse gas (GHG) emissions from commercial crystalline silicon (mono- and multi-crystalline) and thin-film (amorphous silicon, cadmium telluride, and copper indium gallium diselenide) PV power systems, the National Renewable Energy Laboratory (NREL) LCA Harmonization Project was developed and applied a systematic approach to review 400 published PV system studies, identify primary sources of variability, and reduce variability in GHG emissions estimates through a meta-analytical process called "harmonization" (NREL, 2013).

Table 2.1 shows the key technical parameters such as (1) Solar irradiation, the average energy flux from the sun, in kilowatt-hours per square meter per year, (2) Operating lifetime of the PV system and components, in years, (3) Module efficiency, the percentage of the solar energy converted to direct current electricity by the module, and (4) Performance ratio, the ratio of alternating current electricity actually produced by the system, after accounting for losses, to the electricity calculated based on the direct current-module efficiency and irradiation.

Table 2.1

Harmonization Parameters

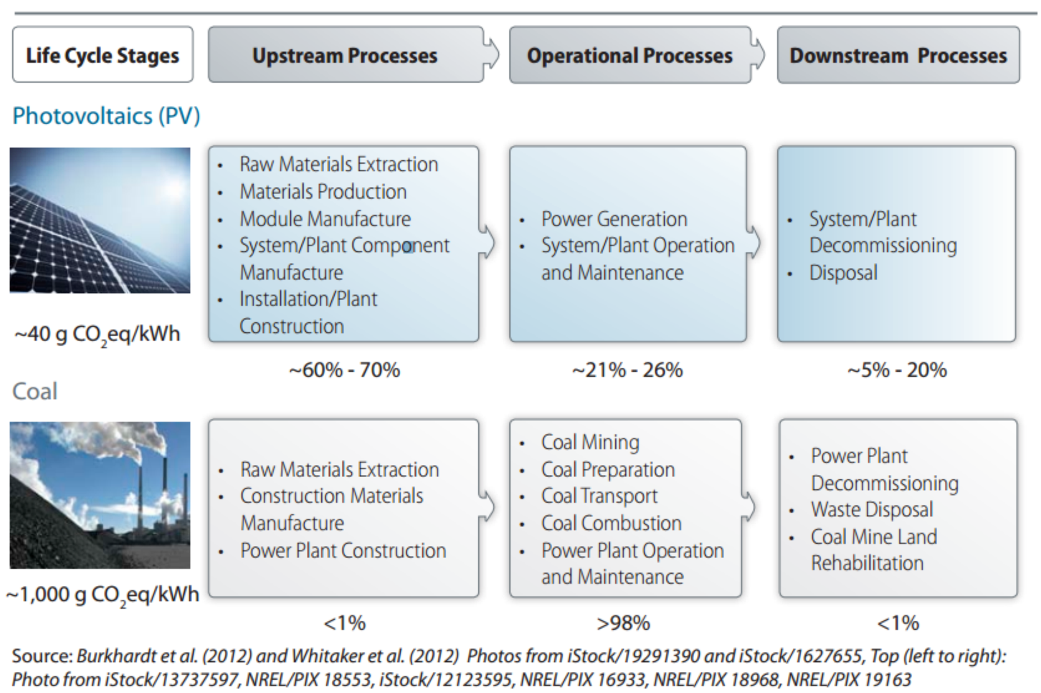
Parameter	Value
Solar Irradiation (kWh/m²/yr)	1,700 | 2,400
System Lifetime	30 years
Crystalline Silicon Module Efficiency	
Mono-crystalline	14.0%
Multi-crystalline	13.2%
Thin Film Module Efficiency	
Amorphous silicon (a-Si)	6.3 %
Cadmium telluride (CdTe)	10.9%
Copper indium gallium diselenide (CIGS)	11.5%
Performance Ratio	
Ground-Mounted	0.80
Rooftop	0.75

Source: NREL, 2012

For example, figure 2.9 shows that LCA can help determine environmental burdens and facilitate comparisons of energy technologies. Compared to the life cycle stages and proportions of GHG emissions from each stage for PV, coal-fired power plants, fuel combustion during operation emits the vast majority of GHGs. For PV power plants, the majority of GHG emissions are upstream of operation in materials and module manufacturing.

Overall, the data from the Life Cycle show that PV power production is similar to other renewable and much lower than fossil fuel in total life cycle

GHG emissions. Adjustment to a consistent operating lifetime is also a driving factor in decreasing the variability of the harmonized data. Analysis between mono-Si and multi-Si technologies suggests that these do not significantly differ in life cycle GHG emissions. No significant differences in GHG emissions from ground-mounted and roof-mounted systems were observed for c-Si or TF PV technologies.



Source: Environmental Protection Agency, 2014

Figure 2.9 LCA Energy Systems

CHAPTER 3

(RENEWABLE ENERGY POLICIES)

3.1 U.S. Energy Agenda

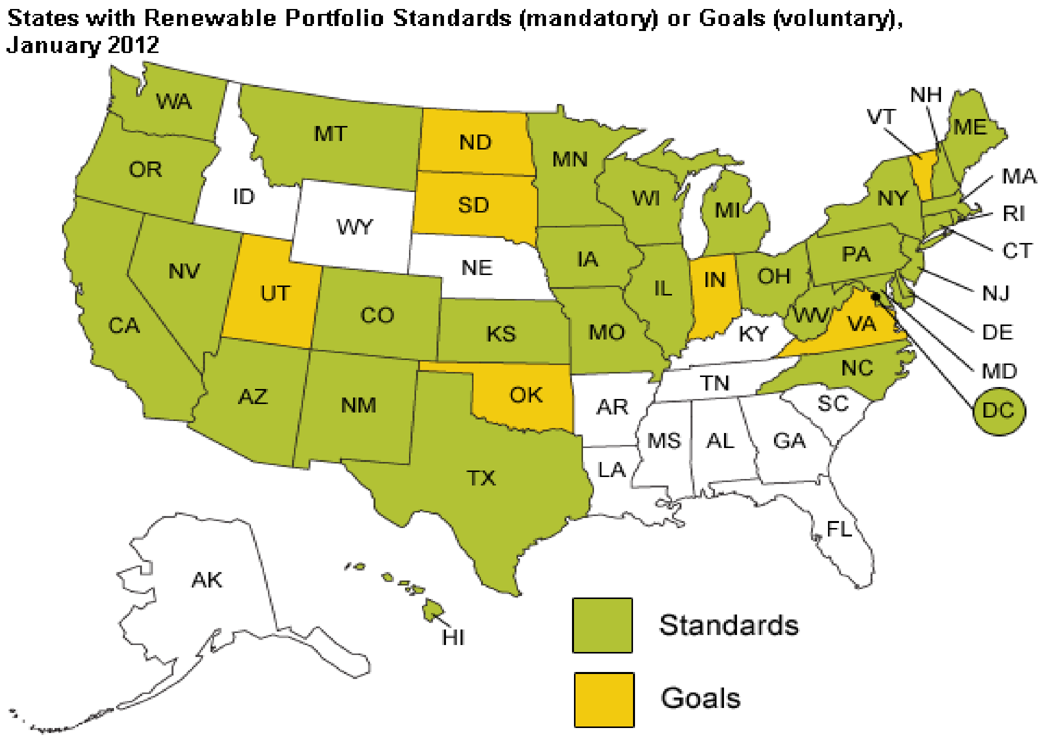
The American Clean Energy and Security Act of 2009 (ACES), was passed by the House of Representatives on June 26, 2009. This legislation created a cap-and-trade mechanism, a market-based incentive to reduce carbon emissions. It mandated a combined renewable electricity and energy efficiency standard requiring that 20% of electricity sales by 2020 be met by renewable energy and energy efficiency (ACEEE, 2013). In addition, allowances from the trade of carbon credits in the cap-and-trade have offered funding for a number of effective energy schemes. Together, these thoughts were able to support people and business to benefit in the economy and enhance environmental quality.

The Feed-in Tariff (FIT) scheme is a government policy mechanism designed to accelerate investment in renewable energy technologies such as low-carbon electricity generation (EIA, 2013). FITs are used to a limited extent around the United States, but they are more common internationally. A FIT program guarantees customers who own a FIT-eligible renewable electricity generation facility to receive a set price from their utility for all of the electricity they generate and provide to the grid.

There are two main ways that the tariffs help the electricity producers to make money via generating one's own energy. The Generation and Export Tariff where the producer earn a fixed income for every kilowatt hour of electricity the producer generate via either using it for oneself or exporting it to the grid. Other types of policies encouraging development of new renewable capacity that are more commonly used in the United States is a Renewable Portfolio Standard (RPS).

The RPS, also known as renewable electricity standard (RES), is a regulatory mandate in the U.S. to catch three birds with one stone. (1) Save the environment and reduce global warming, (2) Depend less of fossil fuels, and (3) Increase the production of energy from renewable sources such as wind, solar, biomass and other alternatives to fossil and nuclear electric generation (NREL, 2014). In recent years, many RPS proposals have been tried out through the U.S. Congress; however, there is set standard program in place at the National level. As shown in figure 3.1, each state have different policies to either require (mandatory) or encourage (voluntary) electricity producers to supply a certain minimum share of their electricity from chosen renewable energy resources by a certain date/year.

These programs vary widely in terms of program structure, enforcement mechanisms, size, and application. Other States also set goals for detailed types of renewable energy or technologies to encourage growth. Currently every state in the United States holds some type of financial programs for alternative energy via availability of Federal tax incentives, State programs, and market conditions, and as well as by State RPS policies. And most significantly, as with all investments, one of the critical questions is whether polices for residential, commercial, and utility scale solar installations will provide sufficient economic returns to capital investments.



Source: Energy Information Administration, 2012

Figure 3.1 U.S. Renewable Portfolio Standards

RPS is most successful in stimulating alternative energy projects when combined with federal investment tax credit (ITC). For example, the federal government allows you to deduct 30% of your solar power system costs off your federal taxes through an ITC (Solar City) before 31, 2016. After this date, the commercial credit will drop to 10 percent and the residential credit will drop to zero. Tax credits apply to certain actions such as purchasing an energy-efficient vehicle or installing an eco-friendly home/firm; however, when ITC have been withdrawn RPS alone can be ineffective (DSIRE, 2014 a1&a2).

In figure 3.2, the financial incentives for Solar PV tend to vary from tax credit incentives, grants, loans, rebates, and performance based incentives for individual and business investments. The Energy Department's Loan Program guarantees loans to eligible clean energy projects with low interest rate and provides direct loans to eligible manufacturers of advanced technology (Dept of Energy, 2013). The Federal Grants are money that agriculture producers and rural small business doesn’t have to repay and is based on one’s financial need. They are also available for state government entities, local governments, tribal governments, land-grant colleges and universities (DSIRE, 2014b). The 25 percent grant has been made possible through the USDA Rural Energy for America (REPA) Grants program.

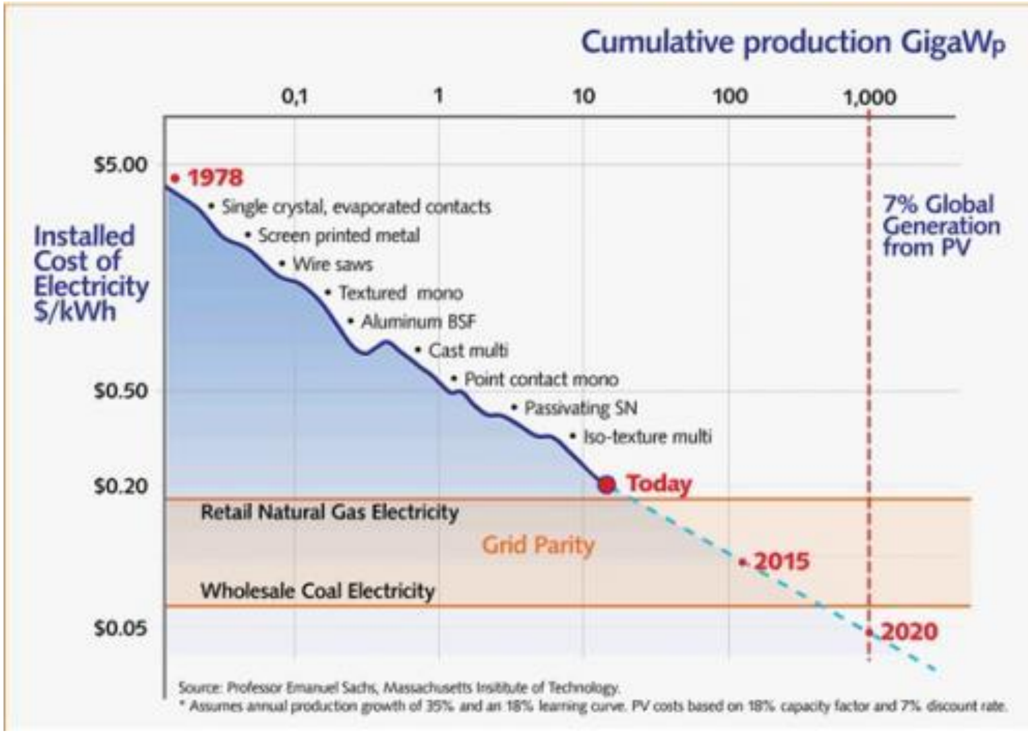
Source: DSIRE, 2009

Figure 3.2 U.S. Financial Incentives for Solar PV

Rebate is different from refunds where it gives back a portion of the money taxpayers submitted earlier (ehow, 2010). The American Recovery and Reinvestment Act of 2009 provides a renewable energy Production Tax Credit (PTC) of $0.020 per kilowatt (kW) for the first 10 years or individuals who are eligible for the PTC eligible for the U.S. Treasury investment tax credit (ITC) (DSIRE, 2014c). The ITC equals to a 30 percent credit on all solar system expenditures with no maximum credit (DSIRE, 2014c).

Gird parity happens when a renewable energy can generate electricity at a levelized cost (LCoE) that is less than or equal to the price of purchasing power from the electricity grid without subsidies or government support (REA). In most countries (including the U.S.), solar system is currently just a small part of the total energy production and consumption where PV remains a policy-driven market. To become cost-competitive with other primary traditional resources, solar energy must gain a larger share of the market via policy incentives that decrease the overall costs to install solar panels and to put a high pricing method for conventional electricity generation. Other renewable resources, such as marine, geothermal and solar thermal, benefit from being more controllable, but will make a smaller contribution than wind and solar due to their higher costs and more limited resources (WEP, 2013).

Luckily, according to Lux research associate, “A 'golden age of gas' can be a bridge to a renewable future as recent foundation of shale gas (year 2013) will replace coal and act as a steppingstone until solar becomes cost-competitive without subsidies with natural gas by 2025. In addition, in figure 3.3, it describes that the cost per kilowatt hour of solar electricity has steadily declined from nearly $5/kWh in 1978 to about $0.20 today, where the price of PV is projected to become cost-competitive in the later future.



Source: MIT, 2009

Figure 3.3 Grid Parity

3.2 Renewable Policy Programs in Georgia

As of January 2012, 30 out of 50 U.S. states and the District of Columbia have implemented mandatory Renewable Portfolio Standards (RPS) while seven states have set voluntary goals for renewable generation (EIA, 2012). Regulations vary from state to state and currently there is no RPS program in place at the National level. The Georgia Chamber of Commerce does not support any renewable portfolio program that has the ability to create an "economic imbalance nationally, regionally or for Georgia" (Georgia Chamber of Commerce). In other words, Georgia is not enrolled in either a standard or goal for renewable energy. Therefore, in the state of Georgia, both individuals and businesses can seek to voluntarily participate in renewable generation, especially solar power system, from a combination of federal incentives, state programs, and market conditions.

The incentives are as follow in the table 3.1: (1) Georgia Green Loans Save and Sustain Program, (2) Federal Renewable Energy Tax Credit, and (3) Solar Buyback Program from Georgia Power (DSIRE, 2014d).

Table 3.1

Available Incentives in Georgia

Name	State	Incentive Type	Expiration Date	Amount
Federal Renewable Tax Credit	Federal	Residential, Commercial, Utility	~ Dec 31, 2016	30% of the costs (installation)
Georgia Clean Energy Tax Credit	State	Residential, Commercial, Utility	~ Dec 31, 2014	\$10,500 / \$500,000 for residential / nonresidential
Georgia Power – Solar Buyback	Local	Residential, Commercial, Utility		\$0.17 / kw/h ($X \leq 100$ kW) \$0.04 / kw/h (100 kW $< X \leq$ 80MW)

Source: DSIRE, 2014

3.3 About Georgia Power

The changing climate is affecting trends in weather across the nation. As temperatures in the Southeast coast rise, humans will have to adjust to the lengthening of cold seasons under extreme weather conditions. In 2011, Coal accounted for 35 percent of Georgia Power's energy portfolio, Gas and Oil generated 39 percent, Nuclear with 23 percent, and only three percent of the consumed electricity was generated using hydro (Georgia Power Company, 2013). Every customer in Georgia is connected to the electrical grid where they receive electricity from one of Georgia’s Public Service Commission (PSC) approved utility providers. Georgia PSC tries to make sure that consumers receive safe, reliable, and reasonable electricity price and natural gas price from financially viable and technically experienced companies.

Currently, Georgia Power Company owns 18 generating plants and 20 hydroelectric dams across the state which provides electricity to 2.4 million customers and consumers. Georgia Power is looking for improved ways to create electricity and minimize environmental impact by investing $7 billion in environmental control technologies until year 2015. However, Georgia Power does not sell or recommend a specific system in regard to renewable energy.

Georgia Power is pushing for individuals and businesses to increase their energy efficiencies to reduce the demand for electricity due to the likeliness of power outage during peak consumption periods. Currently, they offer a voluntarily solar buyback program for electricity generated through solar panels that pays at a higher rate than standard net metering. Under the five year contract, if the Georgia Power customers (commercial, residential, and industrial) generate electricity they have the opportunity to sell some or all of the electricity back to Georgia Power (DSIRE, 2014f). Small generators ($X \leq 100$ kW) are eligible to sell their electricity under the Renewable & Non-renewable Tariff (RNR-8) at a rate equal to Georgia Power's avoided energy cost.

Georgia Power purchases energy from eligible providers on a first-come, first-serve basis until the cumulative generating capacity of all renewable sources reaches a specific amount set by the Georgia Public Service Commission. The company will pay avoided energy cost as defined by the most recent informational filing made by the company in compliance with the final order in the PURPA Avoided Cost Docket 4822-U (Georgia Power Company, 2013). Additional energy may be purchased by the company at a cost agreed to by it and the Provider. Georgia Power will purchase energy from solar generating facilities through the RNR tariff at the company's Solar Avoided Cost rate as approved by the Georgia Public Service Commission.

Moreover, under the Solar Purchase Tariff (SP-2), customers can sell the electricity that they have generated back to Georgia Power at a premium price, currently 17.00 cents/kWh (Georgia Power Company, 2013). The amount of capacity Georgia Power can contract for through the SP-2 Tariff is limited. This limit is based on the amount of blocks of Premium Green Energy sold. And for large customers (100 kW $<$ X $\leq$ 80MW), they may sell their electricity as a Qualifying Facility (Georgia Power), where the fixed price is at 4.00 cents/kWh.

CHAPTER 4

(LITERATURE REVIEW ON FORECASTING ELECTTRICITY PRICES)

4.1 U.S. Electricity Outlook

The price of electricity power generation depends largely on the type and market price of the fuel, technology, government subsidies, government and industry regulation, local weather patterns, and other factors. Moreover, electricity rates not only differ at the state level, but also typically vary for residential, commercial, and industrial customers. While the cost to generate electricity changes minute-by-minute, most consumers end up paying rates based on the seasonal cost of electricity (EIA, 2012). Electricity prices are highest in the summer, and demand is usually highest in the afternoon and early evening when usage is at a peak.

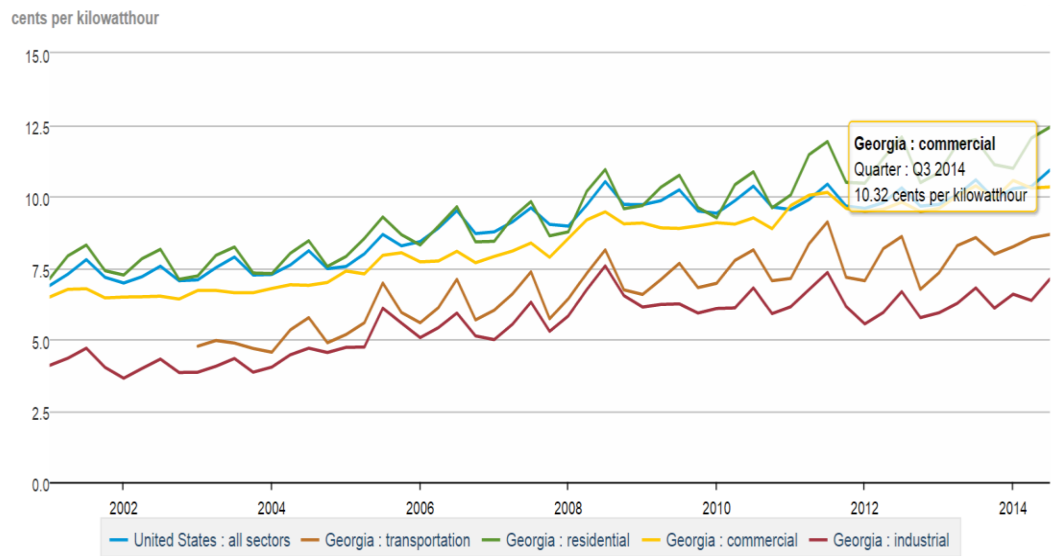
Both table 4.1 and figure 4.1 show the nominal average retail price of electricity to ultimate customers by end-use in the state of Georgia. There are four different electricity sectors (residential, commercial, industrial and transportation) prices are normally higher for transportation, residential, and commercial consumers than industrial consumers due to higher distribution costs. The higher distribution costs stem from the fact that, those sectors generally use less electricity and take their electricity at lower voltages it has to be stepped down before it gets to the consumers (EIA, 2012). However, as UGA falls under the commercial sector, we will focus on the latest commercial average electricity price, 10.28cents per kWh ($0.1028 per kWh) in year 2014.

Table 4.1

Average Retail Price of Electricity to Ultimate Customers by End-Use Sector

Year	Residential (Cents / kWh)	Commercial (Cents / kWh)	Industrial (Cents / kWh)	Transportation (Cents / kWh)
2014	11.57	10.28	6.52	6.31
2013	11.46	9.99	6.27	8.03
2012	11.17	9.58	5.98	7.65
2011	11.05	9.87	6.60	7.94
2010	10.07	9.06	6.22	7.46
2009	10.13	8.94	6.12	7.03
2008	9.93	9.07	6.67	7.15
2007	9.10	8.07	5.53	6.42
2006	8.91	7.81	5.38	6.12
2005	8.64	7.67	5.28	5.90
2004	7.86	6.88	4.43	5.12
2003	7.70	6.66	4.02	4.81
2002	7.63	6.46	3.95	N/A
2001	7.72	6.61	4.28	N/A
				(In terms of nominal value)

Source: Environmental Protection Agency, 2015

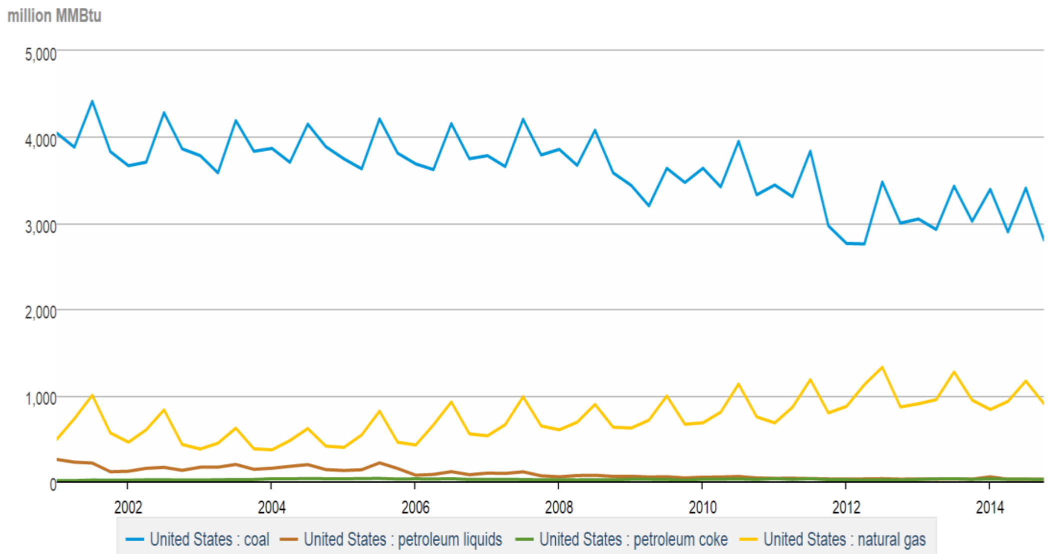


Source: Environmental Protection Agency, 2015

Figure 4.1 Average Nominal Retail Price of Electricity, quarterly

4.2 Forecasting

The rapid increase in electricity demand over the last 100 years has challenged both generating unit and system operators to build more nuclear power plants, hydroelectricity dams, and small parts of systems related to renewable energy to meet users' supply. Because supply and demand for electricity must balance in real-time, forecasting electricity demand is a critical component of planning and operating electric generation and distribution. Based on the needs of the market, a variety of approaches for forecasting electricity price have been proposed in the last decades. Figure 4.2 shows the U.S. Consumption for electricity generation (Btu) for electric utility, quarterly from year 2000 to 2014.



Source: Energy Information Administration, 2015

Figure 4.2 Consumption for electricity generation (Btu) for electric utility, quarterly

In contrast to other tradable commodities, electricity has two characteristics (Eydeland and Wolyniec 2003; Kaminski 2013; Weron 2006). First electric power cannot be stored economically. Second, power system stability requires a constant balance between production and consumption. At the same time, electricity demand depends on a variety of factors including the weather (temperature, wind speed, precipitation, etc.) and the intensity of business activities (working hours, weekdays vs. weekends, holidays and near-holidays, etc.).

The characteristics of electricity loads can be seen in three ways: (1) Time dependence, where electricity loads change according to the hour of the day or time of year. For example, in terms of seasonality, every each year there are two load peaks during summer and winter; (2) Regional dependence, where during the same point in time across different locations, the electricity loads can be dissimilar due to different consumption structures at each given region; and (3) Temperature dependence, where different climate circumstances such as low or high temperature affect electricity demand.

Electricity price can be forecasted in a variety of ways. One is the interval estimate where one estimates prediction intervals (PI) via two averaging schemes: simple average, and least absolute deviation (LAD). The second method uses the concept of quintile regression and a pool of point forecasts of individual time series models to construct prediction intervals. The latter can be thought of an extension of LAD averaging. A lot of conventional ways such as the AR(I)Max-GARCH model and the neural network model, have been used to predict normal range electricity prices, however it ignores price spike measure (Gaussian Mixture model, and K-NN model), which is caused by a number of complex factors and exist during periods of market stress.

In the premature stage of data pre-processing, price spikes were truncated before application of the forecasting model to decrease the influence of observations on the estimation of the method parameters; otherwise a large forecast error would be generated at price spike occasions (Yamin, 2004; Rodriguez and Anders, 2004; Weron, 2006). In addition to understanding price behavior, improved analysis of spikes is important for risk management as well.

On the other hand, the simple point estimates such as Artificial Neural Network (ANN) can predict electricity price in nonlinear approximation via direct forecasting method. Generalized regression neural network (GRNN) is practical where it deals with few samples and sparse data in multidimensional space. Recurrent neural networks (RNNs) are autoregressive nonlinear dynamic models that show arbitrary nonlinear dynamic systems. Cross-validation is a resampling technique that uses multiple training and test subsamples to avoid the over fitting problem (Nima Amjady and Farshid Keynia, 2008). A result from the cross-validation analysis provides valuable insights on the reliability or robustness of neural networks with and is better than autoregressive (AR) error models (Hsiao-Tien Pao, 2006).

The existed regression models are unable to cope with the nonlinear relationships. Therefore, Artificial neural network (ANN) and support vector machine (SVM) with nonlinear artificial intelligence forecasting methods been suggested as the electricity loads are nonlinear. Besides in several engineering problems, one-day ahead prediction using NN performed satisfactory outcome (Chang et al. 2007). Pino et al. employed one-step ahead forecast method (Enders 2004) within experimental procedure based on ANN with encouraging outcome (Pino et al. 2008). Support Vector Machine (SVM) is an artificial Intelligence Technologies based on statistical learning theory, which approximates the relation curve by using only a small amount of training data.

Furthermore, SVM can effectively stay away from the over-fitting problem by attaining an appropriate trade-off between empirical accuracy and model complexity (Wen Yu, Haibo He, Nian Zhang, 2009); it shows better performance compared to other traditional methods. Over-fitting is defined as having too many parameters relative to the number of observations will normally have bad predictive performance; particularly for noisy processes (Andreas S. Weigend, Ashok N. Srivastava, Morgan Mageas, 1995).

On the other hand, relevance Vector Machine (RVM) is based on Bayesian estimation theory, developed for regression and classification problems. It can provide a solution function that depends on a very small number of training samples, the relevance vectors (RVs). It shows better performance than many other methods in terms of higher forecasting accuracy, model running time (faster speed), and model complexity (Guoqiang Sun, Yue Chen, Zhinong Wei, Xiaolu Li, and Kwok W. Cheung, 2014). However, the rules generated from conventional statistical methods (i.e., ARIMA), and artificial intelligence technologies (i.e., SVM and ANN) are not easily comprehensive for policy-maker.

4.3 Types of Forecasting Method

The appropriate forecasting methods depend largely on what data are available. The three factors for accurate forecasts needed are weather influence, time factors, and customer classes. For weather influence, electric load has a correlation to the weather where the important variables are dry and wet temperature, dew point, humidity, wind speed and direction, sky cover, and sunshine. The time factors such as the day of the week, the hour of the day and holidays must be considered. In details, the three load forecast are short term forecasts (one hour to a week), medium forecasts (a month up to a year), and long term forecast (over one year). And finally, electric utilities serve different types of customers such as residential, commercial, and industrial.

With all the considerations described above, electricity price forecasting methods can be divided into five sections. The first group is the production-cost (or cost-based) models which simulate the operation of generating units aiming to satisfy demand at minimum costs (Wood, Wollenberg, 1996; Perez-Ruiz and Conejo, 2000). It is the traditional engineering approach which ignores strategic bidding practices (market power, gaming).

The second forecasting method is the equilibrium (or game theoretic) approaches cost-based models with strategic bidding, agent-based models which focus on the impact of bidder strategic behavior on electricity prices. It is said that the spot market prices are closely related to the bidding and pricing strategies of the market participants (Day, Hobbs and Pang, 2002, Green, 1992; Smeers, 1997; Ventosa et al., 2005, Guan, 2001; Bajpai and Singh, 2004). It poses problems if quantitative conclusions have to be draw. The modeling risk associates the players, their potential strategies, the ways they interact and the set of payoffs have to be defined.

Third is the fundamental (or structural) method which describes price dynamics by modeling the impact of important physical and economic factors on the price of electricity (Kanamura, 2006; Skantze, 2001; Vahvilainen, 2005). It is better suited for medium-term rather than short-term price forecasting (STPF).

Fourthly, the artificial intelligence-based (or non-parametric) techniques model price processes via non-parametric tools such as neural networks (NN), fuzzy logic, etc. (Amjady, 2006; Gonzalez et al. 2005; Mandal et al. 2006; Rodriguez, 2004). The method is flexible and can handle complexity and non-linearity. However it is not intuitive and can perform below expectations.Neural Network (NN) combines prediction from both Auto Regressive Moving Average (ARMA) and GARCH models with historical price and demand data helps to forecast a final normal range price.

Five short-term forecasting techniques were analyzed and evaluated by Mogham and Rahman (1989), and autoregressive integrated moving averages (ARIMA), forecasting homogeneous non-stationary performance was applied to load forecasting (Hagan and Behr, 1987; Erdogdu, 2007). To overcome the restrictions of linear models and to give a reason for nonlinear patterns, several ways of nonlinear models have been proposed. These include threshold autoregressive (TAR-type) models (Robinson, 2000) and an autoregressive conditional heteroscedastic (ARCH) model of Engle (1982) and its extended version GARCH, which simulates the heteroscedasticity of the residuals that continues even after price spikes were gained from the original price time series, (Bollerslew, 1986; Garcia, 2005; Jablonska, 2008). Also, ANNs have been recommended as another way for time series predicting (Zhang 2005; Catalão, 2007).

Despite that both linear regression based models and ANNs models have attained achievement in linear or nonlinear relationship, nothing suits all situations as a universal model. Since it is hard to recognize the uniqueness of the data in an actual problem, hybrid methodology that has both linear and nonlinear modeling has been projected. A model combining a NN model with a seasonal time series ARIMA model has been studied by Tseng and Yu (2002). This model did better than ARIMA and ANN models in terms of precision. Wu and Shahidehpour (2010) extended a hybrid model for day-ahead price forecasting, composed of linear (ARMAX) and nonlinear (ANN) relationships of prices and explanatory variables such as electricity demand.

And lastly, the fifth forecasting approach is the quantitative and statistics (or stochastic, econometric, reduced-form) model which characterize the statistical properties of electricity prices over time, with the ultimate objective of derivatives evaluation and risk management (Bunn, 2004; Burger et al.2004;

Eydeland, 2003; Geman, 2006; Kaminski, 1999; Lucia, 2002; Weron, 2007). If there are no data available or if the data available are not relevant to the forecasts, then the qualitative and statistics (Q and S) forecasting methods are recommended.

They are fulfilled when the numerical data about the past is accessible, and it is rational to assume that some parts of the previous patterns are likely to continue. Most Q and S forecasting problems use either time series data (collected at regular intervals over time) or cross-sectional data (collected at a single point in time). However, the main disadvantage comes from difficulties involved in including physical characteristics of power systems.

The latter tries to predict the value of something we have not observed, using the information on the cases that we have observed. It is used when the variable to be forecast exhibits a relationship with one or more other predictor variables. Under this model, any change in predictors will affect the output of the system in a predictable way, assuming that the relationship does not change. Models include regression models, additive models, and neural networks.

For the former (e.g.: ARMA(X), AR(X)-GARCH, (S)ARIMA, (S)TAR(X), Markov regime-switching models), it is useful when we are forecasting something that is changing over time (e.g., stock prices, sales figures, profits). In other words, it uses data on the variable to forecast, and does not attempt to find the reasons which affect its performance. Therefore it will look for trend and seasonal patterns, but ignore all other information such as marketing initiatives, competitor activity, and changes in economic conditions.

4.4 Data Mining and Combining Forecast Method

Data mining techniques for forecasting electricity price spikes were extended by Lu (2005). Jablonska (2011) introduced spikes into diffusion models by providing an idea of Poisson jump component plus time varying parameters. Data mining techniques were applied to the spike forecasting problem, and achieved hopeful results (Lu, 2005; Zhao, 2007a). These approaches have revealed reliable forecasting accuracy and stoutness, even with deficient information and noisy market data. Data mining technique based on Bayesian idea did better than other alternative techniques (decision tree, neural network, winnow, SVM and K-nearest neighboring) bearing in mind prediction accuracy and decision benefits (Zhao, 2007b).

Combining forecasts, sometimes referred to as composite forecasts, can reduce errors arising from faulty assumptions, bias, or mistakes in data. The idea of combining forecasts goes back to the late 1960s, giving credits to Bates and Granger (1969) and Crane and Crotty (1967). Since then, many authors have recommended the better performance of forecast combinations over the use of individual models: see e.g. Clemen (1989), de Menezes et al. (2000), Timmermann (2006).

Joining them is useful to the extent that they are used when there exists (1) uncertainty as to the selection of the most accurate forecasting method, (2) uncertainty associated with the forecasting situation, and (3) a high cost for large forecast errors (Armstrong, 2001). In addition, the key principles for combining forecasts are to use (1) different methods or data or both, (2) forecasts from at least five methods when possible, (3) formal procedures for combining, (4) $ equal weights when facing high uncertainty, (5) $ trimmed means, etc, (Armstrong, 2001).

Some researchers object to the use of combining. Statisticians object because combining brings disorder with traditional statistical procedures will result in the calculations of statistical meaning. Others object because making a comprehensive model that includes all of the related information might be more effective; there is one right way to forecast. Despite the objections, the combined forecast is never less accurate compared to the typical component forecast.

4.5 Conclusion

In conclusion, when predicting price movements each specific model gives different forecast. However, it is not feasible to pick a single model to make it the most reliable one. For instance, Aggarwal et al. (2009) compared results from 47 publications and concluded: there is no systematic proof of one model out performing over the other models. This fact is valuable information to take into account that combining method for electricity price forecasts is crucial.

Recently, this approach has been carried out in the literature by Bordignon et al. (2013), Nowotarski et al. (2014) and Raviv et al. (2013). All three cited papers give analogous conclusions - they believe the advantage of merging can forecasts for more accurate and point/range forecasts of electricity prices.

CHAPTER 5

(METHODOLOGY)

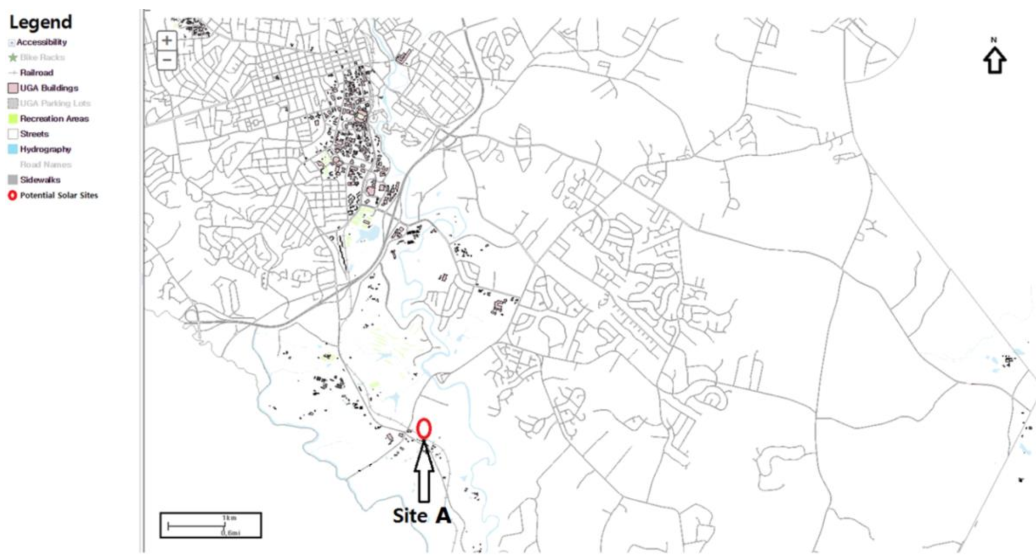
5.1 Introduction

In this chapter, the methodology for determining the net present value of benefits and costs for a solar array installation at the University of Georgia is described in two separate scenarios. In Scenario A the electricity generated by the array is sold to Georgia Power and distributed onto the power grid. In Scenario B the electricity generated by the array is used by University of Georgia facilities, thereby reducing the amount of electricity the University purchases from Georgia Power. In addition to the difference in the end-user, the two scenarios have different physical capital requirements, as depicted in figures 5.2 and 5.3.

The remainder of the chapter is organized as follows. Section 5.2, 5.3 and 5.4 describes about the net present value (NPV), present value of benefits, and present value of costs. In section 5.5 explains the Price of Electricity, and section 5.6 compare and contrast among the different types of arrays, and decided which is the most efficient array used among the three. And finally, the last section 5.7 discusses whether UGA can satisfy the 2020 strategic goal.

5.1.1 Site Description

As stated in Chapter 1, site A, a 10 acre (40,469 m^2) site near the intersection of Whitehall Road and Phoenix Road shown in Figure 5.1, are the possible study sites. Scenario A focuses on transferring the electricity to the utility grid via Georgia Power Buy-Back Program, which requires a transformer to transfer electricity to the utility grid via Georgia Power Buy-Back Program with the transformer. And scenario B concentrates on distributing electricity to UGA facilities such as the livestock arena and the UGA botanical garden, which does not require a transformer and the electricity is directly used at UGA facilities.

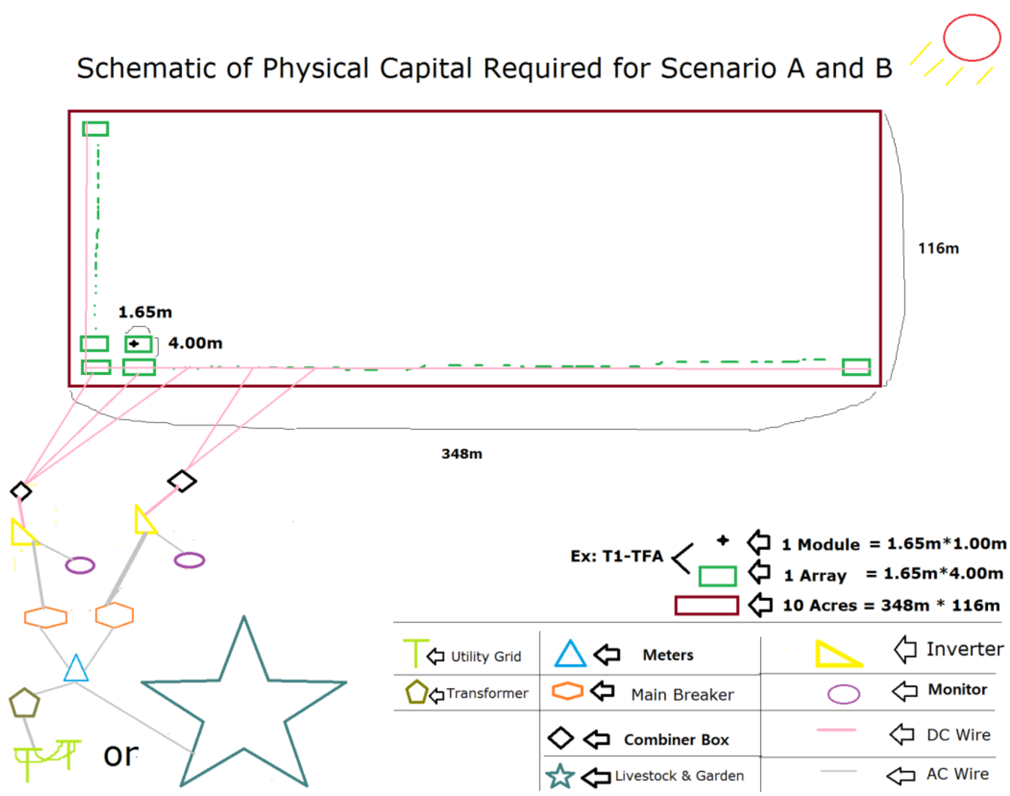


Source: Arc GIS

Figure 5.1 Capacity Potential for Installing Solar Panel at Site A

For easier view, we have drawn the system to get a rough estimate based on the area available for the PV system. Figure 5.2 describes how the solar PV system will be built in site A where no battery backup is necessary. In a given 10 acres, depending on the size of the module and array (acknowledging the space between the arrays), we can fit multiple modules and arrays. Once all the arrays are connected with the DC wire, we connect all the DC lines with the combiner boxes in order to connect with the inverter and monitor.

Once the electricity is converted to AC power via the inverter, we connect it to the main breaker and meters via AC wires. From this point on, the difference is that while scenario A requires a transformer to connect to the grid, scenario B does not require a transformer and is connected straight to the UGA livestock and garden.



Source: Lim, 2015

Figure 5.2 Schematic of the System's Physical Capital Requirements for Scenario A and B

5.2. Net Present Value

Net Present Value (NPV) is often used in capital budgeting to analyze the profitability of an investment or project; it is the difference between the present value of cash inflows and the present value of cash outflows. The present value of cash flows is computed by discounting them at the appropriate discount rate (Weitzman, 1998).

The discount rate is the rate at which present and future cash flows are traded off. It incorporates preference for current consumption, expected inflation, uncertainty in future cash flows, and reduced liquidity via investing or loaning out cash (Damodaran, 1996). The discount rate also represents the decision maker's patience – the lower the discount rate the more patient one is and vice-versa.

As a general rule of thumb, a higher discount rate will lead to a lower value for cash flows in the future. It is also an opportunity cost, since it captures the returns that an individual would have on the next best opportunity. In a discounted cash flow analysis, the sum of all net future cash flows benefits_t minus costs_t through the final period (T) is discounted back to the present using a discount rate (r). In the analysis that follows the discount rate is fixed at 4%. There is no particular set value; however, this is the lowest possible discount rate at which projects are being financed in a solar market. The final period, T, is set to the expected life of the panel, 30 years. Figure 5.3 shows the formula for calculating NPV of a solar photo-voltaic system:

$$\text{Net Present Value} = \sum_{t=1}^{T} \frac{(\text{Benefits}_t - \text{Costs}_t)}{(1+r)^{(t-1)}}$$

Figure 5.3 Equation for Net Present Value

5.3 Present Value of Benefits

In order to calculate the NPV of the project, we first estimate the PVB. Figure 5.4 shows the formula for calculating PV of benefits for a solar PV system. The PVB consists of two parameters - the life span of panels (T=30years) and the discount rate (r=4%) - and the benefits in each time period (B_t) which are a function of the amount of the expected amount of electricity generated each year by the system (EG_t), and the yearly price of electricity (PE_t). The detail explanation for EG_t is provided in the rest of section 5.3.

$$\text{Present Value of Benefits} = \sum_{t=1}^{30} \frac{EG_t * PE_t}{(1+r)^{(t-1)}}$$

Figure 5.4 Equation for Present Value of Benefits

5.3.1 DC System Size (kW/Site) Before the Inverter

Solar cells are typically named after the semiconducting raw material of which they are made. The first generation cell, also called conventional or wafer-based cells, are made of crystalline silicon. The second generation cells are thin film solar cells that are made of either amorphous silicon, CdTe, or CIGS cells. For this paper, we decided to use three types of models (panels), (1) mono-crystalline (c-Si), (2) poly-crystalline (poly-Si), and (3) thin-film (CdTe).

As shown in figure 5.5, each of the three modules are mounted on top of the different types of array to calculate the DC system size before the inverter ($DCSSBI_{i,j}$, in terms of kW/site). $DCSSBI_{i,j}$ is the direct current power rating of the photovoltaic array in kilowatts at standard test conditions (PVWatts, 2015). The DC system size before the inverter consists of module capacity (MC_i, in terms of kW), number of available modules per array ($NAMA_{i,j}$), number of available arrays with space per site ($NAASS_{i,j}$), and array efficiency (AE_j). And among the three types of arrays used, we must first compare and contrast among the different types of arrays to decide which is the most efficient array used among the three.

$$\mathrm{DCSSBI}_{\mathrm{i,j}}(\mathrm{kW/Site}) = \mathrm{MC}_{\mathrm{i}} * \mathrm{NAMA}_{\mathrm{i,j}} * \mathrm{NAASS}_{\mathrm{i,j}} * \mathrm{AE}_{\mathrm{j}}$$

Figure 5.5 Equation for DCSSBI

Moreover, the three module types (i) and three array types (j) are evaluated in this study. The three tracking arrays evaluated in this study vary in surface area and, therefore, vary in the number of modules a tracking array can hold. It also follows that the number of tracking arrays that can be assembled into a system on the site varies, based on the surface area of the array and the movement of the tracking device.

5.3.1.1 Module (Panel) Types

In this section, we searched for companies that produce different types of modules. And when considering three criteria such as durability (in years), price, and amount of kW produced per panel, we chose Ben Q, Hanwha, and First Solar because they are not only the top solar module manufacturers, but also has high efficiency, in terms of product, with reasonable price. As shown in table 5.1, it shows the technical specification of different solar modules (panels). The Direct Current (DC) system size is the DC power rating of the photovoltaic array in kilowatts (kW) at standard test conditions (STC). To calculate the Module Generating Capacity (DC kW), it is equal to the Module Size (m^2) × Efficiency (%) × 1kW/ m^2; Watts already include the module efficiency. However, this fixed-tilt array area is the total module area, and does not include space between the modules.

Table 5.1

Technical Specification of Different Solar Modules (Panels)

Product Name	T1	T2	T3
Company	Ben Q	Hanwha	FirstSolar
PV Cell Type	Mono-crystalline	Poly-crystalline	Thin-film (CdTe)
Model	PM250M01-260W	HSL60P6-PA-4-245TB	FS-390
# of Available Cells per Module	60	60	154
Price	$269	$230	$150
Efficiency	15.90%	14.8%	12.5%
Watts (STC)[a]	260W (0.26kW)	245W (0.245kW)	90W(0.090kW)
Initial Cost	$1.04/Wdc	$0.94/Wdc	$1.67/Wdc
Module (Panel) Size	1.65m(L)×1.00m(W) = 1.65m²	1.65m(L)×1.00m(W) = 1.65m²	1.20m(L)×0.60m(W) = 0.72m²

Source for T1: Ecodirect, 2014
Source for T2: Hanwhasolarone, 2014
Source for T3: First solar, 2014
a: Average watts generated under Standard Test (STC) Conditions using a fixed mounting

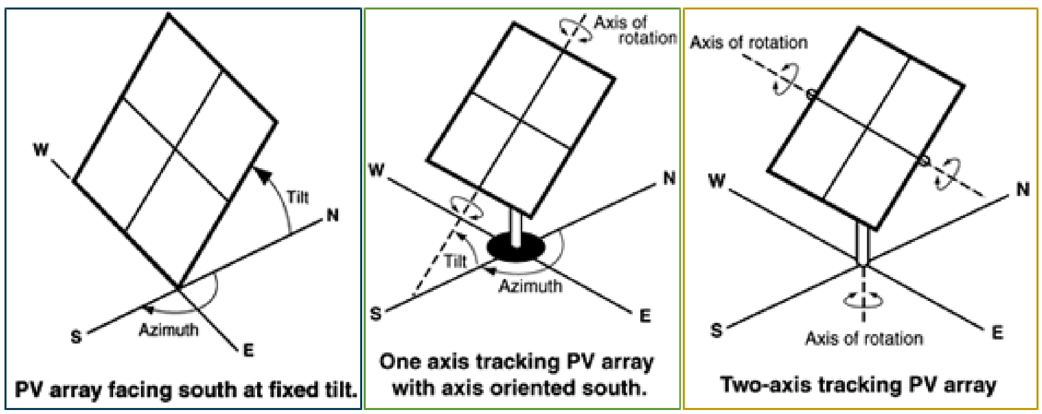
5.3.1.2 Array (Fixed, and Tracking) Types

Once we have found out the different types of panels to use, we would need to find the most efficient array, in terms of high efficiency and low costs. When comparing identical mounting system (either fixed or tracking), the tracking-arrays will annually outperform the former in terms of energy generation. As described in table 5.2 and figure 5.6, the annual improvement between the two in the U.S can range from 0 to 40 percent depending on the location and solar resource. There are four different types of mounting system that brings different amount of efficiency and they are either fixed, single-axis, two-axis. Commonly, except for the fixed, they all use motors to adjust the array's zenith, changing its angles to capture as much sun's rays as possible all year long (PVWatts NREL, 2014).

In a more detail sense, in table 5.2, the EmperySolar Company describes that their tilted (Single-Axis) tracking array (TSTA) improves the efficiency by average of 30% (between 25~35%) which would be equivalent to solar panels with the average of 30% higher efficiency rating. Also, the BIG SUN Energy Technology Company produces a universal (Two-Axis) tracking array (UDTA) where the panels become average of 40% (between 35~45%) more efficient. These two trackers create more efficiency because these devices change their orientation throughout the day to follow the sun's path to maximize energy capture.

By virtue of having moving machinery, the tracking arrays always come at an added cost relative to fixed-tilt arrays. The main drawbacks are as follow: (1) Depending on the type of the array used, the motor in the device consumes on average about 10% of the energy produced annually or simply between 10kWh and 15kWh per year (Easy Solar Poland, 2014; Big Sun Energy, 2015). (2) As shown in table 5.18, the operations and maintenance costs (O&M) gets higher in the order of fixed, single, and double. Also compared to mono and poly, thin-film was $5 higher as well (Electric Power Research Institute, 2010). (3) Due to the size of the array, installing the tracking-arrays increase land use and land costs for the developer (PVWatts NREL, 2014).

As a whole, it is more cost-effective to install a fixed array for residential. However, for commercial PV installations with an economy of scale that the residential PV doesn't have, it is better to use either single-axis or double-axis tracking array (Kerr, 2013).



Source: Energy Information Administration, 2012

Figure 5.6 Fixed, Tilted, and Double Array Types

Table 5.2

Relative Average Generating Potential Across Array Systems

Array (Mounting) System	Tilted Fixed Array (TFA)	Tilted (Single-Axis) Tracking Array (TSTA)	Universal (Two-Axis) Tracking Array (UDTA)
Company	DPW Solar Inc.	EmperySolar	BIG SUN Energy Technology Inc.
Array Type	Standard Roof/Ground Mounts for 3 Type I	Tilt Single-Axis Tracking (EPR-TSA)	TS-T6024AG (iPV)
Original Array Size (Without Pole and space) **New Array Size** (With Pole and Space)	1.65m(L), 4.00m(W), 1.93m(H), 3.50m(B) 3.15m(L), 4.00m(W), 2.23m(H), 6.54m(B)	2.97m(L), 9.90m (W), 4.78m(H), 8.67m(B) 4.47m(L), 9.90m(W), 5.08m(H), 16.20m(B)	6.60m(L), 6.20m(W), 3.00m(H), 5.43m(B) 8.10m(L), 6.20m(W), 3.30m(H), 10.14m(B)
Array Tilt Angle (°) (Oriented from South to North) **Tracking Range Angle(°)** (East to West) **Tracking Range Angle(°)** (South to North)	28.90° Fixed Fixed	28.90° ± 45° Fixed	28.90° ± 45° ± 45°
Efficiency Factor	100	130	140
Array Power Consumption	none	10 kWh/year	14kWh/year
Costs of Array	$431 per TFA	$1,404 per TSTA	$3,120 per UDTA

Source for TFA: DPW, 2015; N. Arizona Wind & Sun, 2015

Source for TSTA: EmperySolar, 2013; Alibaba, 2013

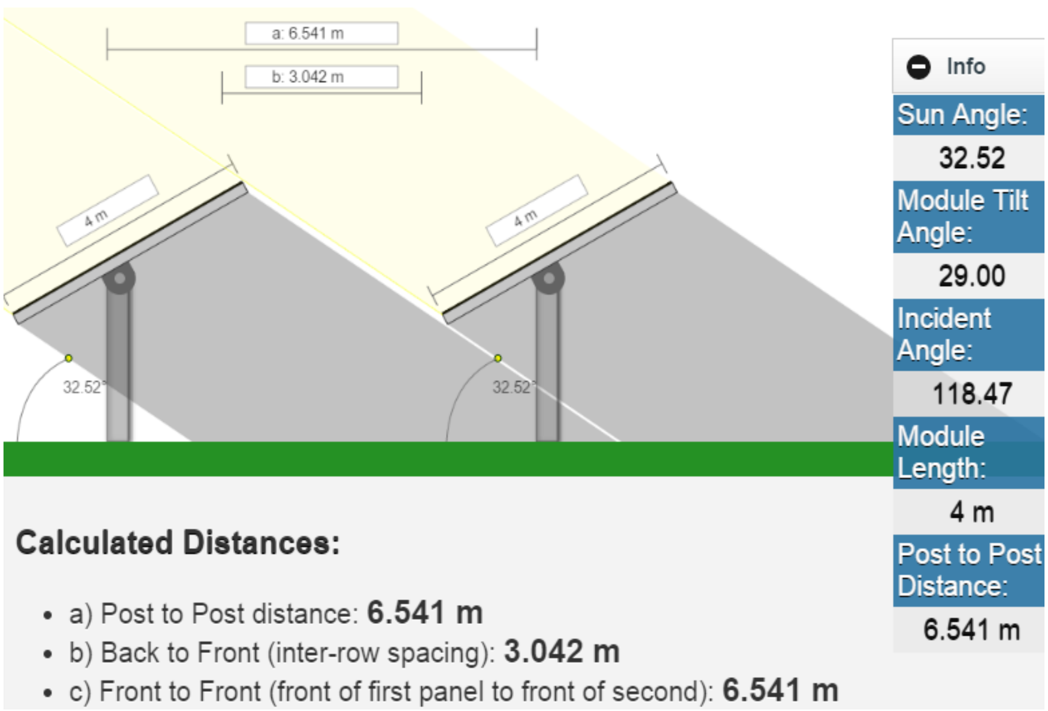
Source for UDTA: BigSunEnergy, 2015, EnergyTrend, 2014

As shown in table 5.2, once we have chosen three types of arrays from three different companies (DPW Solar, Empery Solar, and Big Sun Energy) we can now estimate to see which is the most efficient with least costs array to use. As similarly described in previous chapter 5.3.1.1, we have chosen three different companies for the arrays because they are not only the top solar array manufacturers, but also has high efficiency, in terms of product, with reasonable price.

First of all, when designing a solar array shading is the enemy. Most locations for solar projects tend to get around five to six net sun-hours per day, so anything that obstructs that sunlight needs to be avoided at all costs. Shading just one corner of a module can cut production in half, so avoiding shade on the array is important (Reme). Therefore, rows and columns of solar panels need to be optimally spaced to best use the available space.

The procedure for calculating shadow spacing starts with the altitude angle of the installed array. For example, the city of Athens (Georgia) has the latitude of 33.95°N, and longitude of 83.33°W (National Weather Service). And if the latitude is between 25°N and 50°N, then the best tilt angles to use is to use the latitude, times 0.76, plus 3.1 degrees. After careful calculation we get the angle of 28.9°N, which is the optimum angle for the tilt array.

Secondly, if we input the width of the array, select the location as site A, and the tilted angle at 28.9°, in the solar shading calculator provided by RBI Solar Company. This calculator program will help to provide the width of the array (with space) which is from the front of first panel to front of second. And for the length wise we add 1.5 meters for each array. Figure 5.7 shows an example for monocrystalline tilted fixed array.



Source: RBI Solar Company

Figure 5.7 Estimated Monocrystalline Tilted Fixed Array Space

Lastly, as table 5.1 and 5.2 describes the size and angle for the different types of modules, arrays, and site, we can find out the total number of modules available per array and total number of arrays available per site as shown in appendix A. In addition, when plugging the final numbers listed in appendix A to solve the equation in figure 5.5, we finally get table 5.3 which is equal to the DC system size (kW/site) before installing the inverter.

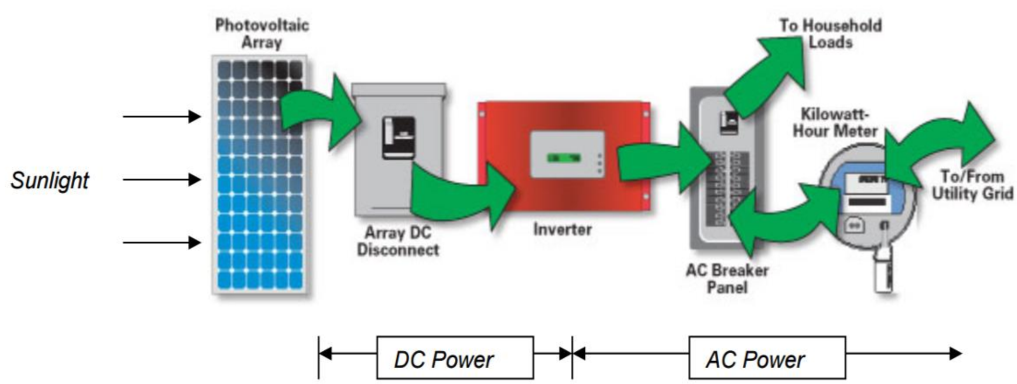
Table 5.3

DC System Size Before the Inverter (kW per site)

	Module Capacity (kW)	Total # of Modules Available per Array	Total # of Arrays Available per Site	Array Efficiency	DCBI (kW per site)
T1-TFA	0.260	4	1,870	1.00	1,945
T2-TFA	0.245	4	1,870	1.00	1,833
T3-TFA	0.090	6	1,870	1.00	1,010
T1-TSTA	0.260	18	539	1.30	3,279
T2-TSTA	0.245	18	539	1.30	3,090
T3-TSTA	0.090	40	539	1.30	2,523
T1-UDTA	0.260	24	473	1.40	4,132
T2-UDTA	0.245	24	473	1.40	3,894
T3-UDTA	0.090	50	473	1.40	2,980

5.3.2 DC System Size (kW/Site) After the Inverter

PV arrays produce direct current (DC) from sunlight; and this DC current is converted to alternating (AC) current with an inverter. This AC Power is then used for operating all kinds of devices such as electric lights, kitchen appliances, and air cone, or exporting it to the grid. As the inverters are not 100% efficient, and energy is lost during this conversion process. A simplified schematic for a residential PV installation is shown in figure 5.8.



Source: Homepower (2007)

Figure 5.8 Illustration of Grid-connected PV System

In figure 5.9, DC system size after the inverter ($DCSSAI_{i,j}$, in terms of kW/site) is a function of DC system size before the inverter ($DCSSBI_{i,j}$, in terms of kW/site) with the inverter conversion ($IC_{i,j}$). In order to find out the equation for $DCSSAI_{i,j}$, we found a German SMA solar energy company that sells different inverters depending on the amount of size required that needs to be converted. As shown in table 5.4, to avoid the amount of kW loss from the arrays, we chose three inverters (A, B, and C) in the order of big, medium and small.

$$\mathrm{DCSSAI_{i,j}(kW/Site)} = \mathrm{DCSSBI_{i,j}} * \mathrm{IC_{i,j}}$$

Figure 5.9 Equation for DCSSAI

Table 5.4

Different Types of Inverter

Inverter Type (Model)	**Price**	**Input (DC) Maximum Power**	**Output (AC) Nominal Power**
Inverter A (SUNNY CENTRAL 1,000CP XT)	$164,201	1,066kW	978kVA (929kW)
Inverter B (SUNNY CENTRAL 500CP XT)	$107,841	560kW	525kVA (499kW)
Inverter C (SUNNY Tripower 24,000TL-US)	$4,582	25kW	23kVA (22kW)

Source: SMA

Since we have three different inverters, we first searched for an inverter that is capable of holding the maximum input power for all types of arrays and then converting it into AC. For example, one giant inverter A can hold input (DC) maximum power of 1,066kW from table 5.4. This means that from the $DCBI_{i,j}$ of 1,945kW (T1-TFA) from table 5.3, we first divide it by 1,066kW/inverter to find out that it can actually hold 1.82 inverters. However, as T1-TFA has a leftover of 0.82 (equivalent to 879kW) which is not fully converted by the giant inverter A, we again use the medium size inverter B to divide 879kW by 560kW/inverter to find out the number of inverters required.

Finally, since T1-TFA still has an excess of 319kW which is not converted by the giant inverter B, we take the small size inverter C to divide 319kW by 24.5kW to get 13 inverters. Table 5.5 shows that when adding inverter A, inverter B, and inverter C, T1- TFA creates a total of 1,683kW per site. When comparing this number with 1,945kW per site from the previous mentioned table 5.3, we can notice that about 15.54% of the electricity has been lost during the conversion via inverter.

Table 5.5

DC System Size After the Inverter (kW per site)

	Maximum Number of Inverter A	**Actual Number of Inverter A**	**Leftovers from Inverter A**	**Inverter A (kVA) AC Output Power**	**Inverter A (kW) DC Output Power**
T1-TFA	1.82	1	878.800	978	929
T2-TFA	1.72	1	766.600	978	929
T3-TFA	0.95	0	1,009.800	978	929
T1-TSTA	3.08	3	81.276	978	929
T2-TSTA	2.90	2	958.087	978	929
T3-TSTA	2.37	2	390.520	978	929
T1-UDTA	3.88	3	934.128	978	929
T2-UDTA	3.65	3	695.736	978	929
T3-UDTA	2.80	2	847.900	978	929
	Maximum Number of Inverter B	**Actual Number of Inverter B**	**Leftovers from Inverter B**	**Inverter B (kVA) AC Output Power**	**Inverter B (kW) DC Output Power**
T1-TFA	1.569	1	318.800	525	499
T2-TFA	1.369	1	206.600	525	499
T3-TFA	1.803	1	449.800	525	499
T1-TSTA	0.145	0	81.276	525	499
T2-TSTA	1.711	1	398.087	525	499
T3-TSTA	0.697	0	390.520	525	499
T1-UDTA	1.668	1	374.128	525	499
T2-UDTA	1.242	1	135.736	525	499
T3-UDTA	1.514	1	287.900	525	499
	Maximum Number	**Actual Number of**	**Leftovers from**	**Inverter C (kVA)**	**Inverter C (kW)**

	of Inverter C	Inverter C	Inverter C	AC Output Power	DC Output Power
T1-TFA	13.01	13	0.30	23	22
T2-TFA	8.43	8	10.60	23	22
T3-TFA	18.36	18	8.80	23	22
T1-TSTA	3.32	3	7.78	23	22
T2-TSTA	16.25	16	6.09	23	22
T3-TSTA	15.94	15	23.02	23	22
T1-UDTA	15.27	15	6.63	23	22
T2-UDTA	5.54	5	13.24	23	22
T3-UDTA	11.75	11	18.40	23	22
	Inverter Efficiency	**DCAI (kW per site)**			
T1-TFA	0.958	1,683			
T2-TFA	0.958	1,577			
T3-TFA	0.958	875			
T1-TSTA	0.958	2,808			
T2-TSTA	0.958	2,662			
T3-TSTA	0.958	2,149			
T1-UDTA	0.958	3,555			
T2-UDTA	0.958	3,342			
T3-UDTA	0.958	2,555			
Note: To Convert AC to DC we calculate via X (kVA) * 0.95 (kW/kVA) = 0.95X (kW)					

5.3.3 Expected Amount of Electricity Generated per Year (kWh/Site/Year)

In order to calculate the DC system capacity (kWh/Site/Year), we have used solar radiation $(\mathrm{kWh/m^2/year})$, derate factor (system losses), efficiency for different solar modules, 365 days per year, array power consumption and step-up transformer (if needed) to solve the equation in figure 5.10. The expected amount of electricity generated per year (EG_t, in terms of kWh/Site/Year) is itself a function of DC system size after the inverter ($DCSSAI_{i,j}$, in terms of kW/site), solar radiation ($SR_{i,j}$, in terms of $\mathrm{kWh/m^2/year}$), derate factor ($DR_{i,j}$), efficiency for different solar modules ($EDSM_{i,j}$), $\frac{365\ \mathrm{days}}{1\ \mathrm{year}}$, array power consumption ($APC_{i,j}$), and step-up transformer ($SUT_{i,j}$), if necessary. More details about each of the components are explained below.

$$\mathrm{EG_t} = [(\mathrm{DCSSAI_{i,j}} * \mathrm{SR_{i,j}} * \mathrm{DR_{i,j}} * \mathrm{EDSM_{i,j}} * 365\mathrm{days}) - \mathrm{APC_{i,j}}] - \mathrm{SUT_{i,j}}$$

Figure 5.10 Equation for EG

5.3.3.1 Solar Radiation Information

Solar Radiation (SR) is the amount of solar radiation energy received on a given surface during a given time (PVWatts NREL, 2014). PV modules use the light spectrum to generate electricity via the semiconductor material. Four estimates of average daily solar radiation per month for the study area were found in the literature (UGA Department of Geography, Synergy Environment Engineers, NREL PVWatts1, and NREL PVWatts2). Each estimate used a weighted average method that assigns a different weight to the global horizontal irradiance, direct normal irradiance, temperature, wind speed, and other meteorological data values to generate estimated of solar radiation (PVWatts NREL, 2014).

Rather than picking just one estimate among the four, the average monthly solar radiation of the four estimates was used to calculate the average daily SR. Ideally it would be best to use a radiation for the next 30 years, incorporating climate change projections. However, there is no future radiation available at this point. Each month’s average SR was multiplied by the number of days in the month, and summed across all months. The total was then divided by 365.26 days to get the final average daily SR (kWh/m^2/day). For more details, refer to table 5.6.

Table 5.6

Solar Radiation (Athens, GA)

Month	**SR1**	**SR2**	**SR3**	**SR4**	**Avg. SR by month**
January	3.99	2.67	3.32	3.69	3.42
February	4.44	3.26	4.39	4.77	4.22
March	5.28	4.36	5.22	5.4	5.07
April	5.99	5.31	5.95	5.82	5.77
May	5.70	6.12	6.06	5.70	5.90
June	5.73	6.04	6.17	5.69	5.91
July	5.70	5.93	3.08	5.69	5.10
August	5.61	5.51	5.8	5.61	5.63
September	5.08	4.57	5.27	5.31	5.06
October	5.51	3.79	5.15	5.51	4.99
November	3.94	2.85	3.89	4.34	3.76
December	3.80	2.39	3.34	3.80	3.33
Average daily solar radiation					4.85 kWh/m^2/day

Source for SR1: UGA Department of Geography, 2014
Source for SR2: Synergy Environment Engineers, 2014
Source for SR3: NREL PVWatts1, 2014
Source for SR4: NREL PVWatts2, 2014

5.3.3.2 Derate Factor (System Losses)

Inverters are just one source of power loss when converting from DC to AC power. Therefore the inverter's DC-to-AC conversion efficiency is a separable input under the section 5.3.2. An example of other factors that contribute to power losses in PV systems is shown in appendix B. The table taken from NREL data used in the PVWATTS tool shows that there are additional 11 factors that contribute to power losses.

There are many environmental factors that affect how much power a system can produce. These include transformer and transmission line losses, resistive factors, environmental conditions, and inverter losses. These factors are combined for an estimated efficiency/derate value used in total system generating size (PVWatts NREL, 2014). For the default values in the PVWATTS tool, the forecast of overall derate factor is 0.77. In addition, as the array efficiency is already included in the previous array section, we factor it out in the derate factor.

5.3.3.3 Overall Solar Module Efficiency

Solar panel manufacturers put sufficient amount of effort into making solar panels robust so that it can withstand heat/cold cycles and heavy weather. In other words, this will help to reduce the expenses for the operations and maintenance costs. However, solar panels are not perfect and they tend to inevitably age. Table 5.7 illustrates the overall efficiency for different solar modules where the solar system will wear down every year due to its ordinary use and exposure.

The rated power output of solar system typically degrades at about 0.37% per year. Polycrystalline silicon degrades the fastest among the thin-film solar panels (CdTe) and monocrystalline silicon. The Pre and Post refer to installations prior to and post 2000. In addition, if we are to apply table 5.7 to our solar system, table 5.8 shows that monocrystalline still has higher efficiency with the average of 96.70% during the 30 year period.

Table 5.7

Overall Efficiency for Different Solar Modules 1 (30 years)

Technology	**Output loss in percent / year**	
	Pre	**Post**
Amorphous silicon (a-Si)	1.30	0.95
Cadmium telluride (CdTe)	0.69	0.30
Copper indium gallium selenide (CIGS)	3.50	0.02
Monocrystalline silicon (mono-Si)	0.90	0.23
Polycrystalline silicon (poly-Si)	0.60	0.59

Source: Jordan and Sarah, 2012

Table 5.8

Overall Efficiency for Different Solar Modules 2 (30 years)

	T1-All	T2-All	T3-All
Year 1	1.000	1.000	1.000
Year 2	0.998	0.994	0.997
Year 3	0.995	0.988	0.994
Year 4	0.993	0.982	0.991
Year 5	0.991	0.976	0.988
Year 6	0.989	0.971	0.985
Year 7	0.986	0.965	0.982
Year 8	0.984	0.959	0.979
Year 9	0.982	0.953	0.976
Year 10	0.979	0.947	0.973
Year 11	0.977	0.941	0.970
Year 12	0.975	0.935	0.967
Year 13	0.972	0.929	0.964
Year 14	0.970	0.923	0.961
Year 15	0.968	0.917	0.958
Year 16	0.966	0.912	0.955
Year 17	0.963	0.906	0.952
Year 18	0.961	0.900	0.949
Year 19	0.959	0.894	0.943
Year 20	0.956	03888	0.943
Year 21	0.954	0.882	0.940
Year 22	0.952	0.876	0.937
Year 23	0.949	0.870	0.934
Year 24	0.947	0.864	0.931
Year 25	0.945	0.858	0.928
Year 26	0.943	0.853	0.925
Year 27	0.940	0.847	0.922
Year 28	0.938	0.841	0.919
Year 29	0.936	0.835	0.916
Year 30	0.933	0.829	0.913
Average	0.967	0.914	0.957

Source: Jordan and Sarah, 2012

5.3.3.4 Array Power Consumption

As described in table 5.2, TFA uses zero power, TSTA with 10 kWh per year, and UUDTA consumes 14kWh per year. And we plugged in the array power consumption in the equation of figure 5.10 to find out the expected amount of electricity generated (kWh/Site/Year). Table 5.9 shows the expected amount of electricity generated (kWh per Site per Year) which requires no transformer. The electricity created from the PV system will be directly used for UGA.

Table 5.9

Expected amount of electricity generated (kWh per Site per Year) – FOR UGA

	DC System Size After the Inverter	**Solar Radiation** ($kWh/m^2/year$)	**Derate Factor**	**Efficiency for Different Solar Modules**	**Days/Year**
T1-TFA	1,683	4.85	0.854	1	365
T2-TFA	1,577	4.85	0.854	1	365
T3-TFA	875	4.85	0.854	1	365
T1-TSTA	2,808	4.85	0.854	1	365
T2-TSTA	2,662	4.85	0.854	1	365
T3-TSTA	2,149	4.85	0.854	1	365
T1-UDTA	3,555	4.85	0.854	1	365
T2-UDTA	3,342	4.85	0.854	1	365
T3-UDTA	2,555	4.85	0.854	1	365
	Array Power Consumption (kWh)	**Step-up Transformer (kWh)**	**Expected amount of electricity generated (kWh per Site per Day)**	**Expected amount of electricity generated (kWh per Site per Year)**	**Expected amount of electricity generated (mWh per Site per Year)**
T1-TFA	Not Applicable	Not Applicable	6,969	2,543,720	2,544
T2-TFA	Not Applicable	Not Applicable	6,528	2,382,578	2,383
T3-TFA	Not Applicable	Not Applicable	3,623	1,322,536	1,323
T1-TSTA	10	Not Applicable	11,617	4,240,013	4,240
T2-TSTA	10	Not Applicable	11,011	4,019,081	4,019

T3-TSTA	10	Not Applicable	8,889	3,244,427	3,244
T1-UDTA	14	Not Applicable	14,706	5,367,718	5,368
T2-UDTA	14	Not Applicable	13,823	5,045,435	5,045
T3-UDTA	14	Not Applicable	10,566	3,856,479	3,857

5.3.3.5 Step-Up Transformer

Electricity has to be transmitted from large power plants to the consumers via extensive networks. The transmission over long distances creates power losses. The major part of the energy losses comes from joule effect in transformers and power lines. The energy is lost as heat in the conductors. Considering the main parts of a typical Transmission & Distribution network, the average values of power losses at the different steps are as follow: (a) 1-2% for step-up transformer from generator to transmission line, (b) 2-4% for transmission line, (3) 1-2% for step-down transformer from transmission line to distribution network, and (4) 4-6% for distribution network transformers and cables (Schonek, 2013). The overall losses between the power plant and consumers is then in the range between 8 and 15%.

However, among the different power losses at different stages, we will only have to focus on step-up transformer and transmission line loss from PV system to the utility grid. And the losses are between the range of one to six percent, and we assumed the average of three percent for our analysis. In order to calculate the transmission and transformer loss, we used appendix C to calculate the $SUT_{i,j}$ loss. Table 5.10 shows the expected amount of electricity generated (kWh per Site per Year) which requires transformer. The electricity created from the PV system will be directly sold to Georgia Power.

Table 5.10

Expected amount of electricity generated (kWh per Site per Year) – TO SELL

	DC System Size After the Inverter	**Solar Radiation** $(kWh/m^2/year)$	**Derate Factor**	**Efficiency for Different Solar Modules**	**Days/Year**
T1-TFA	1,683	4.85	0.854	1	365
T2-TFA	1,577	4.85	0.854	1	365
T3-TFA	875	4.85	0.854	1	365
T1-TSTA	2,808	4.85	0.854	1	365
T2-TSTA	2,662	4.85	0.854	1	365
T3-TSTA	2,149	4.85	0.854	1	365
T1-UDTA	3,555	4.85	0.854	1	365
T2-UDTA	3,342	4.85	0.854	1	365
T3-UDTA	2,555	4.85	0.854	1	365
	Array Power Consumption (kWh)	**Step-up Transformer (kWh)**	**Expected amount of electricity generated (kWh per Site per Day)**	**Expected amount of electricity generated (kWh per Site per Year)**	**Expected amount of electricity generated (mWh per Site per Year)**
T1-TFA	Not Applicable	209	6,760	2,467.408	2,467
T2-TFA	Not Applicable	196	6,332	2,311,101	2,311
T3-TFA	Not Applicable	109	3,515	1,282,860	1,283
T1-TSTA	10	349	11,268	4,112,703	4,113
T2-TSTA	10	331	10,681	3,898,399	3,898
T3-TSTA	10	267	8,622	3,146,985	3,147
T1-UDTA	14	442	5,206,533	5,206,533	5,207

T2-UDTA	14	415	4,893,919	4,893,919	4,894
T3-UDTA	14	317	3,740,631	3,740,631	3,741

5.4 Present Value of Costs

Once the calculation for PV of benefits is complete, we turn to calculating the PV of costs in order to reach the final goal for obtaining the NPV. Figure 5.11 shows the formula for calculating PV of costs for a solar PV system. Present Value (PV) of costs consists of three variables: T equal to the life span of panels (30years), r equal to the discount rate (4%), the costs in each time period (C_t) which are a function of the purchasing costs of system ($PCoS_t$), purchasing costs of balance of system (PCoBoS), total PV system soft costs ($TPVSSC_t$), total operations and maintenance costs ($TOMC_t$), and available incentives (AI_t). The detail explanations for each component are provided in the rest of section 5.4.

$$\text{Present Value of Costs} = \sum_{t=1}^{30} \frac{C_t[(PCoS_t + PCoBoS + TPVSSC_t + TOMC_t) - AI_t]}{(1+r)^{(t-1)}}$$

Figure 5.11 Equation for Present Value of Costs

5.4.1 Purchasing Costs of System

First of all, figure 5.12 shows the purchasing costs of system ($PCoS_t$). $PCoS_t$ is itself a function of (1) module price (MP_i), (2) number of modules per array ($NPA_{i,j}$), (3) array price (AP_j), and (4) number of arrays per site ($NAS_{i,j}$). Since we have already found out the amount and price for the modules per array and arrays per site required in table 5.3, we use this information to calculate the purchasing costs for the systems in table 5.11.

Moreover, the three module types (i) and three array types (j) are evaluated in this study. The three tracking arrays evaluated in this study vary in surface area and, therefore, vary in the number of modules a tracking array can hold. It also follows that the number of tracking arrays that can be assembled into a system on the site varies, based on the surface area of the array and the movement of the tracking device.

$$\mathrm{PCoS_t} = \mathrm{MP}_i * \mathrm{NPA}_{i,j} * \mathrm{AP}_j * \mathrm{NAS}_{i,j}$$

Figure 5.12 Equation for PCoS

Table 5.11

Purchasing Costs of System

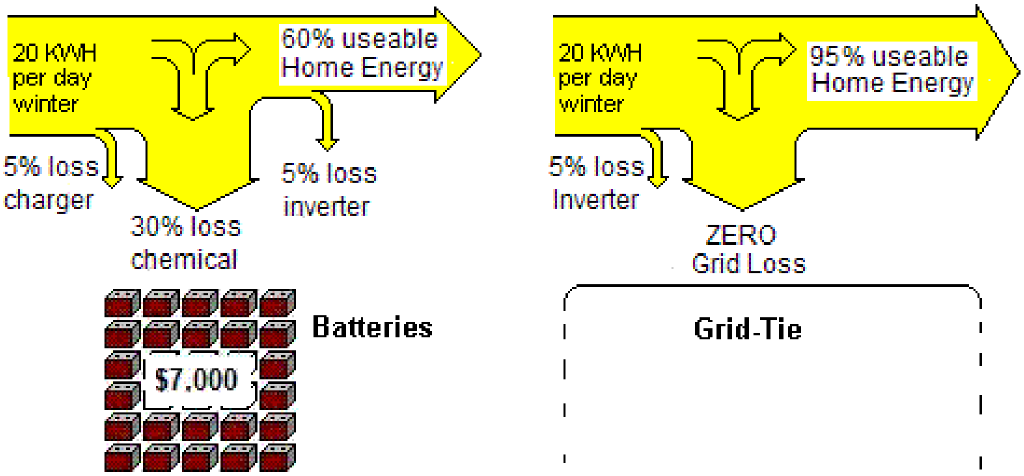
	Module Price ($/unit)	**Total # of Modules Available per Array**	**Array Price ($/unit)**	**Total # of Arrays Available per Array**	**Total Purchasing Costs of System ($/unit)**
T1-TFA	$269	4	$431	1,870	$2,818,090
T2-TFA	$230	4	$431	1,870	$2,526,370
T3-TFA	$150	6	$431	1,870	$2,488,970
T1-TSTA	$269	18	$1,404	539	$3,366,594
T2-TSTA	$230	18	$1,404	539	$2,988,216
T3-TSTA	$150	40	$1,404	539	$3,990,756
T1-UDTA	$269	24	$3,120	473	$4,529,448
	$230	24	$3,120	473	$4,086,720

T2-UDTA T3-UDTA	$150	50	$3,120	473	$5,023,260
Note: System= Modules and Arrays					

5.4.2 Purchasing Costs of Balance of System

Balance of system consists of transformer, monitor, meters, combiner box, wiring, DC main breaker, AC main breaker, battery and inverter. For our case we do not include the inverter because off-grid (with battery storage) is mostly used when there is no grid access. In other words, it is best for a remote area where the power lines don't reach, or when it is too expensive to extend power lines to the desired location.

Moreover, the battery not only wastes 30% or more of solar power in charging/discharging losses, throws away all excess solar power once batteries are fully charged on an epic summer day, and requires high costs of O&M and replacement fee, but also causes environmental harm due to lead, cadmium, and mercury (Bob, 2011). Therefore, this paper will not consider off-grid system. For more details in regard to battery waste, refer to figure 5.13.



Source: APRC, 2011

Figure 5.13 Off-Grid vs. Grid-Tie (Energy Loss)

Figure 5.10 shows the purchasing costs of balance of system (PCoBoS) is a function of (1) derate factor costs (SLC), and (2) inverter costs (IC). In appendix C, it describes both technical and price specification for the balance of system. Also, we have already found out the amount and price for the inverters in table 5.5. Therefore, by using this information, we calculate the number of equipment required for each of the components in order to calculate the total costs for the balance of system via figure 5.14. Table 5.12, table 5.13, table 5.14, and table 5.15 shows the difference between not needing the step-up transformer and requiring it. And it is easy to notice that the latter table has higher costs compared to the former table because of requiring the extra step of installing the step-up transformer.

$$\mathrm{PCoBoS} = \mathrm{SLC} + \mathrm{IC}$$

Figure 5.14 Equation for PCoBoS

Table 5.12

Purchasing Costs of Balance of System ($) – FOR UGA & TO SELL

	Transformer Costs ($/unit)	**Monitor Costs ($/unit)**	**Meters Costs ($/unit)**	**Combiner Box Costs ($/unit)**	**Wiring Costs ($/unit)**
T1-TFA	$15,000	$509	$429	$319	$280
T2-TFA	$15,000	$509	$429	$319	$280
T3-TFA	$15,000	$509	$429	$319	$280
T1-TSTA	$15,000	$509	$429	$319	$280
T2-TSTA	$15,000	$509	$429	$319	$280
T3-TSTA	$15,000	$509	$429	$319	$280
T1-UDTA	$15,000	$509	$429	$319	$280
T2-UDTA	$15,000	$509	$429	$319	$280
T3-UDTA	$15,000	$509	$429	$319	$280
	AC Main Breaker Costs ($/unit)	**Battery Cost ($/unit)**	**Inverter A Costs ($/unit)**	**Inverter B Costs ($/unit)**	**Inverter C Costs ($/unit)**
T1-TFA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T2-TFA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T3-TFA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T1-TSTA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T2-TSTA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T3-TSTA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T1-UDTA	$1,012	Not Applicable	$164,201	$107,841	$4,582
T2-UDTA	$1,012	Not Applicable	$164,201	$107,841	$4,582

T3-UDTA	$1,012	Not Applicable	$164,201	$107,841	$4,582
Note: Step-up Transformer (38,000kWh for DC System), Monitors (1,000kW for after inverter), Meters (12.5kW for after inverter), Combiner Box (100kW for before inverter)					

Table 5.13

Number of Balance of System – FOR UGA

	# of Transformer (38,000 kWh)	**# of Monitors (1,000kW)**	**# of Meters (12.5kW)**	**# of Combiner Boxes (100kW)**	**# of Wirings (76.2m)**
T1-TFA	Not Applicable	2	135	19	66
T2-TFA	Not Applicable	2	127	18	66
T3-TFA	Not Applicable	1	71	10	66
T1-TSTA	Not Applicable	3	225	33	66
T2-TSTA	Not Applicable	3	213	31	66
T3-TSTA	Not Applicable	2	172	25	66
T1-UDTA	Not Applicable	4	285	41	66
T2-UDTA	Not Applicable	3	268	39	66
T3-UDTA	Not Applicable	3	205	30	66
	# of AC Main Breakers	**# of Battery**	**# of Inverter A**	**# of Inverter B**	**# of Inverter C**
T1-TFA	1	Not Applicable	1	1	13
T2-TFA	1	Not Applicable	1	1	8
T3-TFA	1	Not Applicable	0	1	18

T1-TSTA	1	Not Applicable	3	0	3
T2-TSTA	1	Not Applicable	2	1	16
T3-TSTA	1	Not Applicable	2	0	15
T1-UDTA	1	Not Applicable	3	1	15
T2-UDTA	1	Not Applicable	3	1	5
T3-UDTA	1	Not Applicable	2	1	11

Table 5.14

Number of Balance of System – TO SELL

	# of Transformer (38,000 kWh)	**# of Monitors (1,000kW)**	**# of Meters (12.5kW)**	**# of Combiner Boxes (100kW)**	**# of Wirings (76.2m)**
T1-TFA	1	2	135	19	66
T2-TFA	1	2	127	18	66
T3-TFA	1	1	71	10	66
T1-TSTA	1	3	225	33	66
T2-TSTA	1	3	213	31	66
T3-TSTA	1	2	172	25	66
T1-UDTA	1	4	285	41	66
T2-UDTA	1	3	268	39	66
T3-UDTA	1	3	205	30	66
	# of AC Main Breakers	**# of Battery**	**# of Inverter A**	**# of Inverter B**	**# of Inverter C**

T1-TFA	1	Not Applicable	1	1	13
T2-TFA	1	Not Applicable	1	1	8
T3-TFA	1	Not Applicable	0	1	18
T1-TSTA	1	Not Applicable	3	0	3
T2-TSTA	1	Not Applicable	2	1	16
T3-TSTA	1	Not Applicable	2	0	15
T1-UDTA	1	Not Applicable	3	1	15
T2-UDTA	1	Not Applicable	3	1	5
T3-UDTA	1	Not Applicable	2	1	11

Table 5.15

Total Purchasing Costs of Balance of System ($) – TO SELL & FOR UGA

	Total Purchasing Costs of BoS ($/unit) - TO SELL	**Total Purchasing Costs of BoS ($/unit) - FOR UGA**
T1-TFA	$431,076	$425,849
T2-TFA	$404,323	$398,872
T3-TFA	$258,933	$221,408
T1-TSTA	$649,260	$710,440
T2-TSTA	$646,638	$673,454
T3-TSTA	$514,554	$543,767
T1-UDTA	$840,926	$899,476
T2-UDTA	$786,945	$845,522
T3-UDTA	$619,891	$646,477

5.4.3 Total PV System Soft Costs

According to the US Energy Department's National Renewable Energy Laboratory, soft cost is defined as financing and other non-hardware costs (excluding the operations and maintenance). And the total PV system soft costs ($TPVSSC_t$) is a function of (1) customer acquisition costs ($CAC_{i,j}$), (2) installation labor costs ($ILC_{i,j}$), (3) permitting, inspection, and interconnection costs ($PIIC_{i,j}$), and (4) labor for 3rd party financing costs ($L3PFC_{i,j}$). The detail explanations for each component are provided in the rest of section 5.4.3.

$$\mathrm{TPVSSC_t = CAC_{i,j} + ILC_{i,j} + PIIC_{i,j} + L3PFC_{i,j}}$$

Figure 5.15 Equation for TPVSSC

As shown in figure 5.15, the benchmark 2010 soft cost includes areas of (1) customer acquisition; (2) permitting, inspection, and interconnection (which assumes the permitting fee); (3) installation labor; and (4) installer labor for arranging third-party financing. Including assumed permitting fees, in 2010 the average soft costs benchmarked in this analysis total \$1.50/W for residential systems (ranging from \$0.66/W to \$1.66/W).

First of all, customer-acquisition activities can add considerable time and cost to PV installations, perhaps especially in states with less-mature markets where perceived technology risk and unfamiliarity with PV might increase bid-failure rates. Expenses related to customer acquisition—such as lead generation, bid and pro-forma preparation, contract negotiation, and system design—increase sunk costs to the installer.

Secondly, the installation labor cost is simply where electrician labor comes in and helps to install the whole system size (PV, array, balance of system, etc.).

Third, regulatory requirements and permitting processes for U.S. PV installations are often burdensome and costly compared with those in leading PV nations such as Germany (Langen 2010). Permitting, Inspection, and Interconnection labor requirements includes the following elements: (1) Permit Preparation—determination of a jurisdiction's permitting requirements, travel time to site, drawing of system plans, structural calculations, zoning application, and delays; (2) Permit Package Submittal—travel time to and from the permitting office and wait time at the permitting office;

(3) Permitting Inspection—paperwork, travel time to and from the site, wait time for inspector, and physical inspection; (4) Interconnection Process—paperwork, travel time to and from the site, wait time for representative from utility, and physical interconnection; (5) Financial Incentive Application Process—determination of eligibility, paperwork, travel time to and from the site, wait time for inspector, and physical inspection.

Moreover, permitting and interconnection fees also significantly affect total permitting costs. Total fees in the United States range from a low of $0 per installation to an approximate high of $2,500 per installation (Vote Solar 2011, Goodrich et al. 2012). For the purposes of this report, we assume a permitting fee of $430 for a 5 kW residential system, or $0.09/W.

As with the residential survey results, the PII labor costs shown for commercial PV do not include the cost of permitting or interconnection fees, which may significantly surpass the direct PII labor costs. This report assumes a $25,000 commercial PV systems permit fee, which equates to an additional $0.35/W, in the median case, among survey respondents with average system sizes smaller than 250 kW (assuming a system size of X>72 kW) and $0.03/W among respondents with average system sizes larger than 250 kW (assuming a system size of X>750 kW).

Lastly, as the upfront capital requirements of PV installations can deter PV adoption, innovative third-party financing schemes that address these high upfront requirements, such as solar leases and power purchase agreements (PPAs) via financial analyst, are becoming more prevalent. For example, in 2010 approximately 33% of residential systems (by capacity) installed through the California Solar Initiative used- third-party financing arrangements (California Solar Statistics, 2012). And in 2011, this percentage grew to approximately 46%.

In table 5.16, the median 2010 benchmarked soft costs of commercial systems are \$0.99/W for systems smaller than 250 kW (ranging from \$0.51/W to \$1.45/W) and \$0.25/W for systems larger than 250 kW (ranging from \$0.17/W to \$0.78/W). And when we use information to solve figure 5.15, we get the calculation in table 5.17 which is the PV system soft costs for different types of arrays.

Table 5.16

Summary of Commercial PV system Soft Costs in year 2010

Soft Cost Category	Residential Systems		Small Commercial Systems (<250 kW)		Large Commercial Systems (> 205kW)	
	Cost ($/W)	Proportion of System Price	Cost ($/W)	Proportion of System Price	Cost ($/W)	Proportion of System Price
Customer Acquisition	0.67	10%	0.19	3%	0.03	1%
Installation Labor	0.59	9%	0.42	7%	0.18	3%
Permitting, Inspection, and Interconnection	0.13	2%	0.02	0.3%	0.003	0%
Labor for Arranging 3rd Party Financing	0.02	0.3%	0.02	0. 3%	0.01	0.2%
Assumed Permitting Fees	0.09	1%	0.35	6%	0.03	1%
All Surveyed Soft Costs	1.50	23%	0.99	17%	0.25	5%

Source: Ardani, Galen, Robert, Ryan, David, and Sean, 2012

Table 5.17

Total PV System Soft Costs ($)

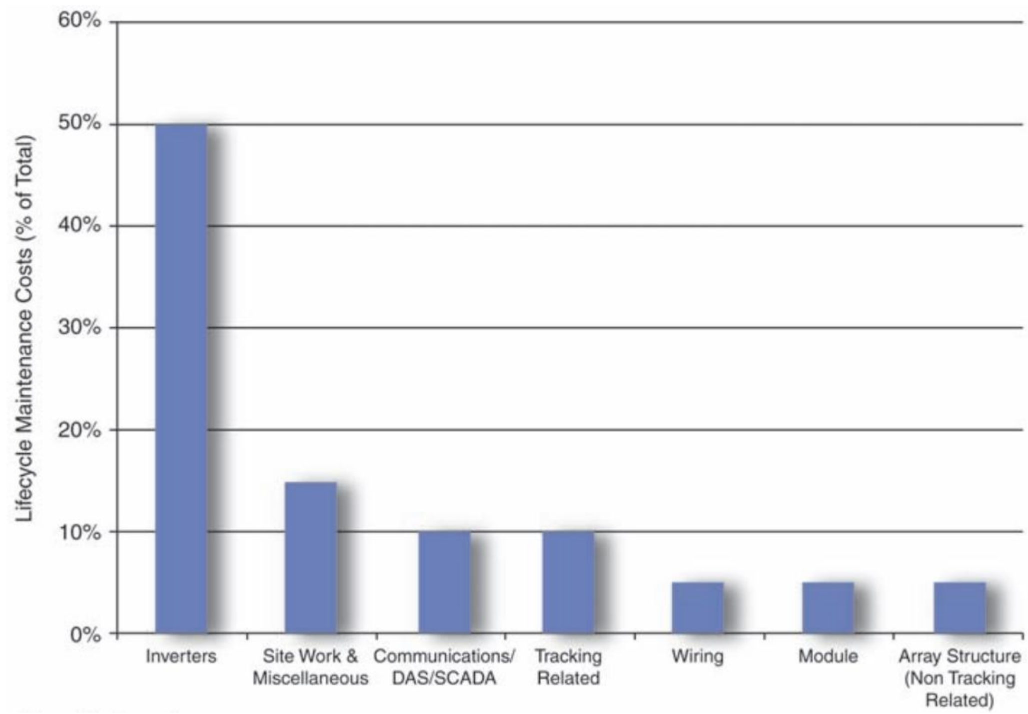
	Customer Acquisition Costs ($)	Installation Labor Costs ($)	PII Costs ($)	Labor for 3rd Party Financing Costs ($)	Total PV System Soft Costs ($)
T1-TFA	$50,496	$302,976	$55,546	$16,832	$425,849
T2-TFA	$47,297	$283,783	$52,027	$15,766	$398,872
T3-TFA	$26,254	$157,527	$28,879	$8,751	$221,408
T1-TSTA	$84,242	$505,452	$92,666	$28,081	$710,440
T2-TSTA	$79.856	$479,137	$87,842	$26,619	$673,454
T3-TSTA	$64.478	$386,870	$70,926	$21,493	$543,767
T1-UDTA	$106,657	$639,944	$117,323	$35,552	$899,476
T2-UDTA	$100,260	$601,557	$110,286	$33,420	$845,522
T3-UDTA	$76,657	$459,944	$84,323	$25,552	$646,477

Note: Permitting, Inspection, and Interconnection (PII) Costs - includes assumed permitting fees, Labor for 3rd Party Financing includes financial analyst

5.4.4 Total Opeartions and Maintenance Costs

Once UGA becomes an asset owner for PV system, however, will demand that they need to consider operations and maintenance (O&M). Contrary to popular belief, PV power plants are not maintenance free; they require a regimen of continual monitoring, periodic inspection, scheduled preventive maintenance, and service calls (Electric Power Research Institute, 2010). These actions address unplanned outages, repair and restart, and various O&M activities needed to enhance long term uptime, performance, and economic viability.

Figure 5.16 offers a high-level percentage breakdown of total lifecycle PV plant operations and maintenance costs for PV installation based on different parts of the United States. Inverters are the most active component in a system, are far and away the main culprit for unplanned PV plant downtime. Miscellaneous site work represents the second largest expense; followed by BOS upkeep, which tends to be the same across different arrays; and repair and upkeep. Wiring issues are fairly minor and are minimized by preventative maintenance practices. And modules, which have a less than 1% industry-wide failure rate, require very little replacement.



Source: Electric Power Research Institute, 2010

Figure 5.16 Solar PV Plant Operations and Maintenance Costs Breakdown

Table 5.18 provides estimates of O&M expenses depending on the type of modules and array. Excerpted from EPRI's Technical Update 1021320, provides a more nuanced breakdown of O&M cost estimates across four major categories — scheduled maintenance; unscheduled maintenance; inverter/equipment replacement; and insurance, property taxes and owner's costs—for five conceptual 10- MW PV plants. All the four categories are not shown in table 5.18, but has already accounted in the costs for modules and array.

Table 5.18

Total O&M Costs Estimates for Different Type of Modules and Array

Type of Modules and Array	**Total O&M Costs ($/kW/year)**
Fixed-tilted monocrystalline	$47/kW/year
Fixed -tilted polycrystalline	$47/kW/year
Fixed -tilted thin-film (CdTe)	$52/kW/year
Tilted single-axis monocrystalline	$60/kW/year
Tilted single-axis polycrystalline	$60/kW/year
Tilted single-axis thin-film (CdTe)	$65/kW/year
Double-axis monocrystalline	$73/kW/year
Double-axis polycrystalline	$73/kW/year
Double-axis thin-film (CdTe)	$78/kW/year

Source: Electric Power Research Institute, 2010

Scheduled Maintenance/Cleaning involves annual or biannual preventative maintenance work and module cleaning, while Unscheduled Maintenance comprises the costs to perform reactive repairs, such as handling inverter problems and mechanical issues. Inverter Replacement Reserve represents capital to refurbish all plant inverters near year 15. And Owner's Costs is composed of costs including monitoring, insurance, property taxes, site communications and access, and other miscellaneous administrative fees and expenses that the owner will incur. These are not costs that would be included in a typical O&M contract, but are expenses that apply to all PV projects.

The total operations and maintenance costs ($TOMC_t$) is a function of (1) fixed operations and maintenance costs ($FFOMC_{i,j}$), (2) scheduled maintenance Costs ($SMC_{i,j}$), (3) unscheduled maintenance costs ($UMC_{i,j}$), (4) inverter/equipment replacement costs ($IERC_{i,j}$), and (5) insurance, property taxes and owner's costs ($IPTWC_{i,j}$). And when we use information from table 5.18 to solve figure 5.17, we get the calculation in table 5.19 of the total operations and maintenance costs.

$$TOMC_t = FFOMC_{i,j} + SMC_{i,j} + UMC_{i,j} + IERC_{i,j} + IPTWC_{i,j}$$

Figure 5.17 Equation for TOMC

Table 5.19

Total Operations and Maintenacae Costs ($)

	Total Operations and Maintenacae Costs ($)
T1-TFA	$79,110
T2-TFA	$74,099
T3-TFA	$45,507
T1-TSTA	$168,484
T2-TSTA	$159,712
T3-TSTA	$139,703
T1-UDTA	$259,533
T2-UDTA	$243,965
T3-UDTA	$199,309

5.4.5 Available Incentives ($)

Most states offer energy incentive programs to help offset energy costs. This section is a comprehensive source of information on the status of local, state, and federal programs and incentives promoting renewable energy; it includes information on financial incentives, net metering policies, and investment programs for PV system. To calculate the Federal Renewable Energy Tax Credit (FRETC), it is equal to 30% of expenditures such as costs of system and BoS previously described in chapter 5.4.1 and 5.4.2, with no maximum credit (Department of Energy 1a). The FRETC is applicable for both personal and business where the last date to apply is Dec 31, 2016.

As part of the Georgia Energy Challenge, Georgia offers tax credits for certain types of energy efficient and renewable energy property. The applicable energy sectors are either the lesser of 35 percent of the cost of the clean energy property, or the sum of $10,500 for residential and $500,000 for nonresidential per dwelling unit (Department of Energy 1b). And for the Georgia Clean Energy Property Tax Credit (GCEPTC), the maximum incentive is $500,000 for UGA PV system. It is also valid for both personal and business, however the last date to apply was Dec 31, 2014.

And finally, the available incentives (AI_t) is a function of (1) Federal Energy Tax Credit ($FETC_{i,j}$). Once satisfying figure 5.18, table 5.20 and table 5.21 shows the calculation for the total incentive benefits. And later we add total incentive benefits to the total costs to reduce the total net costs.

$$AI_t = FETC_{i,j}$$

Figure 5.18 Equation for AI

Table 5.20

Total Available Incentive ($) – FOR UGA

	Federal Energy Tax Credit ($)	The Georgia Clean Energy Tax Credit ($)	Total Available Incentives ($)
T1-TFA	$970,250	Not Applicable	$970,250
T2-TFA	$874,708	Not Applicable	$874,708
T3-TFA	$819,871	Not Applicable	$819,871
T1-TSTA	$1,200,256	Not Applicable	$1,200,256
T2-TSTA	$1,085,956	Not Applicable	$1,085,956
T3-TSTA	$1,347,093	Not Applicable	$1,347,093
T1-UDTA	$1,606,612	Not Applicable	$1,606,612
T2-UDTA	$1,457,600	Not Applicable	$1,457,600
T3-UDTA	$1,688,445	Not Applicable	$1,688,445

Table 5.21

Total Available Incentive ($) – TO SELL

	Federal Energy Tax Credit ($)	The Georgia Clean Energy Tax Credit ($)	Total Available Incentives ($)
T1-TFA	$974,750	Not Applicable	$974,750
T2-TFA	$879,208	Not Applicable	$879,208
T3-TFA	$824,371	Not Applicable	$824,371
T1-TSTA	$1,204,756	Not Applicable	$1,204,756
T2-TSTA	$1,090,456	Not Applicable	$1,090,456
T3-TSTA	$1,351,593	Not Applicable	$1,351,593
T1-UDTA	$1,611,112	Not Applicable	$1,611,112
T2-UDTA	$1,462,100	Not Applicable	$1,462,100
T3-UDTA	$1,692,945	Not Applicable	$1,692,945

5.5 Price of Electricity Information

For this particular paper, the solar PV installation takes place in the state of Georgia and the University of Georgia falls under the commercial sector. Historically, despite the fact that there has been ups and downs, the average Georgia retail price of electricity to commercial has been increasing from 2001

(6.61cents/kWh) to 2014 (10.28cents/kWh). When referring back to table 5.22 the average retail price of electricity to commercial by end-use increased by 3.56%. Then, in order to forecast the electricity price, under the assumption

that the entire solar PV construction at UGA is built by the end of year 2015, we had to project the average price of electricity for 30 year period from 2015 to 2044.

Undoubtedly, there are other factors that play a key role in affecting the future electricity price such as fuels, power plants, transmission and distribution system, weather conditions, policy (regulations), etc. However, to keep things simple, we used the average increment (nominal growth rate) of 3.56% to forecast the estimated electricity price for commercial by end-use from year 2015 to 2044. And in table 5.23, it was projected as 10.660cents/kWh in year 2015 and 30.387cents/kWh in year 2044.

On the other hand, due to the feed-in-tariff program utility companies are required to buy electricity from qualified independent power producers since 1978 (Georgia Power, 2014). Georgia Power buys energy from solar resources to supply the Green Energy Program through the Solar Purchase Tariff (SP-2). Qualifying customers can sell all the energy produced from solar installations (X ≤ 100 kW in size) to GP at the Solar Purchase Price, currently 17 cents per kWh. In addition, Georgia Power has a solar buyback program where the large customers (X < 80 MW) can sell their solar generated back to GP as a Qualifying Facility. According to Georgia Power, the current buyback electricity price is fixed at 0.04cents/kWh for five-year period. This number may increase or decrease in the next every five year period, however, there is no estimated future electricity price over the 30 years. Therefore, we will use 0.04cents/kWh in this study.

Table 5.22

Average Retail Price of Electricity to Commercial by End-Use (Georgia)

Year	**Commercial (Cents / kWh)**	**Nominal Growth Rate for Commercial (%)**
2014	10.28	2.903
2013	9.99	4.278
2012	9.58	(2.938)
2011	9.87	8.940
2010	9.06	1.342
2009	8.94	(1.433)
2008	9.07	12.392
2007	8.07	3.329
2006	7.81	1.825
2005	7.67	11.483
2004	6.88	3.303
2003	6.66	3.096
2002	6.46	(2.269)
2001	6.61	0
Average Nominal Growth Rate		3.56%

Source: EIA, 2012

Table 5.23

Estimated Future Average Retail Price of Electricity to Commercial by End-Use

(Georgia)

In terms of nominal value

Year	Future Price (Cents / kWh)	Year	Future Price (Cents / kWh)
2044	30.387	**2029**	17.368
2043	29.343	**2028**	16.771
2042	28.335	**2027**	16.195
2041	27.361	**2026**	15.639
2040	26.421	**2025**	15.101
2039	25.513	**2024**	14.582
2038	24.637	**2023**	14.081
2037	23.790	**2022**	13.598
2036	22.973	**2021**	13.130
2035	22.184	**2020**	12.679
2034	21.421	**2019**	12.244
2033	19.975	**2018**	11.823
2032	19.289	**2017**	11.417
2031	18.626	**2016**	11.025
2030	17.986	**2015**	10.660

5.6 Compare and Contrast between Three Types of Arrays

As shown in both table 5.24 and table 5.25, we first calculate the present value of all costs (from debt financing) and the DC system capacity for T1, T2, and T3 during 30 years. Then, we find that among the three types of arrays (TFA, TSTA, and UDTA) the tilted single-axis tracking array is the most economically feasible array to use in terms of # of kWh per $1 during the 30 year period. However, if we take a closer look, the difference between TSTA and UDTA were small in terms of number of KWh per $1.

From this point on, we have two options. As our 2020 strategic goal is to reduce fossil fuel CO2 emissions by 20 percent from renewables relative to baseline of 2010 (section 5.7), it would be much better to use UDTA over TSTA as the former produces far more electricity. However, if UGA faces low capital, UGA would have to stay with TFA.

Table 5.24

Compare and Contrast between Three Types of Arrays – FOR UGA

	PV of All Costs in 30 Years ($)	**Expected amount of electricity generated (kWh/site/30Years)**	**# of kWh per $1 for 30Years**
T1-TFA	$2,857,480	56,269,061	19.70
T2-TFA	$2,594,403	37,472,543	14.44
T3-TFA	$2,249,706	27,060,900	12.03
T1-TSTA	$3,679,522	93,792,371	25.49
T2-TSTA	$3,367,064	63,211,012	18.77
T3-TSTA	$3,826,687	66,385,430	17.35
T1-UDTA	$4,907,770	118,738,099	24.19
T2-UDTA	$4,490,553	79,353,230	17.67
T3-UDTA	$4,785,491	78,908,861	16.49

Table 5.25

Compare and Contrast between Three Types of Arrays – TO SELL

	PV of All Costs in 30 Years ($)	**Expected amount of electricity generated (kWh/site/30Years)**	**# of kWh per $1 for 30Years**
T1-TFA	$2,868,316	54,580,990kWh	19.03
T2-TFA	$2,605,239	36,348,367kWh	13.95
T3-TFA	$2,260,542	26,249,073kWh	11.61
T1-TSTA	$3,690,022	90,976,178kWh	24.66
T2-TSTA	$3,377,564	61,312,959kWh	18.15
T3-TSTA	$3,837,187	64,391,627kWh	16.78
T1-UDTA	$4,918,270	115,172,565kWh	23.42
T2-UDTA	$4,501,053	76,970,222kWh	17.10
T3-UDTA	$4,795,991	76,538,458kWh	15.96

5.7 UGA 2020 Strategic Goal

As previously mentioned in chapter 1, the 2020 strategic objective was to reduce fossil fuel CO2 emissions by 20 percent from renewables relative to baseline of 2010. To answer goal one, we did the following order.

(1) In table 5.27, the amount of electricity which is first sold by Georgia Power and then purchased by UGA in year 2010 is 294,961 mWh (294,960,641 kWh). (2) In table 5.26, the annual total output emission rates for greenhouse gases (GHGs) is used as a default factor for estimating GHG emissions from electricity use when developing a carbon footprint or emission inventory (EPA, 2014). Many of the boundaries shown on the map are approximate which is provided by the North American Electric Reliability Corporation (NERC). And under the different geographical boundaries shown, since the state of Georgia falls under the Standards and Enforcement Review Committee (SERC)

Reliability Corporation/Central, we focus on 1,354 lbs of CO_2/mWh, which is the annual total output of carbon dioxide emissions.

As just mentioned above, we mutiply 294,961 mWh and 1,354 lbs of CO_2/mWh to get 399,403,254 lbs of CO_2 produced. (3) In year 2016, which is one full fiscal year, UGA has the capability to generate electricity for either 5,368 mWh (T1-UDTA TO sell), or 5,207 mWh (T1-UDTA FOR UGA) via PV solar system. Then, in order to find out the amount of CO_2 saved via UGA PV generation, we multiply 5,368 mWh (to sell) by 1,354 lbs of CO_2/mWh to get 7,268,376 lbs of CO_2. And same thing applies for the No Transformer (for UGA).

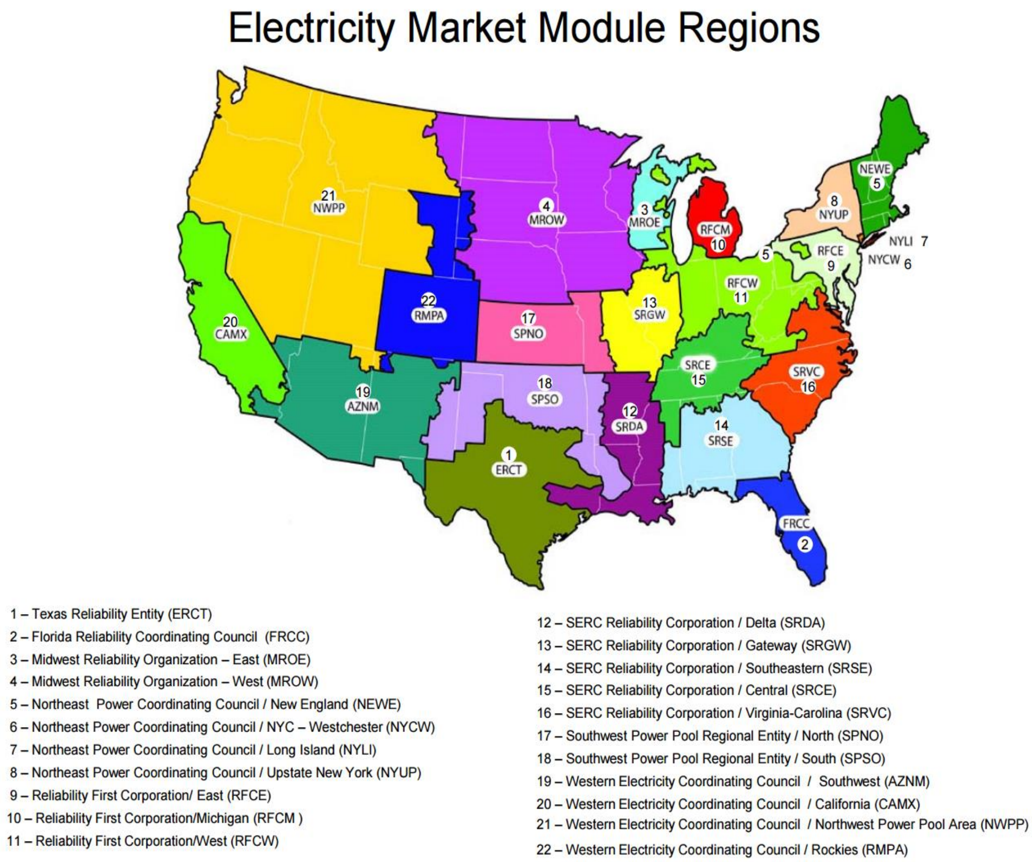
(4) In the end, for the No Transformer – for UGA, in order to calculate the amount of CO_2 reduced from renewables relative to baseline of 2010 in terms of percentage, we calculated via [(7,268,376 lbs of CO_2 divided it by 399,403,254 lbs of CO_2) * 100] to get 1.82%. And for Yes Transformer– to sell, same methods have been approached and resulted in 1.77%. Therefore, it shows that the first goal can't meet the criteria of 20%. Thinking on the positive side, however, if we were to satisfy the goal for all 20%, we would require 11 more lands (10 acres) that consist of PV generating system.

Moreover As shown in table 5.26, goal (4) from the 2020 UGA strategic plan is to increase the generation of energy from renewable sources to 10 percent relative to baseline of 2010. And after the same calculation as goal (1), we could conclude that only 1.82% (For UGA) and 1.77% (To SELL) of solar energy from renewable sources could be generated. In order to meet goal (4), we would need at least six more sites, which is equivalent to 60 acres of land.

Table 5.26

Year 2010 GHG Annual Output Emission Rates by Company

NREC acronym	Carbon Dioxide (CO_2) (lb/MWh)	Methane (CH_4) (lb/GWh)	Nitrous Oxide (N_2O) (lb/GWh)
CAMX	610.82	28.49	6.03
FRCC	1196.71	38.91	13.75
SRSE	1354.09	22.82	20.89
SRVC	1073.65	21.69	17.64
U.S. Average	1,058.82	27.98	14.58



Source: EPA, 2014

Table 5.27

UGA Electricity Usage & CO2 Emission

UGA Energy Usage in year 2010		
Fiscal Year 2009-2010	**Electricity**	294,961 mWh
GHG (CO2 Emission) Annual Output by Georgia Power in Year 2010		
Fiscal Year 2009-2010	**Emission**	1,354 lbs of CO2/mWh
Total GHG (CO2 Emission) Annual Output by Georgia Power in Year 2010		
Fiscal Year 2009-2010	**Emission**	399,403,254 lbs of CO2
UGA PV Generation (2016)		
Fiscal Year 2015-2016	**For UGA (T1-UDTA)**	5,368 mWh
Fiscal Year 2015-2016	**To Sell (T1-UDTA)**	5,207 mWh
GHG (CO2 Emission) Annual Output by Georgia Power in Year 2010		
Fiscal Year 2009-2010	**Emission**	1,354 lbs of CO2/mWh
The Amount of CO2 Saved via UGA PV Generation (2016)		
Fiscal Year 2015-2016	**For UGA (T1-UDTA)**	7,268,376 lbs of CO2
Fiscal Year 2015-2016	**To Sell (T1-UDTA)**	7,050,116 lbs of CO2
The Amount (%) of CO2 Reduced from Renewables Relative to Baseline of 2010		
Fiscal Year 2015-2016	**For UGA (T1-UDTA)**	1.82%
Fiscal Year 2015-2016	**To Sell (T1-UDTA)**	1.77%
The Increased Amount (%) of CO2 from Renewables Relative to Baseline of 2010		
Fiscal Year 2015-2016	**For UGA (T1-UDTA)**	1.82%
Fiscal Year 2015-2016	**To Sell (T1-UDTA)**	1.77%

CHAPTER 6

(RESULTS)

Given the model and the data outlined in the previous section, chapter 6 discusses the assessment of the economic feasibility of installing photovoltaic systems for 30 years. The results for the UGA solar electricity generating potential are based on the solar radiation, module, system size, array type, system losses, available incentives (tax credit), and price of electricity. And for the cost wise, it consists of total equipment costs, total installation, permit, operations, and maintenance costs, etc.

There are two main end-use scenarios that are being examined to see which is more financially beneficial. While scenario A (requiring the transformer) discusses about selling the electricity generated from their solar power to the utility company, scenario B (requiring no transformer) explains the benefit of using their own electricity generation from UGA's PV system. In order to get the net present value (NPV) for both scenario A and B, we have subtracted the PV of costs from the PV of benefits. In addition, among the three types of tracking system, we have decided to use the universal double-axis tracking array (UDTA) as discussed previously in chapter 5.

Table 6.1 and 6.2 describes the total expected amount of electricity generation in each module for T1-UDTA (Mono-crystalline), T2-UDTA (Poly-crystalline), and T3-UDTA (Thin-film, CdTe). However, while table 6.1

represents scenario A (requiring the transformer), table 6.2 shows scenario B (requiring no transformer). And as a result, during the period of 30 years, it is clear that the latter produces 3.1% more electricity compared to the former for each case because each module (T1, T2, and T3) in table 6.2 creates about 3,565,534kW, 2,383,008kW, and 2,367,403kW more electricity than table 6.1. Just to get some idea of how big this numbers are, in year 2013, the average annual electricity consumption for a U.S. residential customer was 10,908 kWh or equivalently an average of 909 kWh per month (EIA, 2015)

For scenario A, under the assumption that the discount rate is fixed at 4% and it includes the transformer with no inverter (to sell), table 6.3, 6.4, and 6.5 shows the NPV of all costs, NPV gross benefit, and breakeven for three different types of modules (UDTA). As stated before, Georgia Power has a solar buyback program where the large customers (X ≤ 80 MW) can sell their solar generated back to Georgia Power as a “Qualifying Facility”. And according to GP, the current average standard electricity buyback price is 0.04cents/kWh. However, from UGA’s perspective in order to generate profit from installing solar PV system in the period of 30 years, the negotiable electricity buyback price must be at least greater than 0.07 cent per kWh, 0.09 cent per kWh, and 0.10 cent per kWh for T1-UDTA, T2- UDTA, and T3- UDTA respectively. If the price is set below this point, UGA will end up making negative profit.

The breakeven point (BEP) in economics, accounting, and finance is defined as the point at which total revenue and total cost are equal: there is no net loss or gain (Holland, 1998). For the break-even points, T1-UDTA, T2-UDTA, and T3- UDTA reached at the end of year 27, year 19, and year 26. In other words, once it reached its breakeven point, each module made a total profit of $195,443 ($5,271,098 - $5,075,655), $354,522 ($4,999,608 - $4,654,086), and $169,796 ($5,119,259 - $4,949,463) in the period of 30 years. In addition, figure 6.1 represents the breakeven year and figure 6.2 shows the net present value for T1-UDTA, T2-UDTA, and T3-UDTA (Yes Transformer – to sell) in a graph. If the PV of Costs was greater than PV of Benefits, nothing was shown in figure 6.1 and 6.2.

On the other hand, scenario B assumes that everything is the same as scenario A, except the transformer is not included in the system and the inverter is installed (for UGA). This means that UGA will be using electricity created from their installed PV plant. Unlike scenario A, in order to forecast the nominal electricity prices (from chapter 5), the total estimated future average retail price of electricity to commercial by end-use increased from 10.660cents/kWh (year 2015) to 30.387cents/kWh (year 2044). So, the average retail price of electricity to commercial by end-use increased by 3.56% (for 30 years).

In table 6.7 through 6.10, we selected from the least to highest possible nominal price growth rate (between 0.10% and 5.00%) based on the average commercial electricity price of 3.56% for T1-UTA, T2-UTA, and T3-UTA. We fixed the electricity price at $0.1066/kWh (10.66Cents/kWh), which was the estimated price for year 2015. We decided to choose this number because 10.66Cents/kWh was the most safe and reasonable price that could be used in calculating the NPV. For example when considering the average nominal growth rate of 0.01%, we had to calculate the PV Gross Benefits by multiplying (1.001)^(# of year minus 1) to the total kWh generated for each year as described in table 6.2.

In table 6.7, 6.8 and 6.9, when assuming the smallest nominal growth rate of 0.10% (1.001) with fixed price of $0.1066/kWh (year 2015), all the module types (UDTA) made a net profit of $3,291,257, $1,516,856, and $739,330 in the period of 30 years. The breakeven years for the three modules were year 12, year 12 and year 20 respectively.

Table 6.1

Total Expected Amount of Electricity Generated (Yes Transformer – to sell)

Expected amount of electricity generated for UDTA (kWh / Site / 30 Years)- TO SELL				
	T1-UDTA	T2-UDTA	T3-UDTA	Expected amount of electricity generated for T1-UDTA (kWh/site/30Years)
Year 1	5,206,533	4,893,918	3,740,631	115,172,565
Year 2	5,194,558	4,865,044	3,729,409	Expected amount of electricity generated for T2-UDTA (kWh/site/30Years)
Year 3	5,170,663	4,807,637	3,707,033	76,970,222
Year 4	5,134,986	4,722,542	3,673,670	Expected amount of electricity generated for T3-UDTA (kWh/site/30Years)
Year 5	5,087,744	4,611,090	3,629,586	76,538,458
Year 6	5,029,235	4,475,063	3,575,142	
Year 7	4,959,831	4,316,645	3,510,789	
Year 8	4,879,978	4,138,368	3,437,063	
Year 9	4,790,187	3,943,037	3,354,573	
Year 10	4,691,030	3,733,662	3,264,000	
Year 11	4,583,136	3,513,376	3,166,080	
Year 12	4,467,183	3,285,358	3,061,599	
Year 13	4,343,888	3,052,754	2,951,382	Expected amount of electricity generated for T1-UDTA (MWh/site/30Years)
Year 14	4,214,006	2,818,608	2,836,278	115,173
Year 15	4,078,315	2,585,791	2,717,154	Expected amount of electricity generated for T2-UDTA (MWh/site/30Years)

Year 16	3,937,613	2,356,948	2,594,882	76,970
Year 17	3,792,709	2,134,453	2,470,328	Expected amount of electricity generated for T3-UDTA (MWh/site/30Years)
Year 18	3,644,414	1,920,367	2,344,341	76,538
Year 19	3,493,535	1,716,424	2,217,747	
Year 20	3,340,868	1,524,013	2,091,335	
Year 21	3,187,188	1,344,179	1,965,855	
Year 22	3,033,247	1,177,635	1,842,006	
Year 23	2,879,765	1,024,778	1,720,434	
Year 24	2,727,425	885,716	1,601,724	
Year 25	2,576,871	760,299	1,486,400	Expected amount of electricity generated for T1-UDTA (GWh/site/30Years)
Year 26	2,428,701	648,155	1,374,920	115
Year 27	2,283,465	548,728	1,267,676	Expected amount of electricity generated for T2-UDTA (GWh/site/30Years)
Year 28	2,141,662	461,315	1,164,994	77
Year 29	2,003,739	385,106	1,067,135	Expected amount of electricity generated for T3-UDTA (GWh/site/30Years)
Year 30	1,870,089	319,214	974,294	77

Table 6.2

Total Expected Amount of Electricity Generated (No Transformer – for UGA)

Expected amount of electricity generated for UDTA (kWh / Site / 30 Years) - FOR UGA				
	T1-UDTA	T2-UDTA	T3-UDTA	Expected amount of electricity generated for T1-UDTA (kWh/site/30Years)
Year 1	5,367,718	5,045,435	3,856,479	118,738,099
Year 2	5,355,372	5,015,667	3,844,910	Expected amount of electricity generated for T2-UDTA (kWh/site/30Years)
Year 3	5,330,738	4,956,482	3,821,840	79,353,230
Year 4	5,293,956	4,868,752	3,787,444	Expected amount of electricity generated for T3-UDTA (kWh/site/30Years)
Year 5	5,245,251	4,753,850	3,741,994	78,908,861
Year 6	5,184,931	4,613,611	3,685,864	
Year 7	5,113,379	4,450,289	3,619,519	
Year 8	5,031,053	4,266,492	3,543,509	
Year 9	4,938,482	4,065,114	3,458,465	
Year 10	4,836,255	3,849,256	3,365,086	
Year 11	4,725,022	3,622,150	3,264,134	
Year 12	4,605,479	3,387,073	3,156,417	
Year 13	4,478,367	3,147,268	3,042,786	Expected amount of electricity generated for T1-UDTA (MWh/site/30Years)
Year 14	4,344,464	2,905,872	2,924,117	118,738
Year 15	4,204,572	2,665,847	2,801,305	Expected amount of electricity generated for T2-UDTA (MWh/site/30Years)

Year 16	4,059,515	2,429,920	2,675,246	79,353
Year 17	3,910,125	2,200,535	2,546,834	Expected amount of electricity generated for T3-UDTA (MWh/site/30Years)
Year 18	3,757,239	1,979,822	2,416,945	78,909
Year 19	3,601,689	1,769,565	2,286,430	
Year 20	3,444,295	1,571,196	2,156,104	
Year 21	3,285,858	1,385,795	2,026,738	
Year 22	3,127,151	1,214,095	1,899,053	
Year 23	2,968,917	1,056,506	1,773,716	
Year 24	2,811,861	913,138	1,651,329	
Year 25	2,656,646	783,838	1,532,434	Expected amount of electricity generated for T1-UDTA (GWh/site/30Years)
Year 26	2,503,889	668,222	1,417,501	119
Year 27	2,354,157	565,716	1,306,936	Expected amount of electricity generated for T2-UDTA (GWh/site/30Years)
Year 28	2,207,964	475,598	1,201,074	79
Year 29	2,065,771	397,029	1,100,184	Expected amount of electricity generated for T3-UDTA (GWh/site/30Years)
Year 30	1,927,984	329,097	1,004,468	79

Table 6.3

Mono-crystalline NPV and Breakeven with Electricity Price of $0.07/kWh (Yes Transformer – to sell)

T1-UDTA - TO SELL							
		Discount Rate (%) =	**0.04**	**Electricity Price ($) =**	**0.0700**	**Present Value of All Costs =**	**$5,075,655.09**
Year	**Total Net Cost ($)**	**Down Payment ($)**	**Loan Payment ($)**	**PV Loan Payment ($)**	**PV Gross Benefits ($)**	**PV Gross Benefits to date ($)**	**Breakeven**
1	$4,918,270.44	$983,654.09	$289,515.96	$289,515.96	$364,457.34	$364,457.34	1
2	$4,918,270.44		$289,515.96	$278,380.73	$349,633.74	$714,091.07	2
3	$4,918,270.44		$289,515.96	$267,673.78	$334,639.83	$1,048,730.90	3
4	$4,918,270.44		$289,515.96	$257,378.63	$319,548.86	$1,368,279.76	4
5	$4,918,270.44		$289,515.96	$247,479.45	$304,431.74	$1,672,711.50	5
6	$4,918,270.44		$289,515.96	$237,961.01	$289,356.51	$1,962,068.01	6
7	$4,918,270.44		$289,515.96	$228,808.67	$274,387.88	$2,236,455.89	7
8	$4,918,270.44		$289,515.96	$220,008.33	$259,586.76	$2,496,042.65	8
9	$4,918,270.44		$289,515.96	$211,546.47	$245,009.97	$2,741,052.62	9
10	$4,918,270.44		$289,515.96	$203,410.07	$230,709.87	$2,971,762.49	10
11	$4,918,270.44		$289,515.96	$195,586.61	$216,734.17	$3,188,496.66	11
12	$4,918,270.44		$289,515.96	$188,064.05	$203,125.77	$3,391,622.43	12
13	$4,918,270.44		$289,515.96	$180,830.81	$189,922.59	$3,581,545.02	13
14	$4,918,270.44		$289,515.96	$173,875.78	$177,157.60	$3,758,702.62	14
15	$4,918,270.44		$289,515.96	$167,188.25	$164,858.78	$3,923,561.40	15

16	**$4,918,270.44**		**$289,515.96**	**$160,757.93**	**$153,049.18**	**$4,076,610.58**	**16**
17	**$4,918,270.44**		**$289,515.96**	**$154,574.94**	**$141,747.09**	**$4,218,357.67**	**17**
18	**$4,918,270.44**		**$289,515.96**	**$148,629.75**	**$130,966.13**	**$4,349,323.80**	**18**
19	**$4,918,270.44**		**$289,515.96**	**$142,913.22**	**$120,715.51**	**$4,470,039.32**	**19**
20	**$4,918,270.44**		**$289,515.96**	**$137,416.56**	**$111,000.24**	**$4,581,039.55**	**20**
21	**$4,918,270.44**		**$0.00**	**$0.00**	**$101,821.37**	**$4,682,860.92**	**21**
22	**$4,918,270.44**		**$0.00**	**$0.00**	**$93,176.34**	**$4,776,037.27**	**22**
23	**$4,918,270.44**		**$0.00**	**$0.00**	**$85,059.25**	**$4,861,096.52**	**23**
24	**$4,918,270.44**		**$0.00**	**$0.00**	**$77,461.17**	**$4,938,557.69**	**24**
25	**$4,918,270.44**		**$0.00**	**$0.00**	**$70,370.49**	**$5,008,928.18**	**25**
26	**$4,918,270.44**		**$0.00**	**$0.00**	**$63,773.26**	**$5,072,701.44**	**26**
27	**$4,918,270.44**		**$0.00**	**$0.00**	**$57,653.48**	**$5,130,354.92**	**27**
28	**$4,918,270.44**		**$0.00**	**$0.00**	**$51,993.46**	**$5,182,348.39**	**28**
29	**$4,918,270.44**		**$0.00**	**$0.00**	**$46,774.12**	**$5,229,122.50**	**29**
30	**$4,918,270.44**		**$0.00**	**$0.00**	**$41,975.27**	**$5,271,097.77**	**30**

Table 6.4

Poly-crystalline NPV and Breakeven with Electricity Price of $0.07/kWh (Yes Transformer – to sell)

T2-UDTA - TO SELL							
		Discount Rate (%) =	0.04	Electricity Price ($) =	0.0900	Present Value of All Costs =	$4,645,086.18
Year	Total Net Cost ($)	Down Payment ($)	Loan Payment ($)	PV Loan Payment ($)	PV Gross Benefits ($)	PV Gross Benefits to date ($)	Breakeven
1	$4,501,052.50	$900,210.50	$264,956.26	$264,956.26	$440,452.66	$440,452.66	1
2	$4,501,052.50		$264,956.26	$254,765.63	$421,013.45	$861,466.11	2
3	$4,501,052.50		$264,956.26	$244,966.95	$400,043.74	$1,261,509.86	3
4	$4,501,052.50		$264,956.26	$235,545.15	$377,849.01	$1,639,358.87	4
5	$4,501,052.50		$264,956.26	$226,485.72	$354,742.09	$1,994,100.95	5
6	$4,501,052.50		$264,956.26	$217,774.73	$331,035.77	$2,325,136.72	6
7	$4,501,052.50		$264,956.26	$209,398.78	$307,035.67	$2,632,172.39	7
8	$4,501,052.50		$264,956.26	$201,344.98	$283,033.75	$2,915,206.14	8
9	$4,501,052.50		$264,956.26	$193,600.94	$259,302.46	$3,174,508.60	9
10	$4,501,052.50		$264,956.26	$186,154.75	$236,089.90	$3,410,598.50	10
11	$4,501,052.50		$264,956.26	$178,994.95	$213,615.96	$3,624,214.46	11
12	$4,501,052.50		$264,956.26	$172,110.53	$192,069.50	$3,816,283.97	12
13	$4,501,052.50		$264,956.26	$165,490.90	$171,606.71	$3,987,890.68	13
14	$4,501,052.50		$264,956.26	$159,125.86	$152,350.46	$4,140,241.14	14
15	$4,501,052.50		$264,956.26	$153,005.64	$134,390.69	$4,274,631.83	15

16	**$4,501,052.50**		**$264,956.26**	**$147,120.80**	**$117,785.68**	**$4,392,417.51**	**16**
17	**$4,501,052.50**		**$264,956.26**	**$141,462.31**	**$102,564.15**	**$4,494,981.66**	**17**
18	**$4,501,052.50**		**$264,956.26**	**$136,021.45**	**$88,727.85**	**$4,583,709.51**	**18**
19	**$4,501,052.50**		**$264,956.26**	**$130,789.86**	**$76,254.76**	**$4,659,964.27**	**19**
20	**$4,501,052.50**		**$264,956.26**	**$125,759.48**	**$65,102.50**	**$4,725,066.77**	**20**
21	**$4,501,052.50**		**$0.00**	**$0.00**	**$55,211.93**	**$4,780,278.70**	**21**
22	**$4,501,052.50**		**$0.00**	**$0.00**	**$46,510.74**	**$4,826,789.45**	**22**
23	**$4,501,052.50**		**$0.00**	**$0.00**	**$38,916.97**	**$4,865,706.42**	**23**
24	**$4,501,052.50**		**$0.00**	**$0.00**	**$32,342.25**	**$4,898,048.66**	**24**
25	**$4,501,052.50**		**$0.00**	**$0.00**	**$26,694.79**	**$4,924,743.45**	**25**
26	**$4,501,052.50**		**$0.00**	**$0.00**	**$21,882.03**	**$4,946,625.48**	**26**
27	**$4,501,052.50**		**$0.00**	**$0.00**	**$17,812.81**	**$4,964,438.30**	**27**
28	**$4,501,052.50**		**$0.00**	**$0.00**	**$14,399.26**	**$4,978,837.56**	**28**
29	**$4,501,052.50**		**$0.00**	**$0.00**	**$11,558.18**	**$4,990,395.74**	**29**
30	**$4,501,052.50**		**$0.00**	**$0.00**	**$9,212.09**	**$4,999,607.83**	**30**

Table 6.5

Thin-film NPV and Breakeven with Electricity Price of $0.07/kWh (Yes Transformer – to sell)

T3-UDTA - TO SELL							
		Discount Rate (%) =	0.04	Electricity Price ($) =	0.1000	Present Value of All Costs =	$4,949,462.96
Year	Total Net Cost ($)	Down Payment ($)	Loan Payment ($)	PV Loan Payment ($)	PV Gross Benefits ($)	PV Gross Benefits to date ($)	Breakeven
1	$4,795,991.24	$959,198.25	$282,317.94	$282,317.94	$374,063.14	$374,063.14	1
2	$4,795,991.24		$282,317.94	$271,459.56	$358,597.06	$732,660.20	2
3	$4,795,991.24		$282,317.94	$261,018.81	$342,736.04	$1,075,396.24	3
4	$4,795,991.24		$282,317.94	$250,979.62	$326,587.90	$1,401,984.14	4
5	$4,795,991.24		$282,317.94	$241,326.56	$310,258.51	$1,712,242.65	5
6	$4,795,991.24		$282,317.94	$232,044.77	$293,850.60	$2,006,093.25	6
7	$4,795,991.24		$282,317.94	$223,119.97	$277,462.78	$2,283,556.03	7
8	$4,795,991.24		$282,317.94	$214,538.43	$261,188.52	$2,544,744.56	8
9	$4,795,991.24		$282,317.94	$206,286.96	$245,115.38	$2,789,859.94	9
10	$4,795,991.24		$282,317.94	$198,352.84	$229,324.30	$3,019,184.23	10
11	$4,795,991.24		$282,317.94	$190,723.89	$213,889.01	$3,233,073.24	11
12	$4,795,991.24		$282,317.94	$183,388.35	$198,875.64	$3,431,948.88	12
13	$4,795,991.24		$282,317.94	$176,334.95	$184,342.42	$3,616,291.31	13
14	$4,795,991.24		$282,317.94	$169,552.84	$170,339.49	$3,786,630.79	14
15	$4,795,991.24		$282,317.94	$163,031.58	$156,908.88	$3,943,539.67	15

16	$4,795,991.24		$282,317.94	$156,761.13	$144,084.59	$4,087,624.26	16
17	$4,795,991.24		$282,317.94	$150,731.86	$131,892.82	$4,219,517.08	17
18	$4,795,991.24		$282,317.94	$144,934.48	$120,352.20	$4,339,869.28	18
19	$4,795,991.24		$282,317.94	$139,360.08	$109,474.21	$4,449,343.49	19
20	$4,795,991.24		$282,317.94	$134,000.07	$99,263.64	$4,548,607.12	20
21	$4,795,991.24		$0.00	$0.00	$89,719.05	$4,638,326.18	21
22	$4,795,991.24		$0.00	$0.00	$80,833.42	$4,719,159.60	22
23	$4,795,991.24		$0.00	$0.00	$72,594.63	$4,791,754.22	23
24	$4,795,991.24		$0.00	$0.00	$64,986.15	$4,856,740.38	24
25	$4,795,991.24		$0.00	$0.00	$57,987.64	$4,914,728.02	25
26	$4,795,991.24		$0.00	$0.00	$51,575.55	$4,966,303.57	26
27	$4,795,991.24		$0.00	$0.00	$45,723.71	$5,012,027.27	27
28	$4,795,991.24		$0.00	$0.00	$40,403.93	$5,052,431.20	28
29	$4,795,991.24		$0.00	$0.00	$35,586.54	$5,088,017.74	29
30	$4,795,991.24		$0.00	$0.00	$31,240.87	$5,119,258.61	30

Table 6.6

Breakeven (year), PV of Benefits, and NPV ($) for T1, T2 and T3 (Yes Transformer – to sell)

T1-UDTA - TO SELL				
Nominal Electricity Price ($/kWh)	**Breakeven (year)**	**PV of Gross Benefits for 30 years ($)**		**NPV for 30 years ($)**
0.01	Not Applicable	$	753,014	($4,322,641)
0.02	Not Applicable	$	1,506,028	($3,569,627)
0.03	Not Applicable	$	2,259,042	($2,816,613)
0.04	Not Applicable	$	3,012,056	($2,063,599)
0.05	Not Applicable	$	3,765,070	($1,310,585)
0.06	Not Applicable	$	4,518,084	($557,571)
0.07	27	$	5,271,098	$195,443
0.08	19	$	6,024,112	$948,457
0.09	16	$	6,777,126	$1,701,471
0.10	13	$	7,530,140	$2,454,485
0.11	12	$	8,283,154	$3,207,499
0.12	10	$	9,036,168	$3,960,513
0.13	9	$	9,789,182	$4,713,526
0.14	9	$	10,542,196	$5,466,540
0.15	7	$	11,295,210	$6,219,554
T1-UDTA Present Value of Costs ($)				$5,075,655.09

T2-UDTA - TO SELL			
Nominal Electricity Price ($/kWh)	Breakeven (year)	PV of Gross Benefits for 30 years ($)	NPV for 30 years ($)
0.01	Not Applicable	$ 555,512	($4,089,574)
0.02	Not Applicable	$ 1,111,024	($3,534,062)
0.03	Not Applicable	$ 1,666,536	($2,978,550)
0.04	Not Applicable	$ 2,222,048	($2,423,038)
0.05	Not Applicable	$ 2,777,560	($1,867,526)
0.06	Not Applicable	$ 3,333,072	($1,312,014)
0.07	Not Applicable	$ 3,888,584	($756,502)
0.08	Not Applicable	$ 4,444,096	($200,990)
0.09	19	$ 4,999,608	$354,522
0.10	15	$ 5,555,120	$910,034
0.11	12	$ 6,110,632	$1,465,546
0.12	11	$ 6,666,144	$2,021,058
0.13	10	$ 7,221,656	$2,576,570
0.14	9	$ 7,777,168	$3,132,082
0.15	8	$ 8,332,680	$3,687,594
T2-UDTA Present Value of Costs ($)			$4,645,086.18

T3-UDTA - TO SELL			
Nominal Electricity Price ($/kWh)	Breakeven (year)	PV of Gross Benefits for 30 years ($)	NPV for 30 years ($)
0.01	Not Applicable	$ 511,926	($4,437,537)
0.02	Not Applicable	$ 1,023,852	($3,925,611)
0.03	Not Applicable	$ 1,535,778	($3,413,685)
0.04	Not Applicable	$ 2,047,703	($2,901,760)
0.05	Not Applicable	$ 2,559,629	($2,389,834)
0.06	Not Applicable	$ 3,071,555	($1,877,908)
0.07	Not Applicable	$ 3,593,481	($1,355,982)
0.08	Not Applicable	$ 4,095,407	($854,056)
0.09	Not Applicable	$ 4,607,333	($342,130)
0.10	26	$ 5,119,259	$169,796
0.11	20	$ 5,631,184	$681,722
0.12	17	$ 6,143,110	$1,193,647
0.13	15	$ 6,655,036	$1,705,573
0.14	13	$ 7,166,962	$2,217,499
0.15	12	$ 7,678,888	$2,729,425
T3-UDTA Present Value of Costs ($)			$4,949,462.96

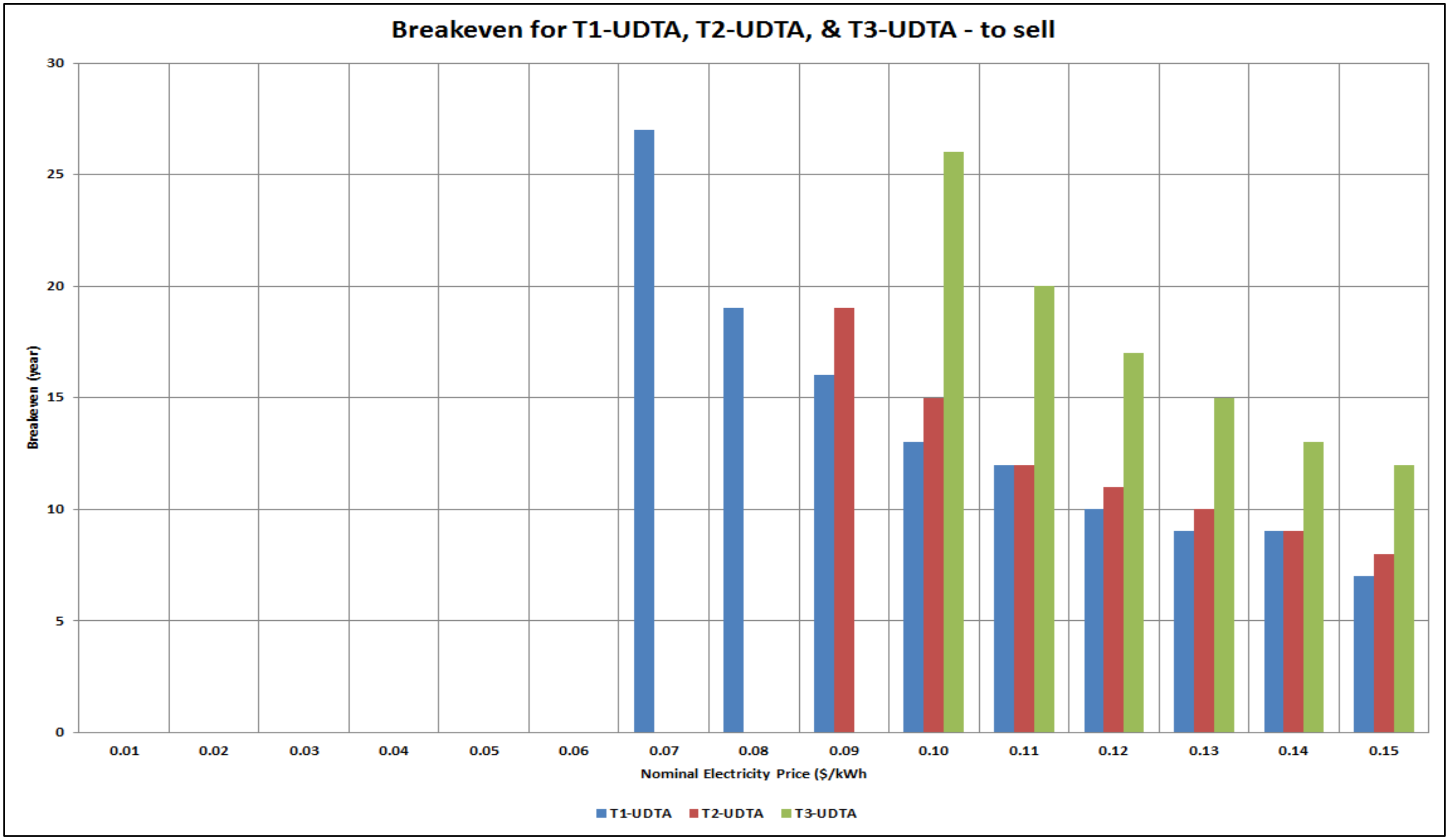


Figure 6.1 Breakeven for T1, T2, & T3 (Yes Transformer – to sell)

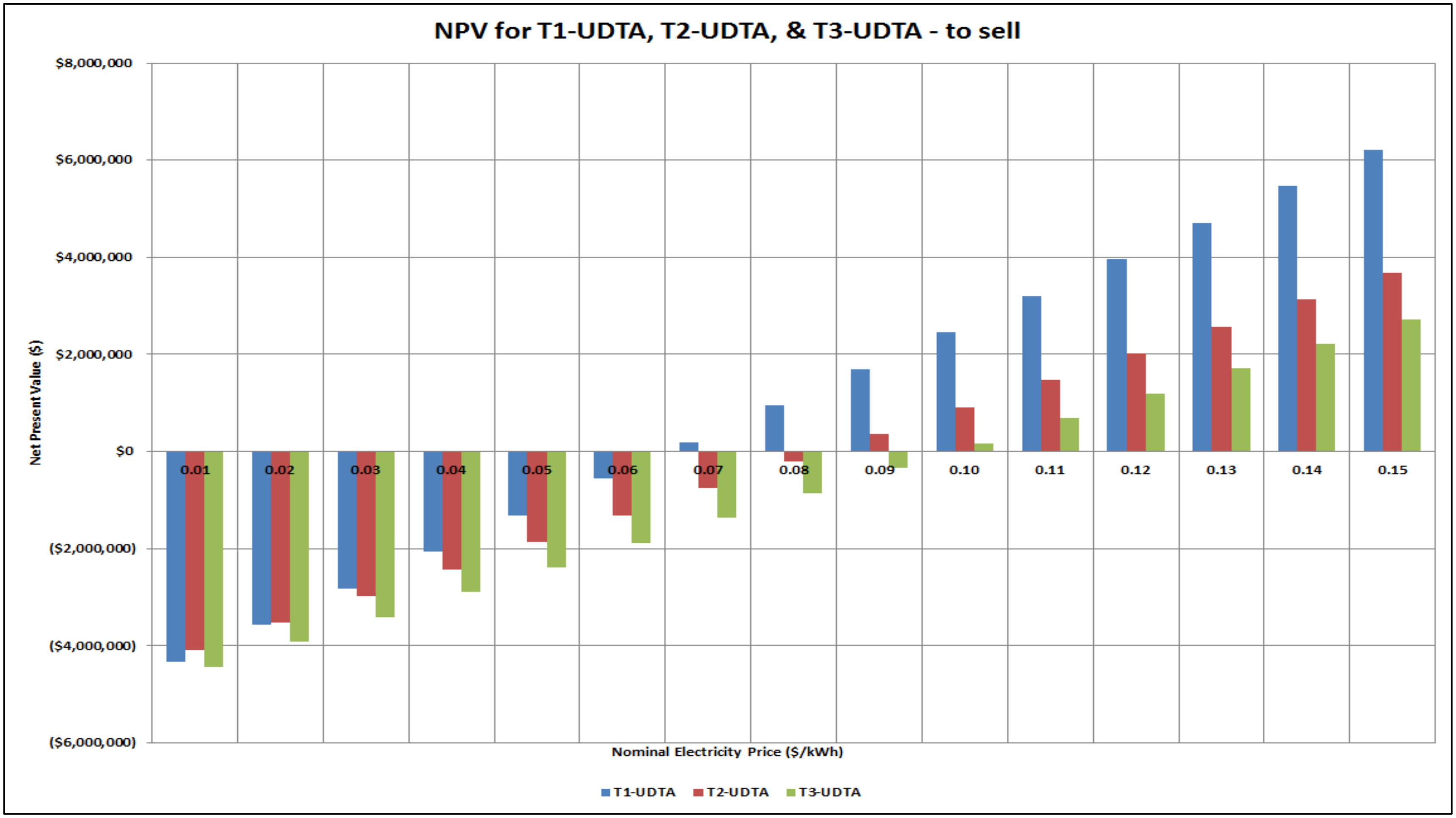


Figure 6.2 Net Present Values for T1, T2, & T3 (Yes Transformer – to sell)

Table 6.7

Mono-crystalline NPV and Breakeven at $0.1006/kWh (No Transformer – for UGA)

T1-UDTA - FOR UGA							
		Discount Rate (%) =	0.04	Electricity Price ($) =	0.1066	Present Value of All Costs =	$5,064,819.09
Year	Total Net Cost ($)	Down Payment ($)	Loan Payment ($)	PV Loan Payment ($)	PV Gross Benefits ($)	PV Gross Benefits to date ($)	Breakeven
1	$4,907,770.44	$981,554.09	$288,897.87	$288,897.87	$572,198.76	$572,198.76	1
2	$4,907,770.44		$288,897.87	$277,786.41	$568,467.43	$1,140,666.20	2
3	$4,907,770.44		$288,897.87	$267,102.32	$563,458.49	$1,704,124.69	3
4	$4,907,770.44		$288,897.87	$256,829.16	$557,203.21	$2,261,327.90	4
5	$4,907,770.44		$288,897.87	$246,951.11	$549,741.23	$2,811,069.14	5
6	$4,907,770.44		$288,897.87	$237,452.99	$541,120.13	$3,352,189.26	6
7	$4,907,770.44		$288,897.87	$228,320.18	$531,394.91	$3,883,584.17	7
8	$4,907,770.44		$288,897.87	$219,538.64	$520,627.44	$4,404,211.61	8
9	$4,907,770.44		$288,897.87	$211,094.84	$508,885.77	$4,913,097.38	9
10	$4,907,770.44		$288,897.87	$202,975.81	$496,243.42	$5,409,340.80	10
11	$4,907,770.44		$288,897.87	$195,169.05	$482,778.62	$5,892,119.42	11
12	$4,907,770.44		$288,897.87	$187,662.55	$468,573.47	$6,360,692.89	12
13	$4,907,770.44		$288,897.87	$180,444.76	$453,713.13	$6,814,406.02	13
14	$4,907,770.44		$288,897.87	$173,504.58	$438,284.95	$7,252,690.97	14
15	$4,907,770.44		$288,897.87	$166,831.32	$422,377.60	$7,675,068.57	15

16	**$4,907,770.44**		**$288,897.87**	**$160,414.73**	**$406,080.24**	**$8,081,148.81**	**16**
17	**$4,907,770.44**		**$288,897.87**	**$154,244.94**	**$389,481.68**	**$8,470,630.49**	**17**
18	**$4,907,770.44**		**$288,897.87**	**$148,312.44**	**$372,669.57**	**$8,843,300.06**	**18**
19	**$4,907,770.44**		**$288,897.87**	**$142,608.11**	**$355,729.64**	**$9,199,029.70**	**19**
20	**$4,907,770.44**		**$288,897.87**	**$137,123.19**	**$338,745.02**	**$9,537,774.71**	**20**
21	**$4,907,770.44**		**$0.00**	**$0.00**	**$321,795.52**	**$9,859,570.23**	**21**
22	**$4,907,770.44**		**$0.00**	**$0.00**	**$304,957.11**	**$10,164,527.34**	**22**
23	**$4,907,770.44**		**$0.00**	**$0.00**	**$288,301.36**	**$10,452,828.71**	**23**
24	**$4,907,770.44**		**$0.00**	**$0.00**	**$271,895.01**	**$10,724,723.71**	**24**
25	**$4,907,770.44**		**$0.00**	**$0.00**	**$255,799.58**	**$10,980,523.29**	**25**
26	**$4,907,770.44**		**$0.00**	**$0.00**	**$240,071.10**	**$11,220,594.39**	**26**
27	**$4,907,770.44**		**$0.00**	**$0.00**	**$224,759.90**	**$11,445,354.29**	**27**
28	**$4,907,770.44**		**$0.00**	**$0.00**	**$209,910.45**	**$11,655,264.74**	**28**
29	**$4,907,770.44**		**$0.00**	**$0.00**	**$195,561.33**	**$11,850,826.07**	**29**
30	**$4,907,770.44**		**$0.00**	**$0.00**	**$181,745.20**	**$12,032,571.27**	**30**

Table 6.8

Poly-crystalline NPV and Breakeven at $0.1006/kWh (No Transformer – for UGA)

T2-UDTA - TO SELL							
		Discount Rate (%) =	0.04	Electricity Price ($) =	0.1066	Present Value of All Costs =	$4,634,250.18
Year	Total Net Cost ($)	Down Payment ($)	Loan Payment ($)	PV Loan Payment ($)	PV Gross Benefits ($)	PV Gross Benefits to date ($)	Breakeven
1	$4,490,552.50	$898,110.50	$264,338.17	$264,338.17	$537,843.35	$537,843.35	1
2	$4,490,552.50		$264,338.17	$254,171.32	$532,408.01	$1,070,251.36	2
3	$4,490,552.50		$264,338.17	$244,395.50	$523,899.68	$1,594,151.03	3
4	$4,490,552.50		$264,338.17	$234,995.67	$512,449.39	$2,106,600.42	4
5	$4,490,552.50		$264,338.17	$225,957.38	$498,238.69	$2,604,839.11	5
6	$4,490,552.50		$264,338.17	$217,266.71	$481,494.90	$3,086,334.02	6
7	$4,490,552.50		$264,338.17	$208,910.30	$462,485.00	$3,548,819.02	7
8	$4,490,552.50		$264,338.17	$200,875.28	$441,508.51	$3,990,327.53	8
9	$4,490,552.50		$264,338.17	$193,149.31	$418,889.56	$4,409,217.09	9
10	$4,490,552.50		$264,338.17	$185,720.49	$394,968.40	$4,804,185.49	10
11	$4,490,552.50		$264,338.17	$178,577.40	$370,092.84	$5,174,278.33	11
12	$4,490,552.50		$264,338.17	$171,709.04	$344,609.65	$5,518,887.98	12
13	$4,490,552.50		$264,338.17	$165,104.84	$318,856.55	$5,837,744.53	13
14	$4,490,552.50		$264,338.17	$158,754.66	$293,154.71	$6,130,899.24	14
15	$4,490,552.50		$264,338.17	$152,648.71	$267,802.31	$6,398,701.55	15

16	$4,490,552.50		$264,338.17	$146,777.60	$243,069.07	$6,641,770.62	16
17	$4,490,552.50		$264,338.17	$141,132.31	$219,192.06	$6,860,962.67	17
18	$4,490,552.50		$264,338.17	$135,704.14	$196,372.75	$7,057,335.43	18
19	$4,490,552.50		$264,338.17	$130,484.75	$174,775.39	$7,232,110.82	19
20	$4,490,552.50		$264,338.17	$125,466.11	$154,526.53	$7,386,637.35	20
21	$4,490,552.50		$0.00	$0.00	$135,715.78	$7,522,353.12	21
22	$4,490,552.50		$0.00	$0.00	$118,397.55	$7,640,750.67	22
23	$4,490,552.50		$0.00	$0.00	$102,593.65	$7,743,344.32	23
24	$4,490,552.50		$0.00	$0.00	$88,296.55	$7,831,640.87	24
25	$4,490,552.50		$0.00	$0.00	$75,473.09	$7,907,113.96	25
26	$4,490,552.50		$0.00	$0.00	$64,068.60	$7,971,182.56	26
27	$4,490,552.50		$0.00	$0.00	$54,011.00	$8,025,193.55	27
28	$4,490,552.50		$0.00	$0.00	$45,214.94	$8,070,408.49	28
29	$4,490,552.50		$0.00	$0.00	$37,585.74	$8,107,994.22	29
30	$4,490,552.50		$0.00	$0.00	$31,023.01	$8,139,017.23	30

Table 6.9

Thin-film NPV and Breakeven at $0.1006/kWh (No Transformer – for UGA)

T3-UDTA - TO SELL							
		Discount Rate (%) =	0.04	Electricity Price ($) =	0.1066	Present Value of All Costs =	$4,938,626.96
Year	Total Net Cost ($)	Down Payment ($)	Loan Payment ($)	PV Loan Payment ($)	PV Gross Benefits ($)	PV Gross Benefits to date ($)	Breakeven
1	$4,785,491.24	$957,098.25	$281,699.86	$281,699.86	$411,100.67	$411,100.67	1
2	$4,785,491.24		$281,699.86	$270,865.25	$408,133.31	$819,233.97	2
3	$4,785,491.24		$281,699.86	$260,447.35	$403,968.15	$1,223,202.13	3
4	$4,785,491.24		$281,699.86	$250,430.15	$398,638.72	$1,621,840.85	4
5	$4,785,491.24		$281,699.86	$240,798.22	$392,188.75	$2,014,029.60	5
6	$4,785,491.24		$281,699.86	$231,536.75	$384,671.55	$2,398,701.15	6
7	$4,785,491.24		$281,699.86	$222,631.49	$376,149.30	$2,774,850.45	7
8	$4,785,491.24		$281,699.86	$214,068.74	$366,692.18	$3,141,542.63	8
9	$4,785,491.24		$281,699.86	$205,835.33	$356,377.41	$3,497,920.04	9
10	$4,785,491.24		$281,699.86	$197,918.58	$345,288.18	$3,843,208.22	10
11	$4,785,491.24		$281,699.86	$190,306.33	$333,512.53	$4,176,720.74	11
12	$4,785,491.24		$281,699.86	$182,986.86	$321,142.16	$4,497,862.90	12
13	$4,785,491.24		$281,699.86	$175,948.90	$308,271.28	$4,806,134.18	13
14	$4,785,491.24		$281,699.86	$169,181.63	$294,995.34	$5,101,129.52	14
15	$4,785,491.24		$281,699.86	$162,674.65	$281,409.89	$5,382,539.41	15

16	$4,785,491.24		$281,699.86	$156,417.93	$267,609.44	$5,650,148.86	16
17	$4,785,491.24		$281,699.86	$150,401.86	$253,686.34	$5,903,835.20	17
18	$4,785,491.24		$281,699.86	$144,617.17	$239,729.79	$6,143,564.99	18
19	$4,785,491.24		$281,699.86	$139,054.97	$225,824.91	$6,369,389.90	19
20	$4,785,491.24		$281,699.86	$133,706.70	$212,051.93	$6,581,441.83	20
21	$4,785,491.24		$0.00	$0.00	$198,485.50	$6,779,927.33	21
22	$4,785,491.24		$0.00	$0.00	$185,194.07	$6,965,121.41	22
23	$4,785,491.24		$0.00	$0.00	$172,239.46	$7,137,360.87	23
24	$4,785,491.24		$0.00	$0.00	$159,676.52	$7,297,037.39	24
25	$4,785,491.24		$0.00	$0.00	$147,552.89	$7,444,590.28	25
26	$4,785,491.24		$0.00	$0.00	$135,908.98	$7,580,499.26	26
27	$4,785,491.24		$0.00	$0.00	$124,777.93	$7,705,277.20	27
28	$4,785,491.24		$0.00	$0.00	$114,185.77	$7,819,462.97	28
29	$4,785,491.24		$0.00	$0.00	$104,151.66	$7,923,614.63	29
30	$4,785,491.24		$0.00	$0.00	$94,688.16	$8,018,302.78	30

Table 6.10

Electricity Price, Breakeven, PV of Benefits, and NPV for T1, T2 and T3 at $0.1066 (No Transformer – for UGA)

Nominal Price Growth Rate (%) under PV Gross Benefits ($)	T1-UDTA - FOR UGA			
	Year 2015 Price ($/kWh)	Breakeven (year)	PV of Gross Benefits for 30 years ($)	NPV for 30 years ($)
0.10% (0.001)	0.1066	12	$ 8,356,076	$ 3,291,257
0.50% (0.005)	0.1066	11	$ 8,689,863	$ 3,625,044
1.00% (0.010)	0.1066	11	$ 9,135,750	$ 4,070,931
1.50% (0.015)	0.1066	11	$ 9,616,159	$ 4,551,340
2.00% (0.020)	0.1066	10	$ 10,134,234	$ 5,069,414
2.50% (0.025)	0.1066	10	$ 10,693,424	$ 5,628,605
3.00% (0.030)	0.1066	10	$ 11,297,520	$ 6,232,701
3.56% (0.0356)	0.1066	10	$ 12,032,571	$ 6,967,752
4.00% (0.040)	0.1066	10	$ 12,657,481	$ 7,592,662
4.50% (0.045)	0.1066	9	$ 13,422,940	$ 8,358,120
5.00% (0.050)	0.1066	9	$ 14,252,575	$ 9,187,755
T1-UDTA Present Value of Costs ($)				$5,064,819

Nominal Price Growth Rate (%) under PV Gross Benefits ($)	T2-UDTA - FOR UGA			
	Year 2015 Price ($/kWh)	Breakeven (year)	PV of Gross Benefits for 30 years ($)	NPV for 30 years ($)
0.10% (0.001)	0.1066	12	$ 6,151,106	$ 1,516,856
0.50% (0.005)	0.1066	12	$ 6,340,645	$ 1,706,395
1.00% (0.010)	0.1066	12	$ 6,590,554	$ 1,956,304
1.50% (0.015)	0.1066	12	$ 6,855,907	$ 2,221,657
2.00% (0.020)	0.1066	11	$ 7,137,875	$ 2,503,625
2.50% (0.025)	0.1066	11	$ 7,437,732	$ 2,803,482
3.00% (0.030)	0.1066	10	$ 7,756,860	$ 3,122,610
3.56% (0.0356)	0.1066	10	$ 8,139,017	$ 3,504,767
4.00% (0.040)	0.1066	10	$ 8,459,054	$ 3,824,804
4.50% (0.045)	0.1066	10	$ 8,845,519	$ 4,211,268
5.00% (0.050)	0.1066	9	$ 9,258,074	$ 4,623,823
T2-UDTA Present Value of Costs ($)				$4,634,250

Nominal Price Growth Rate (%) under PV Gross Benefits ($)	T3-UDTA - FOR UGA			
	Year 2015 Price ($/kWh)	Breakeven (year)	PV of Gross Benefits for 30 years ($)	NPV for 30 years ($)
0.10% (0.001)	0.1066	20	$ 5,677,957	$ 739,330
0.50% (0.005)	0.1066	19	$ 5,892,646	$ 954,019
1.00% (0.010)	0.1066	17	$ 6,178,643	$ 1,240,016
1.50% (0.015)	0.1066	17	$ 6,485,835	$ 1,547,208
2.00% (0.020)	0.1066	16	$ 6,816,089	$ 1,877,462
2.50% (0.025)	0.1066	15	$ 7,171,449	$ 2,232,822
3.00% (0.030)	0.1066	15	$ 7,554,159	$ 2,615,532
3.56% (0.0356)	0.1066	14	$ 8,018,303	$ 3,079,676
4.00% (0.040)	0.1066	14	$ 8,411,685	$ 3,473,058
4.50% (0.045)	0.1066	13	$ 8,892,146	$ 3,953,519
5.00% (0.050)	0.1066	13	$ 9,411,294	$ 4,472,667
T3-UDTA Present Value of Costs ($)				$4,938,626.96

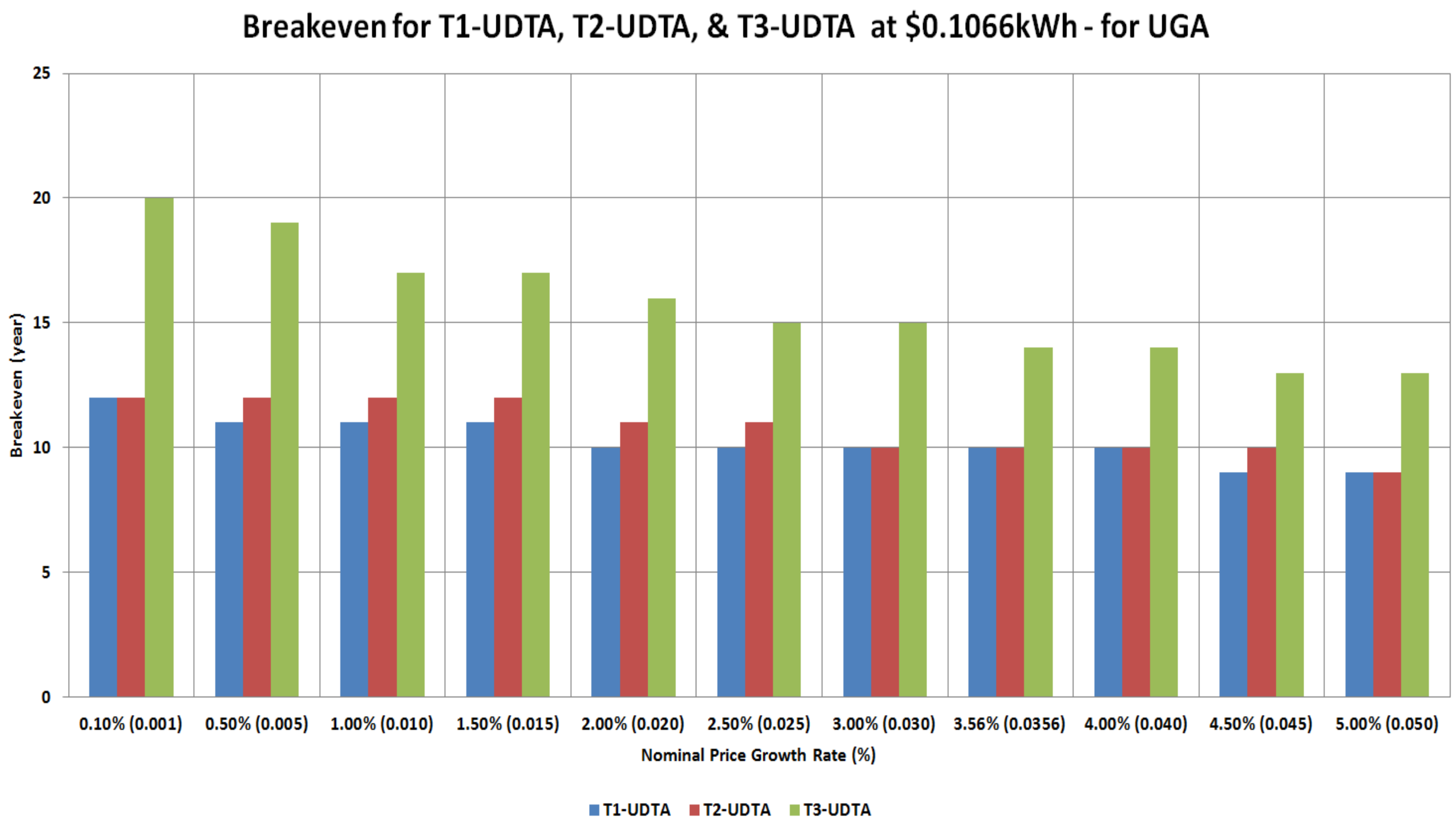


Figure 6.3 Breakeven for T1, T2, & T3 at $0.1006/kWh (No Transformer – for UGA)

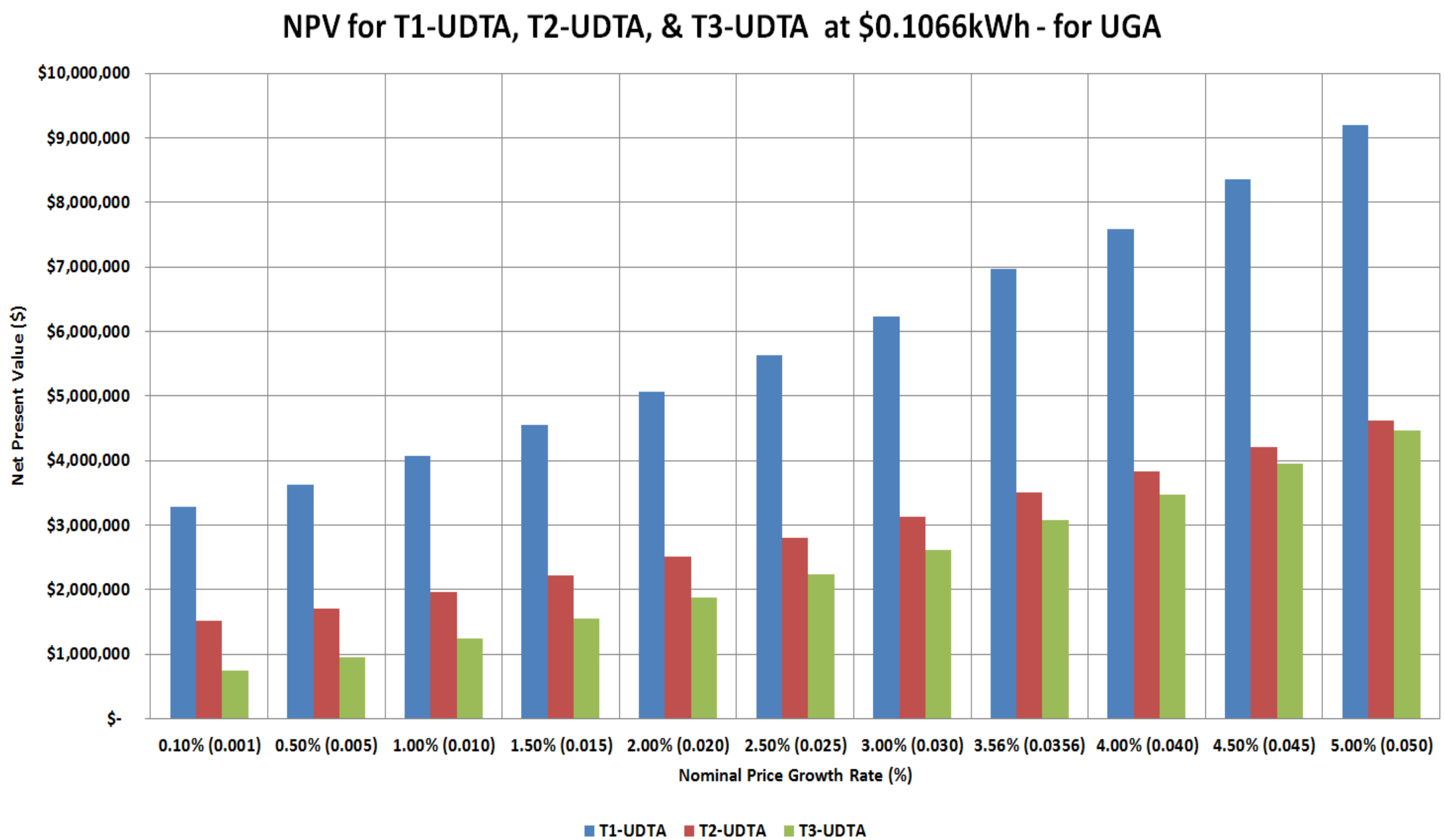


Figure 6.4 Net Present Values for T1, T2, & T3 at $0.1066/kWh (No Transformer – for UGA)

CHAPTER 7

(CONCLUSION)

The main objective in this paper is to evaluate the net present value of installing a photovoltaic (PV) system at the University of Georgia and to estimate the contribution such a system would make toward meeting UGA's CO2 emissions reduction target. While there are many different types of renewable energy available, this paper analyzes three distinct PV panels (mono-crystalline, poly-crystalline and thin-film) across three different solar tracking devices (fixed, single axis tracking, and double axis tracking). Both state and federal renewable energy programs are included in the analysis. Specific objectives of the study are to:

- Determine the degree to which a 10-acre, ground-installed PV system in Athens, GA, will help meet all the energy related criteria listed in the UGA 2020 Strategic plan.

  The UGA 2020 strategic plan is to reduce emissions by 20 percent from renewables or fossil fuels relative to baseline of 2010 (Goal 1). And as discussed in section 5.7, scenario A (yes transformer – to sell) only reached 1.77% and scenario B (no transformer – for UGA) reached only 1.82%. Therefore, it shows that the first goal can't meet the criteria of 20%. Thinking on the positive side, however, if we were to satisfy the goal for all 20%, we would require 11 more lands (10 acres) that consist of PV generating system.

Moreover, goal (4) from the 2020 UGA strategic plan is to increase the generation of energy from renewable sources to 10 percent relative to baseline of 2010. And after the same calculation as goal (1), we could conclude that only 1.82% (For UGA) and 1.77% (To SELL) of solar energy from renewable sources could be generated. In order to meet goal (4), we would need at least six more sites, which is equivalent to 60 acres of land.

- Identify key parameters and design features that determine whether the system has a positive net present value over its lifetime. Also, estimate the number of years it takes for the system to realize a positive net present value under different parameterizations.

Under the assumption that the running period is between year 2015 and 2045, installing solar panels can't meet the break-even point by year 2020 for both scenario A (requiring transformer – to sell) and B (requiring no transformer – for UGA). However, if Georgia Power agrees to buy the electricity from UGA (scenario A) at a price greater than 0.07 cent/kWh, 0.09 cent/kWh, and 0.10 cent/kWh for UDTA (T1, T2, and T3), each module made a total profit of $195,443, $354,522, and $169,796 respectively in the period of 30 years. For the break-even points, T1-UDTA, T2- UDTA, and T3- UDTA reached at the end of year 27, year 19, and year 26.

On the other hand, for scenario B (requiring no transformer – for UGA), we used $0.1066/kWh (10.66Cents/kWh) as fixed end-use average retail electricity price. And when the nominal price growth rate was set at 0.10% (1.001), all the module types (UDTA) made a net profit of $3,291,257, $1,516,856, and $739,330 in the period of 30 years. The breakeven years for the three modules were year 12, year 12 and year 20 respectively.

- Determine whether it will be more cost-effective for UGA to use their own created electricity or create positive financial returns on PV investment by selling it back to Georgia Power.

When we compared scenario A and B, it would be more cost-effective for UGA to use their own created electricity rather than selling it back to Georgia Power (GP) because scenario B (requiring no transformer – for UGA) made further more profit. Even though GP decides to increase their current fixed average electricity buyback price set higher than 0.04cents/kWh, it is most likely impractical for them because GP is likely to lose money.

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APPENDIX A

Size for the Different Module, Array, and Site

	Maximum # of Module Length (m) Available per Array	**Actual # of Module Length Available per Array**	**Maximum # of Module Width (m) Available per Array**	**Actual # of Module Width Available per Array**	**Total # of Modules Available per Array**
T1-TFA	1.00	1	4.00	4	4
T2-TFA	1.00	1	4.00	4	4
T3-TFA	1.38	1	6.67	6	6
T1-TSTA	6.00	6	2.97	3	18
T2-TSTA	6.00	6	2.97	3	18
T3-TSTA	8.28	8	4.95	5	40
T1-UDTA	4.00	4	6.20	6	24
T2-UDTA	4.00	4	6.20	6	24
T3-UDTA	5.50	5	10.33	10	50
	Maximum # of Array Length (m) Available per Site	**Actual # of Array Length Available per Site**	**Maximum # of Array Base (m) Available per Site**	**Actual # of Array Base Available per Site**	**Total # of Arrays Available per Site**
T1-TFA	110.48	110	17.71	17	1,870
T2-TFA	110.48	110	17.71	17	1,870
T3-TFA	110.48	110	17.71	17	1,870
T1-TSTA	77.85	77	7.16	7	539

T2-TSTA	77.85	77	7.16	7	539
T3-TSTA	77.85	77	7.16	7	539
T1-UDTA	42.96	43	11.44	11	473
T2-UDTA	42.96	43	11.44	11	473
T3-UDTA	42.96	43	11.44	11	473
Note: Without (W/O), With (W/), Tilted Fixed (No-Axis) Array (TFA), Tilted Single-Axis Tracking Array (TSTA), Universal Double-Axis Tracking Array (UDTA), South to North (S to N), East to West (E to W), New Solar Array Width is the front of first array to front of second array					

APPENDIX B

Derate Factors Used

Component of Derate Factors	Range	Definition
PV module nameplate DC (a)	0.800 – 1.050 (0.950)	The nameplate rating loss accounts for the accuracy of the manufacturer's nameplate rating. Field measurements of the electrical characteristics of photovoltaic modules in the array may show that they differ from their nameplate rating. A nameplate rating loss of 5% indicates that testing yielded power measurements at STC that were 5% less than the manufacturer's nameplate rating.
Transformer & Transmission Line (b)	0.980 – 0.990 (0.985)	Discussed more in the later section 5.3.4.5
Mismatch (c)	0.970 – 0.995 (0.980)	Electrical losses due to slight differences caused by manufacturing imperfections between modules in the array that cause the modules to have slightly different current-voltage characteristics.
Diodes and connections (d)	0.990 – 0.997 (1.00)	Resistive losses in electrical connectors in the system.
DC wiring (e)	0.970 – 0.990 (0.980)	Resistive losses in the DC wires connecting modules, inverters, and other parts of the system.
AC wiring (f)	0.980 – 0.993 (0.990)	Resistive losses in the AC wires connecting modules, inverters, and other parts of the system.
Soiling (dirt, snow) (g)	0.300 – 0.995 (0.995)	Losses due to dirt, snow, and other foreign matter on the surface of the PV module that prevent solar radiation from reaching the cells.

System availability (h)	0.000 – 0.995 (0.980)	Reduction in the system's output caused by both scheduled and unscheduled system shut down for maintenance, grid outages, and other operational factors.
Shading (Reduction Factor) (i)	0.000 – 1.000 (1.000)	Reduction in the incident solar radiation from shadows caused by objects near the array such as buildings or trees, or by self-shading for fixed arrays or arrays with two-axis tracking.
Light-Induced Degradation (j)	0.980 – 0.990 (0.980)	Effect of the reduction in the array's power during the first few months of its operation caused by light-induced degradation of photovoltaic cells.
Age (k)	0.700 – 1.000 (1.000)	Effect of weathering of the photovoltaic modules on the array's performance over time.
Overall DC to AC DF	0.854 0.842	W/O Transformer = a × b × c × d × e × f × g × h × i × j × k = 0.854 W Transformer (leaving out b) = a × b × d × e × f × g × h × i × j × k = 0.842

Source: NREL PVWATTS, 2014; Jacuqes, 2013

APPENDIX C

Technical and Price Specification for the Balance of System (BoS)

Model Input	Definition
Transformer	Price: $15,000 Model: 15kv Step-up power transformer Details: Each monitor supports voltage capacity of 40,000kVA (38,000kWh) and lose 3% of the energy from the DC System.
Monitor	Price: $508.98 Details: Each monitor can support the size of 1,000kW inverter.
Meters	While PV meter helps to keep track of how much energy is produced by the solar panels, net meter is used to keep track of energy flowing to and from your utility provider (Pacific Power, 2014). Price: $429.00 Details: Can hold up to 12,500 Watts (12.5kW)
Combiner Box	Name: Circuit Combiner Box Model: MNPV16 Holds Output of: 100,000 W (100kW) Price: $319.20
Wiring	Name: Aluminum MC Cable / Model Number: 68584201 Outside / Inside: Aluminum / Copper Length: 250ft = 76.2m Price: $280
AC Main Breaker	Name: Schneider Electric Model: Square D QO140M200 Convertible Main Breaker Load Center Details: requires only 1 for each system Price: $1,011.46

Source for Transformer: Alibaba, 2014
Source for Monitor: Lowes, 2015
Source for Meters: MW&S, 2015
Source for Combiner Box: Solar panel store, 2015
Source for Wiring: Lowes, 2015
Source for AC Main Breaker: Saving lots, 2015