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A Novel Approach For Evaluating The Impact Of Fixed Variables On Photovoltaic (pv) Solar Installations Using Enhanced Meta Data Analysis Among Higher Education Institutions In The United States

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A NOVEL APPROACH FOR EVALUATING THE IMPACT OF FIXED VARIABLES ON PHOTOVOLTAIC (PV) SOLAR INSTALLATIONS USING ENHANCED META DATA ANALYSIS AMONG HIGHER EDUCATION INSTITUTIONS IN THE UNITED STATES

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Dedication

This dissertation is dedicated to my beloved mother, the late Mrs. Maria Navarro De Hoyos and my esteemed father, the late Mr. Esteban De Hoyos Sr., both native Texans who believed their children's life would be enriched through education. I have lived an extraordinary life because of the incredible sacrifices they made to ensure that my brother and sisters would have the opportunity to receive an advanced education. Their devotion to our family was significant and honorable. The first and most important teachers in life are our parents. I am who I am, because how they raised me, how I saw them live their daily lives and how much they loved me. For the sacrifices they made and their selfless willingness to encourage me to believe that any dream was possible, including obtaining this prestigious and significant degree, I am forever grateful. Any and all of my accomplishments are in tribute to their legacy and how they lived their life - with honesty, respect and integrity. *I am so very proud to be their daughter.*

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by

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I graduated with my undergraduate degree at the age of 21. I received my Master's degree at the age of 36. And at the age of 58 and with the completion of this degree, I have completed my "unfulfilled" dream. *And for this, I am extremely grateful*.

Abstract

The global demand for electric energy has continuously increased over the last few decades. Some mature, alternative generation methods are wind, power, photovoltaic panels, biogas and fuel cells. In order to find alternative sources of energy to aid in the reduction of our nation's dependency on non-renewable fuels, energy sources include the use of solar energy panels. The intent of these initiatives is to provide substantial energy savings and reduce dependence on the electrical grid and net metering savings during the peak energy-use hours.

The focus of this study explores and provides a clearer picture of the adoption of solar photovoltaic technology in institutions of higher education. It examines the impact of different variables associated with a photovoltaic installation in an institutions of higher education in the United States on the production generations for universities. Secondary data was used with permission from the Advancement of Suitability in Higher Education (AASHE). A multiple regression analysis was performed to determine the impact of different variables on the energy generation production. A Meta Data transformation analysis offered a deeper investigation into the impact of the variables on the photovoltaic installations.

Although a review of a significant number of journal articles, dissertations and thesis in the area of photovoltaic solar installations are available, there were limited studies of actual institutions of higher education with the significant volume of institutions. However a study where the database included a significant number of data variables is unique and provides a researcher the opportunity to investigate different facets of a solar installation. The data of the installations ranges from 1993 - 2015. Included in this observation are the researcher's experience both in the procurement industry and as a team member of a solar institution of higher education in the southern portion of the United States.

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Chapter 1: Introduction To Research

There are types of several developed, alternative generation methods such as wind, power, photovoltaic panels, biogas and fuel cells. Among them photovoltaic panels are the most accepted and most convenient methods that can be used. This type of technology of sustainable energy has been identified as a form of renewable energy utilizing funding allocated by the United State government.

From all the projects undertaken by university institutions, initiatives related to conserve energy on campus are the most preferred. It is perhaps because "campus energy costs typically constitute 30% of a university's total operations and maintenance budget" (Ayres & Frankl, 1998). Energy audits, energy-efficient lighting retrofit or upgrade, buildings insulation, high- efficient equipment installation and maintenance, movement sensors and timers installation, energy facts cultural awareness, course scheduling, solar panel installation, the use of wind and geothermal alternative sources of energy, energy use policy, and green computing are some of the practices used to fulfill the goals of this alternative. As a result, numerous universities have saved many dollars in energy cost (Prugh, Costanza & Daly, 2000).

University buildings cover a whole range of styles and dates, from older period style buildings dating back to early establishments, to modern builds incorporating the latest in style and functionality. Some new build University campuses will already have considered and have incorporated aspects of eco-building into their designs, but there are many buildings which have been built over the past few decades which do not yet make the most of solar energy. Nearly all Universities own modern buildings that would be suitable and viable candidates for installing solar

paneling. If a campus building has a good sized area of roof space, it has a wasted potential to use this space to generate solar electricity through the use of photovoltaic solar panels installations.

The American Recovery and Reinvestment Act of 2009 (ARRA) (Tonn, B., Hawkins, B., & Rose, E. 2016). commonly referred to as the Stimulus or The Recovery Act, was a stimulus package enacted by the 111th United States Congress in February 2009 and signed into law on February 17, 2009, by President Barack Obama. In Order to respond to the Great Recession, the primary objective for ARRA was to save and create jobs almost immediately. Secondary objectives were to provide temporary relief programs for those most affected by the recession and invest in infrastructure, education, health, and renewable energy. (American Recovery and Reinvestment Act of 2009 (2016, April 13).

The approximate cost of the economic stimulus package was estimated to be $787 billion at the time of passage, later revised to $831 billion between 2009 and 2019 (Kwon, 2012).

As a result of this incentive, many institutions throughout the United States perceived this as an opportunity to contribute to the overall commitment to aid in the reduction of global greenhouse emissions while obtaining renewable sources of energy.

Figure 1.1 represents the thought process of how this dissertation is structured.

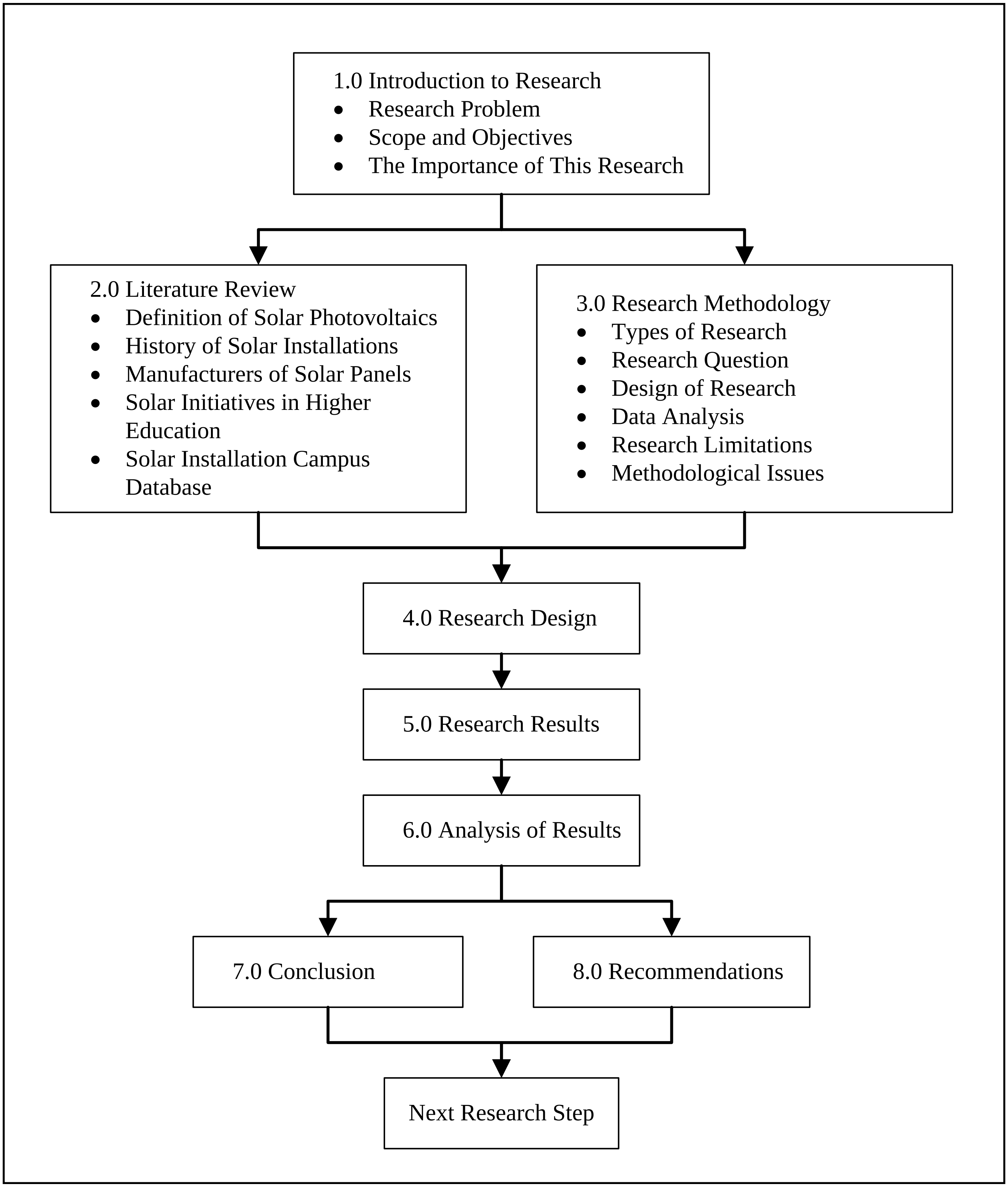

Figure 1.1: Thought Diagram for the Development of the Proposal

To better understand the concept of how the implementation of a solar installation has an impact on the annual productivity, this research conducted a statistical analysis of actual photovoltaic solar installations on college campuses throughout the United States. Further details about the background of this study and the analytical technique used to conduct this research will be addressed in Chapter 2 and 3 respectively. In this chapter, a brief history and background research problem, research scope and limitations, importance of this research, projected outputs and desired outcomes are presented (Figure 1.2). This chapter also specifies the research purpose and objectives. The assumptions concerns and benefits will also be discussed. Chapter 2 deals with the body of knowledge upon which the study will be built. It commences with a historical review of the solar industry, the impact of the operational components of the actual solar panel module on the annual production in kilowatt hours, a review of the trend of the photovoltaic solar panel manufacturing industry and the impact of the installations on college campuses throughout the United States. Chapter 3 primarily deals with the research methodology tests, acceptability criteria and treatment of data. Chapter 4 will present the findings of the study and Chapter 5 will summarize the results and conclusion of this study.

A thought diagram for the development of Chapter 1 is presented in Figure 1.2.

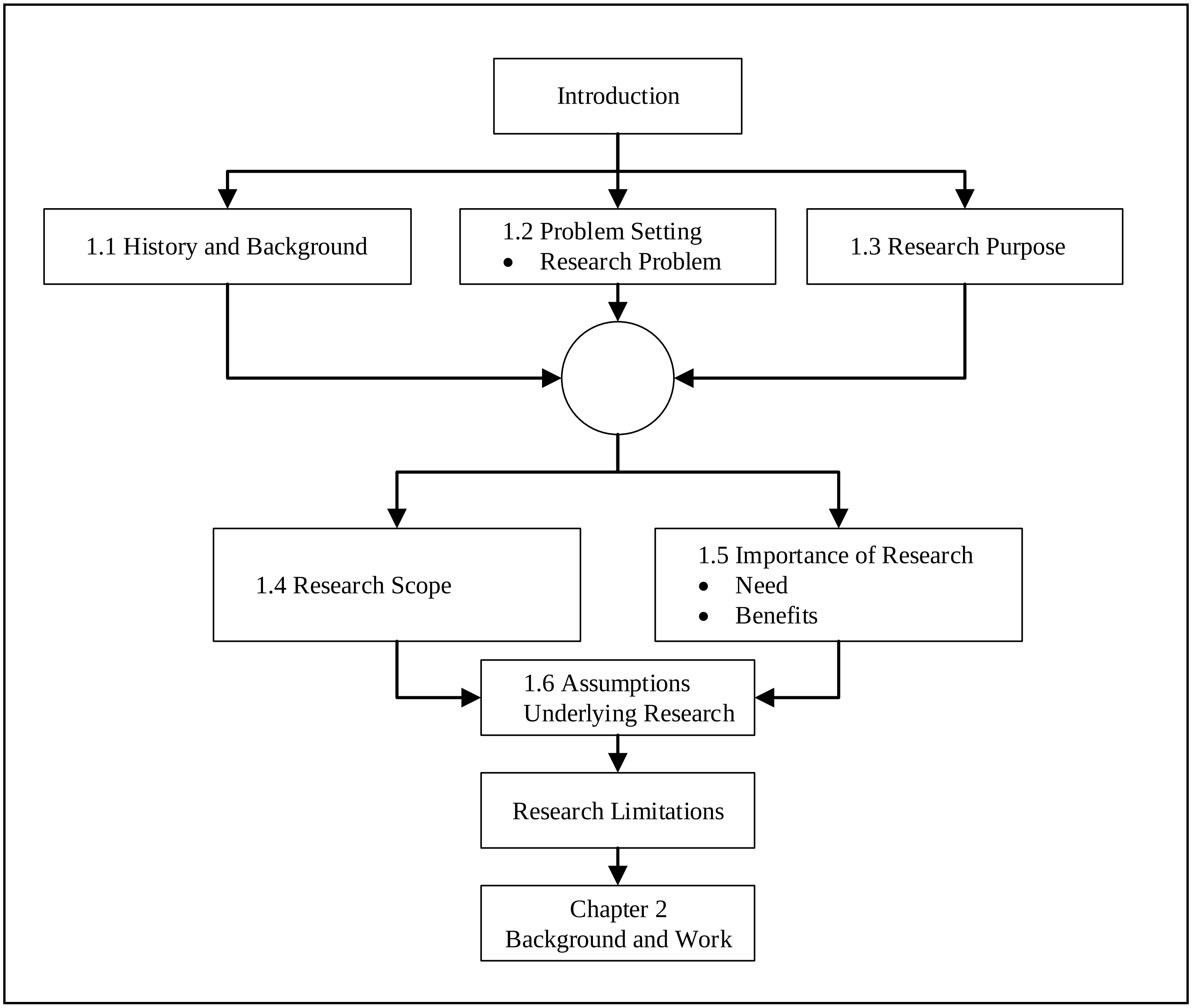

Figure 1.2: Thought Diagram for the Logical Development of Chapter 1.

1.1 History and Background

Solar energy is clean and is abundantly available. Solar technologies use the sun to provide heat, light, electricity, etc. for industrial applications. With the alarming rate of depletion of the major conventional energy resources such as coal, petroleum and natural gas, coupled with the environmental degradation caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy resources that would power the future adequately without degrading the environment through greenhouse gas emission. The energy potential of the sun is infinite, but despite this limitless solar energy resource, harvesting it is a challenge mainly because of the limited efficiency of the array cells. The best conversion efficiency of most commercially available solar cells is in the range 10- 20% (Green, 1982) (Green, Emery, Hishikawa, Warta & Dunlop, 2013).

Although recent breakthrough in the technology of solar cells shows significant improvement but the fact that the maximum solar cell efficiency still falls in the less than 20% range shows there is enormous room for improvement. The purpose of this research was to examine the impact of different variables associated with a photovoltaic installation in an institutions of higher education in the United States on the production generation for each respective institution.

1.2 Research Problem Setting

There is an infinite variety of possible problem settings in which to address the subject of annual photovoltaic efficiency on campus installations in the United States. This type of annual photovoltaic efficiency itself has been well-defined, investigated, and studied in a variation of ways and approaches. There are different methods to addressing photovoltaic efficiency on

campus installations. All lend and contribute to the understanding of photovoltaic efficiency in this environment. It is the view, in this research that any approach to the study of photovoltaic efficiency on any campus in the US needs to incorporate, or at least understand, each photovoltaic efficiency model so as to render a more representative view of the subject. Even though this research is specifically from an engineering perspective, other academic approaches are studied and reviewed to give this work a through approach.

1.2.1 Research Problem

The initial cost of a photovoltaic system can be directly offset by government incentives at the federal, state and even at the local level. The savings earned from solar production depends on the amount of power produced on site and the cost of electricity and the cost avoidance achieved over a period of time. Installation costs and energy production can be used to calculate the payback time for a photovoltaic system. Since the price of electricity will predictably rise over time, maybe substantially as carbon emissions are we penalized and global peak oil and North American peak natural gas production are approached, it is practical to assume an inflation rate for the price of conventional electricity when calculating the payback of photovoltaic systems? System payback or break even time, is the length of time it takes for the project's initial cost to be recovered through energy savings. The definitions and subsequent specifications of photovoltaic efficiency, themselves are addressed in this research. The works of Ayres (1998), Pearce (2002), Prugh (2000) and Fan (2014) are based heavily on the attempt to understand and thus, better design Photovoltaic efficiency. The research problem here is: What is the difference in the Photovoltaic efficiency level of a campus installation when compared to several states in different areas of the United States using different variables of a solar installation, taking into consideration the different types

of mounting installations and implementation initial investment costs? This research will investigate the photovoltaic efficiency produced by the top ten states with the highest number of installations in institutions of higher education un the United States as identified by the Association for Advancement of Sustainability in Higher Education (AASHE) during the period from 1993 until 2015 with the highest concentration between 2010 and 2011.

1.3. Research Purpose

The purpose of this research is to attempt to better understand the concept of photovoltaic efficiency of campus installation from 1993 to 2015 across institution of higher education in the United States. To do this, extensive literature review, analysis of photovoltaic efficiency were undertaken with secondary data obtained through permission from a public website (see Appendix B). This literature review ventures out of the normal realm of the environmental engineering literature because the subject area requires it. Secondly this document presents a photovoltaic efficiency concept on which the research is based.

1.4 Scope of This Research

The scope of this research is driven by the need in the field of engineering to better understand what impacts photovoltaic efficiency on campus installations when compared to institutions of higher education throughout campus locations throughout the United States. We need to review what we know about photovoltaic efficiency from a variety of possible and logical avenues, and then funnel this knowledge into a comprehensive conception of photovoltaic efficiency in different campus installations across the United States when comparing different components which have an impact on the efficiency. This would include but not limited to: location of installation, type of panel, type of inverter, type of mount and the cost associated with

the implementation. That, is bring together as much as is known of photovoltaic efficiency from the relevant subject area and portray both a working set of definitions and a conceptual model that are scientifically researchable from an engineering standpoint.

1.4.1 Research Questions

The general questions addressed by this research is:

- Have the recipients of these federally funded monies been good stewards of federal funds as required?
- What was the impact of the different quantitative and qualitative variables on the efficiency of the solar installations? (i.e. state, institution, year, location, installer, panels, inverter type, installation costs, capacity, annual production, installation mounting type, installation panel type, NOP (number of panels) and efficiency).

These primary objectives of the study included the following:

- **Objective One -** Examined trends via data analysis by developing a statistical model which included the impact of cost on the output of energy annual production for the purpose of prediction through multiple regression analysis.
- **Objective Two** - Examined Cost Effectiveness Analysis (CAE) by comparing the installations costs and production outcome with the other independent variables through multiple regression analysis. Efficiency was calculated by as a percentage ratio with the production (kWh) divided by the implementation cost ($).
- **Objective Three** – Examined the transformation of the dataset through Meta-data analysis to develop a statistical model which will perform a deeper dive into the secondary data to

determine other additional factors which may impact the output of energy annual production using frequency distribution and multiple regression analysis.

- **Objective 4** – Revision of initial proposed full predictive model. Once the initial model was examined, a statistical analysis was performed to investigate a re-coded variable (location) using multiple regression analysis.

There have been few empirical studies on the successful photovoltaic efficiencies in the implementation of a solar photovoltaic installation on institutions of higher education. Those studies will be discussed in the literature review in Chapter 2 of this dissertation.

The purpose of this research also considers two main points:

1) The application of a photovoltaic efficiency model from an environmental engineering standpoint to propose and test an application efficiency model.
2) To increase the knowledge and understanding of photovoltaic efficiency when compared across different institutions of higher education throughout the United States.

This study focused on the photovoltaic efficiency of different institutions of higher education across the United States. This entailed the monitoring of historical photovoltaic efficiency changes demonstrating the consistency of total photovoltaic efficiency in campus installations across the United States. Efficiency in photovoltaic solar panels is measured by the capability of a panel to convert sunlight into serviceable energy for human consumption. Knowing the efficiency of a panel is significant in order to select the accurate panels for a photovoltaic system. And lastly, efficiency was defined as the percent ratio of energy output (production) from the solar cell to the initial cost of implementation.

1.5 Importance of This Research

This research was significant because there is a current revenant and potential benefits to be derived from its completion.

The reason for conducting this research was multifaceted. First, it contributed to the body of knowledge, benefiting, researchers (in engineering as well as other related fields), practitioners (management professionals) and students of the subject matter. The way in which Photovoltaic efficiency was measured helps to determine the results. This contribution expands the body of knowledge by assisting in better understanding the concept of photovoltaic efficiency. Even crude photovoltaic indicators can advance photovoltaic efficiency performance, especially if their shortcomings are recognized and acknowledged. If progression improvement is sought and if efforts are made to compensate in analysis and interpretation in relation for limitations of the numbers themselves, an advancement is being made. This study was motivated by the prospect that many institutions will be compelled to continue to implement renewable energy initiatives that will aide in the global quest for alternative sources of energy. Although, the methodology is not new or revolutionary, the concept of photovoltaic efficiency comparisons between institutions of higher education throughout the United States is. The results obtained should provide a benchmark for other institutions and be seen as an opportunity to improve in the area of photovoltaic solar installations in institutions of higher education. Finally, this research benefits the field of environmental engineering by challenging us to re-evaluate the concept of the impact that different variable may have on photovoltaic efficiency.

1.5.1 Need of This Research

The need for this research is both theoretical and practical in nature. Photovoltaic efficiency is considered one of the most important elements in determining the success of a photovoltaic implementation on an institution of higher education. Today many universities are facing heavy pressure from an environmental perspective to seek alternative methods for renewable energy so they look to re-engineering, energy savings, and other programs to obtain these results. If changes are being made in an institution, there is a need to study how the institution is performing with respect to these new challenges. This information is then essential in developing ways to help institutions function at maximum efficiency and obtain the desired results.

1.5.2 Benefits of This Research

In the literature review, we will witness that although the concept of solar energy has been for the past several centuries, progressive developments in the materials utilized to manufacturer solar panels resulting in continue to be undertaken. This research will serve as a platform to continue to measure photovoltaic efficiencies as a result of these new developments. And the impact they will have on the measurement and contribution on photovoltaic efficiency as a form of renewable energy resulting in lower cost and savings to institutions throughout the United States.

1.6 Assumptions Underlying This Research

All research studies have implicit underlying assumptions. So as to assist the reader and the researcher to better comprehend the research to be undertaken, the assumptions for this research are as follows:

1.) The definition of the Photovoltaic efficiency has been developed from an extensive literature search and the researcher's observation of experience in a photovoltaic campus solar implementation.

2.) The complexity of a concept as photovoltaic efficiency can be operationally defined and modeled in such a way that is suitable for scientific and statistical analysis.

3.) The photovoltaic efficiency mathematical model which will be used is assumed to be a strong concept using definitions that are representative of photovoltaic efficiency.

4.) The use of data from one database of significant number of photovoltaic installations is representative of normal engineering practices.

1.7 Expected Research Outputs

This research will generate several outputs. Specifically, the outputs include an updated literature review of photovoltaic efficiency and the solar panel manufacturing industry. This literature review is an in-depth compilation of the research and conception of photovoltaic efficiency from a physical, and historical perspective. Secondly, this research provides a specific research agenda (program) to further the knowledge of the study of photovoltaic efficiency for solar implementation of institutions of higher education. This research will generate a specific application which analyzes the photovoltaic efficiency of a significant number of institutions of higher education in the United States to predict the impact of different variables on the production of renewable energy with data provided by the actual institutions to a public website.

1.8 Research Limitation

All research efforts have limitations. It is a difficult things for a researcher to list all the limitations of the proposed project. Expanding on the information provided in section 1.4, this research is restricted by:

1.) The research is based on secondary data collected through a public website.
2.) The study was an initial research effort of a projected research agenda so the results will be limited in this generality.
3.) Due to time and cost limitations, the study was conducted data from only one database where only certain questions asked, were mandated resulting in only certain questions being answered by the responding institution.
4.) The research will use a specific mathematical model (multiple linear regression analysis).
5.) The design of this research is based on a specific secondary data which limits what can be learned about the whole population of photovoltaic solar installations throughout the United States in institutions of higher education.

1.9 Summary

The desired outcomes of this research are linked directly to the photovoltaic efficiency output and the impact of the different variables on the production of the solar installation. The literature review provides a historical and industrial perspective to the concept of the solar industry, the manufacturing of photovoltaic solar panels and the efficiency produced as a result of installations in institutions of higher education throughout the United States. In addition, it is providing a comprehensive reference source on the literature of the prior mentioned topics relating to renewable energy as a result of Photovoltaic usage. The outcome of the research agenda is to

focus efforts on the secondary data obtained through a public website and the efficiency and generation of renewable energy of the installations studied.

Chapter 2: Literature Review

In this chapter, a review of the literature is provided. The purpose of this chapter is to present the history and the many facets of the impact of diverse variables on photovoltaic efficiency, renewable energy generation and to give a global view of the body of knowledge on which the research is based. First in section 2.1, a brief history of photovoltaic efficiency and the solar industry is presented, to put the concept of photovoltaic efficiency into the context of this evaluation. The concept of photovoltaic efficiency is presented as a critical area of study for all of Engineering. This is followed by section 2.2 where the history of the solar industry is discussed. The trend in manufacturing of solar panels and the impact of the installation types along with the tracking devices installed on the roofs of certain building on college campuses throughout the United States are also conversed. The advantages and benefits of a solar installation implementation is also investigated. Section 2.3, describes the evolution of the solar cells and the types on which this research is based. The proposed methodology will be applied in actual results from the campus installation database (AASHE, 2015). In section 2.4, a discussion surrounding the photovoltaic manufacturers and the environment to gain a working perspective is undertaken that builds on the exposition provided in section 2.3. Section 2.5 describes the importance and factors affecting photovoltaic efficiency. Section 2.6 explains the different solar array mounting and tracker types which impact photovoltaic efficiency. This chapter concludes with Section 2.7 which is a description of the different types of campus installations. Figure 2.1 represents the logical development of Chapter 2.

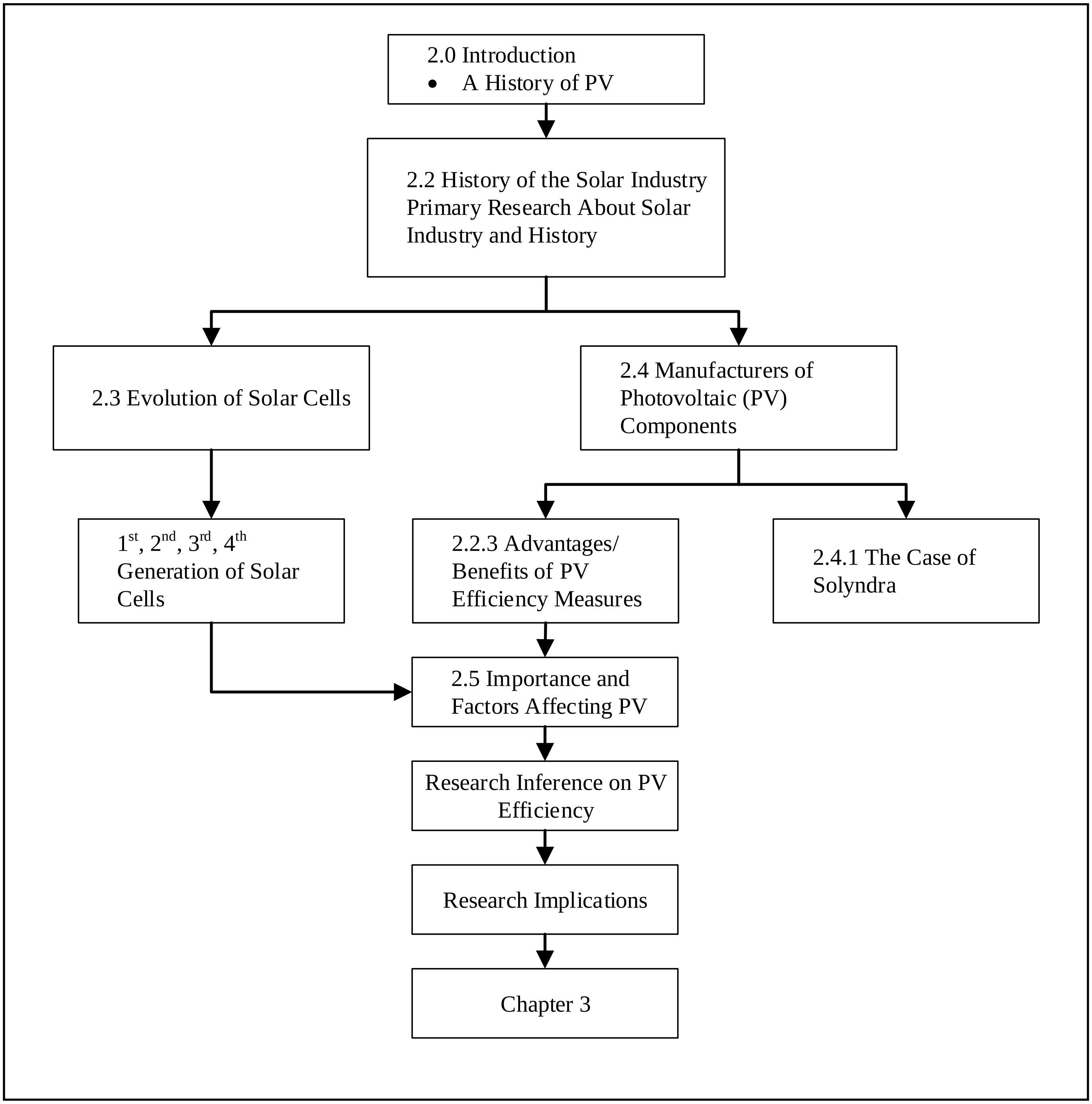

Figure 2.1: Thought Diagram for the Development of Chapter 2

2.1 Introduction: A History of Photovoltaic Efficiency

Global environmental concerns and the escalating demand for energy, coupled with steady progress in renewable energy technologies, are opening up new opportunities for consumption of renewable energy resources. Solar energy is the most plentiful, infinite and clean of all the renewable energy resources to date. The power from sun intercepted by the earth is about 1.8×1011 MW, which is many times larger than the current rate of all the energy consumption. Photovoltaic technology is one of the paramount ways to harness the solar power (Parida, Iniyan, & Goic, 2011). Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere. Photovoltaic installations are simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts. Hence they are utilized for power source, water pumping, remote buildings, solar home systems, communications, satellites and space vehicles, reverse osmosis plants, and for even megawatt scale power plants. With such an immense range of applications, the demand for photovoltaics is increasing every year (Survey of Energy Resources 2007, World Energy Council).

The reasons to pursue building a solar array are numerous, but the motivation is often an institutional initiative on sustainability. Once there is top-level support for the effort to reduce consumption and generate clean power, there is a way to find funds for the appropriate project. The American College & University Presidents Climate Commitment sets a goal of zero net greenhouse gas emissions on participating campuses. As of April 2008, over 500 college and university presidents and chancellors had signed on. With the challenge critical and the stakes mounting, the need for climate leadership has never been greater. The good news is that the higher education sector is responding to global warming, with more than 575 colleges and universities

committed to achieving climate neutrality and many others working toward substantial emissions-reduction targets. Despite these commitments, however, actual greenhouse gas emissions continue to rise on most campuses. Gains from energy efficiency and conservation have been outpaced by growth in student populations and new construction. How can colleges and universities significantly reduce their net carbon dioxide (CO2) and other greenhouse gas (GHG) emissions over a relatively short time? What sort of roadmap or blueprint will show the way? By drawing upon the experiences and expertise of leading campuses, it outlines some steps for creating effective climate action plans. It also highlights best practices from the handful of schools that are leading the way in campus-wide climate planning. The planning process will extend beyond campus borders, and the implementation of climate action plans will generate valuable resources and expertise that will help businesses, communities, states and other entities to significantly cut their emissions possibly in partnership with the campus. Higher education's pioneering work on climate action plans will play an important role in achieving a more secure, just and sustainable future.

According to *Energy.gov.*, the conversion efficiency of a photovoltaic cell, or solar cell, is the percentage of the solar energy shining on a photovoltaic device that is converted into electrical energy, or electricity. Improving this conversion efficiency is a key goal of research and helps make photovoltaic technologies cost-competitive with more traditional sources of energy. Much of the energy from sunlight reaching a photovoltaic cell is lost before it can be converted into electricity. But certain characteristics of solar cell materials also limit a cell's efficiency to convert the sunlight it receives. Light is composed of photons—or packets of energy—that range in wavelength. When light strikes the surface of a solar cell, some photons are reflected and do not enter the cell. Other photons pass through the material. Of these, some are absorbed but only have

enough energy to generate heat, and some have enough energy to separate electrons from their atomic bonds to produce charge carriers—negative electrons and positive holes.

Further investigation by the researcher to better understand the concept of photovoltaic systems solar installations are listed in Table 2.1. Each of these analysis contribute to the overall understanding of the solar industry in the United States and globally as it relates to photovoltaic installations, the history of solar cells and the manufacturing of the panels needed for these installations. They provide a foundation from which this research was founded. It not only explores the history, but the evolution of the solar cell industry in addition to the manufacturing trends in the United States and on a global scale and the competitiveness amongst vendors of solar components include modules and cell component. There are also additional explorations regarding actual campus installations in higher education.

2.2 History of the Solar Industry

Today, solar power is part of everything from solar powered structures to solar powered automobiles. Table 2.2 chronicles significant milestones in the history of the solar industry to the development of solar technology in the 1900's (US Department of Energy). Photovoltaics research and development will exist with attention to new materials, all designs, and innovative approaches to solar material and product development. Forthcoming technology roadmaps plan the research and development pathway to full competitiveness of concentrating solar power with conventional power generation technologies within the next decade. Directed solar power could connect the sun's heat energy to offer large scale, domestically safe and environmentally friendly electricity.

Table 2.1: List of Significant Research Articles

Applications	Researchers	Description
Solar Energy	Devabhaktuni, Alam, Depuru, Green, Nims, & Near, (2013).	Knowledge of the global demand for energy to meet future energy demands efficiently, energy security and reliability. Addresses long-term issues by utilizing alternative and renewable energy sources. This paper illustrates the need for the utilization of alternative energy sources, and evaluates the global scenario of installed generation systems, reviews technologies underlying various solar powered devices, and discusses several applications and challenges in this area.
Photovoltaics Industry Growth	Basore, Chung & Buonassisi, (2015, June).	This article describes the past decade's record of growth in the photovoltaics manufacturing industry indicating that global investment in manufacturing capacity for photovoltaic modules tends to increase in proportion to the size of the industry.
Solar Manufacturing Industry Trends	Platzer (2012 & 2015)	This article describes the trends in solar panel manufacturing on a global scale and the competitiveness of solar photovoltaics as a source of electric generation. It is making it harder for solar to complete as an energy source.
Solar Efficiency	Aribisala (2013)	The thesis explored and expanded beyond the scope of the a solar project to research different avenues for improving the efficiency of solar photovoltaic power system from the solar cell level to the solar array mounting, array tracking and DC-AC inversion system techniques.
Solar Projects in Institutions of Higher Education	Graham (2012)	Examining the environmental sustainability and strategic planning initiatives of a campus of higher education. This study is qualitative in nature and is a single exploratory case study examining the environmental sustainability and strategic planning initiatives of one campus.

The federal government has a variety of tax credits and targeted research and development programs to encourage the solar manufacturing segment. In 2011, the total number of grid-connected photovoltaic systems nationwide reached more than 215,000 with an estimated 100 U.S. manufacturing facilities employing an estimated 25,000 workers. (Platzer, 2012). By year-end

2013, the total number of reached more than 445,000 with approximately 75 Manufacturing facilities employing nearly 30,000 US workers according to SEIA (Platzer, 2015). Solar World's is the largest solar cell and module plant in the United States and located in the state of Oregon with the capacity to produce 500 MW of solar cells per year at full production. Other foreign-based firms, such as Sanyo Solar and SMA Solar, also operate photovoltaic primary component plants in the United States (Platzer, 2015). Table 2.2 depicts the evolution of the solar industry.

Table 2.2: History of Solar (Parish, R.,n.d.)

Year	**Event**
1905	Albert Einstein published his paper on the photoelectric effect.
1954	Photovoltaic technology is born in the United States by Daryl Chapin, Calvin Fuller, and Gerald Pearson at Bell Labs.
1959	Hoffman Electronics achieves 10% efficient, commercially available photovoltaic cells.
1960	Hoffman Electronics achieves 14% efficient photovoltaic cells.
1983	Worldwide photovoltaic production exceeds 21.3 megawatts, with sales of more than $250 million.
1994	The National Renewable Energy Laboratory develops a solar cell that becomes the first one to exceed 30% conversion efficiency.
1999	The National Renewable Energy Laboratory achieves a new efficiency record for thin-film photovoltaic solar cells of 18.8 % efficient. Cumulative worldwide installed photovoltaic capacity reaches 1000 megawatts.
2000	First Solar begins production in Perrysburg, Ohio at the world's largest photovoltaic manufacturing plan with an estimated capacity of producing enough solar panels each year to generate 100 megawatts of power.
2002	The largest solar power facility in the Northwest – the 38.7 kilowatt White Bluffs Solar Station – goes online in Richland, Washington.

Solar Photovoltaics photovoltaic systems can generate clean, cost –effective power anywhere the sun shines. It has no emissions, no moving parts, it does not make any noise and it doesn't need water or fossil fuels to produce power. According to SEIA, U.S. solar manufacturing sector in 2014 was made up of about 75 U.S manufacturing facilities employing 30,000 U.S

workers. And more than 450 additional domestic facilities that manufacture other photovoltaic - related products such as tracking hardware and manufacturing equipment (SEIA, 2014).

2.2.1 Introduction of Photovoltaic Panels and Systems

The following outline characteristics about a photovoltaic panel which can ultimately impact the cost of an installation. The savings earned from solar production depend on the amount of power produced on site, and the cost of electricity purchases avoided, through time.

- Photovoltaic panels do not require vast amount of space such as wind farms nor do they require large amounts of steel for construction like wind energy.
- Photovoltaic panels do not need collection and fermentation plants like the biogas power generation systems.
- Photovoltaic panels are also unlike fuel cell power generation, which requires a special structure and cumbersome maintenance process.

After purchasing and installing the solar panels, they can be used to produce electricity immediately. Meanwhile, the operation stage of photovoltaic panel does not need too much maintenance and does not need special conditions of use, such as the specific temperature, particular PH value and so on (Cristaldi, Faifer, Rossi &Ponci, 2012). Therefore, photovoltaic panels have been used in various residential and commercial buildings, such as commercial centers, supermarkets, public parking garages and residential apartments. Currently, building integrated photovoltaic system can be divided into two categories: roof structure photovoltaic system and wall structure photovoltaic system (Vats & Tiwari, 2012). The photovoltaic on roof structure is more convenient in the construction of the buildings that have been completed, because there is no additional land requirement or additions to other facilities. Therefore, many buildings

have been built with a photovoltaic roof structure. Solar radiation is an abundant, inexhaustible, clean and cheap energy source. Currently, the efficiency of polycrystalline cell is about 16% - 17%, and the efficiency of monocrystalline silicon cell is about 18-20 % (Taube, W. R., Kumar, A., Saravanan, R., Agarwal, P. B., Kothari, P., Joshi, B. C., & Kumar, D. 2012). The continuous and steady solar power generation and the advantages of clean energy production from photovoltaic panels make their benefits more apparent. At the same time, the cost of manufacture and use of photovoltaic panels is reduced. Consequently, the applications of the photovoltaic panels are increasing. With the continuous development of the photovoltaic technology, the efficiency of solar panels is constantly improving. Today, a wide range of applications of photovoltaic technology is used, and the photovoltaic panel is playing an increasingly important role in alternative power generation.

2.2.2 Trend of Photovoltaic Systems in the U.S.

In the U.S., the capacity of photovoltaic panels has reached a level close to 14GW. The goal of the solar power industry is to meet 10% of U.S. peak electricity generation capacity by 2030 (Dincer, 2011).

Photovoltaic solar electricity is the most advanced method to produce electricity without moving parts, emissions or noise. This is accomplished by converting abundant sunlight without practical limitations. Photovoltaic solar industry indeed will contribute considerably in the coming decades to the global electricity supply requirements. Component manufacturers will be discussed in detail further in this chapter. This prediction has to be paralleled by a technology roadmap which should validate on a technical level how production cost can follow this price decrease. Importance is made on the fact that the customer needs as described before are challenging for the

most suitable technology. Subsequently a variation of co-existing technologies like crystalline silicon, thin film, III–V and new technologies will be present in the future (Borenstein, 2008). The generational evolution of the solar cells will also be discussed in section 2.3 of this chapter.

By looking at the solar installations at other colleges and universities, we were able to observe solid and successful examples of solar working in different ways. As an example of an institution of higher education, a university located in the western portion of the United States has solar panel systems on eight of its buildings, the largest of which produces 590,000 kWh per year. This university also purchases renewable energy from offsite sources and has a wind turbine mounted on one of its buildings. Combined, 17% of their electricity comes from renewable sources, while saving them money on the use of fuel and utilities ("Sustainability…" 2013). This institution is clearly making a statement about being green and moving towards cleaner technologies. Another institution located in the southern portion of the United States is currently building one of the nation's largest college campus solar fields. It is a 2.7 megawatt field that will contain 9,000 solar panels. The solar field is expected to save about $185,000 a year on energy costs and account for 20% of the campus' electrical usage ("One of Nation's…" 2014). This array produces such a large portion of the college's energy. In addition, field arrays have to be built away from the campus, making the use of solar less noticeable. This type of system offers energy savings and becomes iconic to the university. Solar panels offer both an environmental and economic benefit, especially at universities where energy consumption is high. Solar photovoltaics will help reduce this institutions electricity bills, protect against rising energy costs, and increase sustainability initiatives.

2.2.3 Benefits of Using Photovoltaic Solar Panels

General benefits for solar generating systems include low maintenance requiring occasional cleaning, remote performance monitoring, annual checks for the electrical wiring inverter and panels. The systems have a 30 plus year life. Solar systems also utilizes underused property (rooftops, parking lots, etc.) to provide onsite electricity on a college campus. Solar distributed generation provides localized electricity – no extra burden on transmission infrastructure and it is an extremely important component to help us meet increasing global electricity needs. The power source of the sun is absolutely free and produces no pollution, and it is infinite in nature.

In considering a solar electric project, a campus energy or sustainability office, should consider the following benefits of the investment:

1) **Environmental benefits:** Solar power greatly reduces emissions of pollutants such as SO2, NOX (tropospheric ozone), CO, CO2, and particulates associated with fossil fuel sources, and does not carry the risk associated with nuclear energy sources.

2) **Stabilization of energy costs:** As fossil fuels become more scarce, prices will increase, while solar resources remain abundant and constant, meaning little energy price inflation and good investment potential.

3) **Correlation of supply and demand:** Peak hours of a solar array production correspond to peaks in consumption between 9:00-5:00pm, when people are active, and heating and cooling systems are employed. In some regions "time of- use" rates apply a higher tariff to these peak kilowatt hours. Photovoltaic arrays tend to have maximum output when summer cooling is peaking and hourly rates in many parts of the country are highest.

4) **Self-sufficiency:** Solar power is an inherently local source and can boost the local economy. Design and installation occur locally, and domestic manufacturer source may be prioritized. Foreign oil associated with extraction and transportation of fossil fuels is eliminated. An off-grid array uses photovoltaics to charge a battery system for power in remote locations, where utility access would be costly

5) **Simplicity and low-maintenance:** Some arrays actively track the sun to increase efficiency; however, most photovoltaic technology has no moving parts. The installation consists of mounting DC-current producing modules, which are then tied to the utility service through a DC/AC inverter. Maintenance and operation costs tend to be extremely low.

6) **Visibility:** A solar array can and should serve as a focal point on a campus – which means, of course, that it would be best if the system were installed in a highly visible location. The sleek appearance of the system draws the eye, and compels thoughts on renewable energy, while the slow- or backward-spinning electric meter symbolizes energy conservation.

7) **Education:** The solar array may serve as an educational resource for the student body, or exist because of it. A working system can be incorporated into classes in Engineering, Environmental Studies, Business, Architecture and Design. Professors researching emerging solar technologies may want to install working models as a way to promote interest. Tours conducted in conjunction with the photovoltaic installation to generally raise awareness on campus about energy alternatives and sustainability.

Additional advantages of the use of solar power include the following:

1) **Plenty of power:** In just one second, the sun produces enough energy to fulfill 500,000 years' worth of current worldwide energy needs.

2) **Guaranteed fuel costs:** The cost of most fuels tend to go up over time, due to supply and demand, the profit motive, and general price inflation. But solar photovoltaic is different. The cost of sunshine—solar' s "fuel"—is, and will remain, zero.
3) **Competitive return on investment:** Installing solar photovoltaics is an investment.
4) **Simplicity:** Photovoltaic installations are reliable and mostly maintenance-free (though certain system components, such as inverters, will need to be replaced over time).
5) **Energy independence:** Solar users generate their own energy while remaining connected to the grid just in case.
6) **Clean and carbon free:** Solar power prevents millions of pounds of CO_2 emissions from being pumped into the atmosphere every year.

2.2.4 The Cost of Photovoltaic Installations

The cost of a photovoltaic system is the product of several factors. The initial price of the installed array can be directly offset by government incentives at the federal, state, and local level. The savings earned from solar production depend on the amount of power produced on site, and the cost of electricity purchases avoided, through time. Assuming that retail electricity rates will remain the same over the lifetime of the system, estimates of installation cost and energy production can be used to calculate the payback time for a system. Since we know the price of electricity will inevitably rise over time, maybe substantially as carbon emissions are penalized and global peak oil and North American peak natural gas production are approached, it is reasonable to assume an inflation rate for the price of conventional electricity when calculating the payback of a photovoltaic systems.

System payback, or break-even time, is the length of time it takes for the project's initial cost to be recovered through energy savings. A rough calculation of "simple payback" (P) – which assumes a constant price for avoided electricity costs -- for an array of size W can be done:

$$Y = D * I * W * R * C$$

$$(U - G) / Y = P$$

where: D = 365 d/y

I = avg. annual insolation (full sun-hours/day)

W = the nameplate system size (kW)

R = system performance ratio or efficiency; use 0.7 to make rough estimates

C = cost of electricity from utility ($/kWh)

Y = yearly savings resulting from self-production

U = initial cost of the array

G = grants, incentives, and other reductions

P = simple payback time (y)

After P years, the system savings become revenue for the college or university. While residential systems often utilize and benefit by net-metering, wherein the local utility agrees or is required to buy a photovoltaic system-generated kilowatt hours in excess of those consumed on-site at full retail rates, net-metering is less of an issue for campus photovoltaic systems because the campus buildings and distribution systems they are connected to generally consume much more electricity than the photovoltaic systems produce. Nonetheless a power purchase agreement and/or grid inter-tie agreement with then utility may be required. In this dissertation, a proposed full model with efficiency (ratio of annual production and the implementation cost measured in percentage) as the dependent variable were statistically analyzed. And other independent predictor variables were

statistically analyzed to determine which of the variables had an impact on efficiency. This was completed using multiple regression analysis, and is discussed in further detail in Chapter 3 and Chapter 4.

The cost of solar panels is a variable that actually depends on the time, place and scale of solar panel installation. Other factors influencing the overall solar panel cost include the efficiency and life expectancy of the solar panels, installation costs including actual installation of the solar panels and electrical connections, additional equipment required such as inverters, batteries and cabling. These variables are part of the proposed model.

2.3 Evolution of Solar Cells

The use of photovoltaic cells, commonly called solar cells, is well known. Solar cells are conventionally obtained as slices cut from specially prepared single crystal semiconductor ingots. The greater the area of a solar cell, the greater is the power obtained from the cell. But, the greater the area, the less is the efficiency of the cell. By connecting many little cells together as a panel, it is possible to increase the power without decreasing the efficiency. Present methods of interconnecting many solar cells are expensive, inconvenient, and unreliable (Aribisala, 2013) There are three major solar photovoltaic technologies. They are:

- Polycrystalline silicon
- Mono-crystalline silicon
- Solar Cadmium Telluride (CdTe) thin film.

Different types of solar cells will discussed in detail in the following sections.

2.3.1 1st Generation Solar Cells (Crystalline silicon (c-Si) Photovoltaic technology)

Photovoltaic effect was first documented by the French physicist, Aleixandre-Edmond Becquerel in 1839, but the first modern solar cell with sufficient efficiency for power applications was not developed until 1954 at Bell Labs in New Jersey in 1954. While experimenting with semiconductors, Bell lab, by accident found that silicon doped with certain impurities was very sensitive to light. This was the beginning of the 1st generation solar cell technology. It is Silicon-based technology and is the leading technology in the marketable production of solar cells, and accounts for more than 86% of the solar cell market. It is reliable and has succeeded in achieving market penetration, primarily in off-grid remote areas and lately in grid-connected applications. There are several inherent limits to the 1st generation technology from the onset. Silicon wafers are very gentle and the process involved in the manufacturing is difficult and arduous resulting in a greater cost. There are two approaches to manufacturing crystalline silicon based solar cells; monocrystalline and polycrystalline cells. Monocrystalline cells are created through a process of crystal growth. The cells are made by cutting slender wafers from the crystal, which are then processed into cells. Polycrystalline cells are created using melted silicon that cools and hardens in molds. These two types of panels will be discussed in more detail in the following sections.

2.3.1.1Monocrystalline Panels

Monocrystalline silicon, or single-crystal silicon, is formed by developing a large pure crystal of silicon in a furnace. The pure crystal is then sliced into wafers and amassed in an array. The resulting silicon is highly efficient, but costly and laborious to mass-produce. Further, because the silicon has to be cut prior to assembly, approximately 50 % of material goes unused, and is

therefore wasted. Monocrystalline silicon makes up about 35 % of the world photovoltaic production.

The Single crystal silicon wafers (c-Si) or the Mono-crystalline Solar Cells in which the crystal lattice of the entire sample is constant and complete with no grain boundaries and is still one of the most effective photovoltaic solar cells. The process of manufacture includes crystalline silicon rods being removed from melted silicon and then sliced into thin plates. About half of the manufacturing cost derives from wafering; a very time-consuming and costly process in which ingots are cut into thin wafers with about 200 micrometers of thickness. If the wafers are too thin, the entire wafer will breakdown in the process and due to this thickness requirement, a photovoltaic cell requires a substantial amount of raw silicon and close to half of this not very inexpensive material is lost as sawdust in the wafer processes. Monocrystalline panels are square with missing corners. They are black and even in color and are more expensive. However they do have higher efficiency and are more space efficient.

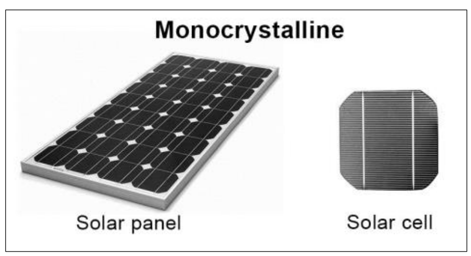

Figure 2.2 Monocrystalline Panel (Arthur, 2014)

2.3.1.2 Polycrystalline Panels

Polycrystalline silicon, or multicrystal silicon, is created by casting molten silicon in blocks. While this process is a little less expensive and faster than the process used for growing a single crystal, the resulting multi-crystal silicon is less efficient than its single-crystal counterpart. Polycrystalline silicon makes up about 45 % of the world's photovoltaic production. Thin film

photovoltaics are generally made with amorphous silicon (silicon in non-crystalline form), cadmium telluride (CdTe), or copper indium selenide/sulfide (CIGS).

The polycrystalline approach uses distinct cells on silicon wafers cut from multi-crystalline ribbons; the process is less costly than the single crystalline cells. The average price for single-crystal modules is about \$3.97 per peak watt compare to \$2.43 for poly-crystal modules. Though it is more expensive, monocrystalline silicon cells are generally more durable and efficient and produce more wattage per square foot than their polycrystalline cell counterpart. Other benefits of crystalline silicon based solar cells are that they have broad spectral absorption range and high carrier mobility. The efficiency of mono-crystalline silicon solar cell currently peaks at about 28% while poly-crystalline cells are approaching about 20% (NREL, 2012). Polycrystalline panels are square shaper, blueish in color and have a characteristic "metal sheet" pattern on the surface. They are more sensitive to heat and lose efficiency more quickly as temperature rises and so produce slightly less energy each year. They are less expensive and more esthetically pleasing.

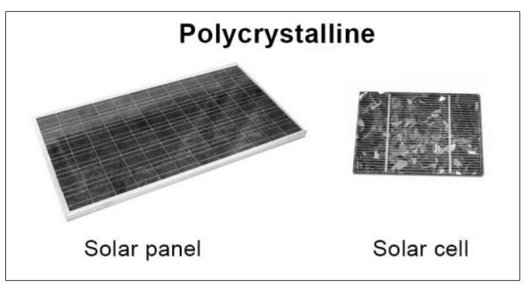

Figure 2.3 Polycrystalline Panel (Arthur, 2014)

2.3.2 2 nd Generation Solar Cells: Thin-film Technology Solar Cells

Because of the high cost of manufacturing of the 1st generation solar cells, a 2nd generation solar cells known as thin film technologies was developed. The technology involves depositing a

thin layer of photo-active material (Non-crystalline silicon) onto inexpensive substrates material using plasma enhanced chemical vapor deposition (PECVD) process. .

Photovoltaic cells can be grouped into a module. One common type of photovoltaic module is seen as the first solar panels attached to signal lights and buoys. Thin film solar cells are made by depositing a very thin layer of silicon (or another semiconductor substance, depending on the application) on a very thin supporting material, such as glass, plastic, or metal foil. This process is known as chemical vapor deposition. Although less commonly used than crystalline types, thin film can counterbalance many of the disadvantages associated with crystalline silicon manufacturing because it uses only a fraction of the amount of pure silicon.

2.3.3 3 rd Generation Solar Cells

The 3rd generation solar cells involve different semiconductor technologies that are fundamentally different from the previous semiconductor devices. It has been estimated that 3rd generation solar technologies will achieve higher efficiencies and lower costs than 1st or 2nd generation technologies. Some of these technologies are: nanocrystal solar cells, photo-electrochemical cells, dye-sensitized hybrid solar cells and polymer solar cells.

2.3.4 4th Generation Solar Cells and Future Trends

This category of solar cells combined the 3rd generation technologies to form the 4th generation solar cells technology. An example is the nanocrystal/polymer solar cell, a composite photovoltaic cell technology which combines the elements of the solid 26 state and organic photovoltaic cells to form the hybrid-nanocrystalline oxide polymer composite cell. Although most of these technologies are still in the embryonic development stage, it is predicted that because

of the lower cost of material, this type of solar cell would significantly make solar deployment affordable. Another area where photovoltaic solar cell technology has achieved significant efficiency milestone is in the concentrator solar cell technology. An example is the Multi-junctions (III-Vs) solar cells which has recorded efficiency of greater than 41% (SEIA, 2010, 2011, 2012, 2013). Figure 2.2 below shows best research solar cell efficiency to date, courtesy of NREL (National Renewable Energy Laboratory) and Spectrolab.

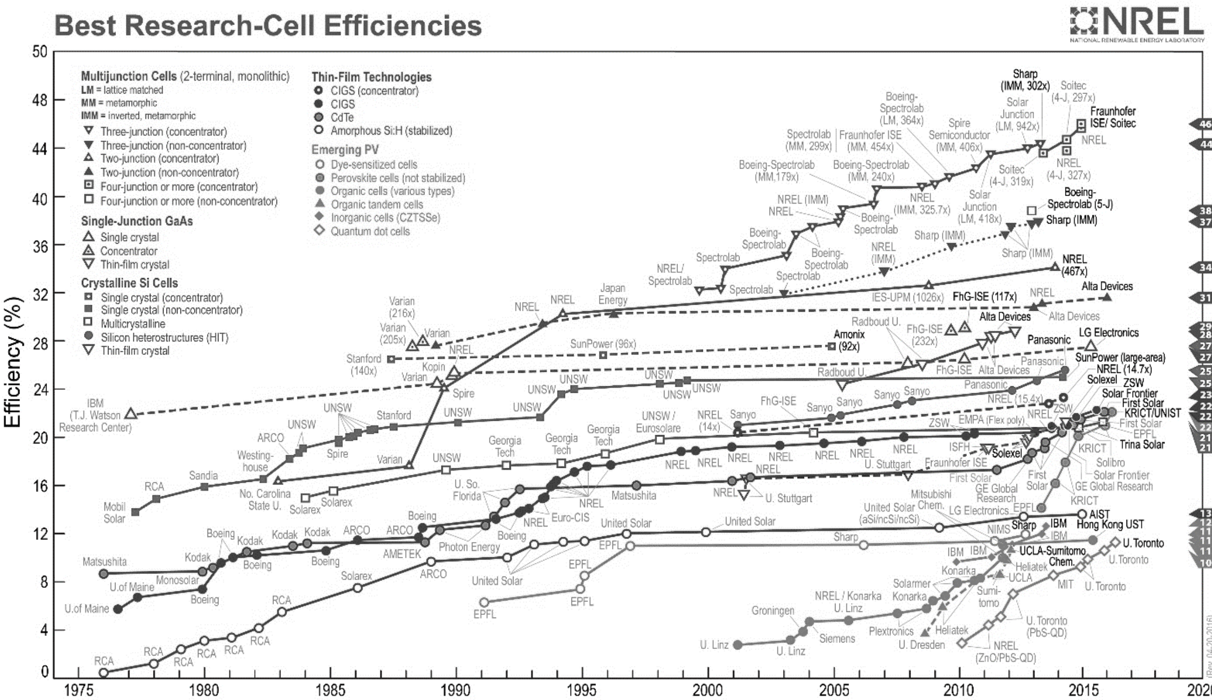

Figure 2.4: Best Research Cell Efficiencies (National Renewable Energy Laboratory, 2015)

The National Renewable Energy Laboratory (NREL, 2015) maintains a plot of compiled values of highest confirmed conversion efficiencies for research cells, from 1976 to the present, for a range of photovoltaic technologies. Devices included in this plot of the current state of the art have efficiencies that are confirmed by independent, recognized test labs (e.g., NREL, AIST, and Fraunhofer) and are reported on a standardized basis. The measurements for new entries must be with respect to Standard Test or Reporting Conditions (STC) as defined by the global reference

spectrum for flat-plate devices and the direct reference spectrum for concentrator devices as listed in standards IEC 60904-3 edition 2 or ASTM G173. The reference temperature is 25°C and the area is the cell total area or the area defined by an aperture. Cell efficiency results are provided within different families of semiconductors: (1) multijunction cells, (2) single-junction gallium arsenide cells, (3) crystalline silicon cells, (4) thin-film technologies, and (5) emerging photovoltaics. Some 26 different subcategories are indicated by distinctive colored symbols. The most recent world record for each technology is highlighted along the right edge in a flag that contains the efficiency and the symbol of the technology. The company or group that fabricated the device for each most-recent record is bolded on the plot.

2.4 Manufacturers of Photovoltaic Components

All major photovoltaic solar manufacturers maintain global sourcing strategies. The only U.S.-based manufacturer ranked among the top ten global cell producers in 2010 sourced the majority of its panels from its factory in Malaysia. Some photovoltaic manufacturers have expanded their operations beyond China to places like the Philippines and Mexico. Overcapacity has led to a significant drop in module prices, with solar panel prices falling more than 50% over the course of 2011. Several photovoltaic manufacturers have entered bankruptcy and others are reassessing their business models. Although hundreds of small companies are engaged in photovoltaic manufacturing around the world, profitability concerns appear to be driving consolidation, with ten firms now controlling half of global cell and module production (Platzer, 2012)

The Photovoltaics value chain tracks all distinct processes required to build a photovoltaic system. In the case of crystalline silicon modules, it involves reducing sand to raw silicon followed by purification, wafer cutting, doping, cleaning and coating. These are cells which are subsequently connected and laminated to form a module, which is to be assembled in array and

combined with electrical components to make a system. The thin-film value chain is much shorter, as the modules are manufactured in one single step from raw silicon and other compounds by depositing the photovoltaic material and other chemicals on glass or plastic. In concentrating photovoltaics, either crystalline silicon cells or thin-film substrates need to be combined with optical systems for concentration, cooling sink and in-built tracker before it can be assembled into an array. A complex value chain, as is the case with concentrating photovoltaics, makes for a much more complex supply chain.

In Figure 2.3 the photovoltaic value chain is illustrated. Each solar panel assembler uses different sourcing strategies, and the levels of vertical integration vary across the industry. At one extreme, a company based in Europe, is highly integrated, controlling every stage from the raw material silicon to delivery of a utility-scale solar power plant. At the other extreme, some large manufacturers are pure-play cell companies, purchasing polysilicon wafers from outside vendors and selling most or all of their production to module assemblers. A number of solar manufacturers seem to be moving toward greater vertical integration for better control of the entire manufacturing process. Vertical integration also reduces the risk of bottlenecks holding up delivery of the final product (Platzer, 2012 & 2015)

The Photovoltaics value chain tracks all distinct processes required to build a photovoltaic system. In the case of crystalline silicon modules, it involves reducing sand to raw silicon followed by purification, wafer cutting, doping, cleaning and coating. These are cells which are subsequently connected and laminated to form a module, which is to be assembled in array and combined with electrical components to make a system. The thin-film value chain is much shorter, as the modules are manufactured in one single step from raw silicon and other compounds by depositing the photovoltaic material and other chemicals on glass or plastic. In concentrating

photovoltaics, either crystalline silicon cells or thin-film substrates need to be combined with optical systems for concentration, cooling sink and in-built tracker before it can be assembled into an array. (Baumgaertner, J. (2013).

Table 2.3 represents the trends in solar manufacturing (Platzer, 2015). It takes into account the total number of photovoltaic systems in the U.S. in 2012 and 2015. As shown in the Table 2.3, the number of photovoltaic systems increased from 2012 to 2015, however the number of manufacturing facilities decreased. In 2012 the states with the most production locations were: California, Oregon, Texas and Ohio. By 2015, Washington was added to this list. In 2012, 10 firms controlled the cell and module production and by 2015 less than 12 firms did the same. Table 2.4 reflects the number of facilities that closed throughout the United States according to SEIA during the timeframe from 2011 – 2014. Many of these facilities opened between 1998 and 2010. Companies either merged or closed altogether.

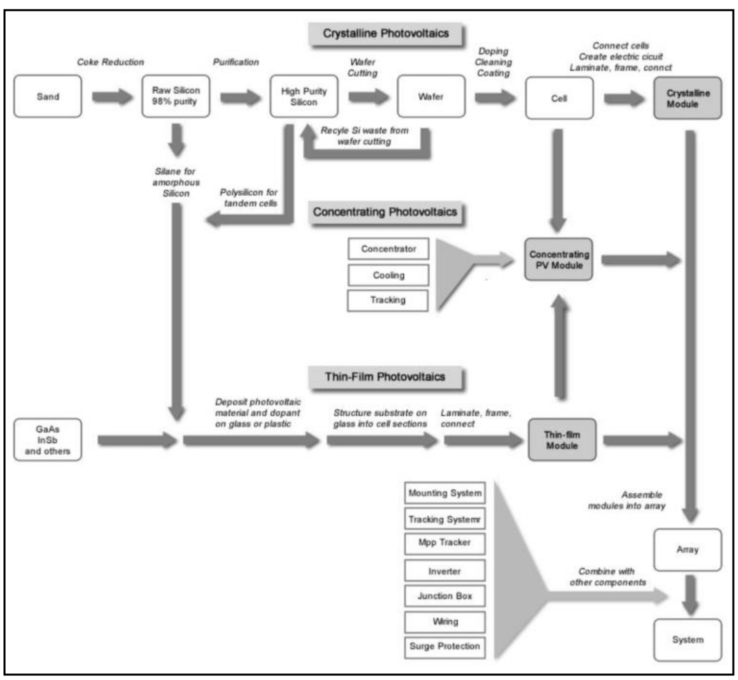

Figure 2.5: The Photovoltaic Value Chain (Baumgaertner, J., 2013)

Table 2.3: Trends in Solar Manufacturing (Platzer, M., 2012 & 2015)

Trend	**2012**	**2015**
Total Number of Photovoltaic Systems – US	214,157	445,000
U.S Manufacturers	100 with 25,000 workers	75 with 30,000 workers
US Production Locations	California, Oregon Texas, Ohio	California, Ohio, Oregon, Texas, Washington
Cell and Module Production	10 firms control cell and module production	Less than 12 forms control half of the global module cell and module production

SEIA 2014 data shows that in 2014, approximately two dozen U.S. facilities either produced raw material for the photovoltaic industry or were involved in component production such as wafer/ingot. Another 50 facilities made cells or assembled modules and some 30 were involved in the production of solar inverters.

Challenging market conditions have led to numerous bankruptcies and manufacturing consolidations among solar firms. Many of the facilities that have operated for less than five years have closed. In Table 2.4, the closure status of a number of firms which opened as far back as 1998 until present are shown. These firms produce an array of products needed for the photovoltaic solar installation system. As can be seen in Table 2.4, many of the producers of wafers, modules and ingots, all major components of a solar module were closed from 2011 to 2014. The majority closed in 2011. The facilities were located throughout the United States including: Arizona, California, Colorado, Maryland Massachusetts, Michigan, New Jersey, New York, Pennsylvania, Texas and Wisconsin,

Table 2.4: Selected Recent Photovoltaic Facility Closures (SEIA, 2010-13)

Company	**Status**	**Year Online**	**Year Closed**	**State**	**Products**
Abound Solar	Closed	2009	2012	CO	Module
Evergreen Solar Inc.	Closed	2008	2011	MA	Wafers
Hellos USA	Closed	2010	2013	WI	Modules
MEMC Southwest Inc.	Closed	1995	2011	TX	Ingots
Nanosolar	Closed	2009	2013	CA	Modules
MX Solar	Closed	2010	2012	NJ	Modules
Solar World Americas	Closed	2007	2011	CA	Modules
Solon America Corp	Closed	2008	2011	AZ	Modules
Salon Power Industries	Closed	2003	2011	PA	Cells, Modules
Solyndra Inc.	Closed	2010	2011	CA	Modules
Spectra Watt Inc.	Closed	2009	2011	NY	Cells
BP Solar	Closed	1998	2012	MD	Cells, Modules
Energy Conversion Devices	Closed	2003	2011	MI	Cells, Modules
Suntech	Closed	2010	2013	AZ	Modules
Sharp Solar	Closed one factory	2003	2014	TN	Modules
Sanyo	Closed one factory	2003	2012	CA	Wafers

According to the SEIA Annual Market Reports, (2010, 2011, 2012, and 2013) some of the changes which occurred with several of the manufacturers listed above were:

- SolarWorld purchased the California facility from Royal Dutch Shell in 2006 and expanded it with a $30 million investment. It remains open for sales and marketing activities, but production was moved to Oregon.
- SpectraWatt was a 2008 spinoff from an internal research project by the Intel Corporation. The company began shipments from its New York facility in 2010.

- A plant originally owned by Solarex, opened it in 1981. In 1995, Amoco/Enron acquired Solarex and subsequently BP acquired it. In 2005, BP announced plans to double the plant's capacity.
- Sharp Solar ended production in Memphis, TN, in March 2014 to focus on its domestic Japanese market. (Annual Market Reports, 2010, 2011, 2012, and 2013)

These are just a few examples of the ever changing solar component manufacturing environment.

According to Top Ten Reviews, the following comparisons were recorded. As shown several of the manufacturers listed were a part of the 379 solar installations. In Table 2.5 the average total cost of an installation and the time to recoup the initial investment is listed. This average is provided for comparison purposes only. The information was includes several of the solar panel manufacturers included in this study including Kyocera, SunTech and Sharp.

Table 2.5. Comparison of Manufacturer and Payback (Purch, 2016)

	Manufacturer	**Average Total Cost**	**Time to Recoup Investment (Years)**
1	Kyocera	$14,606	21.68
2	Canadian Solar	$14,247	20.74
3	Grape Solar	$15694	21.26
4	Grape Solar	$15,955	21.57
5	SunTech	$14,716	18.87
6	Sumsung	$17,3792	20.91
7	Sharp	$14,842	20.34
8	Lumos	$17,354	23.41
9	Sharp	$15,343	22.10

Solar panels also represents a large investment so is it important to find a panel than has the durability to last for a significant number of years. These panels must be back up by warranties indicating the manufacturer can ensure the longevity of the panel once installed in the solar array. Table 2.6 represents the amount of electricity a panel converts from sunlight per surface area. And the type of panel used which was discussed in detail in the literature review (Chapter Two) of this dissertation. Table 2.6 also demonstrates the cost associated with each type of panel. The range of the panel cost is also shown and the cost varies from $222.77 to $585.00 being the highest cost. The most efficient panel was the Kyocera panel with a 16% efficiency. 30 of the institutions reported used the Kyocera brand. SunTech was highest reported and is shown to have a 15.7 % efficiency.

Table 2.6: Solar Efficiency and Cost Comparison (Purch, 2016)

	Manufacturer	**Solar Efficiency (%)**	**Cell Technology Type**	**Cost Per Panel**
1	Kyocera	16	Poly	$399.00
2	Canadian Solar	15.9	Mono	$222.77
3	Grape Solar	15.21	Mono	$585.00
4	Grape Solar	15.1	Mono	$399.00
5	SunTech	15.7	Mono	$272.85
6	Sumsung	15.62	Mono	$375.00
7	Sharp	15	Poly	$319.00
8	Lumos	14.68	Mono	$499.00
9	Sharp	14.4	Poly	$353.00

The price of solar photovoltaics are dropping significantly. The demand for solar photovoltaics is rising and economies of scale as well as the learning curve effect are causing a

drop in price. Over the last 30 years the price of solar energy has decreased by a factor of ten. (Arvizu, Balaya, Cabeza, Hollands, Jäger-Waldau, Kondo & Xu, 2011). Projected costs by the International Energy Agency shows that it will continue to drop through 2050 (SIEA, 2010) with a possibility of a 50% drop in price by 2020 (Breyer, 2009). As solar becomes more affordable and efficient, the economics of solar will become more favorable. Appropriations and grants can play a significant role in making solar energy more competitive as they directly impact the price of a solar installation. Merging solar development with research allows an institution of higher education to develop its solar portfolio while also pursuing its core mission of academia. Students have an opportunity to participate in the campus solar installations acquiring first-hand knowledge in understanding the complexity and challenges in this quest for a solar initiative of this magnitude.

2.4.1 The Case of Solyndra

The firm Solyndra received a significant funding in excess of $500 million from the U.S. Energy Department. They were the first recipient of a loan guarantee under President Barack Obama's economic stimulus program, the American Recovery and Reinvestment Act of 2009 (Stephens & Leonning, 2011). It was one of several companies that received assistance from the government, in an attempt to push back on China’s strategic targeting of green-energy manufacturing. Solyndra was a startup solar-power equipment manufacturer based in Fremont, California that went bankrupt at the end of August of 2011.

Solyndra was a manufacturer of cylindrical panels of copper indium gallium selenide (CIGS) thin film solar cells based in central California. This company designed, manufactured, and sold solar photovoltaic systems comprised of panels and mounting hardware for large commercial rooftops. The solar panels were proclaimed to be different than any other product

ever used in the solar industry. The panels were made of racks of cylindrical tubes (also called tubular solar panels), as opposed to traditional flat panels. Solyndra engineers thought the cylindrical solar panels absorbed energy from any direction - direct, indirect, and reflected light (Biello, 2008). Each Solyndra cylinder, one inch in diameter, was made up of two tubes. The company used equipment it had developed to deposit CIGS on the outside of the inner tube, which includes up to 200 CIGS cells. On top of the CIGS material, it added an "optical coupling agent", which concentrated the sunlight that shined through the outer tube. After inserting the inner tube into the outer tube, each cylinder was filled with a silicone oil, then sealed with glass and metal to exclude moisture, which eroded CIGS's performance. The hermetic sealing expertise was generally used in fluorescent lamps (Wang, 2008).

Systems that employ the panels on a given rooftop could yield significantly more electricity in a given year. The other advantage claimed by the company was that the panels did not have to move to track the Sun. The panels were always presenting some of their face directly perpendicular to the Sun (Green, 2008). The daily production of flat solar panels had an output curve that has a clear peak while Solyndra claimed their system produced more power throughout the day. The Solyndra panels allowed wind to blow through them. According to the company, these factors enable the installation of photovoltaics on a broader range of rooftops without anchoring or ballast, which could be inherently problematic. Solyndra claimed that wind and snow loads were negligible and that its panels were lighter in weight per area (Biello, 2008). The company claimed the cells themselves converted 12 to 14 % of sunlight into electricity, an efficiency better than competing CIGS thin-film technologies (Wang, 2008). However, these efficiencies were for the cells laid flat (Wang, 2008). The company never produced any data to support this claim. In 2006, Solyndra began deploying demonstration systems globally. The

company stated the total count was 14 systems and that these systems were each instrumented with sensitive radiation, wind speed, temperature, and humidity measurement devices to aid in the development of energy yield forecasting software tools. The company manufactured its products in its second fabrication plant, Fab 2, a new $733 million state-of-the-art robotic facility in Fremont, California, which opened in September 2010. Fab 2 was built with the support of a $535 million federal loan guarantee along with at least $198 million from private investors. The projected annual production capacity of the plants was projected to be 610 megawatts by 2013.

In November of 2010, Solyndra announced that it would lay off around 40 employees and not renew contracts for about 150 temporary workers as a result of the consolidation (Woody, 2010). Between 2009 and mid-2011 the price of polysilicon, the key ingredient for most competing technologies, dropped by about 89% (Lott, 2011).

On August 31, 2011, Solyndra stated it was filing for Chapter 11 bankruptcy protection, laying off 1,100 employees, and shutting down all operations and manufacturing. (McGrew, 2011). On September 1, 2011, the company terminated all business activity, filed for bankruptcy under Chapter 11, Title 11 of the United States Bankruptcy Code (Bathon, 2012), (White, 2011), (Elliott, 2012). On September 8, 2011, Solyndra was raided by the FBI investigating the company (Leonning, 2011). Subsequently, the company touted by the Obama Administration as the poster child for solar energy progression ended in a bankruptcy court.

2.4.2 Actual Solar Photovoltaic Installation Case Study

According to Bhat & Prakash (2009), one of the reasons, so many campuses have adopted photovoltaic system installations is due to the practicality, the aesthetics and the functionality. Along with the soaring energy costs, many Universities are facing ever spiraling energy bills when

it comes to heating and providing electricity to the many rooms within their buildings. Solar energy is one very affordable option for Universities to consider, paying for itself in a matter of a few years and then continuing to slice the energy bills faced by academic establishments. Nearly all Universities own modern buildings that would be suitable candidates for installing solar paneling. If the building has a good sized area of roof space, it has a wasted potential for using this space to generate solar electricity. Installing solar panels also provides a great resource for all environmental elements of academia.

The southwestern portion of the United States has one of the best potential conditions to generate electrical energy from the sources of sun known as solar energy. The state of Texas ranks at 9 among the 51 states of the United States installed capacity of solar energy technology and this lack of popularity of solar energy technology in Texas is due to the present electricity facilities, high volume of research in producing oil and gas through fracturing of shale reservoir, the variable generation nature of solar energy, and problems to the transmission line. Through the analysis of various data from the government agencies and research paper, it has found in the future, Texas has shown twice the solar potential than any other state. This could be achieved through increase in demand and decrease in the price of solar technology, broadly working on the state and federal policies related to the solar energy technology which would help in increasing the investment by investors. Hence, the following improvement in development of industries related to the processing of silicon, manufacturing of solar panels and inverters and research regarding cost effective installation of solar technology, inclusion of solar energy in the state's Renewable Portfolio Standards (RPS) and employing the Solar Renewable Energy Credits (SERCs), so that the owners would get reimbursement on excess production and motivating institutions which provide third party solar leasing models that would allow the owners to save the upfront cost that

could lead in attracting more investor towards solar energy in Texas. Thus, incorporation of these major three areas like state and federal policies, technology advancement and third party financing would enhance the growth of solar technology in Texas.

An institution located in central Texas, had an excellent potential for solar energy production. The University worked in securing outside sources of revenues to offset costs of installing solar systems on campus due to the economic barriers. Until the price of solar energy are reduced through more efficient manufacturing, these subsidies are a way forward for the early development of solar energy on campus. This particular institution of higher education installed the largest solar panel system in the area through the use of a 1.6 million dollar grant from the State Energy Conservation Office. With a total investment of two million dollars, the institution installed a 400,000 kilowatt-hours solar panel system in open fields on a research facility. This adoption of solar panels on the campus was expedited through a research grant which would study the performance of three different types of solar panels under the same conditions. This is an example of a demonstration project that not only serves to advance research, but also to change public perception of solar technologies. The choice to locate its first large-scale solar photovoltaic system in one of the most visible places on the campus makes a statement about the value solar energy. For future development, the University's development of solar energy outlined the general strategies for future development:

- Pursue subsides and research grants to offset costs.
- Off-site solar systems from the main campus.
- Utilize existing roof space on campus.

Social barriers decrease the amount of solar energy potential, but there is a still substantial amount of roof space available. The only obstacle preventing wide spread adoption is fiscal. The

campus produces its own electricity on the campus through a natural gas power plant. The plant is very efficient and economical. The cost of electricity production on campus is seven cents per kilowatt-hour. This low cost of electricity is an economic barrier to the adoption of solar photovoltaic, as any installation of solar photovoltaic panels would have to compete with the natural gas generation.

The average breakeven point was $12.25 per square meter per year. Depending on the payback period the economic feasibility can be determined by multiplying it by the breakeven value. Assuming a payback period of 10 years, the University can install solar photovoltaic systems that cost $122.50 per square meter. Currently the price to install solar photovoltaics is $1.40/ kWh for a typical solar system. (Bloomberg, 2010) Translated to area, this will cost about $1,400 per square meter installed, more than 10 times the break-even point. The price of solar photovoltaics is dropping significantly. Demand for solar photovoltaics is growing and economies of scale as well as the learning curve effect are causing a reduction in the price. Over the last 30 years the price of solar energy has decreased by a factor of ten. (Arvizu *et.al*, 2011) Projected costs by the International Energy Agency shows that it will continue to drop through 2050. (IEA, 2010) with a possibility of a 50% drop in price by 2020. (Breyer, 2009). As solar becomes more reasonably priced and efficient, the economics of solar will become more encouraging. Both solar installations at this institution were made possible in a large part by state grants. Coupling solar development with research allows this University to develop its solar portfolio while also pursuing its core mission. As a public institution committed to sustainability research, this campus could use its extensive solar potential for ongoing research and development on solar energy production. Furthermore, although extensive installation of solar panels cannot be justified solely on an economic savings basis today, the price of solar photovoltaics is dropping and solar power may be

economically advantageous for an institution of higher education interested in implementing a solar installation in the future.

New Jersey is the second largest market in the U.S. for solar energy, but its growth was threatened by a less-than-perfectly administered Solar Renewable Energy Credit (SREC) market. The new legislation, S1925/A2966, confronts the imbalance of SREC supply and pricing, which created uncertainty in the market for project developers and solar customers. According to the SEIA, the new law "accelerates the state's Renewable Portfolio Standard (RPS) solar requirement by about four years. Declining costs and an attractive investment environment caused solar deployment in the state to outpace demand. Acceleration of the RPS solar requirement will bring supply and demand in the market back into balance." The law also reduces the Solar Alternative Compliance Payment, clarifies program eligibility for net-metered systems, defines SREC program eligibility for grid-connected solar energy projects, promotes development of projects on brownfields and landfills, authorizes aggregated net metering for certain public entities, and increases SREC ‘banking life. New Jersey edged out California in the first quarter of this year for the lead in solar installations with 174 megawatts. And with this new legislation, the New Jersey solar miracle might keep rolling along, despite threats to derail its momentum. (SEIA, 2012).

2.4.3 Primary Reason for Photovoltaic Campus Installation on Campuses of Higher Education

The primary reason for the recent installations on campus of higher education is due to the commitment to sustainable initiatives and the search for alternative sources of energy. All institutions face constant challenges to seek opportunities to reduce costs. Recently there has been much development in solar energy technology with an increased efficiency to lower installation

costs. Increased demand has also generated lower costs. The most popular choice for colleges and institutions of higher education has been photovoltaic systems. The stimulus for an institution to pursue this type in installation is sustainability. Over 650 schools have joined the American College & University Presidents Climate Commitment (ACUPCC). This breakthrough program is reshaping institutions and communities while training the future political, business, and scientific leaders who will help solve climate change and launched in May of 2007. ACUPCC signatories commit to measure and report their greenhouse gas emissions, take immediate actions to reduce them, and develop and implement a plan to go climate neutral. (ACUPCC, 2009)

Perhaps the most important reason to install solar on campus is one of stimulation. The college environment is one in which questions, interest, and debate thrive. Students in engineering, environmental studies, economics, ecology, policy, and natural resources disciplines can use the system as a case-study model, or an introduction to the field of renewables. Concepts such as the life-cycle analysis, carbon emissions mitigate on, and the environmental commodities market benefit from a first-hand example. Future architects, planners, and designers may draw inspiration from a campus structure artfully soaking up light energy to power its ventilation systems.

2.5 Importance and Factors Affecting Photovoltaic Efficiency

As the main market segments being served today show widespread reception implying that a sound demand for many years to come, with a continued annual growth between 25% and 30% may be anticipated for the future. The projected module turnover in the 2020's will be in the range of 100–200 billion h/year—a market that will support employment on the order of several million people worldwide (Hoffman, 2006)

The competitiveness of solar photovoltaic as a source of electric generation in the United States will likely be adversely affected both by the expiration of these tax provisions and by the rapid development of shale gas, which has the potential to lower the cost of gas-fired power generation and reduce the cost-competitiveness of solar power, particularly as an energy source for utilities. In light of these developments, the ability to sustain a significant U.S. production base for photovoltaic equipment is in question (Platzer, 2015). Photovoltaic cells are a relatively simple, affordable way to convert the sun's energy into electricity. Originally developed to power satellites, photovoltaic cells absorb light (in the form of photons) and use semiconductors to convert them into electricity (in the form of electrons). Many cells are connected together and packaged into a frame, or solar panel, which can then be grouped together into larger solar arrays to power residential and commercial buildings.

The United States still has the highest prices among major photovoltaic markets. U.S. installed photovoltaic prices are more than double German prices for systems under 100 kW, but also much higher than prices in the UK, Italy and France. U.S. installed prices are even higher than Japanese installed photovoltaic system prices for the 10-100 kW range, even though Japan has by far the highest photovoltaic module prices of any major market. Prices for photovoltaic plants above 5 MW completed in 2013 remained steady at $3.00 per watt. Installed photovoltaic system costs varied widely from state to state, depending on segment.

The next section will describe the importance and those factors which ultimately impact photovoltaic efficiency.

Solar cells, also called photovoltaic cells by scientists, convert sunlight directly into electricity. The name photovoltaic originates from the process of converting light (photons) to electricity (voltage), which is called the photovoltaic effect. The photovoltaic effect was

discovered in 1954, when scientists at Bell Telephone discovered that silicon (an element found in sand) produced an electric charge when exposed to sunlight. Today, thousands of people power their businesses with individual solar photovoltaic systems. Photovoltaic technology is also used for large power stations. Panels are mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight. Many solar panels joined together to produce one system is called a solar array. For large electric utility or industrial applications, hundreds of solar arrays are interconnected to form a large utility-scale photovoltaic system.

The solar panels are made up of photovoltaic cells, which convert sunlight into direct current (DC) electricity throughout the day. Solar or photovoltaic (photo = light, voltaic = voltage or electricity) cells are created from special materials such as Silicon (Si) mixed with other elements, which when exposed to sunlight will generate an electrical current. Basically sunlight is absorbed into the photovoltaic material, which in turn knocks electrons within the material loose. This allows the electrons to flow freely within the material structure, creating an electrical current.

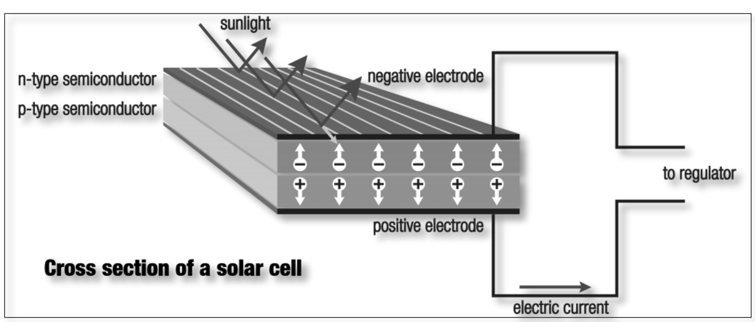

Figure 2.6.: How a Solar Panel Works (Solar World Corporate Website, 2016)

Solar panel refers to a panel designed to captivate the sun's rays as a source of energy for generating electricity or heating. A photovoltaic module is a packaged, connected assemble of typically six to ten solar cells. Solar photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar energy electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges form 100- 135 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. There are few solar panels than exceed 19% efficiency.

Solar photovoltaic technologies convert solar energy into useful energy forms by directly absorbing solar photons—particles of light that act as individual units of energy—and either converting part of the energy to electricity (as in a photovoltaic cell) or storing part of the energy in a chemical reaction (as in the conversion of water to hydrogen and oxygen).

A power tower system uses a large field of flat, sun-tracking mirrors known as heliostats to focus and concentrate sunlight onto a receiver on the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. The energy-storage capability, or thermal storage, allows the system to continue to dispatch electricity during cloudy weather or at night.

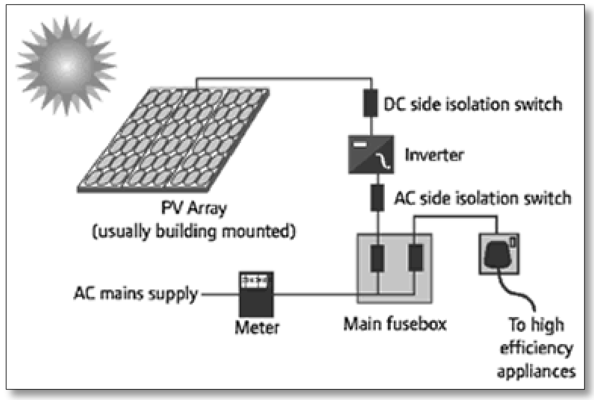

Figure 2.7: Conversion of Solar Photovoltaic Technologies (Green, M.A., 1982)

Solar cells are devices that convert sunlight directly into electricity. Solar cells are made of layers of semiconductor materials. When sunlight is immersed by these materials, the solar energy knocks electrons free from their atoms, allowing the electrons to flow through the material to yield electricity. Figure 2.5 depicts this process.

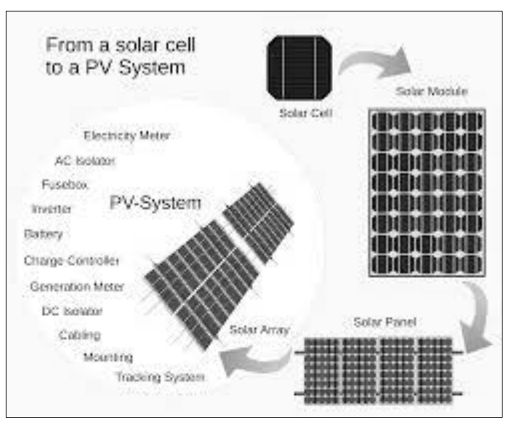

Figure 2.8: Conversion of Solar Cell to a Photovoltaic System (Green, M.A., 1982)

Solar cells are generally very small, and each one may only be capable of generating a few watts of electricity. They are typically combined into modules of about 40 cells; the modules are in turn assembled into photovoltaic arrays up to several meters on a side. These flat-plate

photovoltaic arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture more sunlight. For utility-scale electricity generating applications, hundreds of arrays are interconnected to form a single, large system. Figure 2.6 represents the conversion of solar cells to a photovoltaic system.

2.5.1 Types of Photovoltaic Mounting Options

Photovoltaic mounting systems (also called solar module racking) are used to fix solar panels on surfaces like roofs, building facades, or the ground. These mounting systems generally enable retrofitting of solar panels on roofs or as part of the structure of the building. There are three different types of mounting options for solar systems which are rooftop, ground or canopy structures.

2.5.1.1 Rooftop

The solar array of a photovoltaic system can be mounted on rooftops, generally with a few inches gap and parallel to the surface of the roof. If the rooftop is horizontal, the array is mounted with each panel aligned at an angle. If the panels are planned to be mounted before the construction of the roof, the roof can be designed accordingly by installing support brackets for the panels before the materials for the roof are installed. If the roof is already constructed, it is relatively easy to retrofit panels directly on top of existing roofing structures. For a small minority of roofs (often not built to code) that are designed so that it is capable of bearing only the weight of the roof, installing solar panels demands that the roof structure must be strengthened before-hand. In all cases of retrofits particular consideration to weather sealing is necessary. There are many low-weight designs for photovoltaic systems that can be used on either sloped or flat roofs, most

however, rely on a type of extruded aluminum rails. Several types of the most common – roof top are: flush mounted, affixed, ballasted tilt mounter and affixed tilt – mounted.

2.5.1.2 Canopy

Carport solar canopies offer numerous benefits to public and private organizations that have large parking lots, including commercial properties, colleges and universities, sports stadiums and manufacturing facilities. Facility owners gain a source of clean, low-cost energy and high awareness of their commitment to solar power. Solar canopies can be built at ground level, in elevated locations or on rooftops and can create covered walkways as well as carports. These canopies use space efficiently and effectively.

2.5.1.3 Ground or Pole Mount

Ground-mounted photovoltaic systems are usually large, utility-scale photovoltaic power stations. The photovoltaic array consist of solar modules held in place by racks or frames that are attached to ground based mounting supports. Ground-based mounting supports include:

- Pole mounts, which are driven directly into the ground or embedded in concrete.
- Foundation mounts, such as concrete slabs or poured footings
- Ballasted footing mounts, such as concrete or steel bases that use weight to secure the solar module system in position and do not require ground penetration. This type of mounting system is well suited for sites where excavation is not possible such as capped landfills and simplifies decommissioning or relocation of solar module systems.

A typical system is comprised of crystalline panels, is either roof or ground mounted, is grid tied with fixed mounting, net metered and distributed generation. What can differ in systems

is system size, location, building height, flush/tilt, and ballasted/affixed. Table 2.5 distinguishes between the different types of photovoltaic solar mounting options.

Table 2.7: Types of Photovoltaic Solar Mounting Options (Redarc.com. 2016)

Mounting Type	**Definition**
Roof Top Mounted System	Solar modules held in place by racks or frames attached to roof-based mounting supports.
Ground Mounted System	Large, utility scale solar power plants. Modules held in place by racks or frames that are attached to ground based mounting supports.
Solar Parking Canopies	Solar structures in a parking lot making use of existing real estate and provide some level protection from the sun. All shapes and sizes.

2.4.1.4 Financial Factors Impacting Efficiency

In order to fairly evaluate the financial benefits of a solar in stallion the following variables must be taken into consideration:

- Payback - the length of time it takes for your upfront solar investment to pay for itself through solar energy savings
- Return on Investment (ROI) - ROI (Return on Investment) can provide another relatively simple perspective of how much money will be saved over the entire (typically 25 to 30 year) lifetime of a solar project.

A comprehensive ROI formula for commercial solar could include:

- The current utility kilowatt-hour (kWh) rate and any demand charges.
- The annual bill without solar.
- The projected annual increase of utility costs over 25 to 30 years based on historical increases.

- The projected amount of solar kWh the system will produce over 25 to 30 years
- The lifetime costs associated with the solar installation, including installation costs, inverter replacement, operations and maintenance cost
- The estimated value of all solar rebates, performance based incentives, and tax incentives received over 25 to 30 years.
- Any applicable taxes.
- Any applicable interest/loan costs.
- Net Present Value (NPV)

While ROI takes into account all of the financial benefits and costs of going solar, it doesn't take into account the future value of the money being invested. That is, it doesn't factor in inflation, risk, or the lost opportunity of investing in another type of investment, such as stocks and bonds. However, simple payback does not account for inflation, depreciation, maintenance costs, project lifetime, and other factors. So, it doesn't really give the true value of solar over the full lifetime. A deeper dive would be required to perform a total economic analysis of a solar installation.

2.6 Solar Array Mounting and Tracking Types

A solar cell performs the best when its surface is perpendicular to the sun's rays, which change continuously over the course of the day and season. It is a common practice to tilt a fixed photovoltaic module (without solar tracker) at the same angle as the latitude of array's location to maximize the annual energy yield of module. For example, rooftop photovoltaic module at the tropics provides highest annual energy yield when inclination of panel surface is close to horizontal direction.

The conversion efficiency of a solar panel is directly proportional to the amount of direct solar irradiance that is absorbed. Irradiance is the amount of solar radiation that strikes the surface of a solar cell or panel and it is expressed in kW/m^2. The irradiance multiply by time is a measure of solar insolation. The peak sun hours is the number of hours per day when the solar insolation $=1kw/m^2$. Apart from the effect of atmospheric attenuations, solar energy absorption is also affected by the earth's distance from the sun and the earth tilt angle with respect to the sun. The angle between the true south and the point on the horizon directly below the sun is the Azimuth angle, measured in degrees east or west of true south. For south facing locations in the northern hemisphere, the default value is an azimuth angle of 180°. Increasing the azimuth angle maximizes afternoon energy production. For a fixed photovoltaic, 28 array, the azimuth angle is the angle clockwise from true north that the photovoltaic array faces and for a single axis tracking system, the azimuth angle is the angle clockwise from true north of the axis of rotation. The azimuth angle is not applicable for dual axis solar tracking photovoltaic arrays (Chang, 2009).

Photovoltaic modules consists of a number of interconnected solar cells (typically 36 connected in series) encapsulated into a single, long-lasting, stable unit. The key purpose of encapsulating a solar photovoltaic output depends on orientation, tilt, and tracking. Because photovoltaic panels are able to capture more solar energy when they are pointed directly at the sun, installers may configure systems to optimize output by adjusting the orientation and tilt of a system, or by using mechanisms that track the sun as it traverses the sky (U.S. Energy Information Administration, 2014).

Solar cells, since they are relatively thin, are prone to mechanical damage unless protected. In addition, the metal grid on the top surface of the solar cell and the wires interconnecting the individual solar cells may be corroded by water or water vapor. The two key functions of

encapsulation are to prevent mechanical damage to the solar cells and to prevent water or water vapor from corroding the electrical contacts.

Many different types of photovoltaic modules exist and the module structure is often different for different types of solar cells or for different applications. For example, amorphous silicon solar cells are often encapsulated into a flexible array, while bulk silicon solar cells for remote power applications are usually rigid with glass front surfaces. Module lifetimes and warranties on bulk silicon photovoltaic modules are over 20 years, indicating the robustness of an encapsulated photovoltaic module. A typical warranty will guarantee that the module produces 90% of its rated output for the first 10 years and 80% of its rated output up to 25 years.

One important component of the photovoltaic module system is the tracker. The trackers direct the solar panels or modules toward the sun for maximum energy production. The trackers changes the orientation during the day to follow the sun to optimize the captured energy. These trackers minimize the angle of incidence (Vişa, Diaconescu, Dinicu & Burduhos, 2007). Incidence is the angle a ray of light makes with a line perpendicular to the surface between the incoming light and the panel, which will increase the amount of energy the installation will produce. Single-axis solar trackers rotate on one axis moving back and forth in a single direction. Different types of single-axis trackers include horizontal, vertical, tilted, and polar aligned, which rotate as the names imply. Dual-axis trackers continually face the sun because they can move in two different directions. Types include tip-tilt and azimuth-altitude. Dual-axis tracking is typically used to orient a mirror and redirect sunlight along a fixed axis towards a stationary receiver. Because these trackers follow the sun vertically and horizontally they help obtain maximum solar energy generation. The use of solar trackers can increase electricity production by around a third and as much as 40% in some regions compared with a module at a fixed angle (Aribisala, 2013).

A solar tracker is a device that keeps the photovoltaic modules or thermal collectors perpendicular to the sun’s rays during the day. Solar trackers are also used for orienting lenses, reflectors or other optical devices toward the sun. The required tracking accuracy depends on the application. Solar concentrators require high accuracy of tracking; they are not able to operate without tracking. On the other hand, flat plate collectors require less accuracy. There are two types of solar trackers based on the rotation axes: single axis and dual-axis. Single axis trackers have one degree of freedom as an axis of rotation. Three orientations of single axis solar trackers are common: horizontal, vertical, and tilted (Mehrtash, 2013).

2.6.1 Horizontal axis

This type of single axis trackers has a horizontal axis of rotation with respect to the ground. Figure 2.7 shows a schematic of a horizontal single axis tracker. These trackers are effective in low latitude locations where the sun passes overhead in the sky. This axis could be oriented in east-west or north-south directions, depending on the selected strategy for tracking.

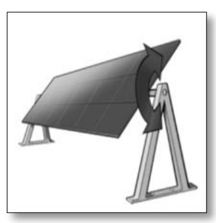

Figure 2.9: Horizontal axis tracker, (Linak, 2012)

2.6.2 Vertical axis

This type of single axis trackers has a vertical axis of rotation and they are effective in high latitude locations. Vertical axis trackers track the sun from East to West over the course of the

day. Photovoltaic panels are installed on vertical axis with a tilt angle. Figure 2.8 schematically shows a vertical single axis tracker which are also called by azimuth trackers.

Figure 2.10: Vertical axis tracker, (Linak, 2012)

2.6.3 Tilted axis

Tilted axis trackers have an inclined axis of rotation. Figure 2.9 schematically depicts a tilted axis tracker. If the tilt angle of axis is equal to the latitude of installation location it would be called polar tracker.

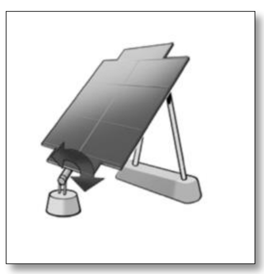

Figure 2.11: Tilted axis tracker, (Linak, 2012)

2.6.4 Dual-axis

Dual axis trackers have two degrees of freedom as rotation axes; they have both horizontal and vertical axes to track the sun more precisely. Figure 2.10 schematically illustrate a dual axis tacker.

Figure 2.12: Dual-axis tracker, (Linak, 2012)

2.7 Types of Campus Installations

An array should be designed with the primary goal of maximum light exposure over the year. Choices between rooftop, and ground-mounted systems; stationary, and sun tracking racks; and tilted or flat panels are common questions that arise to this end. One important thing to remember is that a single shaded and therefore dormant panel can reduce the production of other panels in series around it. Ideally, at no more than a fraction of daybreak or sundown should a panel experience shade. The placement and form may also be important considerations for campus aesthetics and simple practicality. The rooftop and the ground mount are the two most common choices for high-sunlight capture. In urban areas, and generally in the Northeast, where land is at a premium, arrays are more often put atop existing buildings, or integrated into the designs for new ones. In the more spacious Western U.S., there may be a better option to install a photovoltaic system in a nearby field, otherwise unused.

Once a location is chosen for the array, the panel orientation is considered. Tracking systems that use either one (east-west) or two axes (north-south; east-west) to follow the sun's daily path can boost total energy capture by about 20%. The operation and maintenance of moving parts is the primary drawback of a tracking array. An institution of higher education recently installed a single-axis tracking array of 1.2 MW that will produce around 40% of the campus

demand at peak hours, and after an estimated 14 year payback period, will generate positive saving of $300,000 annually. Tracking arrays of a few kW are often installed as educational tools, and can help study Earth-sun geometry in a practical application. More common is the choice between flat and tilted mounting of stationary panels on campus. South facing (plus or minus 30°), sloped roofs offer a decent location for a photovoltaic array. Their slope can bring the incident angle closer to perpendicular for more of the year, allow natural washing by rainfall, and prevent accumulation of snow in winter. Latitude may be the most important factor in deciding whether to tilt an array or not, granted a flat surface to work with. In southern regions, sunlight is more persistent, and solar elevation (i.e. the height of the sun above the horizon) is less variable over the course of a year. In order to maximize annual incident solar radiation, the installation should ideally sit at an angle about equal to the local latitude. For example, stationary solar collectors in San Diego, CA should sit at about 33°, facing as close to due south as possible. Using this formula one might then tilt panels installed in Burlington, VT at about 44°. But, in northern regions, this rule fails to account for the fact that the longest, sunniest days tend to be May to October, when the sun remains between 60-70° overhead for a longer period. A flat lying collector does not necessarily miss much sunlight during the winter, although it will not keep free of snow. Since 2005, schools have adopted a unique approach that improves campus parking service and produces renewable power. The use of solar modules mounted as an awning for parking spots prevents cars from baking on sunny days, and has recently found its way onto a number of campuses.

The amount of available sunlight is another important factor though photovoltaic can work well in all areas. Where there is less sun, compensate by adding panels to meet a given load. This adds cost and stretches out payback but it works. Where snow may cover panels during winter months, panels can be tilted to shed snow or photovoltaic array output can be pro-rated downward

to allow for a number of weeks or months when output is nil. The performance of grid-interconnected photovoltaic is generally measured in terms of annual power production and most photovoltaic production occurs during the warmer months when days are longer and there is less cloud cover. In areas where winter days are cold and clear, angling panels to take advantage of those conditions becomes more important. There are a variety of financial models for installing photovoltaic on campus. Campus can design, purchase and install its own system -- typically with the technical assistance of a consultant or supplier.

Chapter 3: Research Methodology

This chapter describes in detail the research methodology used in applying the photovoltaic efficiency model for solar installations on institutions of Higher Education in the United States. Figure 3.1 presents a thought diagram detailing the logical development for this chapter.

There following sections are covered in this chapter: the research process, the type of resource conducted, the design of the research, the treatment and analysis of the data, methodological issues, and research limitations and expected findings for a group of 379 solar installations on campuses of higher education in the United States.

Section 3.1 (the research process) allows smooth reading of the presented methodology. A detailed description of the research process is provided in Appendix A for the reader who wishes to review in more detail the researcher views on this subject. In section 3.2, the specific type of research conducted is described. This is followed by a section on the specific design of this research effort (section 3.3). In section 3.4 the criteria for data acceptance is described. In section 3.5 (treatment and analysis of data), a full explanation of how the data will be handled and statistical technique used to evaluate the data is presented. Section 3.6 looks at the testable research processes and the types of analysis which will be researched for solar installations efficiency. This is followed by section 3.7 where critical issues dealing with methodology are discussed (reliability and validity). In section 3.8, limitations of the research efforts are discussed.

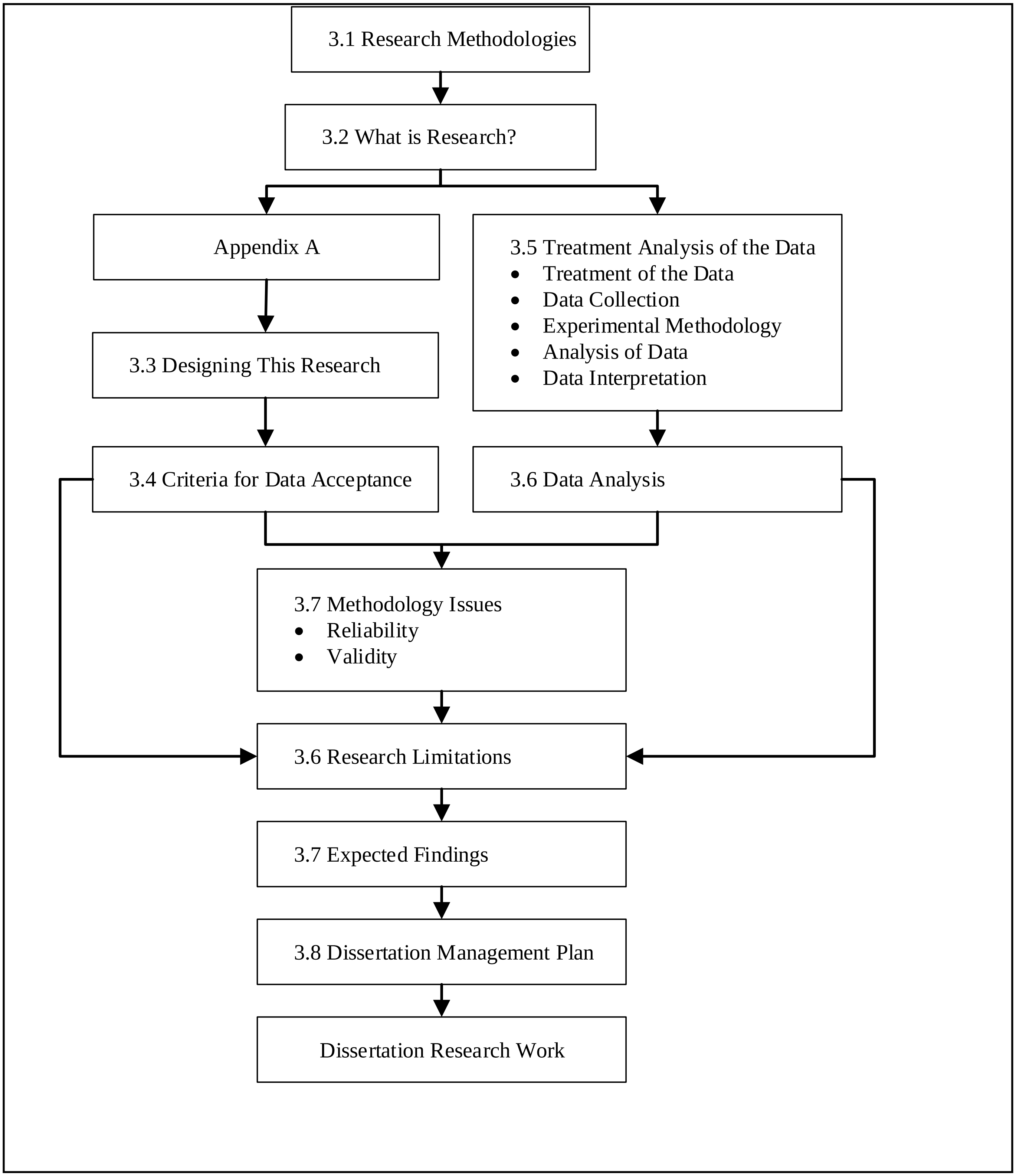

Figure 3.1: Thought Diagram Detailing Logical Development for Chapter 3

3.1 The Research Process

Research can be approached and classified in a variety of ways (basic, applied, technology, inductive, deductive, exploratory, confirmatory, etc.). A researcher's belief of what constitutes research is critical to understanding the research effort itself. The following section provides the type and design of this research,

3.2 Type of Research Conducted

This type or research is an empirical confirmatory study of photovoltaic efficiency. Perhaps an alternative perspective is: What were the different factors which have impacted the production or generation of renewable energy in kilowatt hours in an institution of higher education where federal grants have been awarded? Based on the initial cost investment, did the production generation equal the result? This research has both only applied research elements with respect to purpose, focus, desired results, level of generalization and key assumptions (see Appendix A for further detail). The ultimate determining factor in this decision is that the results contribute to the theory of photovoltaic efficiency and renewable energy generation.

Since the research is a confirmatory study, the logic is deductive in nature. So the research is applied, deductive, empirical and confirmatory study in to the nature of photovoltaic efficiency on a campus installation environment.

3.3 Research Design

The driving force behind the design of this research effort is the definitions of all of the contributing factors described in Chapter 2. The solar installation contributing factors are: state, institution, year, location, installer, panel manufacturer, inverter type, installations costs, capacity,

annual production, installation type (mount), installation type details (type of panel), NOP (number of panels) and efficiency.

The purpose of this section is to answer the what, who, where, why and how the experimental design will be conducted. Section 3.3.1 will present the specific data set to be tested. Examples of the data set can be seen in Appendix F of this dissertation. Section 3.3.2 (the data) answers what specific data will be gathered for the research. Section 3.3.3. answers the who, when and where with respect to environment characteristics data for the research, Finally section 3.3.4 will describe in detail the characteristics of the photovoltaic solar installations.

3.3.1 Research Data

For the investigation of the development of this research, the secondary information and data will be collected through the AASHE (Association for the Advancement of Sustainability in Higher Education) database. The Association for the Advancement of Sustainability in Higher Education (AASHE) is a non-profit membership organization that empowers higher education faculty, administrators, staff and students to be effective change agents and drivers of sustainability innovation. The organization works with and for higher education to ensure that the future leaders are motivated and equipped to solve suitability challenges (AASHE, 2015).

The organization's goals are designed to:

- Make sustainable practices the standard within higher education.
- Facilitate institutional efforts to integrate sustainability into teaching, research, operations, and public engagement.
- Distribute information and best practices and promote resource sharing.
- Support all sectors of campus in achieving sustainability goals.

- Increase collaboration among individuals, institutions, and external partners to speed the adoption of sustainability practices.
- Influence education policy so that sustainability is a focus at local, state and national levels.

The essential element in all research is the data collected. The data and the selection of the result, in part, of the photovoltaic characteristics being explored define much of the research to be conducted.

Data can be two types: primary data and secondary data (Leedy, 1989). This research gathered for this study is secondary from a public website which represents data closest to the phenomena being investigated. Each of the campus installations were implemented in a period from 1993 to 2015 with the concentration being in 2010 during which correlates with the time the United States government made funding available to institutions of higher education as a result of the AARA (American Recovery Act and Reinvestment Act of 2009) act intended to stimulate the US economy. Included in these initiatives were monies allocated towards renewable energy initiatives. The amount allocated for energy efficiency and renewable energy programs was $40 billion including $2.9 billion to weatherize modest-income homes; $4.6 billion for fossil fuel research and development; including $8.5 billion to subsidize loans for renewable energy projects.

3.3.2 Research Methodology

The methodology in this research consists of the institutions of higher education logging into a database and entering the data requested. The institution must have a membership to the AASHE organization. There is a fee associated with the membership depending on the student population of the institution.

All data will be logged by each individual institution choosing to share their respective data. Because this is secondary data outside of the control of the researcher, the data will be analyzed with the information made available through the website. The assumption is made that the information obtained is reasonably accurate. The researcher obtained permission to utilize the data (See Appendix B). And examples of the data set from the AASHE website can be seen in Appendix G.

3.3.3. Research Environment

This research will be conducted utilizing secondary data from the AASHE on institutions of higher education in the United States. The institutional installations occurred during the time period from 1993 - 2015 and in ten states throughout the United States. The information is the following information listed in section 3.3.4 describes the information collected from the AASHE database. (See Appendix C)

3.3.4 Characteristics of the Solar Photovoltaic Installations

The following characteristics of Photovoltaic installations were examined: The definitions are defined by the American Association for the Advancement of Sustainability in the Higher Education (AASHE).

1. State – The state of the installation.
2. Institution – The institution of the installation.
3. Year - The year of the installation implementation.
4. Location – Location of Installation to include City and State
5. Installer - The company/partner that installed the system.

6. Panels - Brand name, manufacturer(s) and type (ex. thin film or monocrystalline silicon) of panel component.
7. Inverters Type - Brand name, manufacturer(s), and type of inverter component.
8. Installation Costs - Total installer cost in USD. (US Dollars)
9. Capacity - Total installer capacity in kilowatts.
10. Annual Production - Total annual production in kilowatt hours.
11. Installation type – The installation type e.g. roof mount, pole mount, canopy. Etc.
    a. Roof Top Mount
    b. Ground or Pole Mount
    c. Wall Mound
    d. Canopy
    e. Building Integrated photovoltaic
    f. Other
12. Installation Type Details – Additional description of the installation panel type
    a. Monocrystalline
    b. Polycrystalline
13. Number of Panels – The number of panels during the initial installation.
14. Efficiency – A simple percentage ratio of the annual production and the initial implementation costs.

Examples of the data from the AASHE database can be seen in Appendix G.

3.4 Criteria For Data Acceptance

One of the basic elements of research is the interpretation of data. Not all data is good data (mistakes, etc.) and the quality of the data is the determining factor in the quality of the results obtained. Therefore, common sense and discretion will be employed by the researcher when dealing with the data collected. To administer control over the amount and quality of data collected, data collection will be restricted to the secondary information obtained from the campus solar data on the AASHE (Association of Advancement of Sustainability in Higher Education) website. The assumption is made that the information obtained is reasonably accurate. The website is a public website and permission was obtained from AASHE to utilize the data. This permission is noted on Appendix B.

3.5 Treatment and Analysis of Data

In this section, the "how" of the research is described: specifically how the data will be treated (collected, field work methodologies to be used)? This is followed by how the collected data were analyzed and interpreted (statistical design incorporated to rest for data significance).

3.5.1 Treatment of the Data

As indicated in section 3.3, the secondary data used were the solar installations characteristics from the website mentioned in section 3.3.4. Described below is how the data will be treated (collected). Due to the nature of the research question, a predictive model with a dependent variable with different types of independent variables and ideally a future outcome, a correlation and multiple linear regression analysis will be conducted to examine the relationship efficiency has with various potential predictors

3.5.2. How Data Will Be Collected

Data collection will be restricted to the information from the AASHE public website. For the investigation of the development of solar energy in the United States, other important and vital information will be collected through various federal and state government agencies reports from websites of National Renewable Energy Laboratory, Texas State Energy Conservation Office, Center for Natural Resources & Center for Economic Freedom, Texas Public Policy Foundation, US Energy Department, the Solar Foundation, International Renewable Energy Agency, Solar Energy Industries Association and the US Energy Information Administrative, Institute of Energy Research (Devabhaktuni, V., Alam, M., Depuru, S. S. S. R., Green, R. C., Nims, D., & Near, C., 2013).

3.5.3. Analysis of Data

For the individual variables, annual production is reported in kilowatt hours (kWh) and capacity are reported in terms of kW (kilowatts). Costs are reported is U.S. Dollar currency. All efficiency will be reported in percentages.

3.5.4 Data Interpretation

The sanitized data representative of 379 institutional solar implementations will be analyzed. The frequency distribution of the different variables will be analyzed. From there the data was statistically analyzed using multiple linear regression analysis to determine the impact of different variables on renewable energy generation. Once the data was reviewed, it was determined that the sample size was sufficient to have an outcome of statistically significant results making a valid inference. Once this was complete, the appropriate statistical analysis to run on

the research data were determined using SPSS software. Examples of the SPSS software results can be seen in Appendix E.

3.6 Data Analysis

After the collection of various data from the secondary source (AASHE), an analysis was conducted to help in understand the efficiency of a Photovoltaic system on an institution of Higher Education. The cost analysis development model is made to understand the economic such as photovoltaic efficiency which were considered while setting up the solar installation project. By understanding the above economic term it will demonstrate the impact of the different variables which are key components for the installations.

The analysis of data consisted primarily of testing the selected statistical procedure that will help answer the proposed research questions. Once the historical data from the AASHE public website was compiled, analysis for each different variable as a predictor of efficiency. An example of the compilation of this data can be seen in Appendix F. A Meta-Data transformation analysis which is an expanded version of secondary data to provide descriptive information will also be conducted. A statistical analysis will then be conducted on the output in SPSS. Examples of the SPSS software results can be seen in Appendix E.

A multiple regression analysis was applied to the data to determine whether or not the difference of the photovoltaic efficiency of these different parameters was statistically significant. A linear regression, a variant of the basic multiple regression procedure that allows to specify a fixed order of entry for variables in order to control for the effects of covariates or to test the effects of certain predictors independent of the influence of others.

There are four key assumptions which are important in simple and multiple linear regression analysis. It is important to comply with these assumption in simple and multiple regression. These four assumptions are not highly robust to violations, or easily dealt with through design of the study, that researchers could easily check and deal with, and carry substantial benefits. There are assumptions and their definitions are:

- **Linear relationship** - Standard multiple regression can only accurately estimate the relationship between dependent and independent variables if the relationships are linear in nature. As there are many instances in the social sciences where non-linear relationships occur (e.g., anxiety), it is essential to examine analyses for non-linearity. If the relationship between independent variables (IV) and the dependent variable (DV) is not linear, the results of the regression analysis will under-estimate the true relationship.
- **Reliability of Measurement -** With each independent variable added to the regression equation, the effects of less than perfect reliability on the strength of the relationship becomes more complex and the results of the analysis more questionable. With the addition of one independent variable with less than perfect reliability each succeeding variable entered has the opportunity to claim part of the error variance left over by the unreliable variable(s). The apportionment of the explained variance among the independent variables will thus be incorrect. The more independent variables added to the equation with low levels of reliability the greater the likelihood that the variance accounted for is not apportioned correctly. This can lead to erroneous findings and increased potential for Type II errors for the variables with poor reliability, and Type I errors for the other variables in the equation. This becomes increasingly complex as the number of variables in the equation grows.

- **Homoscedasticity** - Homoscedasticity means that the variance of errors is the same across all levels of the IV. When the variance of errors differs at different values of the IV, heteroscedasticity is indicated. According to Berry and Feldman (1985) and Tabachnick and Fidell (1996) slight heteroscedasticity has little effect on significance tests; however, when heteroscedasticity is marked it can lead to serious distortion of findings and seriously weaken the analysis thus increasing the possibility of a Type I error. This assumption can be checked by visual examination of a plot of the standardized residuals (the errors) by the regression standardized predicted value.
- **Normality** - Regression assumes that variables have normal distributions. Non-normally distributed variables (highly skewed or kurtotic variables, or variables with substantial outliers) can distort relationships and significance tests. There are several pieces of information that are useful to the researcher in testing this assumption: visual inspection of data plots, skew, kurtosis, and P-P plots give researchers information about normality, and Kolmogorov-Smirnov tests provide inferential statistics on normality. Outliers can be identified either through visual inspection of histograms or frequency distributions, or by converting data to z-scores.

In statistics, multicollinearity (also collinearity) is a phenomenon in which two or more predictor variables in a multiple regression model are highly correlated, meaning that one can be linearly predicted from the others with a substantial degree of accuracy. In this situation the coefficient estimates of the multiple regression may change erratically in response to small changes in the model or the data. Multicollinearity does not reduce the predictive power or reliability of the model as a whole, at least within the sample data set; it only affects calculations regarding individual predictors. That is, a multiple regression model with correlated predictors can indicate how well

the entire bundle of predictors predicts the outcome variable, but it may not give valid results about any individual predictor, or about which predictors are redundant with respect to others.

In order to determine the linear relationship between two variables a simple regression analysis was used to help predict the measure of the linear association between two variables. Linear regression is the next step up after correlation. It is used when we want to predict the value of a variable based on the value of another variable. The variable we want to predict is called the dependent variable (or sometimes, the outcome variable). The variable we are using to predict the other variable's value is called the independent variable (or sometimes, the predictor variable). The p-value is the probability of observing a certain result from your sample. If the p-value is less than .05, there is in fact a statistically significant difference in the means and it is not due to sampling error).

The purpose of multiple regression is to predict a single variable from one or more independent variables. (Pearson, 1908) Multiple regression with many predictor variables is an extension of linear regression with two predictor variables. A linear transformation of the X variables is done so that the sum of squared deviations of the observed and predicted Y is a minimum. The computations are more complex, however, because the interrelationships among all the variables must be taken into account in the weights assigned to the variables. The interpretation of the results of a multiple regression analysis is also more complex for much the same reason.

The prediction of Y is accomplished by the following equation:

$$Y'_i = b_0 + b_1X_{1i} + b_2X_{2i} + \dots + b_kX_{ki}$$

The "b" values are called regression weights and are computed in a way that minimizes the sum of squared deviations in the same manner as in simple linear regression. (Hair, 2010)

Once a regression model has been constructed, it may be important to confirm the goodness of fit of the model and the statistical significance of the estimated parameters. Commonly used checks of goodness of fit include the R-squared, analyses of the pattern of residuals and hypothesis testing. Statistical significance can be checked by an F-test of the overall fit, followed by t-tests of individual parameters. Interpretations of these diagnostic tests rest heavily on the model assumptions. ("Regression Analysis", 2016)

For this study a multiple linear regression analysis was performed with the efficiency as the dependent variable and the following variables as the independent variables: capacity, NOP (number of panels), installation type (re-coded) and panel type (re-coded).

For this research the following prediction model will be used:

$$\hat{y}_{\text{efficiency}} = \beta_1 X_{NOP} + \beta_2 X_{Capacity} + \beta_3 X_{New\_Install} + \beta_4 X_{New\_Panel}$$

A Meta data transformational analysis was conducted to provide descriptive statistics. Once this analysis was completed, it was determined that location was a statistically significant predictor and a revised proposed full model was used as seen below.

$$\hat{y}_{\text{efficiency}} = \beta_1 X_{NOP} + \beta_2 X_{Capacity} + \beta_3 X_{New\_Install} + \beta_4 X_{New\_Panel} + \beta_5 X_{Location\ 1} + \beta_6 X_{Location\ 2}$$

Results of these models are depicted in Chapter 4.

3.6.1. Predictive Modeling

Predictive modeling uses statistics to predict outcomes (Geisser, 1993). Most often the event one wants to predict is in the future, but predictive modeling can be applied to any type of unknown event, regardless of when it occurred (Finlay, 2014). In many cases the model is chosen

on the basis of detection theory to try to guess the probability of an outcome given a set amount of input data. Depending on definitional boundaries, predictive modelling is synonymous with, or largely overlapping with, the field of machine learning, as it is more commonly referred to in academic or research and development contexts. When deployed commercially, predictive modeling is often referred to as predictive analytics. This methodology will used to understand which variables are significant. The independent and dependent variables will be identified tested. These results will be detailed in Chapter 4.

3.6.2 Photovoltaic Efficiency

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaics into electricity. The efficiency of the solar cells used in a photovoltaic system, in combination with latitude and climate, determines the annual energy output of the system. For example, a solar panel with 20% efficiency and an area of 1 m^2 will produce 200 W at Standard Test Conditions, but it can produce more when the sun is high in the sky and will produce less in cloudy conditions and when the sun is low in the sky.

Several factors impact a cell's conversion efficiency rate, including its reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency, and conduction efficiency values. Because these parameters can be difficult to measure directly, other parameters are measured instead, including quantum efficiency, V_{OC} ratio, and fill factor. Reflectance losses are accounted for by the quantum efficiency value, as they affect "external quantum efficiency." Recombination losses are accounted for by the quantum efficiency, V_{OC} ratio, and fill factor values. Resistive losses are predominantly accounted for by the fill factor value, but also contribute to the quantum efficiency and V_{OC} ratio values.

As of December 2014, the world record for solar cell efficiency at 46% was achieved by using multi-junction concentrator solar cells, developed from collaboration efforts of Soitec, CEA-Leti, France together with Fraunhofer ISE, Germany. (Freund & Littell, 1981)

Not all of the sunlight that reaches a photovoltaic cell is converted into electricity. In fact, most of it is lost. Multiple factors in solar cell design play roles in limiting a cell's ability to convert the sunlight it receives. Designing with these factors in mind is how higher efficiencies can be achieved. Several factors affecting conversion efficiency are:

- **Wavelength** - Light is composed of photons—or packets of energy—that have a wide range of wavelengths and energies. The sunlight that reaches the earth's surface has wavelengths from ultraviolet, through the visible range, to infrared. When light strikes the surface of a solar cell, some photons are reflected, while others pass right through. Some of the absorbed photons have their energy turned into heat. The remainder have the right amount of energy to separate electrons from their atomic bonds to produce charge carriers and electric current.
- **Recombination** - One way for electric current to flow in a semiconductor is for a "charge carrier," such as a negatively-charged electron, to flow across the material. Another such charge carrier is known as a "hole," which represents the absence of an electron within the material and acts like a positive charge carrier. When an electron encounters a hole, they may recombine and therefore cancel out their contributions to the electrical current. Direct recombination, in which light-generated electrons and holes encounter each other, recombine, and emit a photon, reverses the process from which electricity is generated in a solar cell. It is one of the fundamental factors that limits efficiency. Indirect recombination is a process in which the electrons or holes encounter an impurity, a defect

in the crystal structure, or interface that makes it easier for them to recombine and release their energy as heat.

- **Temperature -** Solar cells generally work best at low temperatures. Higher temperatures cause the semiconductor properties to shift, resulting in a slight increase in current, but a much larger decrease in voltage. Extreme increases in temperature can also damage the cell and other module materials, leading to shorter operating lifetimes. Since much of the sunlight shining on cells becomes heat, proper thermal management improves both efficiency and lifetime.

- **Reflection -** A cell's efficiency can be increased by minimizing the amount of light reflected away from the cell's surface. For example, untreated silicon reflects more than 30% of incident light. Anti-reflection coatings and textured surfaces help decrease reflection. A high-efficiency cell will appear dark blue or black (Fraunhofer, 2016)

Multi-junction cells are used in concentrator photovoltaic (CPV) systems to produce low-cost electricity in photovoltaic power plants, in regions with a large amount of direct solar radiation. It is the cooperation's second world record within one year, after the one previously announced in September 2013, and clearly demonstrates the strong competitiveness of the European photovoltaic research and industry.

According to Joel Murphy (2011) a solar blogger, a photovoltaic cell is most typically a slice of crystalline silicon 200—300 µm thick. (µm = micron = micro-meter = one-millionth of a meter). The construction can either be monocrystalline or polycrystalline. Monocrystalline varieties have a minor benefit in efficiency: such as 18% vs. 15%. The cell is doped into what we call a p-n junction, which is basically a diode. More importantly is that the junction is very near the front surface of the cell, and it is here that energy is effectively harvested. A photon of light

comes in from the sky, penetrating some depth into the silicon. If it has enough energy it can pop an electron out of the lattice, leaving a "hole" behind (Murphy, 2011)

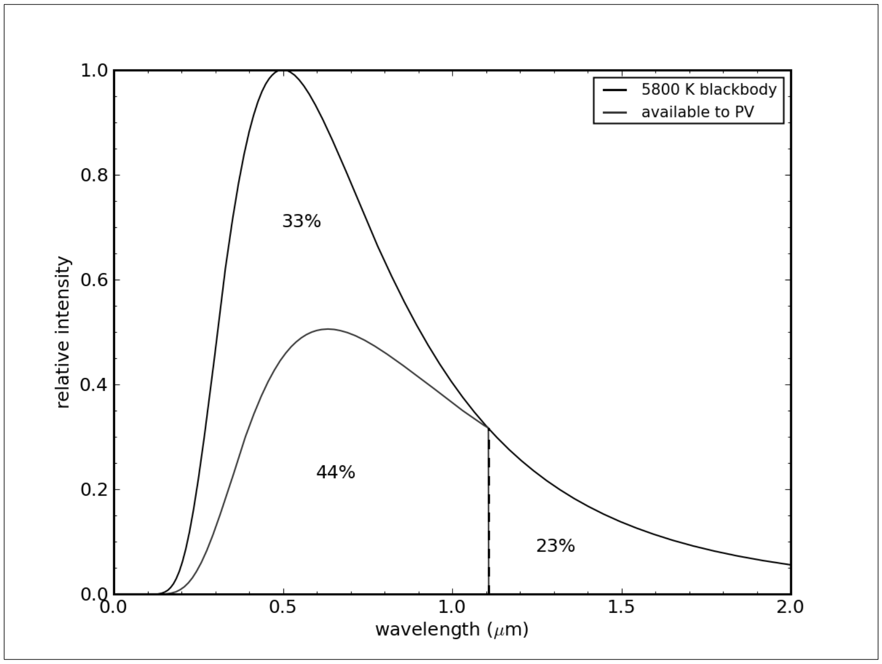

Figure 3.2: Photon Energy Effects (Murphy, 2011)

The first piece of knowledge is that photons below a certain energy cutoff called the bandgap energy (1.12eV in silicon; consistent to a wavelength of 1.1μm) are not captivated by the material: they sail right through as if going through clear glass. Second, the photons that are absorbed only need to have 1.12eV of energy to release an electron out of the lattice. Any extra is wasted, popping the electron out at high speed.

If a perfect blackbody solar spectrum is incident on the photovoltaic cell (ignoring atmospheric effects on spectrum), we lose 23% of the light to infrared transparency beyond 1.1 μm, plus a thermal loss that increases with increasing photon energy (shorter wavelength). The net

effect is that we get to keep 44% for photovoltaic energy production. It represents an upper limit to efficiency expectations.

We see these effects in Figure 3.2. At 1.1μm, the photon is well-matched to the necessary energy for liberating an electron, and we use 100% of its energy. As we go to shorter wavelengths, a smaller fraction of the photon energy is utilized, resulting in 33% of the incident energy going to waste heat. So this most basic investigation specifies that we are doing practically well to capture 16% efficiency out of a silicon photovoltaic cell when the crudely-determined upper limit is 44%.

Considering only photon energy effects, a silicon photovoltaic cell ignores 23% of the incoming energy, and wastes 33% in light that arrives with more energy than can be used resulting at most 44% available.

A typical location within the U.S. gets a yearly average of 5 full-sun-equivalent hours per day. This implies that the 1000 W/m^2 solar flux reaching the ground when the sun is straight overhead is effectively accessible for 5 hours each day. Each square meter of panel is essentially exposed to 5 kWh of solar energy per day. At 15% efficiency, our square meter captures and delivers 0.75 kWh of energy to a home. A typical American home uses 30 kWh of electricity per day, so we'd need 40 square meters of panels. This works out to 430 square feet, or about one sixth the typical American house's roof (the roof area of a two-car garage) (Murphy, 2013).

Included in this discussion the following needs to be considered:

- The expected penetration depth of the photon into the silicon depends on wavelength/energy. Photons near the bandgap can travel a very long way before being absorbed, while high-energy photons are absorbed practically at the front surface.

- Photovoltaic cells are often fabricated with a reflective back surface (also acts as the electrode), so that photons passing through the entire wafer still have a chance to be absorbed on the rebound trip. The reflective barrier also reduces heating from infrared light that otherwise would be absorbed at the back of the cell.
- Shorter wavelength light suffers more reflection loss at the front surface than longer wavelengths (Murphy, 2015).

A higher solar panel efficiency rating means a panel will produce more kilowatt-hours of energy per watt of power capacity. Because one high-efficiency panel can generate more electricity than a similarly sized panel with a standard efficiency rating, efficiency is particularly important if you have limited roof space and large energy bills.

One of the mathematical models being used in this research is multiple linear regression analysis. It is the practice of building successive linear regression models, each adding more predictors. The full proposed model includes efficiency as the dependent variable. The independent variables or predictors are capacity, NOP (number of panels), installation type referring to the different types of mounting installation (re-coded) and panel type referring to different panel types (re-coded). In other words, what is the impact of the different variable on the production in kilowatt hours of the solar installations on campuses of higher education? Through a number of statistical analysis, we will answer this very important question.

3.7 Methodological Issues

There are several methodological issues that all research efforts must deal with: representatives, reliability, replicability, and reactivity (Krippendorf, 2012). The question of validity can be added. There are four relevant quality tests of research, construct, validity, internal

validity, external validity and reliability (Yin, 1989). Table 3.1 is a representation of these four test of research quality. At the heart of analyzing methodological issues is the understanding by the researcher of, “what is a methodology?” Once this resolved, the question (issues) of quality of research methodology can more clearly be addressed. Leedy (1989) defines methodology as “an operational” framework within which the facts are placed so that their meaning may be seen more clearly. The operational framework or approach is then the researcher’s construction of the research process itself. This is evident in the second part of the definition where it is stated “within which facts are placed”. With this in mind, it is understandable that dealing with methodological issues raises the questions”. How trustworthy and representative are the instruments with which the results were obtained? What may have influenced the results? How valid are the results? This section addresses these questions.

Table 3.1: Quality of Research Issues (Yin, 1989)

Test	**Definition**
Construct Validity	Establish correct operational measurement for the concept being studied.
Internal Validity	Establish a causal relationship, whereby certain conditions are shown to lead other conditions, as distinguished from spurious relationships.
External Validity	Establish the domain to which a study’s findings can be generalized.
Reliability	Demonstrates that operations of a study – such as the data collection procedures can be repeated with the same results.

3.7.1 Reliability

The possibility of reliability problems is always a threat to research. The question of reliability is relevant to several components of the research process: test instruments,

questionnaire, etc. (Leedy, 1989). With respect to this research, the question of reliability presents an area of concern. All the data is electronically entered by a designated representative of the respective institution. This would entail entering the information into a database. This can allow for operator error or operator omission of certain variable factors of the photovoltaic solar installation. The assumption is that the information is reasonably accurate.

3.7.2 Validity

"With any type of measurement, two consideration are very important. One of these is validity, the other is reliability. Validity concerns the soundness of the measuring instrument" (Leedy, 1989, pg.26). Yin (1989) agrees with this premise and presents three types of validity: construct, internal and external. Leedy (1989) lists six types of validity: face criterion, content, construct, internal and external. In this section these issues are addressed. The question of face validity is very similar to representatives. Face validity relies pm the subjective judgement of the researcher (and the reader) when it is supposed to measure. And, it is the sample being measured adequate and representative? Content validity of the research was covered in the design of the research. The issue of construct validity is concerned with convergence and discriminability (Leedy, 1989). That is convergence looks at different measuring methods that convergence of focus the results. Discriminability looks at the ability of the instrument to discriminate the construct being studied. With respect to convergence, this research established and maintained a chain if evidence (literature review, results and observation) so that any reviewer of this research is convinces that the steps taken and the reasoning used lead to the results.

Since this study is a confirmatory study, the generalization will be statistical generalizations drawn from the data. In essence, what will be examined here is statistical significance. Generalization to other cases were limited since this study is the (model case) analysis of the

proposed research agenda. The data will be analyzed to understand the statistical differences of the impact of the variables on production generation using a multiple regression analysis. The type of variables were selected after a significant of statistical analysis and it was determined that only four variables needed further study. These variables were: capacity, NOP (number of panels), type of installation and type of panel as the predictors of the dependent variable - efficiency.

3.7.2 Research Limitations

All research efforts have limitations. It is a difficult thing for a researcher to list all limitations of the proposed research to do a faithful job of presenting the limitations. Expanding on the information provided in section 1.4, this research is restricted by:

1) The research is based on a specific type of college campuses only model (Sumanth, 1989). This although focusing the research confines the research to a specific paradigm.
2) Due to the time and cost limitations, the study was only on a limited number of photovoltaic solar installations on institutions of higher education only.
3) The data collection was tied only to the public database where representative is institution of higher education entered into the database.
4) This study was research of a projected research agenda so the results will be limited in this generality.

Chapter 4: Field Study Results, Analysis and Discussion

This chapter presents the results obtained from the study conducted for 379 solar installations on institutions of higher education from the period of 1993 – 2015. The secondary data used for this research was obtained from the following public website, "Association for the Advancement of Sustainability in Higher Education", (AASHE). Figure 4.1 is a thought diagram detailing the logical development for this chapter. In this chapter, the statistical analysis results of 379 photovoltaic solar installations are addressed. Permission was requested and attained from the AASHE organizational representative and is included in Appendix C. Section 4.1 introduces the chapter and sets the stage for the sections to follow. Here the secondary data is described in detail. In section 4.2, the photovoltaic solar installation variables results are discussed. This includes the identification and description of the photovoltaic solar installation efficiency variables In section 4.4 the different statistical methods of analysis for the data are presented in detail followed by a general perspective of the data results which is presented in section 4.5. The Meta Data transformational analysis is presented in section 4.6. And in section 4.7., a general interpretation of the data results will follow. In section 4.8, a summary of Chapter 4 is described. And finally in section 4.7, the next steps for Chapter 5 will be discussed.

4.1 Introduction

The following sections are representative of the data gathered in the photovoltaic installations efficiency study conducted.

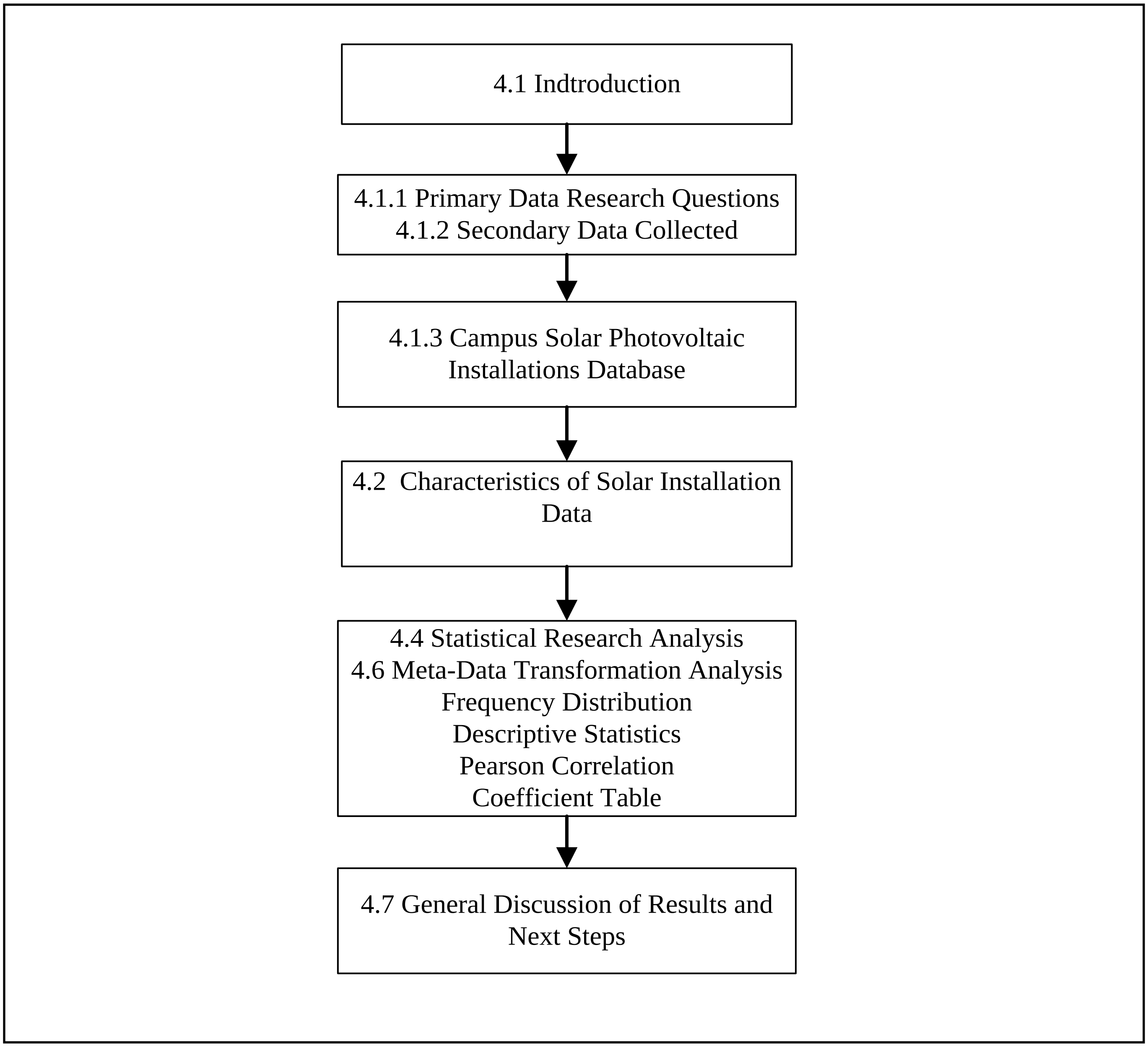

Figure 4.1: Thought Diagram Detailing Logical Development for Chapter 4

4.1.1 Primary Data Analysis Research Questions

The primary questions represented by this data analysis are and should be considered.

- Have the recipients of these federally funded monies been good stewards of federal funds as required?

- What is the impact of the different quantitative and qualitative variables on the efficiency of the solar installations? (i.e. state, institution, year, location, installer, panels, inverter type, installation costs, capacity, annual production, installation mounting type, installation panel type, and NOP (number of panels).

These primary objectives of the study included the following:

- **Objective One -** Examined trends via data analysis by developing a statistical model which included the impact of cost on the output of energy annual production for the purpose of prediction through multiple regression analysis.
- **Objective Two** - Examined Cost Effectiveness Analysis (CAE) by comparing the installations costs and production outcome with the other independent variables through multiple regression analysis. Efficiency was calculated by as a percentage ratio with the production (kWh) divided by the implementation cost ($).
- **Objective Three** – Examined the transformation of the dataset through Meta-data analysis to develop a statistical model which will perform a deeper dive into the secondary data to determine other additional factors which may impact the output of energy annual production using frequency distribution and multiple regression analysis.
- **Objective 4** – Revision of initial proposed full predictive model. Once the initial model was examined, a statistical analysis was performed to investigate a re-coded variable (location) using multiple regression analysis.

4.1.2 Secondary Data Collected

The following four points could be useful to those conducting a similar study research.

First, the researcher should familiarize themselves with the solar photovoltaic efficiency installations themselves. It is important for the researcher to be aware of any factors which may have a direct impact on the total photovoltaic efficiency measurement of an organization.

Second, it is imperative for the researcher to have knowledge of the solar industry inner workings including manufacturing of the solar panel, inverters and installation mounting options. A review of the most important paradigms of the solar industry are essential. An institution of higher education must be able to produce renewable energy to justify the implementation cost of a photovoltaic solar installation.

Thirdly, the amount of data collected in this study was a subset of the final number of installations. The data was obtained with permission from the Association for the Advancement of Sustainability in Higher Education (AASHE) and is located in Appendix C of this dissertation.

Fourth, there needs to be more of a focus on a formal measurement program which would support and enhance improvement to encourage the design of measurements and evaluations systems. Depending on how sophisticated the existing data collection system, the degree data collection modification may vary. The data collecting points must be cataloged carefully. The individuals submitting data must be trained and accountability must be appropriately assigned. Ideas on costs regarding renewable energy initiatives such as photovoltaic initiatives must be discussed with the leadership of the institution. The solar array can also be incorporated into the learning curriculum of several classes and will help educate students about the benefits of solar energy and the technical aspects of installing an array. Some of the learning outcomes include:

- Working knowledge of the benefits and limitations of a solar energy system and conducting an economic assessment of its return on investment.

- Basic understanding of state and federal regulations and requirements in the energy systems field surrounding grant awards designed to increase renewable energy initiatives.
- Understanding of the importance of safety in an energy system environment.

The Association for the Advancement of Sustainability in Higher Education (AASHE) is a non-profit 501(c) (3) membership organization that empowers higher education faculty, administrators, staff and students to be effective change agents and drivers of sustainability innovation. AASHE enables its members to translate information into action by offering essential resources and professional development to a diverse, engaged community of sustainability leaders. The organization works with and for higher education to ensure that future leaders are motivated and equipped to solve sustainability challenges. AASHE defines sustainability in an inclusive way, encompassing human and ecological health, social justice, secure livelihoods, and a better world for all generations.

4.1.3 Campus Solar Photovoltaic Installations Database

AASHE's Campus Solar Photovoltaic Installations database contains information on 585 solar photovoltaic installations on 333 campuses in 46 states and provinces. The total capacity is 222,253 kilowatts and the average capacity is 385 kilowatts. (AASHE, 2016)

4.2 Identification and Description of the Photovoltaic Solar Installations Variables

The following characteristics of photovoltaic installations were considered for the 379 installations included in this research. The definitions are defined by the American Association for the Advancement of Sustainability in Higher Education, (AASHE) database. The fourteenth variables is efficiency and was calculated using a percentage ration model of production in kilowatt

hours divided by the implementation cost in US dollars. This was used as the dependent variable as it was a calculated using both the results of the production and cost variable results. The variables are:

1. State – The state of the installation.
2. Institution – The institution of the installation.
3. Year - The year of the installation implementation.
4. Location – Location of Installation to include City and State
5. Installer - The company/partner that installed the system.
   - Panels - Brand name, manufacturer(s) and type (ex. thin film or monocrystalline, silicon) of panel component.
6. Inverters Type - Brand name, manufacturer(s), and type of inverter component.
7. Installation Costs - Total installer cost in USD. (US Dollars)
8. Capacity - Total installer capacity in kilowatts.
9. Annual Production - Total annual production in kilowatt hours.
10. Installation type – The installation type e.g. roof mount, pole mount, canopy. Etc.
    - Roof Top Mount
    - Ground or Pole Mount
    - Wall Mound
    - Canopy
    - Building Integrated photovoltaic
    - Other
11. Installation Type Details – Additional description of the installation panel type
    - Monocrystalline
    - Polycrystalline
12. Number of Panels – The number of panels during the initial installation.

13. Efficiency – A simple percentage ratio of the annual production and the initial implementation costs.

4.3 Research Type of Study

It is important to identify the type of research was conducted for this study. There are two types of research. Qualitative (data which can be observed but not measured) and quantitative (data which can be measured). Qualitative research is primarily exploratory and used to gain an understanding of underlying reasons, opinions and motivations whereas quantitative research is used to quantity the problems by way of generating numerical data or data that can be transformed into useable statistics. Quantitative research uses measureable data collection methods and generalize data to formulate facts and uncover patterns in research. It is more structured. The data in this research is more quantitative in nature since the secondary data extracted from the AASHE (Association for the Advancement of Sustainability in Higher Education) website will be analyzed using statistical analysis to identify defined variables. What is also important is the identification of the dependent and independent variables. In examining the relationship between the variables it was important to identify which variable may cause change in the other variable. The dependent variable is the effect or the variable being examined.

The decision to use only a subset of the entire variables set for the multiple regression analysis was made after a significant number of a statistical analysis were conducted on the original dataset. The output of these analysis allowed the researcher to focus on the most significant variables. These variables were: 1. capacity, 2. NOP (number of panels), 3. type of panel (re-coded), 4. type of installation (re-coded), 5. location (re-coded) and 6. efficiency (using the variables production and cost in the calculation). Several iterations were conducted and the results will be described later in the following section.

4.4 Statistical Research Analysis Results

The total data set for the analysis is 379 solar installations in institutions of higher education throughout the United States. The 379 installations were located in ten states throughout the United States. This section will show the statistical analysis for the following variables: state, institution, year, location, installer, panel manufacturers, inverter types, installation costs, capacity, annual production, installation type, type of panel, NOP number of panels and efficiency. This will include: frequency distribution, and multiple regression analysis, Meta – Data transformational analysis for the initial proposed full model. Once this was complete a multiple regression analysis was conducted for a revised initial proposed full model.

The multiple regression analysis was conducted to examine the relationship between efficiency (dependent variable) and various potential predictors (capacity, NOP (number of panels), panel type and installation type. A Meta-Data analysis transformation was conducted and as a result of this analysis, a revised model was statistically analyzed and the results will discussed later in this chapter. In this research the dependent variable was efficiency. The independent variables is the explanatory variable. In the initial proposed model there were four independent variables: 1. capacity, 2. NOP (number of panels), 3. type of panel (re-coded) and 4. type of installation (re-coded).

Once the Meta data analysis was completed, a new revised model was statistically analyzed to include the location variable. The revised model included efficiency as the dependent variable and the following independent variables as predictors: 1. capacity, 2. NOP (number of panels), 3. type of panel (re-coded), 4. type of installation (re-coded) and 5. location re-coded). The results of this analysis will be shown later in the chapter.

The first statistical analysis conducted was the frequency distribution. This can be seen for the following variables: 1. state, 2. institution, 3. year, 4. location, 5. installer, 6. panel manufacturers, 7. inverter types, 8. installation costs, 9. capacity, 10. annual production, 11. installation type, 12. type of panel, 13.NOP (number of panels) and 14. efficiency. Table 4.1 depicts the solar installations by state. The top ten states to examine were chosen because they had the highest number of solar installations.

Table 4.1: Frequency Distribution of Total Solar Installations by State (AASHE, 2016)

Ranking	State	Frequency	%
1	Arizona	116	30.6%
2	California	83	21.9%
3	Massachusetts	43	11.3%
4	Colorado	28	7.4%
5	Texas	28	7.4%
6	Ohio	19	5.0%
7	Oregon	17	4.5%
8	New York	16	4.2%
9	Wisconsin	15	4.0%
10	New Jersey	14	3.7%
	Total	379	100.0

Arizona had the highest number of installations with 116 at nine different institutions. The highest number of installation were at Arizona State University located in Tempe, Arizona with 87 installations. The next institution was The University of Arizona located in Tucson, Arizona with 21 installations. All 379 institutions reported their respective state of installations.

4.4.1 Solar Installation Frequency Distribution - Year

Table 4.2 depicts the year the solar installation was completed. The range of years is from 1993 to 2015. The earliest installation took place in 1993 at State University of New York at

Farmingdale located in New York. The largest number of installations were in 2010 with 94 or 24.8% installations. 377 institutions reported the year of their solar installations.

Table 4.2: Frequency Distribution of Solar Installations by Year - From 1993 to 2015 (AASHE, 2016)

Year	**Frequency**	**%**
1993	1	0.3
1994	1	0.3
1998	1	0.3
2000	2	0.5
2001	6	1.6
2002	4	1.1
2003	10	2.6
2004	9	2.4
2005	11	2.9
2006	13	3.4
2007	10	2.6
2008	18	4.7
2009	53	14.0
2010	94	24.8
2011	71	18.7
2012	23	6.1
2013	27	7.1
2014	13	3.4
2015	10	2.6
Missing Data	2	0.5
	379	100

Figure 4.2 is a bar chart depicting the number of installations per year. The majority of installations took place in 2010 which was during the time when the federal government was disbursing funds allocated for renewable initiatives for institutions of higher education.

As observed in Table 4. 3, there were 94 installations in 2010, the highest number of the 379 installations. Of the 94 installations, 22 or 23.4% were in Arizona. The next year with the highest installations was in 2011 with 71 installations. The third year with the highest number of

installations was 2009 with 53 installations. In 1993, 1994 and 1998 there was only one solar installation reported per year.

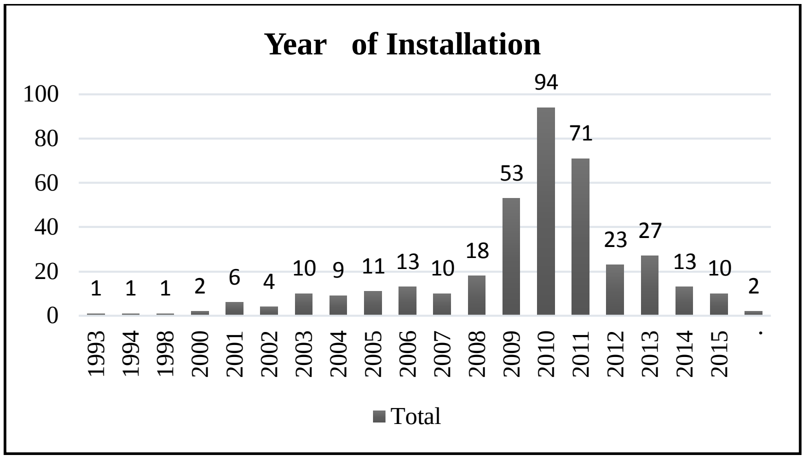

Figure 4.2: Bar Chart of the Frequency Distribution of Solar Installations by Year (AASHE, 2016)

4.4.2 Solar Installation Frequency Distribution - State

The top ten states with the highest number of installations are reflected in Table 4.3. These ten states produce 180,324 kWh in production of renewable energy. Arizona was the leading state with 116 installations. California was next with 83 installations and the state of Massachusetts was third with 43 installations. Colorado came in fourth with 28 installations. Texas was next with 28 installations and Ohio was next with 19 installations. The three states with the lowest number of installations were New York (16), Wisconsin (15) and New Jersey (14).

There were a sporadic number of institutions prior to the federal funding availability by the United States government and a sporadic number of installations after that time as well.

Table 4.3: Frequency Distribution of the Photovoltaic Solar Installation by State (AASHE, 2016)

Ranking	State	Frequency	%
1	Arizona	116	30.6
2	California	83	21.9
3	Massachusetts	43	11.3
4	Colorado	28	7.4
5	Texas	28	7.4
6	Ohio	19	5.0
7	Oregon	17	4.5
8	New York	16	4.2
9	Wisconsin	15	4.0
10	New Jersey	14	3.7
	Total	379	

Figure 4.3 represents the states where the implementation took place. As previously noted, the highest number was in Arizona and the second highest in California, both southwestern states. The locations of the solar installations occurred throughout different areas of the United States.

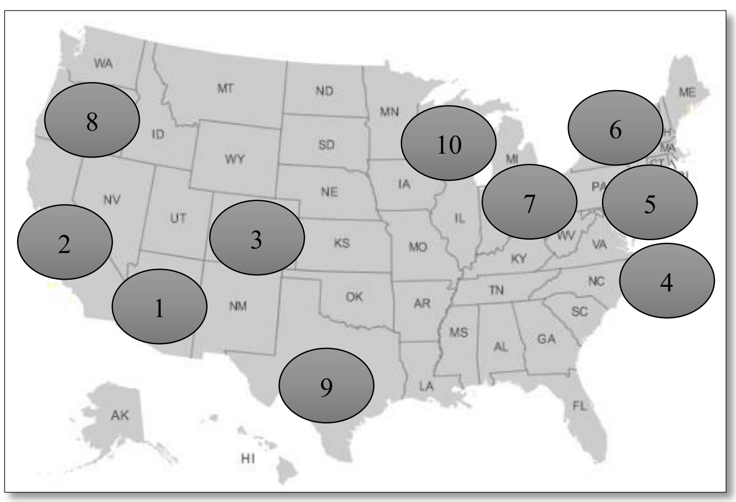

Figure 4.3: The Top Ten States of Solar Installations (AASHE, 2016)

The highest number of installations were in Arizona with 116 installations. These majority of these installations were in Tempe and Tucson, Arizona. The state of California was second with 83 installations.

4.4.3 Solar Installation Frequency Distribution - Institution

Table 4.4 depicts the top ten institutions with the highest number of solar installations. Arizona State University had the highest number of installations with 87 installations followed by The University of Arizona with 21 solar installations. Harvard University, Ohio University, San Diego Community College and San Diego State University reported only four installations each. 379 institutions reported out the information for this variable.

Table 4.4: Top Ten Institutions with Solar Implementation (AASHE)

Ranking	Institution	Frequency	%
1	Arizona State University	87	23.0
2	The University of Arizona	21	5.5
3	Colorado State University	15	4.0
4	University of Colorado Boulder	7	1.8
5	Williams College	6	1.6
6	California State University, Fullerton	5	1.3
7	Harvard University	4	1.1
8	Ohio University	4	1.1
9	San Diego Community College District	4	1.1
10	San Diego State University	4	1.1

4.4.4 Solar Installation Frequency Distribution - Top Ten Locations (Cities)

Table 4.5 represents the top ranking cities with solar installations which was Tempe, Arizona with 87 installations, Tucson, Arizona with 21 installations and Fort Collins, Colorado was ranked third with 15 installations. San Diego, California was fourth with 10 installations and

Austin, Texas was fifth with seven installations. The 379 solar installations were located in 160 cities in ten different states.

Table 4.5: The Top Ten Locations (City and State) of the Solar Installations (AASHE, 2016)

Ranking	City	Frequency	%
1	Tempe, AZ	87	23
2	Tucson, AZ	21	5.5
3	Fort Collins, CO	15	4
4	San Diego, CA	10	2.6
5	Austin, TX	7	1.8
6	Boulder, CO	7	1.8
7	Cambridge, MA	7	1.8
8	Williamstown, MA	6	1.6
9	Fullerton, CA	5	1.3
10	Portland, OR	5	1.3

4.4.5 Solar Installation Frequency Distribution - Installer (Vendor)

Table 4.6 represents the frequency distribution of the top ten installation vendors used in the reported solar installations. There were a total of 83 different vendors reported with locations throughout the United States. Amersco Southwest was the highest installer vendor with 49 solar installations. Amersco was founded in 2000 and is headquartered in Framingham, Massachusetts. The company acquired APS Energy Services in Tempe, Arizona in 2011. Lafferty Electrical Technologies with 20 solar installations began renewable energy operations in 2009 and is located in Phoenix, Arizona. The third vendor used was Ostrow Electrical Company, Inc. with eleven installations and is located in Dorchester, Massachusetts. This company were the installer for nine of the 43 solar installations in Massachusetts. 217 institutions reported data for the installer vendor.

Table 4.6: The Top Ten Installation Vendors (AASHE, 2016)

Ranking	Vendor	Frequency	%
1	Amersco Southwest	49	12.9
2	Lafferty Electric Technologies	20	5.3
3	Ostrow Electrical Company, Inc	11	2.9
4	Chevron Energy Solutions	7	1.8
5	SunPower	6	1.6
6	Bella Energy	5	1.3
7	Hardison-Downey	5	1.3
8	Independent Energy Group	5	1.3
9	PowerLight	4	1.1
10	SPG Solar	4	1.1

4.4.6 Solar Installation Frequency Distribution - Solar Panel Manufacturers

In Table 4.77 the frequency of the brand name of the solar panel manufacturer is shown for the top ten vendors used in the solar installations. 77.8% of the total vendors reported, were comprised of the top ten vendors. 34 or 16% of the total number of institutions used SunTech as the solar panel vendor used. SunTech manufacturers its panels in China. Kyocera with 30 solar installations are manufactured in Mexico and Sharp, the third highest used panel vendor with 18 installations is manufactured in Japan. 212 institutions reported their panel manufacturer.

Table 4.8: Frequency Distribution and Ranking of the Top Ten Panel Manufacturers (AASHE, 2016)

Ranking	Vendor	Frequency	%
1	SunTech	34	16.0
2	Kyocera	30	14.2
3	Sharp	18	8.5
4	Canadian Solar	15	7.1
5	Schott	15	7.1
6	Trina	15	7.1
7	Evergreen Solar	12	5.7
8	Solar World	12	5.7
9	SunPower	11	5.2
10	BP Solar	8	3.8

4.4.7 Solar Installation Frequency Distribution - Inverter Manufacturers

Table 4.8 demonstrates the brand name of the top ten panel manufacturers for the solar installations reported. Seventeen different inverter manufacturers were reported by the institutions. 52 or 13.7 % of the 200 installations reported using SMA as their inverter manufacturer. SMA manufacturers its product in Germany. SMA was used in eight of the ten states that were examined in this study. The eight states included: Arizona, California, Colorado, Massachusetts, Ohio, Oregon, Texas and Wisconsin. The next most used vendor was Advanced Energy with 50 installations and the third was Sacton with 28 different installations. Sacton was the third highest used inverter manufacturer used and photovoltaic Powered was the fourth highest used. PV Powered has been in business since 1981 and was acquired in March of 2010 by Advanced Energy, a global leaders in thin film utility scale manufacturing. They are headquartered in Bend, Oregon.

Table 4.8: Ranking of the Frequency Distribution of the Inverter Manufacturers (AASHE, 2016)

Ranking	Vendor	Frequency	%
1	SMA	52	13.7
2	Advanced Energy	50	13.2
3	Satcon	28	7.4
4	PV Powered	20	5.3
5	Solectria	18	4.7
6	Xantrex	14	3.7
7	Fronius	7	1.8
8	Enphase	2	0.5
9	Solaron	1	0.3
10	Sunpower	1	0.3

4.4.8 Solar Installation Frequency Distribution - Installation Cost

One of the most important questions of this research is to determine the impact of the initial investment cost and the production of renewable energy while understanding the efficiency of the installations. This research asks the question: Is the amount of initial investment make a difference in the output of renewable energy in kilowatt hours? Further investigation and the statistical analysis should answer this very important question. Table 4.9 represents the frequency in ranges in increments of $100,000 USD. 178 institutions that reported installation costs were under an initial investment of $10M USD. There were 38 institutions which incurred installations costs between $2M and $10M. The next category of 37 solar installations invested between $500,000 and $1M. There were 23 institutions with an initial investment of under $100,000. 191 institutions reported their initial investment for their solar institution.

Table 4.9: Frequency Distribution Range of Implementation Costs (AASHE, 2016)

Range – Costs (USD)	Frequency	%
$1.00 - $99, 000	23	12.0
$101,000 - $150,000	9	4.7
$150,001 - $200,000	16	8.4
$200,001 - $300,000	12	6.3
$300,001 - $400,000	7	3.7
$400,001 - $500,000	1	0.5
$500,001 - $1,000,000	37	19.4
$1,000,001 - $2,000,000	35	18.3
$2,000,001 - $10,000,000	38	19.9
$10,000,001 - $15,000,000	5	2.6
$15,000,001 - $30,000,000	7	3.7
$30,001,001 - $50,000,000	1	0.5

The single highest installation cost was at Rutgers, the state of New Jersey with an installation cost of $40,800,000. It is regarded as the largest solar canopy system in the United

States and was completed in 2012. Table 4.10 represents the top twelve installations with the highest initial cost investment. The second highest institution was Contra Costa College in San Pablo, California with an initial investment of $29,000,000 in 2009. The third highest investment was West Hills Community College District in Coalinga, California with an initial investment of $27,000,000 in 2011. It is interesting to observe that six of the 12 highest invented institutions implemented their installations in 2011. The earliest implementation was in 2007 at California State University in Fresno California. This institution invested $11,900,00M in the solar installation. Of the 12, there were two installations in 2009. Of the 12 institutions, six were in California, four in Arizona and the remaining two in New Jersey and Colorado. Figure 4.4 depicts the frequency distribution of the total costs of the solar installations.

Table 4.10: Top Twelve Installations with the Highest Installation Cost (AASHE, 2016)

Ranking	State	Institution	Location	Year	Cost ($USD)
1	New Jersey	Rutgers, the State University of New Jersey	Piscataway, NJ	2012	$ 40,800,000
2	California	Contra Costa College	San Pablo, CA	2009	$ 29,000,000
3	California	West Hills Community College District	Coalinga, CA	2011	$ 27,000,000
4	Arizona	Arizona State University	Tempe, AZ	2011	$ 22,498,084
5	Colorado	United States Air Force Academy	USAFA, CO	2011	$ 18,300,000
6	California	Butte College	Oroville, CA	2011	$ 17,000,000
7	California	San Diego Community College District	San Diego, CA	2010	$ 16,800,000
8	Arizona	Arizona State University	Tempe, AZ	2011	$ 16,203,140
9	California	Las Positas College	Livermore, CA	2009	$ 12,900,000
10	California	California State University, Fresno	Fresno, CA	2007	$ 11,900,000
11	Arizona	Arizona State University	Tempe, AZ	2011	$ 11,171,132
12	Arizona	Arizona State University	Tempe, AZ	2012	$ 10,800,000

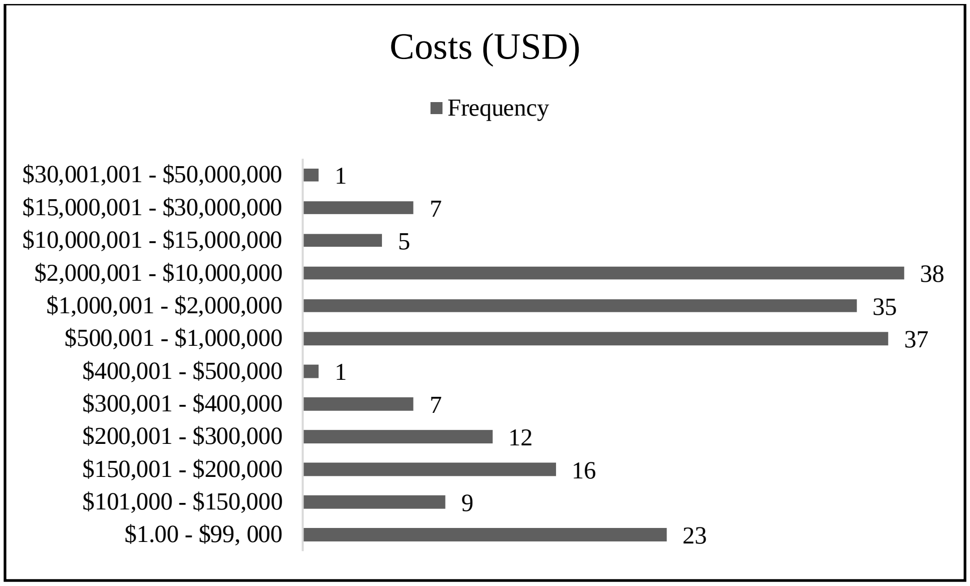

Figure 4.4: Frequency Distribution of the Total Cost of the Solar Installation (AASHE, 2016)

4.4.9 Solar Installation Frequency Distribution - Institutional Capacity (kW)

The next variable for which data is represented is the capacity reported by the institutions in kilowatts (kW). This is shown in Table 4.11. The highest frequency of institutions which reported capacity between one kilowatt and 100 kilowatts were 190 institutions. The next highest range was between 100 kW– 200 kW with 39 institutions in this category. There were 24 institutions which had between 3,000 kW and 9,000 kW capacity and 34 reporting between 2001 kW – 3000 kW. Rutgers University in Piscataway, New Jersey reported the highest capacity output amount of 8,017 kW. The next highest output was also Rutgers with 8,000 kW. 377 of the institutions reported the capacity of their institutions in kilowatts.

Table 4.11: Frequency Distribution Range of the Institutional Solar Capacity in kW (AASHE, 2016)

Range	Frequency	%
1-100	190	50.4
101 - 200	39	10.3
201 - 300	35	9.3
301 - 400	20	5.3
401 - 500	11	2.9
501 - 1000	8	2.1
1001 - 2000	16	4.2
2001 - 3000	34	9.0
3001 - 9000	24	6.4

4.4.10 Solar Installation Frequency Distribution - Annual Production (kWh)

Table 4.12 reflects the annual production for the 379 installations reported in kilowatt hours. There were 98 installations which reported between one kilowatt hour and 100,000 kilowatt hours. The next highest frequency was 39 installations reporting between 100,001 kilowatt hours and 200,000 kilowatt hours. The third highest frequency was 17 installations reported between 200,001 kilowatt hours and 300,000 kilowatt hours and 400,001 kilowatt hours and 500,000 kilowatt hours. Those were five institution which reported between 4, 00,001 kilowatt hours and 12,000, 000 kilowatt hours. There were 220 institutions which reported their annual production.

The range of implementations in the highest producing institutions were implemented from 2008 – 2011.

Table 4.12: Frequency Distribution of Institutional Annual Production in kWh (AASHE, 2016)

Range (kWh)	Frequency	%
1 - 100,000	98	44.5
100,001 - 200,000	39	17.7
200,001 - 300,000	17	7.7
300,001 - 400,000	13	5.9
400,001 - 500,000	17	7.7
500,001 - 600,000	8	3.6
600,001 - 700,000	4	1.8
700,001 - 800,000	6	2.7
800,001 - 1,000,000	3	1.4
1,000,001 - 1,500,000	9	4.1
1,500,001- 2,000,000	8	3.6
2,000,001- 3,000,000	8	3.6
3,000,001- 4,000,000	8	3.6
4,000,001- 12,000,000	5	2.3

Table 4.13 represents the top six institutions with the highest production. The highest producing institution of renewable energy was the United State Air Force Academy in Colorado implemented in 2011 with 11,600,000 kilowatt hours. The second was California State University in Fullerton, California which was implemented in 2010 with 10,000,000 kilowatt hours of renewable energy. Fort Collins, Colorado was the third highest ranking institution with 5,000,000 kilowatt hours. This installation was in 2010. The lowest of the top six was Contra Costa College in San Pablo, California implemented in 2009 with 4,000,000 kilowatt hours reported.

The initial implementation cost associated with the highest producer, United States Air Force Academy in USAFA, Colorado in 2011 was $18,300,000 USD.

Table 4.13: Top Solar Installations Annual Production in kWh (AASHE, 2016)

Ranking	Institution	Year	Location	Production (kWh)
1	United States Air Force Academy	2011	USAFA, CO	11,660,000
2	California State University, Fullerton	2010	Fullerton, CA	10,000,000
3	Colorado State University	2010	Fort Collins, CO	5,000,000
4	Los Angeles Southwest College	2008	Los Angeles, CA	5,000,000
5	San Diego Community College District	2010	San Diego, CA	4,479,616
6	Contra Costa College	2009	San Pablo, CA	4,000,000

4.4.11 Solar Installation Frequency Distribution - Panel Mounting Type

Table 4.14 represents the type of panel mounting used for the solar installations. There were 215 institutions which used the roof top mount. The second most common was the pole mount with 77 installations. It is most economical for the institutions to use the rooftop model because it is easier to use existing structures which may already be on a university campus. There were a total of 349 institutions which reported the installation type.

Table 4.14: Type of Panel Mounting Installation (AASHE, 2016)

Type of Installation	Frequency	%
Roof Top Mount	215	56.7
Pole Mount	77	20.3
Canopy	44	11.6
Other	13	3.4
Data Missing	30	7.9
Total	379	100.0

4.4.12 Solar Installation Frequency Distribution - NOP (Number of Panels)

Table 4.15 reflects the number of panels used on the solar installations. The highest number of panels used was 19,000 from the vendor SunPower. This was at the United States Air

Force Academy in Colorado in 2011. A total of 196 institutions reported the number of panels used during the installation implementations.

Table 4.15: Frequency Distribution of Number of Panels in Installation (AASHE, 2016)

Range	Frequency	%
0-500	110	56.1
500-1000	23	11.7
1001-2000	26	13.3
2001-3000	7	3.6
3001 -4000	7	3.6
4001 - 10,000	19	9.7
10,001 - 20,000	4	2.0

Table 4.16 reflects the Top Ten Institutions which used the highest number of panels. The institution with the highest number of panels was the United State Air Force Academy with 19,000 panels reported. The next highest number of panels was at the University of Oregon with 18,976 panels and the next highest was Colorado State University with 14,352 panels.

Table 4.16: Frequency Distribution of Number of Panels in Top Ten Installations (AASHE, 2016)

#	Institution	Year	Location	Panels	Production	NOP
1	United States Air Force Academy	2011	USAFA, CO	SunPower	11,660,000	19,000
2	University of Oregon	2003	Portland, OR	Missing Data	Missing Data	18,796
3	Colorado State University	2010	Fort Collins, CO	Trina	5,000,000	14,352
4	Butte College	2011	Oroville, CA	Mitsubishi	3,481,920	14,000
5	Arizona State University	2011	Tempe, AZ	SunTech	3,948,963	9,828
6	Cedarville University	2013	Cederville , OH	Missing Data	2,783,200	8,792
7	Colorado State University	2009	Fort Collins, CO	Trina	3,500,000	8,692
8	Arizona State University	2011	Tempe, AZ	Yingli	3,524,442	7,616
9	Rutgers, the State University of New Jersey	2009	Piscataway, NJ	Yingli	1,500,000	7,600
10	University of California, San Diego	2008	La Jolla, CA	Kyocera	1,920,000	7,290

4.4.13 Solar Installation Frequency Distribution - Panel Cell Type

Table 4.17 demonstrates the type of panels utilized. The highest types implemented were polycrystalline panels with 141 and the second most installed were monocrystalline panels with 57 installations. The difference between these two types of panels is discussed in detail in Chapter 2 in section 2.3. There were a total of 216 institutions which reported the type of panel that was used during the installation implementation.

Table 4.17: Type of Panel Used in Installation (AASHE, 2016)

Type	Frequency	%
Polycrystalline	141	65.3
Monocrystalline	57	26.4
Thin - Film	13	6.0
Other	5	2.3

The frequency distribution of the different panels types are shown in Figure 4.5.

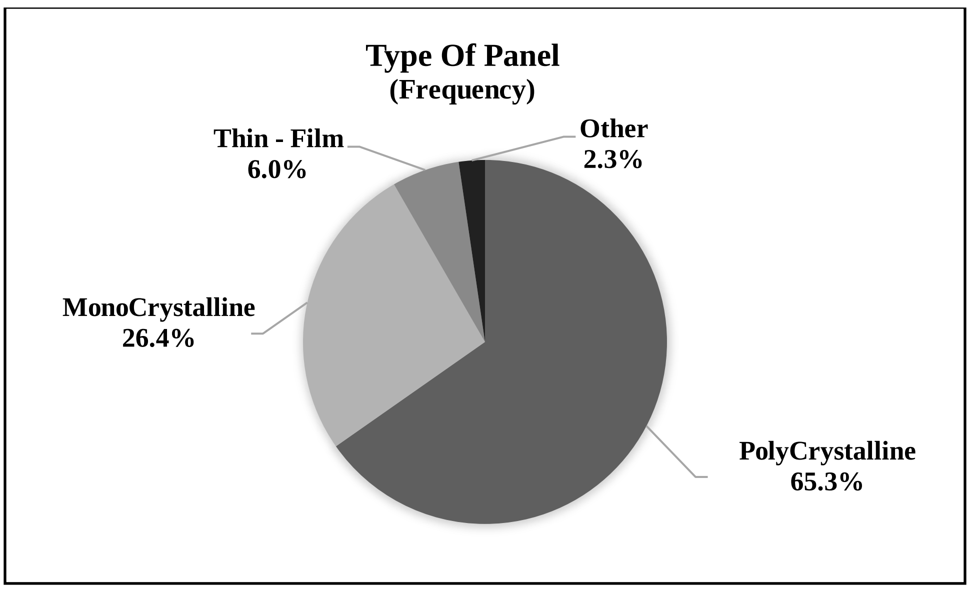

Figure 4.5: Panel Cell Type (AASHE, 2016)

4.4.14 Solar Installation Frequency Distribution - Photovoltaic Efficiency

In order to understand the efficiency of a photovoltaic system on an institution of higher education, a cost analysis development model was made to understand the economics and the efficiency. It is important to recognize that many of the institutions in this study were awarded federally funded grants to aid in the overall cost of the implementation. How much an institution will save over the 25 to 30 year lifetime of a typical commercial solar system depends on many factors, including how it is financed, federal and local incentives, the utility rate, and the amount of sunshine available on the installations.

Table 4.18 represents the efficiency (%) of the solar installations. After reviewing the available data set, it was determined that with the data provided, it would be best to perform a simple percentage of the production costs ($) divided by the annual production (kWh) as shown below. This definition will represent efficiency in this research study. In Table 4.18, it can be seen that, the efficiencies of 76 of the installations were between 10 % and 20 % efficient. This was calculated by using the following formula: 30 institutions reported between 21% and 30 %.

$$\textbf{\textit{Efficiency}}\ (\%) = \frac{\textbf{\textit{Production}}\ (\textbf{\textit{kWh}})}{\textbf{\textit{Cost}}\ (\$)}\ \textbf{\textit{X100}}$$

Table 4.18: Efficiency of Solar Installations (AASHE, 2016)

% Efficiency	**Frequency**	%
0.00 - 10.00	8	5.0
10.01 - 20.00	76	47.2
21.00 - 30.00	60	37.3
31.00 - 40.00	8	5.0
41.00 - 50.00	2	1.2
51.00 - 60.00	1	0.6
61.00 - 70.00	2	1.2
71.00 - 80.00	4	2.5

The bar chart in Figure 4.6 represents the solar installation efficiency frequency.

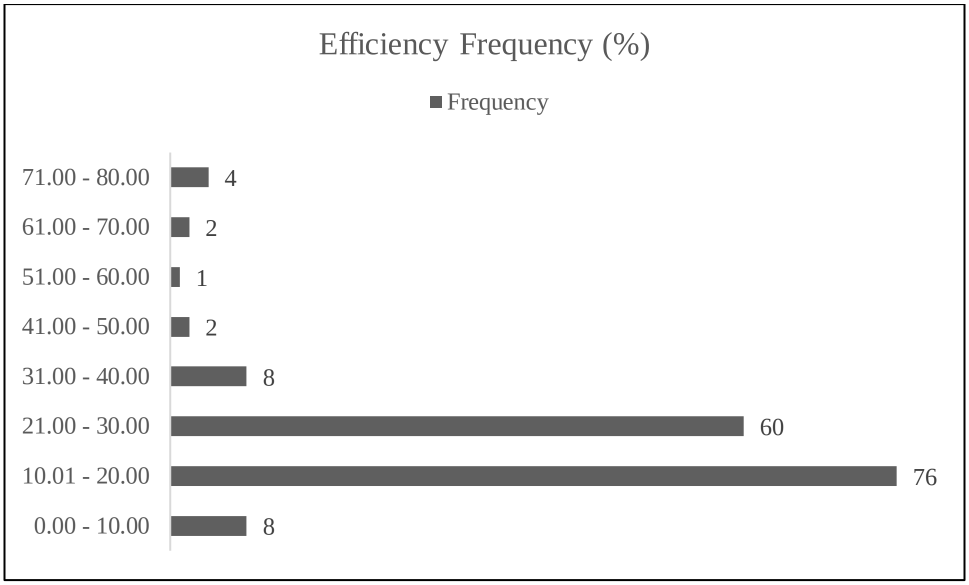

Figure 4.6: Percent (%) Efficiency Frequencies of Solar Installations (AASHE, 2016)

The highest efficiency reported were four institutions which reported between 71% - 80%. These institutions were Arizona State University (2), University of California, Los Angeles and Southern Methodist University. All four were rooftop mounting installations. The ratings were low and this could be due to constraints of missing data.

Most solar panels are around 11-15% efficient. This efficiency rating measures what percentage of sunlight hitting a panel gets turned into electricity that you can use. The higher the efficiency, the less surface area needed in the solar panels. In order to achieve the power performance, in addition to efficiency and size, there are other factors that affect how much power solar panels will generate. It's important to make sure panels are installed in the optimal position. The installers will determine the correct orientation for the panels based on the direction and angle of the roof. A high performing, long lasting solar array can incorporate dozens of factors in its design. The solar panel efficiency was not reported in the data that was

used for this study. What has been discussed is the overall installation efficiency using production and cost in the model as shown on the previous page.

4.5 Multiple Linear Regression Analysis Results

The purpose of this study was to examine the impact of different variables of a solar implementation in an institution of higher education on renewable energy generation. It further examined whether indicators such as state, institution, year, location, installer, panel manufacture, type, inverter type, installation cost, capacity, annual production, installation mounting panel type, and number of panels impacted the efficiency of the solar installations.

The data was statistically analyzed using multiple linear regression analysis to determine the impact of different variables. The dependent variable was efficiency while the independent variables were: capacity, number of panels, type of installation and type of panels used. Once the data was reviewed, it was determined that the sample size was sufficient to have an outcome of statistically significant results making a valid inference. Once this was complete, a multiple regression analysis was conducted on the research data using SPSS software.

In statistics, variables can be dichotomous, ordinal or continuous. In this study there were three continuous variables: Capacity, Efficiency and NOP (number of panels) and two dichotomous variables: install (re-coded), panel (re-coded). The data once codified were then analyzed using multiple regression analysis. Subsequently a Meta-Data transformation analysis was also conducted and the output is represented in Section 4.6. As a result of this, the variable location was determined to potentially have significance on the efficiency of the installation and was also re-coded and re-analyzed. Once complete, a multiple regression analysis was conducted on the revised initial proposed full model and the results will be discussed later in this chapter.

These primary objectives of the study are explained in section 4.1.1. Below is the description for the research that was conducted.

- **Objective One** - Examine trends via data analysis by developing a statistical model which includes the impact of cost on the output of energy annual production for the purpose of prediction through multiple regression analysis. The results of this analysis can be seen in Table 4.20 through Table 4.22.
- **Objective Two** - Examine Cost Effectiveness Analysis (CAE) by comparing the installations costs and production outcome with the other independent variables through multiple regression analysis. Efficiency was calculated by as a percentage ratio with the production (kWh) divided by the implementation cost ($). The results of this analysis can be seen in Table 4.20 through Table 4.22.
- **Objective Three** – Examine the transformation of the dataset through Meta-data analysis to develop a statistical model which will perform a deeper dive into the secondary data to determine other additional factors which may impact the output of energy annual production using frequency distribution and multiple regression analysis
- **Objective 4** – Revision of initial proposed full predictive model. Once the initial model was examined, a statistical analysis was performed to investigate a re-coded variable (location) using multiple regression analysis.

Statistical Analysis Results – Initial Proposed Model

Two of the variables which were re-coded in the initial proposed model were the installation type and the panel type. The recoding and results are represented in Table 4.19.

Table 4.19: Recoded Data (Installation and Panel Type)

Variable	"0"		"1"		Valid Data Points
New_Install	Other (0)	43.3%	Rooftop (1)	58.1%	379
New_Panel	Monocrystalline (0)	2.8%	Polycrystalline (1)	37.2%	379

The following equation represents the multiple regression analysis of the initial proposed full model using efficiency as the dependent variable and the following variables as predictor: NOP (number of panels), capacity, installation type (re-coded) and panel type (re-coded).

$$\hat{y}_{\text{efficiency}} = \beta_1 X_{NOP} + \beta_2 X_{Capacity} + \beta_3 X_{New\_Install} + \beta_4 X_{New\_Panel}$$

Below are the results from the multiple regression analysis.

$$\hat{y}_{\text{efficiency}} = -.986X_{NOP} + 1.252X_{Capacity} - .093\, X_{New\_Install} - .101\, X_{New\_Panel}$$

Table 4.20 summarizes the descriptive statistics results. Descriptions of these predictors were given previously in this chapter. Although there were 379 institutions, there were 119 valid data points for efficiency, NOP (number of panels) and capacity. There were 379 valid data points for the re-coded installation type and for the panel type. The results are depicted in the descriptive statistics in Table 4.20. The Pearson Correlation and Coefficient table results are shown in Table 4.21 and Table 4.22.

Table 4.20: Descriptive Statistics (Efficiency Model)

Descriptive Statistics For Initial Model				
Variables	**Mean/%**		**Std. Deviation**	**N**
Efficiency		20.59	10.883	119
NOP		1499.52	2739.190	119
Capacity		357.99	718.662	119
New_Install	Other (0) Rooftop (1)	43.3% 58.1%		379
New_Panel	Monocrystalline (0) Polycrystalline (1)	62.8% 37.2%		379

The Pearson correlation coefficient, *r*, which shows the strength and direction of the association between two variables, efficiency and the number of panels: This is shown in the first row of the Pearson correlation box in Table 4.21. The Pearson correlation coefficient, *r*, is .271. As the sign of the Pearson correlation coefficient is positive, we can conclude that there is a positive correlation between efficiency and the number of panels; that is, efficiency increases as the number of panel's increases. For capacity, the Pearson correlation coefficient, *r* is .353. We can also conclude that there is a positive correlation between efficiency and capacity and that efficiency increases as the amount of capacity increases.

Table 4.21 and Table 4.22 are the results from the multiple regression analysis conducted using SPSS.

Table 4.21: Pearson Correlation (Efficiency Model)

Correlations						
		Efficiency	NOP	Capacity	New_Install	New_Panel
Pearson Correlation	Efficiency	1.000	.271	.353	-.200	-.174
	NOP	.271	1.000	.964	-.410	-.117
	Capacity	.353	.964	1.000	-.392	-.135
	New_Install	-.200	-.410	-.392	1.000	.192
	New_Panel	-.174	-.117	-.135	.192	1.000

The magnitude of the Pearson correlation coefficient determines the strength of the correlation. Although there are no hard-and-fast rules for assigning strength of association to particular values, some general guidelines are provided by Cohen (1988)

Multiple regression analysis was used to test if the four predictors significantly predicted the efficiency. The results of the regression indicated that two (capacity and number of panels)

explained 21.1 % of the variance and is shown in the result below:

$$R^2=.211, \text{adjusted } R^2 - .183, F(4,114) = 7.620, p=.000$$

The results can be seen on Table 4.22 below.

Table 4.22: Coefficient Table (Efficiency Model)

Coefficients[a]									
		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	22.536	2.158		10.444	.000			
	NOP	-.004	.001	-.986	-3.135	.002	.271	-.282	-.261
	Capacity	.019	.005	1.252	4.012	.000	.353	.352	.334
	New_Install	-2.143	2.120	-.093	-1.011	.314	-.200	-.094	-.084
	New_Panel	-2.278	1.912	-.101	-1.191	.236	-.174	-.111	-.099
a. Dependent Variable: Efficiency									

As a full model, the multiple regression analysis validates that the NOP (number of panels) and the capacity are significant. In this model the panel type (re-coded) and the installation (re-coded) are not. However, it is important for us to know which variables contribute to the efficiency of the overall generation of renewable energy. Both NOP (number of panels) and capacity were significant predictors of efficiency.

The next step was to conduct a Meta Data transformational analysis with the dataset to examine if there was any other variable which proved to be statistically significant though multiple regression analysis. The next section will discuss this.

4.6 Meta-Data Transformation Analysis

Meta-Analysis is an expanded version of secondary analysis. It is used when many studies on exactly the same issue have been conducted. Using this approach the study can systematically summarized to provide descriptive information about common themes as well as to assess the effectiveness of a program or draw general conclusions about the issue. Meta-analysis has the advantage of creating a much larger data base that is potentially very powerful in drawing conclusions. Each individual study might be small and have unique limitations, but, when combined, they provide a larger picture with many more cases. If the results are fairly similar across different studies, the researchers can be more confident in making general statements about program impact.

The researchers typically summarize the key findings and impact measures. They are looking for consistency in the findings. Conclusions will be drawn of the findings are from the high-quality studies are consistent. If not the researchers will report that no conclusions can be made and perhaps suggest what other research might be needed. Meta-data analysis has the potential to see the large patterns and determine whether the results are statistically significant.

Meta Data is a subset of systematic reviews; a method for systematically combining pertinent qualitative and quantitative study data from several selected studies to develop a single conclusion that has greater statistical power. Once the information was generated form the Meta-Data analysis it was analyzed using SPSS software. The hierarchal output is presented in Figure 4.8 in its entirety. In a meta-data analysis, research studies are collected, coded, and interpreted using statistical methods similar to those used in primary data analysis. The result is an integrated review of findings that is more objective and exact than a narrative review. Meta-analysis will aid in the investigation of the relationship between the studied variables and the studied outcomes.

The study features are coded according to the objectives of the review. The variables were transformed to a common metric so that there can be a comparison of the outcomes. Last, the statistical analysis was performed to show the relationships between the studied variables and the studied outcomes. In this section, the results of the Meta-data transformation can be seen. In Figure 4.7, the Meta-Data Transformation Dashboard can be seen. The Dashboard is divided into two categories. The first section represents the quantitative variables which are the year, cost, capacity, production, NOP (number of panels) and efficiency. The second section represents the qualitative variables which include the state, institution and location. The dashboard was run using all the layers as previously described. This produced an excel file which was used for a statistical analysis using multiple regression analysis. The output of this exercise is represented in Figure 4.8. The Meta Data transformational "ribbon" contains all the variable results. The ribbon was separated and each section is separately enlarged and is represented in Figures 4.9 through 4.17. The results from the statistical analysis using multiple regression analysis can be seen in Tables 4.25 - 4.27. Although they are many permutations that are possible with this dashboard, the focus was more on the ability to run the data with one single layer on both the quantitative and qualitative data to develop the hierarchal structure and the impact of the variables in one phase. It would remain a suggestion for a deeper dive analysis to generate different iterations to determine the impact of future scenarios for this research. This methodology of data mining could be used for future study.

The Java source code for the Meta Data transformation analysis can be seen in Appendix H.

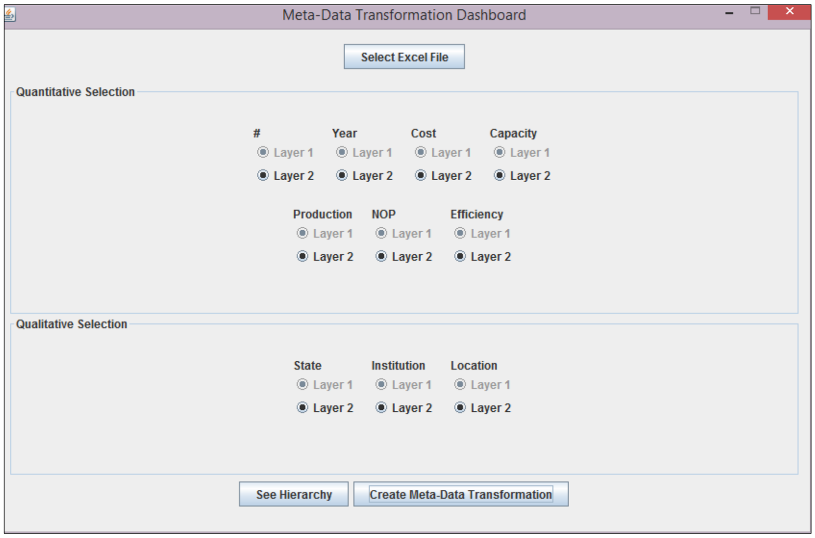

Figure 4.7: Meta-Data Transformation Diagram

Once the dashboard generated a file, the original model was revised and a statistical analysis using multiple regression analysis was conducted with a revised initial proposed model. The dashboard output can be seen in Figures 4.9 to 4.17.

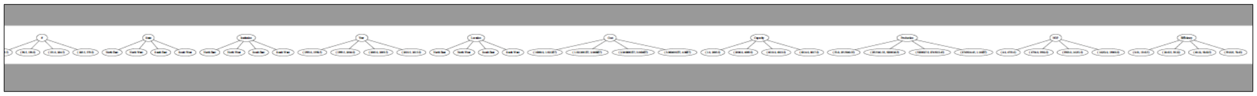

Figure 4.8: Meta-Data Transformation Ribbon – All Variables

Year

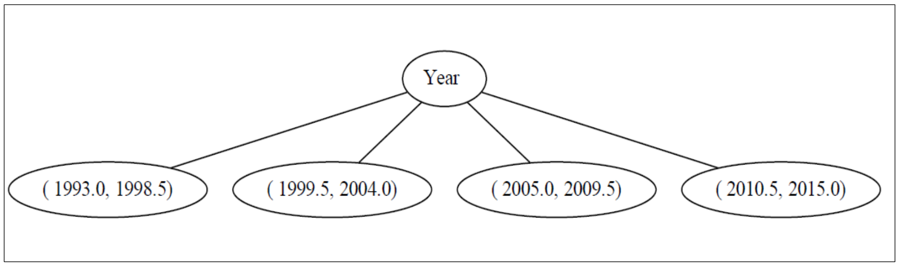

Figure 4.9: Meta-Data Transformation - Year

State

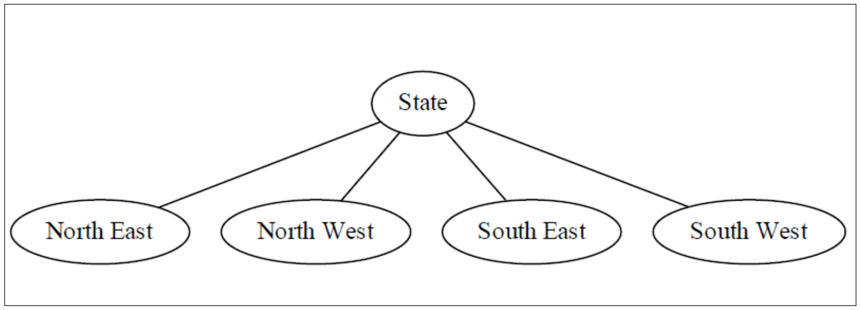

Figure 4.10: Meta-Data Transformation – State

Institution

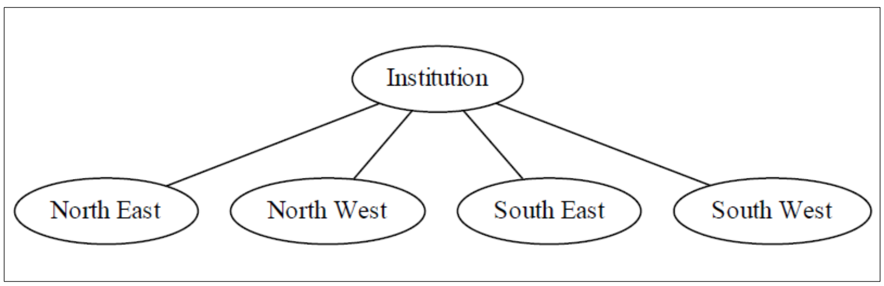

Figure 4.11: Meta-Data Transformation - Institution

Location

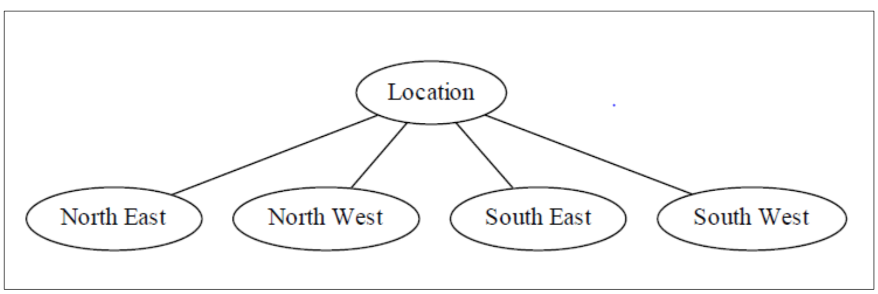

Figure 4.12: Meta-Data Transformation - Location

Cost

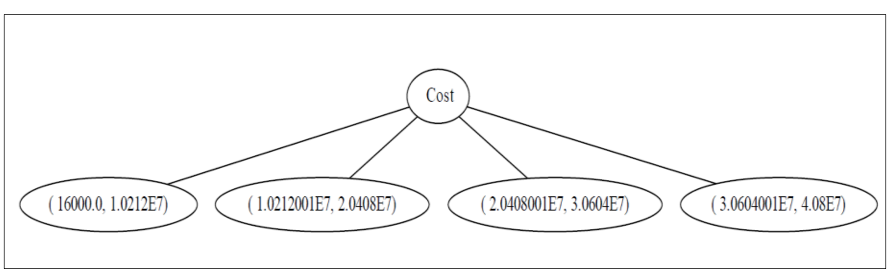

Figure 4.13: Meta-Data Transformation - Cost

Capacity

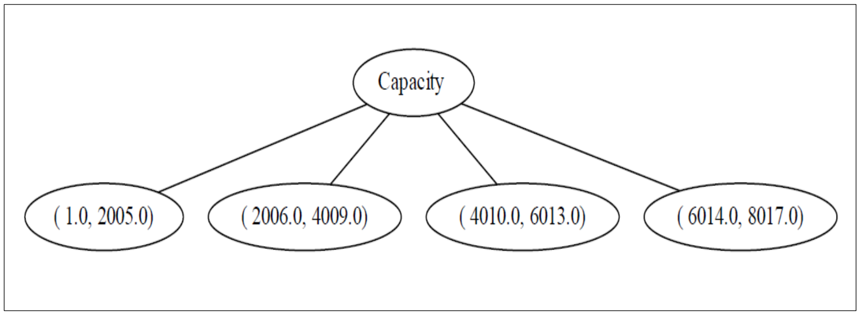

Figure 4.14: Meta-Data Transformation - Capacity

Production

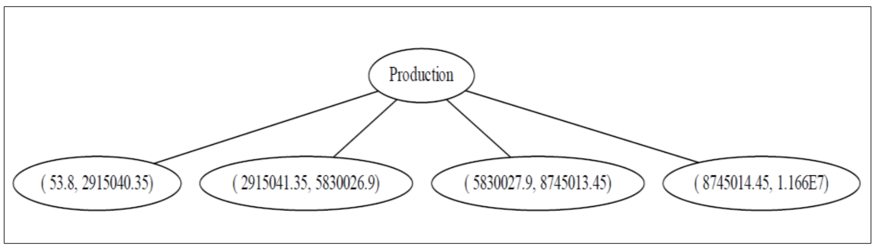

Figure 4.15: Meta-Data Transformation - Production

NOP (Number of Panels)

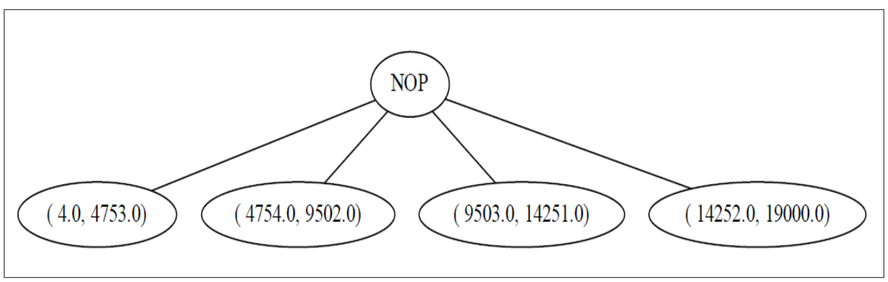

Figure 4.16: Meta-Data Transformation – NOP

Efficiency

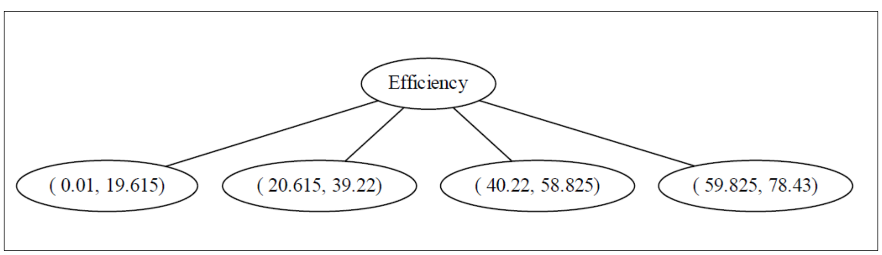

Figure 4.17: Meta-Data Transformation – Efficiency

Statistical Analysis – Revised Initial Proposed Model

A multiple regression analysis was conducted on the Meta-Data transformation results. The data was statistically analyzed, but the groupings for all of the variables except the location appeared to be unbalanced grouping and were discarded. A revised initial model to include a re-coded location into the original dataset was conducted in SPSS. The intent was to answer the question of the impact of location on production - the same models were re-analyzed, but now adding the recoded variables: location1 and location 2 as independent variables on the same models.

It is important to note that the state, institution and location produced four different areas: Northwest, North East, South West and South East. When the statistical analysis was done, only three areas were taken into consideration: North East, North West and South West. The statistical analysis data produced did not create any locations in the South East so this category was discarded. The re-coded data can be seen in Table 4.25.

Once this was complete, the entire dataset was analyzed to identify key categories or hierarchies within the variables through the meta-data procedures. Several key variables that could be examined at the categorical level and the suggested categories, produced very unbalanced groupings.

Table 4.23: Re-Coded Data (Location)

Variable	Re-Coded	Re–Coded
North West	1	0
North East	0	0
Southwest	0	0

In Table 4.24, the re-coded location data is represented. There were 379 valid data points.

Table 4.24: Re-Coded Data and Percentages (Location)

Variable	0	1	Valid Points
Location 1	0 = 333 or 87.9%	1 = 46 or 12.1%	379
Location 2	0= 274 or 72.3%	1= 105 or 27.8%	379

The following equation represents the multiple regression analysis of the revised initial proposed full model using efficiency as the dependent variable and the following variables as predictor: NOP (number of panels), capacity, installation type (re-coded), panel type (re-coded), and location (re-coded and 1 and 2).

$$\hat{y}_{\text{efficiency}} = \beta_1 X_{NOP} + \beta_2 X_{Capacity} + \beta_3 X_{New\_Install} + \beta_4 X_{New\_Panel} + \beta_5 X_{Location1} + \beta_{6Location\ 2}$$

Below are the results from the multiple regression analysis.

$$\hat{y}_{\text{Efficiency}} = -.816\ X_{NOP} + 1.073\ X_{Capacity} - .044\ X_{New\_Install} - .182\ X_{New\_Panel\ -}.142\ X_{Location\ 1} - .256\ X_{Location\ 2}$$

Table 4.25 summarizes the descriptive statistics results for the location SPSS statistical analysis. Descriptions of these predictors were given previously in this chapter. Although there were 379 institutions, there were 119 valid data points for efficiency, NOP (number of panels), capacity and location. There were 379 valid data points for the re-coded installation type and for the panel type. Table 4. 26 reflects the descriptive statistics for the Meta data results. The descriptive statistics for the four predictors and dependent variable of efficiency are depicted in the descriptive statistics here.

The Pearson Correlation and Coefficient table results are shown in Table 4.27 and Table 4.28.

Table 4.25: Descriptive Statistics (Meta-Data – State/Institution/Location)

State					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	North East	107	28.2	28.2	28.2
	North West	45	11.9	11.9	40.1
	South West	227	59.9	59.9	100
	Total	379	100	100	

Table 4.26: Descriptive Statistics (Revised Efficiency Model)

Descriptive Statistics For Revised Model			
	Mean	**Std. Deviation**	**N**
Efficiency	20.59	10.883	119
NOP	1499.52	2739.190	119
Capacity	357.99	718.662	119
New_Install	.664	.4744	119
New_Panel	.630	.4848	119
Loc_1 - NE	28.2%		379
Loc_2 - NW	11.9%		379
Loc_3 - SW	59.9%		379

The Pearson correlation coefficient, *r*, which shows the strength and direction of the association between two variables, efficiency and the number of panels: This is shown in the first row of the Pearson correlation box in Table 4.xx. The Pearson correlation coefficient, *r*, is .271. As the sign of the Pearson correlation coefficient is positive, we can conclude that there is a positive correlation

between efficiency and the number of panels; that is, efficiency increases as the number of panel's increases. For capacity, the Pearson correlation coefficient, *r* is .353. We can also conclude that there is a positive correlation between efficiency and capacity and that efficiency increases as the amount of capacity increases. Table 4.27 is the results from the multiple regression analysis conducted using SPSS.

The same analogy would be applied to the result of the Pearson correlation between efficiency and capacity. The Pearson correlation coefficient, *r*, is .353. As the sign of the Pearson correlation coefficient is positive, we can conclude that there is a positive correlation between efficiency and capacity; that is, efficiency increases as the amount of capacity increases.

Table 4.27: Pearson Correlation Table (Revised Efficiency Model)

Correlations								
		Efficiency	NOP	Capacity	New_Install	New_Panel	Location 1	Location 2
Pearson Correlation	Efficiency	1.000	.271	.353	-.200	-.174	-.171	-.233
	NOP	.271	1.000	.964	-.410	-.117	.035	-.073
	Capacity	.353	.964	1.000	-.392	-.135	-.011	-.088
	New_Install	-.200	-.410	-.392	1.000	.192	.034	.116
	New_Panel	-.174	-.117	-.135	.192	1.000	.046	-.284
	Location 1	-.171	.035	-.011	.034	.046	1.000	-.081
	Location 2	-.233	-.073	-.088	.116	-.284	-.081	1.000

Multiple regression analysis was used to test if the four predictors significantly predicted the efficiency. The results of the regression indicated that three variables (capacity, NOP(\ number of panels) and location explained 28.2 % of the variance and is shown in the result below:

R^2=.282, adjusted R^2 - .244, F (6,112) = 7.331, *p*=.000.

This statistically implies that the higher number of panels, the higher the renewable energy generation, the higher the efficiency. The following equation represents the multiple regression analysis of the initial proposed full model using efficiency as the dependent variable.

Table 4.28: Coefficient Table (Revised Efficiency Model)

Coefficients[a]										
		Unstandardized Coefficients		Standardized Coefficients			Correlations		
Model		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	24.378	2.164		11.266	.000			
	NOP	-.003	.001	-.816	-2.643	.009	.271	-.242	-.212
	Capacity	.016	.005	1.073	3.501	.001	.353	.314	.280
	New_Install	-1.012	2.069	-.044	-.489	.626	-.200	-.046	-.039
	New_Panel	-4.077	1.945	-.182	-2.096	.038	-.174	-.194	-.168
	Location 1	-8.536	4.918	-.142	-1.736	.085	-.171	-.162	-.139
	Location 2	-7.588	2.538	-.256	-2.989	.003	-.233	-.272	-.239
a. Dependent Variable: Efficiency									

As a revised initial proposed model, the multiple regression analysis validates that the NOP (number of panels), capacity and location are significant predictors of efficiency.

4.7 General Discussion of Data Results

This chapter has covered the statistical analysis of the secondary data obtained in the study that was completed. The data was presented (tabulated and graphed) and statistically analyzed. In this chapter, these many results, facts and thoughts are brought together. In section 4.4, the results are summarized. A series of different statistical analysis were performed on both the initial proposed model and the revised proposed model. Different scenarios were calculated to

understand the impact of different variables. When the original data was tested using efficiency as a dependent variable with the following predictors: NOP (number of panels), capacity, installation type and panel type, only the NOP (number of panels) and capacity were found to be significant. After the Meta data analysis was conducted, the model was revised to include location. The multiple regression analysis was completed and the results indicated that the following predictors were significant: NOP (number of panels), capacity, type of panel and location played a role in the success of a solar installation. The efficiency was calculated using a simple percentage formula of production in kilowatt hours divided by the initial cost. Other variables which have impacted this number such as payback, and comprehensive return on investment analysis were not taken into consideration because the information was not available in the dataset. Perhaps this could be undertaken in a future study.

Overall the number of panels had the most significant impact. This would correlate to the fact that the higher number of panels, the more capacity and institution would have to produce renewable energy. Location did also have a significant impact on the generation of renewable energy as was seen in the revised initial proposed model to include location after the Meta data analysis.

The following conclusions were derived from the research of this dissertation:

- **Costs -** As expected, the more money spent on purchasing more panels, more production was generated, but also more costs incurred.
- **Location** - The majority of the installations done during this period were in the state of Arizona.(Southwest)
- **Panels -** The type of panel made a significant contribution to the overall efficiency.

- **Installation Type** - The type of installation made a significant contribution in explaining efficiency.
- **Variables** – The location variable matters and helped in the explanation of the overall efficiency.

4.8 Summary

All institutions must have a clear understanding of the renewable energy environment. It is important for institutions to understand the complexities associated with the magnitude of implementing such a large endeavor. Taking into consideration the understanding of this is affected by one's perception. The renewable space and in particular the area of photovoltaic implementation requires a due diligence of all aspects required for a successful implementation. This is beyond the understanding of costs and the return of investment. This would include the understanding of the stability of the supply base, the location(s) of the installation and the considerations and limitations of all the different variables discussed in this dissertation.

In the solar energy sphere, scientists and economists alike will note that coming up with cheaper, most efficient solar cells is key to the industry's growth. America's colleges and universities are well positioned to lead the nation in advanced energy efficiency and contribute to an energy independent economy. Small changes in deferral incentives can make a big difference for the higher education sector to help contain energy costs and dramatically reduce and manage energy consumption.

The higher education community believes that such changes in tac policy and federal grant programs would allow colleges and universities to increase operational efficiencies, reduce long tem energy expenses and ultimately contribute to administrative efforts to contain college costs,

The U.S higher education sector has made significant studies in increasing the operational efficiency of the academic enterprise. New opportunities exist for colleges and universities to dramatically improve their energy and fiscal stewardship by further reducing energy consumption (demand), altering and expanding their energy source (supply) and maximizing infrastructure improvements that address energy storage (distribution). As designs improve and efficiencies arise, the role of solar power on the national grid is becoming increasingly more important.

Chapter 5

Conclusions of this Research

Recent globalizations of economic activity has been one of the most important and dynamic changes in the business environment of this century. Globalization greatest impact has been the intensification of competitive pressure felt by the economy in industrialized countries. The challenge typically faced by institutions of higher education is to always seeking alternatives ways to save money as well as participate in sustainable initiatives. To meet this global demand and contribution to the advancement, the opportunity to drive savings through solar installations is especially compelling in a university environment. America's colleges and universities are well positioned to lead the nation in advanced energy efficiency and contribute to an energy independent economy.

In this chapter, a further discussion of the results is presented with the intent to go beyond the statistical and factual results and look at some of the substantive issues raised by this research. This is crucial so as to place the results and statistical analysis in the context of the more global question of interests to the engineering community. Thus, the research and practical implications of the field must be addressed. Figure 5.1 presents the thought diagram that describes the logical development for this chapter. Section 5.1 (further discussion) and Section 5.2 (what has been learned) follow with the lessons that have been learned from both the productivity characteristics data, other data, and experience of this study. This leads to Section 5.3 where the implications of this research are addressed, specifically the research implication mainly pertaining to the impact of the initial costs of a solar implementation to the annual production of a system. Here, the researcher also presents some notes to future researchers, detailing some of the inferred knowledge

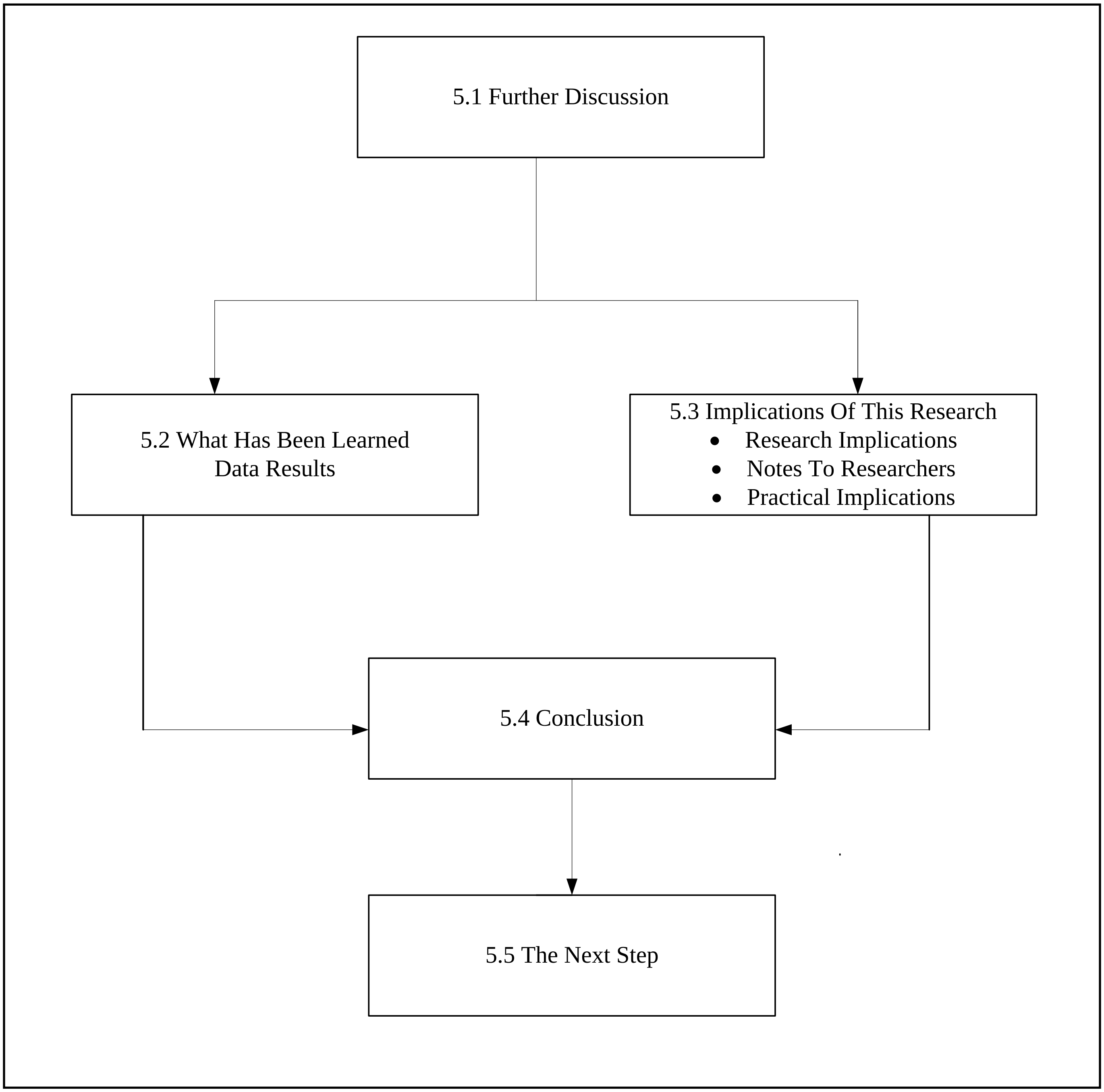

Figure 5.1: Thought Diagram for the Logical Development of Chapter 5.

and pitfalls encountered. It concludes with the next step to be undertaken by the research agenda limited by this research.

5.1 Further Discussion

At this point, the question that usually comes to mine is: "What does this all mean?" Thus far, a good number of results, statistics and inferences have been drawn. The following sections look at two very specific points. What has been learned? What are the implications? By doing this, the research here presented attempts to tie together and begin finality to the original question: What is the impact of the installation cost amongst other variables on production of a solar system on an institution of higher education? This, the historical, physical, philosophical and industrial ideas explored earlier hopefully begin to have a holistic meaning. More importantly this provides engineers, the beginnings of some practical significance with respect to the further study of photovoltaic efficiency in institutions of higher education.

A step by step procedure is essential to achieve a successful solar installation in an institution of higher education. The following steps are a guide, particularly when implementing a solar implementation installation:

1. Identification of potential site(s).
2. Funding of project development.
3. Development of rough technical concept.
4. Assessment of diff erent technical options.
5. Approximate cost/benefits.
6. Permitting needs.
7. Market assessment.
8. Technical and financial evaluation of preferred option.
9. Assessment of financing options.
10. Initiation of permitting process.

11. Development of rough technical concept.
12. Clearly define the scope of work.
13. Permitting.
14. Contracting strategy.
15. Supplier selection and contract negotiation.
16. Financing of project.
17. Preparation of detailed design for all relevant lots.
18. Preparation of project implementation schedule.
19. Finalization of permitting process.
20. Complete understanding from application to interconnection and including all engineering permits and complete installation and integration.
21. Construction supervision.
22. Performance testing.

5.2 What Has Been Learned

The lessons for research are many. Specifically, conclusions can be drawn from the results of the eleven variables and the statistical analysis undertaken on the data. The main reason for the solar installations is the opportunity to help the institution save money.

There were a total of 379 solar installations reported through the AASHE (Association for Advancement of Sustainability in Higher Education Solar Installation Database).

The following conclusions were derived from the research of this dissertation:

- **Costs** - As expected, the more money spent on purchasing more panels, more production was generated, but also more costs incurred.

- **Location** - The majority of the installations done during this period were in the state of Arizona.(Southwest)
- **Panels** - The type of panel made a significant contribution to the overall efficiency.
- **Installation Type** - The type of installation made a significant contribution in explaining efficiency.
- **Variables** – The location variable matters and helped in the explanation of the overall efficiency.

In conclusion, the number of panels and the location played the most statistical significance in relation to renewable energy production. Initial implementation cost would have a direct correlation to this as we observed in the reported data although not always the case.

5.2.1 Solar Installation Variable(s) Results

Below is a summary of the research work that was conducted in this study:

- Step 1 – The variables were analyzed variables through multiple regression analysis before the Meta-Data analysis for efficiency as a dependent variable (DV) with capacity, NOP (number of panels), installation type (re-coded), panel type (re – coded) as the predictors.
- Step 2 – After the Meta data transformation - analyzed the data set to identity key categories that could be examined at the categorical level but since some of these variables produced unbalanced groupings, most were discarded and location was kept as the only feasible variable to examine. Recoding followed and Location 1 and Location 2 were entered in the original dataset.
- Step 3 – The entire dataset was re-analyzed the same model (Step 1) but now adding Location 1 and Location 2 as independent variables (IV).

5.2.2 Experimental Lessons

This research, like all projects that must be managed, provided an invaluable experience to the analyst. To confront many roadblocks, contingencies and misconceptions is a part of the educational experience that simply cannot be taught, but lived. The lesson learned is that one must experience an endeavor of this nature to understand and value the nature of individual research.

5.3 Implications of This Research

In the previous sections, the lessons learned from the solar installation data as a result of the statistical analysis and subsequently the Meta Data transformation analysis, the data results, and the experimental lessons were enumerated. But what can be drawn from these lessons to thus progress this research? This section will look specifically at both the research and practical implications of this study. Thus section 5.3.1 emphasizes the research implications, especially referring back to a re-evaluation of the statistical analysis used to understand the data regarding the solar installations. The practical implications tries to raise some questions as to the way engineers approach, questions, analyze this type of research.

5.3.1 Research Implications

An important part of all research are the implication that result from the study undertaken. This section will cover both the research implications of this research as well as some suggestions to future researchers on what data is required to perform a robust study on the implication of different variables on the production results of renewable generation for a campus of higher education.

5.3.2 Re-evaluating the Efficiency Model

All the components of this model in this research was secondary data obtained from a public website. The results do not indicate an end, but an intimal condition from which to build. Are there more than 14 variables to be considered in future studies? When conducting a study of this nature on different campuses and locations throughout the United States with different financial implementation commitments, should there be different additional characteristics and properties to be considered to accommodate for the different environments? This would include but not limited to: orientation of the solar panel (solar tracker), location of installation on campus and how the installation faces the sun.

5.3.3 Practical Implications

This research has provided a different way in which to do an analysis of solar installation in institution of higher education by looking at a significant number of institutions across the United States. Since 2010, when many institutions implemented solar installations, many factors have changed. Many of the vendors used in this component commodity have changed. Several of the vendors have closed or no longer open. In addition the cost of solar panels, an important and significant component in the module have lowered in costs. In today's environment, it may be a different scenario when implementing a solar installation. In addition, the monies that were available at one time no longer exist. Funding would need to be considered from different sources. And the justification would need to clearly define to the public. The predicted or expected lifetime of a photovoltaic module is one of the four factors which must be taken into consideration as well.

5.4 Conclusion

This study was designed to begin to fill the gap found in the analysis of solar installation specifically in higher education. The main purpose of this study was to explore the variable characteristics of a solar installation in an institutions of higher education in the United States using secondary data from a public website. The study had several aspects that the research was intended for. The grants received by the United States government are not only prestigious and noteworthy but with this comes the responsivity to be good stewards of federal funds. The grant dollars must be used for their intended purpose and the recipient institution must account for costs and justify expenditures. In order to answer this very important question, the variables were first statistically analyzed through multiple regression analysis.to examine trends and patterns of existing data and confirmatory methods. Once they were analyzed, two variables were recoded and statistically analyzed. Once this was complete, the entire dataset was again analyzed to identify key categories within the variables through the meta-data procedures. Several key variables that could be examined at the categorical level and the suggested categories, produced very unbalanced groupings. As a result most were discarded and resulted in the analysis of the location as the only feasible variables to examine. Re-coding followed and Location 1 and Location 2 were entered in the original data set. To answer the question of the impact of location on production the same models were re-analyzed, but now adding the re-coded variables Location1 and Location 2 as independent variables on the same models. The results can be seen in Chapter 4.

The next step was to analyze which of these variable had a direct impact on the success of the installation. In this context, success would be defined as the amount of renewable energy was produced. Ultimately this would aid in the reduction of electricity cost of an institution which has

proven to be a consistent challenges to University administration. While the results were extremely significant, the future of the solar industry as it relates to higher education remains to be seen.

Much research has emerged that examines various aspects of this topic of solar installation, however there is opportunity for further study specifically in the area of installations of higher education. Additional other questions have been raised that is a by-product of any research effort. How has the research addenda presented in the documents been affected by the results obtained? This is addressed next.

The key is to attaining a justifiable advantage in implementing of a solar installation on a college campus. From a research perspective, chapter 4 outlines the statistical analysis performed to better understand the impact of the different variables on the overall installation. We now know from that this research that the initial cost of the implementation does not necessarily have an impact on the production of renewable energy. What does make a difference is the use of a roof top mount and the use of polycrystalline panels. The roof top modules are less to install since many times they are installed on unused properties or buildings that already exists. The vast majority of the installations researched used root top mountings of the solar panels. The polycrystalline panels are more efficient and cost less to produce. The life of a solar panel is currently 30 years. Maintenance on the panels is low. The vendor's supply base (panels, inverters, and installer) had no significant bearing on the renewable energy production.

As discussed earlier in this documents, there are many reasons to pursue this avenue to assist in the lowering of electricity costs. This is the primary reason but should not be the only reason and there are other results which may also be produced to consider this option a success. In addition to the use of this type of installation to subsidize the cost of electricity, there is also the

opportunity to engage in a community visible effort to be part of a forward thinking movement in an area where it also assists in helping out the environment. Ultimately one of the most important by products is the engagement of students as part of the implementation team. There can be no greater opportunity in an institution of higher education than to participate and understand the requirements need for a successful implementation and the opportunity to witness this first hand. That by far is the greatest purpose of such a complex and interesting implementation.

Overall, there needs to be a more of a focus on a formal program which would follow individual installation over a period of several years and document all the variables during that time. There is a need to critically examine these measurements, establish parameters on how the variables are measured to ensure all are being measured in the exact same manner. Once this were established, it would behoove the researchers to visit these institutions to ensure that all the measurements are being reported consistently and with same, measurement technique. Additionally, the complete understanding of the component supply base would add further to the analysis of the research study.

And finally, the rising cost of electricity would only add to the need for further research in this area of research.

5.5 The Next Steps

Four general conclusions that can be drawn from the results discussed: They are:

1. If a researcher has the opportunity to utilize actual data generated from individual institutions where all data is reported, it may result in a more complete study.

2. It may of interest for a researcher to actually follow an installation from the inception including the design, procurement and installation phases. Only in this situation… The only drawback is the timeframe needed to follow from cradle to grave.
3. Benefits can be realized in solar installations by measuring the combined variables discussed in this dissertation and following individual installations and gathering the component data first hand.
4. There already exists a significant number of solar installations in the United States in institutions of higher education. Information from these installations could continue to provide the foundation for future study.

In conclusion, there are three steps envisioned that should be addressed by the researcher as a result of this specific research. First, evaluate the comparative methodology employed in this research. Secondly re-run the study (with the validated and possible redesigned methodology to further strengthen the validity of the results (as mentioned above) in other institutions of higher education. Finally it would be a worthy idea to detail the efficiency definitions further so as to obtain more of an idea of the exact production of renewable energy generated.

Recommendations for a future study include the following:

- Conduct Initial Cost Analysis to determine amount of funding.
- Understand institutional initiatives and commitment on sustainability.
- Familiarization and in-depth knowledge with component manufacturers (panels, inverters) and installation supply base i.e. all business aspects: quality, reliability and financial stability.
- Create Data Collection Model - Complete Primary data including location.

- Obtain information regarding ROI (return on investment) of installation.
- Complete understanding of the solar project from application to interconnection and including all permitting engineering and complete installation and integration.

Further study would also include a historical perspective, perhaps an in-depth 4-5 year study in a larger pool of institutions which may better represent a better representation of institutions of all higher education.

The primary factor driving the dramatic growth of the solar institutions in higher education is the challenge to administrators to reduce electricity costs. Many institutions are currently dependent on local electrical companies. This would enable them to seek alternative energy production while reducing costs as well. The installation costs is a one-time cost only so the institution would be able to benefit once this cost would be recovered through reduction in the use of electricity. The strategic advantages are enormous.

A renewable energy initiative which was launched in 2011 was the SunShot Initiative. The program is within the Office of Energy Efficiency and Renewable Energy at the U. S Department of Energy. The SunShot Initiative aims to reduce the total installed cost of solar energy systems to $.06 per kilowatt-hour (kWh) by 2020. This initiative has the goal to make solar energy cost competitive with other forms of electricity by the end of the decade. This initiative funds cooperative research, development demonstration and deployment projects by private companies, universities, state and local government, nonprofit organizations and national laboratories to drive down the cost of solar electricity to $0.06 per kilowatt-hour. The initiative works across five different areas: photovoltaics , concentrating solar power (CSP), soft costs (or balance of systems costs), systems integration, and technology to market. It is a ten year plan which efforts intended to create a stronger domestic photovoltaic manufacturing base. There are reports associated with

this initiative. One such report is "*On the Path to SunShot".* It is a series of eight reports that examines the lessons learned in the first five years of the initiative and the challenges and opportunities the industry faces in the final five. It identifies the key research, development and market opportunities that can help ensure that solar energy technologies are widely affordable and available to more American homes and businesses. SunShot has recently announced the intent to award 19 projects to a total of $17 million to advance next generation photovoltaics

In addition, the U.S. Department of Energy has established programs as just referred to in the paragraph above, and committed budgetary resources to other sectors (such as industrial facilities and commercial buildings) and specific technologies (such as solar, wind and geothermal), the department's interest in higher education has tended to focus on research. A variety of new federal; policy options could stimulate deep energy-efficiency and renewable energy investments at colleges and universities. Institutions could leverage federal support with state and local government initiatives as well as with institutional funds and private sector investments. Modifications to existing legislation could exponentially expand possibilities and mitigate or eliminate eligibility programs. In summary, this research provides decision makers some guidance to the choices of components and the overall decision of investing the cost for a solar installation in an institution of higher education. With the development of solar technology, the efficiency of solar panels and its components will improve and solar power may eventually replace fossil fuels. The manufacturing cost of solar panels will increase their use of solar panels. (Fan, 2014). Colleges and universities represent the ideal partner for government to engage in advanced energy solutions on a national scale.

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APPENDIX A: THE RESEARCH PROBLEM

This Appendix contains a review and statement.by the author on the research process. Research, per se, is not uniform by any stretch of the imagination. Some of the basic beliefs that are representative of the author's view of the research are presented. The following topics will be covered. See figure A.1 for a thought diagram of this section's logical development.

A1.0 The Research Problem

- A1.1 Research Problems and Questions
- A 1.2 The Circular Nature of Research
- A1.3 Strong Interference

A2.0 Research Classification

- A2.1 Logic
- A2.2 Types of Research

A3.0 Research and Practice

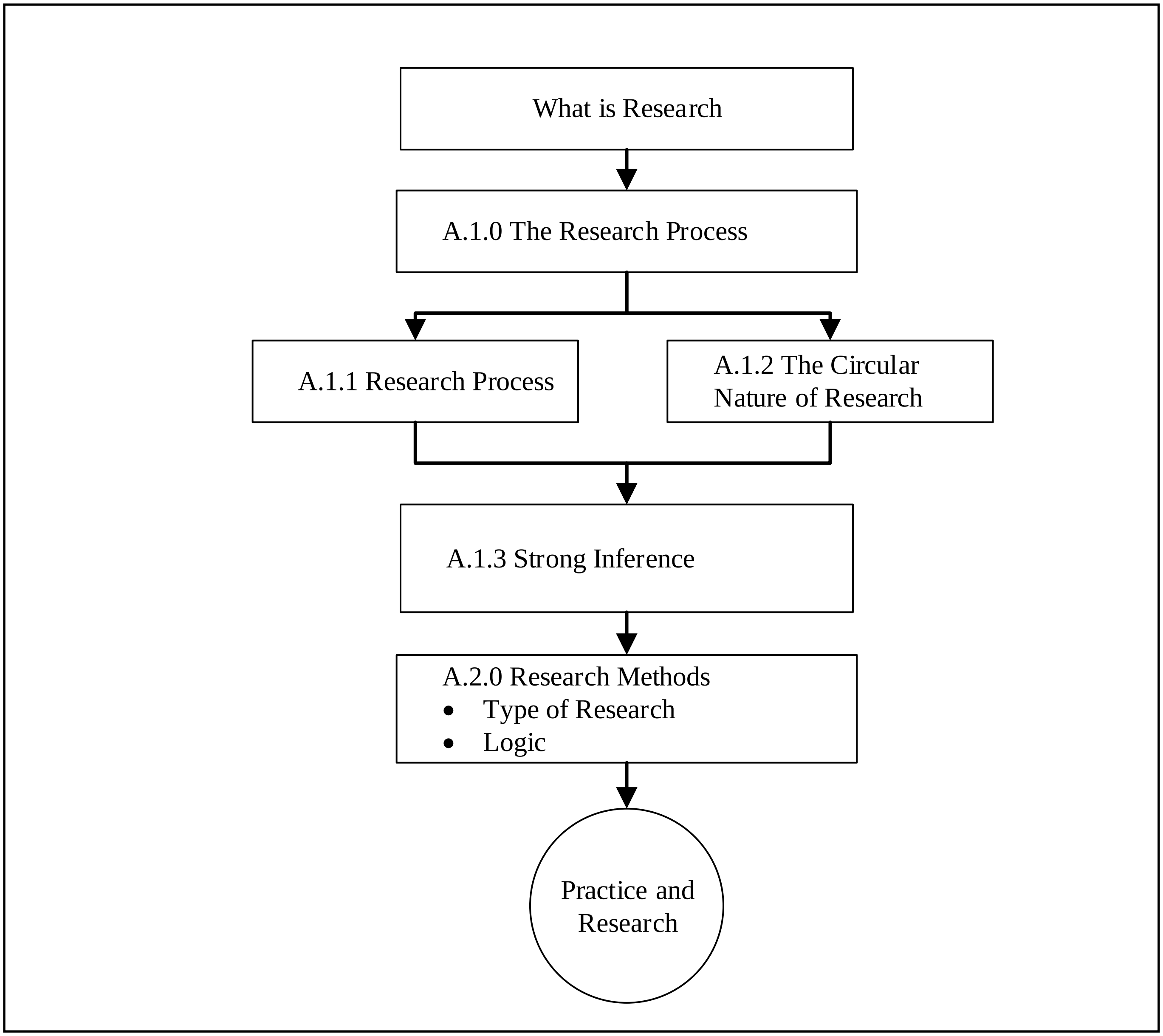

Figure: A .1 Thought Diagram for the Appendix Logical Development

A1.0 Introduction to the Research Process

"Research is the procedure by which we attempt to find systemically and with the support of demonstrable fact, the answer to a question or the resolution of a problem" (Leedy, 1989: p.5). The definition of research by Leedy touches upon a crucial point about research: answering a question or resolving a problem. Leedy (1989) correctly notes that research is not mere information gathering, transportation of fact from one place to another, rummaging for information, or a catchword used to get attention. The essence of research is the resolution of a basic question that has not been answered at all or to the satisfaction of the researcher.

A1.1 The Research Problem And Question

Kurstedt (1991c) believes that research begins with a question. Leedy (1989) goes as far as to state that "quite simply: no problem, no research" (p.45). This may seem a bit blunt, but it exemplifies the essence of both theoretical and practical research. But the research problem and question are more than justly the seeds of research they are in fact the driving force in the continuous efforts that are research. This is because most all research efforts of enduring value can be seen as a sequence of inquiries. This can be seen in Kurstedt's (199c) three key characteristics if a research question:

1.) A research question should focus you and simulate other questions at the same time

2.) Have theoretical and/or practical importance

3.) Generate inference (p.12)

Generating inferences begins what is often termed the circular nature of research (Wallace, 1971: Leedy, 1989: Kurstedt, 1991c).

A1.2 The Circular Nature Of Research

Depicting the circular nature of research was probably best done by Wallace (1971) (See figure A.2 for what is termed the Wallace Wheel). Leedy (1989) depicts the circularity of research in a different way (see figure A.3). Leedy sees a progression of six repeating steps (research question, problem statement ad conceptual model, sub –problems leading to a research model. data collection and data interpretation). With a seventh interacting step (support or rejection of hypothesis). The Leedy model is a progress descriptive model while the Wallace model is more a model of relationships. This conceptualization is a further exposition of the relationships between questions – answers and subsequent questions that is at the heart of the circular nature of research. In Figure A.3, the interplay between the type, logic, and methodologies of research are evident.

A1.3 Strong Inference

"Why should there be such rapid advances in some field and not in others? The primary factor in scientific advances is an intellectual one. These rapidly moving fields are field where a particular method of doing scientific research is systematically used and taught and there is an accumulative method of inductive inference that is so effective that it should be given the name of "strong inference'" (Platt, 1964;p.347). If the circular nature of research does not have an agenda, a goal, then it is quite conceivable that the circulatory of research could lead some research effort to "go around circles In fact, research is a spiral (or helix, see Leedy, 1989); a continuous circular process that builds upon layer. This spiraling action requires a vector, direction, or agenda.

Platt's (1964 strong inference by his own admission, is nothing more than simple old –

fashioned one of inductive inference that dates back to Francis Bacon. The difference is that strong inference is based on a systematic application of the inductive inference procedure. Platt lists the steps as follows:

1.) Devising alternative hypothesis

2.) Devising a crucial experiment (or several of them), with alternative possible outcomes of which will as nearly as possible, exclude one or more of the hypothesis

3.) Carrying out the experiment so as to get a clean result, and

4.) Recycling the procedure, making sub - hypothesis or sequential hypothesis to refine the possibilities that remain, and so on (Platt, 1964; p.347).

Strong inference is based on constructing rigorous syllogisms. No doubt this is a more natural format for the hard sciences. It may be argued that storming inference is not possible in social science research. The general idea of structure and agenda for research in strong inference are transferable and useful.

A2.0 Research Methodologies

Research starts with a problem and/or question. The process itself is circular with respect to process and relationships in the type of research conducted. Research should have a direction or agenda (converting the circular nature of research into a spiral) with "strong inference" as a technique or method used in classifying research.

A2.1 Logic

One way to classify research is by logic used in the research effort itself; inductive versus deductive (Kurstedt, 1991c.). Inductive logic is explaining observation by generalizing, taking a specific situation from facts to general theories. Deductive logic works quite differently; from conjecture (a theory, hypothesis, concept, idea, etc.), the data is collected and analyzed to test the

validity or strength of the conjecture. Thus, inductive and deductive logic are contrary in the sense that one moves facts to theory (inductive); the other from theory to facts (deductive) (Light, Singer, and Wilett, 1990).

A2.2 Type Of Research

There are various ways to classify research. The type and goal of the research is a means of classification (Kurstedt, 1991c.) Research can be termed basic research with the goal to formulate, expand, or evaluate theory. Research can be applied with the goal of seeking solutions to practical problems. Research can be technological focuses on methodology (Brinberg and McGrath, 1985). The methodologies, themselves, can be used to classify the research (see table A .l). All these classifications are useful anchors that help us understand and visualize what research is and how to do it. The essential point to remember is that, like any project, research needs to be managed. But, the ultimate value of the research is; does it teach us anything new?

A.3.0 Research And Practice

The description of a research process is a useful venture in helping put together a researcher's belief on how to do scientific inquiry. But the practice of research determines the belief in the research itself and further defines the philosophical underpinnings that support a research methodology. Chapter 3 and the research agenda presented in Chapter 2, present my current research structure. The concept of strong inference is a guiding idea on research.

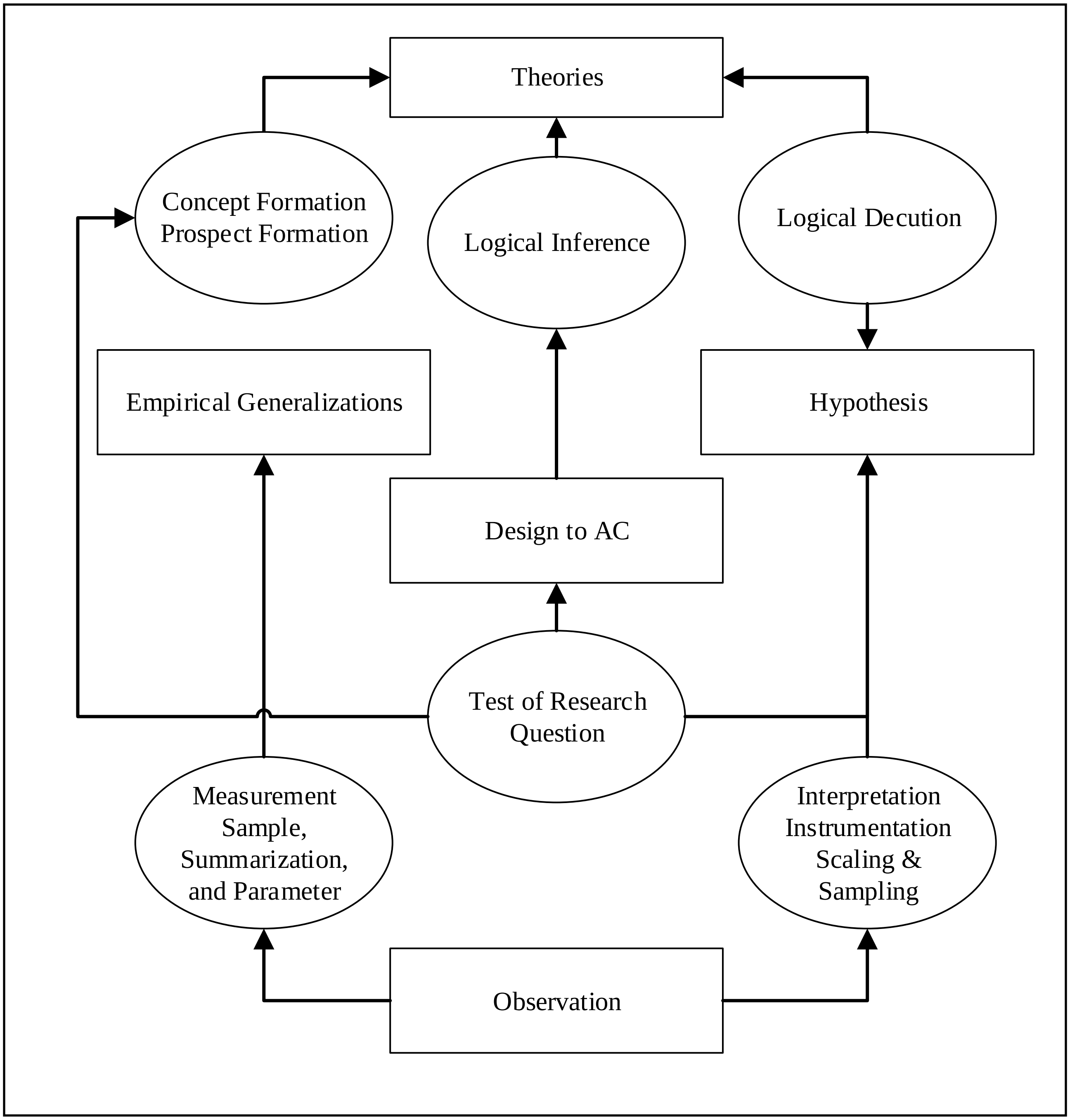

Figure A .3: The Research Process by Leedy, 1989

Appendix B: AASHE (Solar Installation Worksheet)

aashe stars conference Your Account Logout

aashe
The Association for the Advancement of Sustainability in Higher Education

Home | Events | Resources | Connect & Discuss | Membership | About AASHE | Donate

Campus Operations Resources Energy Campus Solar Photovoltaic Installations Database Add An Installation

Add a Solar Installation

Back to Solar Installations

Add information about a new campus solar panel installation using the form below. All submissions are reviewed before being added to the AASHE resource center.

* denotes required fields.

Basic Information

Institution * ---------

Year * 2016

Installation Summary

Developer
The company/partner that developed & designed the system.

Installer
The company/partner that installed the system.

PV system ownership
The owner of the photovoltaic system.

Installed cost (USD)
Total installed cost in USD

Ownership of SRECs * Data Not Provided
Please select the owner of the solar renewable energy credits (SREC) associated with this installation.

Ownership type * Data Not Provided
Please select the type of financial ownership for the solar installation.

Estimated Annual Utility Savings
The annual utility savings in USD.

General Resources for Campus Sustainability

Education & Research Resources

Campus Operations Resources

- Buildings
- Climate
- Dining Services
- Energy
- Grounds
- Purchasing
- Transportation
- Waste
- Water

Planning, Administration & Engagement Resources

AASHE Publications

Sustainability Tracking, Assessment & Rating System (STARS)

Reporting System for the American College & University Presidents' Climate Commitment

AASHE Bulletin

For the latest campus sustainability news, resources, opportunities, and events from the U.S. and Canada:

Subscribe to the AASHE Bulletin

View the latest issue!

http://www.aashe.org/resources/campus-solar-photovoltaic-installations/add/ 5/26/2016

Technical Details

Capacity (kW) *

Total installed capacity in kilowatts

Annual Production (kWh)

Total annual production in kilowatt hours

PV panel type

Brand name, manufacturer(s), and type (ex. thin film or monocrystalline silicon) of panel component

Inverter type

Brand name, manufacturer(s), and type of inverter component

Installation type

The installation type, e.g. roof mount, pole mount, canopy, etc.

Installation type details

Additional description of the installation type, location, special considerations, etc.

AASHE-Internal Contact Information

Please provide project contact information so that AASHE staff can obtain follow-up data, if needed. **This information will NOT be made public.**

First name

Last name

Email

Internal AASHE use ONLY. Will not be published.

Public Contact Information (optional)

Please provide *optional* public project contact information. All or part of this information **may** be published with the solar installation's record. Please obtain necessary permission from anyone you list other than yourself.

First name

Middle name/initial

Last name	
Title/Position	
Phone	
Confirm permission	☐ Check this box to confirm you have obtained permission to provide this contact information.

Additional Information

Provide additional relevant information here. This will be presented verbatim under the "Additional Notes" section of the installation details page.

Additional notes	Include any information you wish to convey about the installation not captured in the above fields.
Project URLs/links	Include press releases, websites, and other relevant links.

Submit New Installation

1536 Wynkoop St., Suite 100, Denver CO 80202 - t: (303) 395-1331
Remittance Address: PO Box 824583, Philadelphia, PA 19182-4583

Appendix C: Permission to Utilize AASHE Data

De Hoyos, Diane N

From:	Monika Urbanski <monika.urbanski@aashe.org>
Sent:	Monday, February 29, 2016 12:29 PM
To:	De Hoyos, Diane N
Subject:	Re: Request for permission to utilize data from AASHE website Campus Installation Database for Dissertation.

Diane,
Thanks for reaching out. That is correct, AASHE grants access to the Solar PV database for research purposes and we are happy to allow you to use the database for your dissertation. We're excited that you plan to use this information and hope you share any published findings with us.

Best,
Monika

On Mon, Feb 29, 2016 at 2:21 PM, De Hoyos, Diane N <dndehoyos@utep.edu> wrote:

> Monica,
>
> Thanks for returning my call and email.
>
> Per our conversation, I wanted to confirm that there is no issue in utilizing the data from the AASHE website regarding your campus installation database
>
> for my dissertation.
>
> Thanks in advance for your assistance.
>
> Diane
>
> **Diane N. De Hoyos, CTPM**
> Assistant Vice President
>
> Purchasing and General Services
> **Email:** dndehoyos@utep.edu

1

Main: (915) 747-5601

Direct: (915) 747-5268

Fax: (915) 747-5932

Purchasing and General Services

500 West University Avenue

Kelly Hall 3rd Floor

El Paso, Texas 79968

admin.utep.edu/pgs

THE UNIVERSITY OF TEXAS AT EL PASO

From: De Hoyos, Diane N
Sent: Monday, February 29, 2016 11:59 AM
To: monika.urbanski@aashe.org
Cc: De Hoyos, Diane N <dndehoyos@utep.edu>
Subject: Meeting Request

Monica,

My name is Diane De Hoyos and I am a doctoral student here at UTEP in the Environmental Science and Engineering Program.

I wanted to ask a question regarding your campus solar installation database.

Please call me at your earliest convenience.

I have also left you a voicemail.

Thanks,
Diane

Diane N. De Hoyos, CTPM
Assistant Vice President

Purchasing and General Services
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500 West University Avenue

Kelly Hall 3rd Floor

El Paso, Texas 79968

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THE UNIVERSITY OF TEXAS AT EL PASO

improperly received information must be returned to this department immediately. Your cooperation in notifying me of erroneous receipt is requested.

--

Monika Urbanski
Data & Content Manager
Association for the Advancement of Sustainability in Higher Education
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Appendix D: IRB Requirement Waived – ORSP

De Hoyos, Diane N

From:	De Hoyos, Diane N
Sent:	Friday, March 4, 2016 11:48 AM
To:	Ramirez, Christina
Cc:	Tseng, Bill; IRB.ORSP
Subject:	Re: IRB Question - Response Requested

Thank you Christina,

Diane

Diane N. De Hoyos, CTPM
Assistant Vice President
Purchasing and General Services
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Sent from my iPhone

On Mar 4, 2016, at 11:47 AM, Ramirez, Christina <cramirez22@utep.edu> wrote:

> As you will not be collecting individual data from human subjects you do not need to submit to the IRB.
>
> Best,
> Christina
>
> **From:** De Hoyos, Diane N
> **Sent:** Friday, March 4, 2016 11:45 AM
> **To:** Ramirez, Christina <cramirez22@utep.edu>

1

Cc: Tseng, Bill <btseng@utep.edu>; IRB.ORSP <IRB.ORSP@utep.edu>
Subject: Re: IRB Question - Response Requested

No.

Diane N. De Hoyos, CTPM
Assistant Vice President
Purchasing and General Services
Email: dndehoyos@utep.edu
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Direct: (915) 747-5268
Fax: (915) 747-5932

Sent from my iPhone

On Mar 4, 2016, at 11:42 AM, Ramirez, Christina <cramirez22@utep.edu> wrote:

Hello Diane,

My apologies for the delay, I had been out of the office.

Are you collecting *individual* non-identifiable information from human subjects?

Best,

Christina Ramirez
IRB Administrator
Office of Research and Sponsored Projects
The University of Texas at El Paso
Kelly Hall
915-747-7693
Email: cramirez22@utep.edu

<image001.png>

From: De Hoyos, Diane N
Sent: Friday, March 4, 2016 9:16 AM
To: Ramirez, Christina <cramirez22@utep.edu>
Cc: Tseng, Bill <btseng@utep.edu>; De Hoyos, Diane N <dndehoyos@utep.edu>
Subject: RE: IRB Question - Response Requested

Hi Christina,

Just following up on the email below.

Thanks in advance for your assistance.

2

Diane

Diane N. De Hoyos, CTPM
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El Paso, Texas 79968
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From: De Hoyos, Diane N
Sent: Friday, February 26, 2016 11:20 AM
To: Ramirez, Christina
Cc: Tseng, Bill; De Hoyos, Diane N
Subject: IRB Question - Response Requested

Ms. Christina Ramirez

ORSP IRB Administrator

Ms. Ramirez,

My name is Diane N. De Hoyos and I am a doctoral student in Environmental Science and Engineering Program under the advisement of Dr. Bill Tseng, Chair, Department of Industrial, Manufacturing and Systems Engineering, and Professor, CmfgE.

I am inquiring regarding the IRB requirement on the topic of my area of study (solar photovoltaic installations on institutions of higher education). The data I will be using is secondary from a public website with no identifiable entities.

I will not be dealing with any human subjects . The websites states the following **: "The IRB provides review and oversight for all human subjects research activities performed on the campus."**

3

I do not believe I would need to submit an IRB form.

Please confirm.

Thanks in advance for your assistance,

Diane

Diane N. De Hoyos, CTPM
Assistant Vice President
Purchasing and General Services
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<image004.jpg>

Appendix E: SPSS Results – Examples (State and Inverter Vendor)

A. STATE

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Arizona	116	30.6	30.6	30.6
	California	83	21.9	21.9	52.5
	Colorado	28	7.4	7.4	59.9
	Massachusetts	43	11.3	11.3	71.2
	New Jersey	14	3.7	3.7	74.9
	New York	16	4.2	4.2	79.2
	Ohio	19	5.0	5.0	84.2
	Oregon	17	4.5	4.5	88.7
	Texas	28	7.4	7.4	96.0
	Wisconsin	15	4.0	4.0	100.0
	Total	379	100.0	100.0	

B. INVERTER VENDOR

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Solaron	1	.3	.3	.3
	Solectria	18	4.7	4.7	5.0
	Sunpower	1	.3	.3	5.3
	Vanner	1	.3	.3	5.5
	.	179	47.2	47.2	52.8
	Advanced Energy	50	13.2	13.2	66.0
	Aurora Inverters	1	.3	.3	66.2
	Broad	1	.3	.3	66.5
	DH Solar	1	.3	.3	66.8
	Ecostart	1	.3	.3	67.0
	Enphase	2	.5	.5	67.5
	Evergreen	1	.3	.3	67.8
	Fronius	7	1.8	1.8	69.7
	Ideal Power Converters	1	.3	.3	69.9
	PV Powered	20	5.3	5.3	75.2
	Satcon	28	7.4	7.4	82.6
	SMA	52	13.7	13.7	96.3
	Xantrex	14	3.7	3.7	100.0
	Total	379	100.0	100.0	

Appendix F: Data Set of Variables (Sample)

#	State	Institution	Year	Installer	Location	Panels	Inverter Type	Cost	Capacity	Production	Installation	NOP	Panel
1	Arizona	Arizona State University	2008	CarbonFree Technology Corp	Tempe, AZ	SunTech	Xantrex	6,104,824.00	711	1,319,591	Roof Top Mount	3,510	PolyCrystalline
2	Massachusetts	Worcester State College	2009	Amersco Southwest	Worcester, MA	Evergreen Solar	.	832,373.00	106	131,770	Roof Top Mount	540	PolyCrystalline
3	Arizona	Arizona State University	2009	CarbonFree Technology Corp	Tempe, AZ	SunTech	Xantrex	7,315,036.00	880	1,705,884	Roof Top Mount	4,320	PolyCrystalline
4	Arizona	Arizona State University	2012	Soitec Solar	Tempe, AZ	.	SMA	.	28	57,600	Pole Mount	.	.
5	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	120,600.00	12	16,802	Roof Top Mount	64	PolyCrystalline
6	Arizona	Arizona State University	2009	CarbonFree Technology Corp	Tempe, AZ	FirstSolar	SMA	793,461.00	108	187,411	Roof Top Mount	400	Thin - Film
7	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	Trina	Satcon	697,435.00	95	174,250	Roof Top Mount	434	MonoCrystalline
8	Arizona	Arizona State University	2004	Amersco Southwest	Tempe, AZ	.	.	.	.	.	.	.	.
9	Arizona	Arizona State University	2010	Independent Energy Group	Tempe, AZ	SunTech	SMA	120,600.00	13	21,158	Roof Top Mount	48	PolyCrystalline
10	Massachusetts	Mount Wachusette Community College	2009	Amersco Southwest	Gardner, MA	BP Solar	Solectria	849,817.00	97	111,861	Roof Top Mount	16	.
11	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	613,287.00	69	103,229	Roof Top Mount	240	PolyCrystalline
12	Arizona	Arizona State University	2011	Independent Energy Group	Tempe, AZ	Trina	Satcon	568,100.00	92	164,646	Roof Top Mount	392	PolyCrystalline
13	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,120,314.00	139	201,696	Roof Top Mount	492	PolyCrystalline
14	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,701,039.00	215	339,933	Roof Top Mount	744	PolyCrystalline
15	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	181,800.00	18	25,203	Roof Top Mount	96	PolyCrystalline
16	Arizona	Arizona State University	2009	Independent Energy Group	Tempe, AZ	SunTech	SMA	151,200.00	15	21,002	Roof Top Mount	80	PolyCrystalline
17	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,952,013.00	246	394,518	Pole Mount	852	PolyCrystalline
18	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	585,360.00	66	103,454	Roof Top Mount	294	PolyCrystalline
19	Arizona	Arizona State University	2012	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,199,175.00	166	269,436	Pole Mount	576	PolyCrystalline
20	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	2,913,725.00	453	799,991	Pole Mount	1,595	PolyCrystalline
21	Arizona	Arizona State University	2011	Independent Energy Group	Tempe, AZ	Trina	Satcon	1,373,736.00	224	371,681	Roof Top Mount	392	MonoCrystalline
22	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	PV Powered	2,750,000.00	251	419,832	Canopy	1,008	PolyCrystalline
23	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	382,200.00	66	104,481	Roof Top Mount	220	MonoCrystalline
24	Arizona	Arizona State University	2010	Independent Energy Group	Tempe, AZ	SunTech	SMA	151,200.00	17	26,447	Roof Top Mount	64	PolyCrystalline
25	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	91,900.00	20	31,736	Roof Top Mount	104	PolyCrystalline
26	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	181,800.00	17	26,447	Roof Top Mount	96	PolyCrystalline
27	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	181,800.00	27	42,315	Roof Top Mount	128	PolyCrystalline
28	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	151,200.00	10	15,868	Roof Top Mount	78	PolyCrystalline
29	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	151,800.00	20	31,736	Roof Top Mount	96	PolyCrystalline
30	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	151,200.00	10	15,868	Roof Top Mount	80	PolyCrystalline
31	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	242,100.00	23	35,892	Roof Top Mount	124	PolyCrystalline
32	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	520,067.00	89	141,819	Roof Top Mount	297	PolyCrystalline
33	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	Trina	Satcon	1,645,056.00	220	406,023	Roof Top Mount	938	PolyCrystalline
34	Arizona	Arizona State University	2013	Tek Star Plumb	Tempe, AZ	Seido	.	150,000.00	105	111,958	Roof Top Mount	.	.
35	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	Trina	Satcon	676,175.00	108	187,123	Roof Top Mount	490	MonoCrystalline
36	Arizona	Arizona State University	2010	Lafferty Electric Technologies	Tempe, AZ	Trina	Satcon	2,438,109.00	386	768,214	Roof Top Mount	1,680	MonoCrystalline
37	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,253,820.00	205	329,561	Pole Mount	682	MonoCrystalline
38	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,438,000.00	254	435,532	Pole Mount	847	MonoCrystalline
39	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,393,960.00	224	392,700	Pole Mount	748	MonoCrystalline
40	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,310,000.00	230	396,136	Pole Mount	768	MonoCrystalline
41	Arizona	Arizona State University	2013	Amersco Southwest	Tempe, AZ	Canadian Solar	Advanced Energy	1,688,033.00	261	443,190	Roof Top Mount	869	MonoCrystalline
42	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	156,030.00	23	40,850	Roof Top Mount	130	PolyCrystalline
43	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	Uni-Solar	Fronius	137,850.00	13	17,435	Pole Mount	.	Thin - Film
44	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	151,200.00	15	21,002	Roof Top Mount	80	PolyCrystalline
45	Arizona	Arizona State University	2009	Amersco Southwest	Tempe, AZ	SunTech	SMA	135,000.00	15	21,002	Roof Top Mount	80	PolyCrystalline
46	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	90,900.00	9	12,603	Roof Top Mount	48	PolyCrystalline
47	Arizona	Arizona State University	2009	Amersco Southwest	Tempe, AZ	SunTech	SMA	90,900.00	9	12,603	Roof Top Mount	48	PolyCrystalline
48	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	90,900.00	9	12,603	Roof Top Mount	48	PolyCrystalline
49	Arizona	Arizona State University	2009	Lafferty Electric Technologies	Tempe, AZ	SunTech	SMA	60,300.00	7	8,404	Roof Top Mount	32	PolyCrystalline
50	Arizona	Arizona State University	2013	Tek Star Plumb	Tempe, AZ	Seido	.	150,000.00	105	111,958	Roof Top Mount	.	.

Appendix G: Solar Installation Data (Examples 1 and 2)

Example 1:

Solar Photovoltaic Installation @ Rutgers, the State University of New Jersey

This database is free and open thanks to a collaboration with EcoMotion - Solar Advisors. EcoMotion's Solar Advisors are available to answer your questions about planning, financing, bidding and implementing your solar project. *EcoMotion offers a free consultation for AASHE Members!*

Back to Solar Installations | Update this Information

Installed in **2009** at **Rutgers, the State University of New Jersey** in Piscataway, NJ.

Installation Summary	
Developer ?	SunDurance Energy
Installer ?	SunDurance Energy
PV System Owner ?	Rutgers University
Installed Cost (USD) ?	$10,000,000
Ownership Type ?	Data Not Provided
Ownership SREC ?	Data Not Provided
Estimated Annual Utility Savings ?	225000

Technical Details	
Capacity ?	1400 kilowatts
Annual Production ?	1,500,000 kWh
Installation Type ?	Ground or pole mount
Installation Type Details ?	Ground-mount, fixed arrays.
PV Panel Type ?	(7,600) Yingli Green Energy Holding Co. YL175WP 175-watt polycrystalline silicon PV panels (13.2% peak efficiency). 20 degree tilt, tubular metal frame fixed racking, 3-4 feet off the ground.
Inverter Type ?	(5) Xantrex GT250 inverters.

Example 2:

Solar Photovoltaic Installation @ Arizona State University

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Back to Solar Installations | Update this Information

Installed in **2011** at **Arizona State University** in Tempe, AZ.

Installation Summary	
Developer ?	Strategic Solar Energy
Installer ?	Strategic Solar Energy
PV System Owner ?	NRG Solar
Installed Cost (USD) ?	$11,171,132
Ownership Type ?	Solar Power Purchase Agreement
Ownership SREC ?	Not Institution-owned
Estimated Annual Utility Savings ?	Data Not Provided

Technical Details	
Capacity ?	2124 kilowatts
Annual Production ?	3,524,442
Installation Type ?	Ground or pole mount
Installation Type Details ?	Ground mount parking canopy. Lot 59 PowerParasol. Fixed. 7,616 panels. 2,124 kWdc. 852 shaded parking spaces.
PV Panel Type ?	Yingli 280 Watts
Inverter Type ?	SATCON PowerGate Plus 500 (4)

Appendix H: Java Source Codes for Meta Data Analysis

1. Numerical Panel

```
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.awt.event.KeyEvent;

import javax.swing.BoxLayout;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JRadioButton;


public class NumericalPanel extends JPanel{
      JRadioButton layer1;
      JRadioButton layer2;

      public NumericalPanel(String name){
            layer1 = new JRadioButton("Layer 1");
            layer1.setMnemonic(KeyEvent.VK_B);
            layer1.setSelected(true);
            layer2 = new JRadioButton("Layer 2");
            layer2.setMnemonic(KeyEvent.VK_B);
            layer2.setSelected(true);
            add(getPanel(name));
      }
      public JPanel getPanel(String name){
            JPanel panel =  new JPanel();
        panel.setLayout(new BoxLayout(panel, BoxLayout.Y_AXIS));
        panel.add(new JLabel(name));
        panel.add(layer1);
        panel.add(layer2);
        return panel;

      }

}
```

2. Quantitative

```
import java.util.LinkedList;


public class Quantitative {
      public Quantitative(){

      }

      public double getMin(LinkedList<Double> column){

            double min = column.get(0);
```

```
            for(int i=1;i<column.size();i++){
                  if(min>column.get(i)){
                        min = column.get(i);
                  }
            }
            return min;

      }
      public double getMax(LinkedList<Double> column){

            double max = column.get(0);
            for(int i=1;i<column.size();i++){
                  if(max<column.get(i)){
                        max = column.get(i);
                  }
            }
            return max;

      }
      public double getMidpoint(LinkedList<Double> column){
            return (getMax(column) + getMin(column)) / 2;
      }
}
```

3. Stats Work

```
import java.math.BigDecimal;
import java.math.RoundingMode;
import java.util.LinkedList;


public class StatsWork {

      public StatsWork(){

      }
      public double correlation(LinkedList<Double> xs, LinkedList<Double>
ys) {

          double sx = 0.0;
          double sy = 0.0;
          double sxx = 0.0;
          double syy = 0.0;
          double sxy = 0.0;

          int n = Math.min(xs.size(),ys.size());

          for(int i = 0; i < n; ++i) {
            double x = xs.get(i);
            double y = ys.get(i);

            sx += x;
            sy += y;
```

```
            sxx += x * x;
            syy += y * y;
            sxy += x * y;
          }

          // covariation
          double cov = sxy / n - sx * sy / n / n;
          // standard error of x
          double sigmax = Math.sqrt(sxx / n -  sx * sx / n / n);
          // standard error of y
          double sigmay = Math.sqrt(syy / n -  sy * sy / n / n);

          // correlation is just a normalized covariation
          return round(cov / sigmax / sigmay, 4);
        }

      public double stdDev(LinkedList<Double> column){
            double mean = getMean(column);
            int count = column.size();
            double numerator = 0;
            for(int i=0; i<count;i++){
                  numerator += Math.pow(column.get(i)-mean,2);
            }
            double variation = numerator/ (count-1);
            return Math.sqrt(variation);
      }
      public double getMean(LinkedList<Double> column){
            int count=column.size();
            double total=0;
            for(int i=0; i<count;i++){
                  total += column.get(i);
            }
            return ( total / count );
      }
      public static double round(double value, int places) {
          if (places < 0) throw new IllegalArgumentException();

          BigDecimal bd = new BigDecimal(value);
          bd = bd.setScale(places, RoundingMode.HALF_UP);
          return bd.doubleValue();
      }

}
```

4. Excel Reader

```
import java.io.File;
import java.io.FileInputStream;
import java.io.FileNotFoundException;
import java.io.IOException;
import java.util.Iterator;
import java.util.LinkedList;
```

```
import org.apache.poi.ss.usermodel.Cell;
import org.apache.poi.ss.usermodel.Row;
import org.apache.poi.xssf.usermodel.XSSFSheet;
import org.apache.poi.xssf.usermodel.XSSFWorkbook;


public class ExcelReader {
      public ExcelReader(){
      }

      public LinkedList<Double> getColumn(String file, int columnNumber)
throws IOException{
             File myFile = new File(file);
         FileInputStream fis = new FileInputStream(myFile);
         LinkedList<Double> values = new LinkedList<Double>();
         // Finds the workbook instance for XLSX file
         XSSFWorkbook myWorkBook = new XSSFWorkbook (fis);

         // Return first sheet from the XLSX workbook
         XSSFSheet mySheet = myWorkBook.getSheetAt(0);

         // Get iterator to all the rows in current sheet
         Iterator<Row> rowIterator = mySheet.iterator();

         // Traversing over each row of XLSX file
         while (rowIterator.hasNext()) {
             Row row = rowIterator.next();

             // For each row, iterate through each columns
             Iterator<Cell> cellIterator = row.cellIterator();
             while (cellIterator.hasNext()) {
                 Cell cell = cellIterator.next();
                 if(cell.getColumnIndex()==columnNumber){
                  switch (cell.getCellType()) {
                     case Cell.CELL_TYPE_STRING:
                       // System.out.println(cell.getStringCellValue()+"S
at column Number "+columnNumber);
                         break;
                     case Cell.CELL_TYPE_NUMERIC:
                       // System.out.println(cell.getNumericCellValue()+"N
at column Number "+columnNumber);
                        values.add(cell.getNumericCellValue());
                         break;
                     case Cell.CELL_TYPE_FORMULA:
                        double roundUp = cell.getNumericCellValue();
                        roundUp = (double) Math.round(roundUp * 100) /
100;
                        values.add(roundUp);
                        break;
                     default:
                  }
                 }
             }
```

```
        }
        return values;
    }
```

5. Graph Viz

```
// GraphViz.java - a simple API to call dot from Java programs

/*$Id$*/
/*
******************************************************************************
 *                                                                            *
 *                    (c) Copyright Laszlo Szathmary                          *
 *                                                                            *
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 * under the terms of the GNU Lesser General Public License as published by   *
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 * This program is distributed in the hope that it will be useful, but       *
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 * along with this program; if not, write to the Free Software Foundation,    *
 * Inc., 675 Mass Ave, Cambridge, MA 02139, USA.                              *
 *                                                                            *
******************************************************************************
 */

import java.io.BufferedReader;
import java.io.DataInputStream;
import java.io.File;
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.FileWriter;
import java.io.InputStreamReader;

/**
 * <dl>
 * <dt>Purpose: GraphViz Java API
 * <dd>
```

```
 *
 * <dt>Description:
 * <dd> With this Java class you can simply call dot
 *      from your Java programs.
 * <dt>Example usage:
 * <dd>
 * <pre>
 *    GraphViz gv = new GraphViz();
 *    gv.addln(gv.start_graph());
 *    gv.addln("A -> B;");
 *    gv.addln("A -> C;");
 *    gv.addln(gv.end_graph());
 *    System.out.println(gv.getDotSource());
 *
 *    String type = "gif";
 *    String representationType="dot";
 *    File out = new File("out." + type);   // out.gif in this example
 *    gv.writeGraphToFile( gv.getGraph(gv.getDotSource(), type, representationType), out );
 * </pre>
 * </dd>
 *
 * </dl>
 *
 * @version v0.6.1, 2016/04/10 (April) -- Patch of Markus Keunecke is added.
 * The eclipse project configuration was extended with the maven nature.
 * @version v0.6, 2013/11/28 (November) -- Patch of Olivier Duplouy is added. Now you
 * can specify the representation type of your graph: dot, neato, fdp, sfdp, twopi, circo
 * @version v0.5.1, 2013/03/18 (March) -- Patch of Juan Hoyos (Mac support)
 * @version v0.5, 2012/04/24 (April) -- Patch of Abdur Rahman (OS detection + start subgraph
+
 * read config file)
 * @version v0.4, 2011/02/05 (February) -- Patch of Keheliya Gallaba is added. Now you
 * can specify the type of the output file: gif, dot, fig, pdf, ps, svg, png, etc.
 * @version v0.3, 2010/11/29 (November) -- Windows support + ability to read the graph from a
text file
 * @version v0.2, 2010/07/22 (July) -- bug fix
 * @version v0.1, 2003/12/04 (December) -- first release
 * @author  Laszlo Szathmary (<a href="jabba.laci@gmail.com">jabba.laci@gmail.com</a>)
 */
public class GraphViz
{
    /**
     * Detects the client's operating system.
     */
    private final static String osName = System.getProperty("os.name").replaceAll("\\s","");
```

```
    /**
     * The image size in dpi. 96 dpi is normal size. Higher values are 10% higher each.
     * Lower values 10% lower each.
     *
     * dpi patch by Peter Mueller
     */
    private final int[] dpiSizes = {46, 51, 57, 63, 70, 78, 86, 96, 106, 116, 128, 141, 155, 170, 187,
206, 226, 249};

    /**
     * Define the index in the image size array.
     */
    private int currentDpiPos = 7;

    /**
     * Increase the image size (dpi).
     */
    public void increaseDpi() {
        if ( this.currentDpiPos < (this.dpiSizes.length - 1) ) {
            ++this.currentDpiPos;
        }
    }

    /**
     * Decrease the image size (dpi).
     */
    public void decreaseDpi() {
        if (this.currentDpiPos > 0) {
            --this.currentDpiPos;
        }
    }

    public int getImageDpi() {
        return this.dpiSizes[this.currentDpiPos];
    }

    /**
     * The source of the graph written in dot language.
     */
    private StringBuilder graph = new StringBuilder();

    private String tempDir;

    private String executable;

    /**
```

```
 * Convenience Constructor with default OS specific pathes
 * creates a new GraphViz object that will contain a graph.
 * Windows:
 * executable = c:/Program Files (x86)/Graphviz 2.28/bin/dot.exe
 * tempDir = c:/temp
 * MacOs:
 * executable = /usr/local/bin/dot
 * tempDir = /tmp
 * Linux:
 * executable = /usr/bin/dot
 * tempDir = /tmp
 */
public GraphViz() {
   if (GraphViz.osName.startsWith("Windows")) {
      this.tempDir = "C:/Windows/Temp";
      this.executable = "graphviz-2.38/release/bin/dot.exe";
   } else if (GraphViz.osName.startsWith("MacOSX")) {
      this.tempDir = "/tmp";
      this.executable = "graphviz-2.38/release/bin/dot.exe";
   } else if (GraphViz.osName.startsWith("Linux")) {
      this.tempDir = "/tmp";
      this.executable = "graphviz-2.38/release/bin/dot.exe";
   }
}

/**
 * Configurable Constructor with path to executable dot and a temp dir
 *
 * @param executable absolute path to dot executable
 * @param tempDir absolute path to temp directory
 */
public GraphViz(String executable, String tempDir) {
   this.executable = executable;
   this.tempDir = tempDir;
}

/**
 * Returns the graph's source description in dot language.
 * @return Source of the graph in dot language.
 */
public String getDotSource() {
   return this.graph.toString();
}

/**
 * Adds a string to the graph's source (without newline).
```

```
 */
public void add(String line) {
   this.graph.append(line);
}

/**
 * Adds a string to the graph's source (with newline).
 */
public void addln(String line) {
   this.graph.append(line + "\n");
}

/**
 * Adds a newline to the graph's source.
 */
public void addln() {
   this.graph.append('\n');
}

public void clearGraph(){
   this.graph = new StringBuilder();
}

/**
 * Returns the graph as an image in binary format.
 * @param dot_source Source of the graph to be drawn.
 * @param type Type of the output image to be produced, e.g.: gif, dot, fig, pdf, ps, svg, png.
 * @param representationType Type of how you want to represent the graph:
 * <ul>
 *    <li>dot</li>
 *    <li>neato</li>
 *    <li>fdp</li>
 *    <li>sfdp</li>
 *    <li>twopi</li>
 *    <li>circo</li>
 * </ul>
 * @see http://www.graphviz.org under the Roadmap title
 * @return A byte array containing the image of the graph.
 */
public byte[] getGraph(String dot_source, String type, String representationType)
{
   File dot;
   byte[] img_stream = null;

   try {
      dot = writeDotSourceToFile(dot_source);
```

```
        if (dot != null)
        {
            img_stream = get_img_stream(dot, type, representationType);
            if (dot.delete() == false) {
                System.err.println("Warning: " + dot.getAbsolutePath() + " could not be deleted!");
            }
            return img_stream;
        }
        return null;
    } catch (java.io.IOException ioe) { return null; }
}

/**
 * Writes the graph's image in a file.
 * @param img   A byte array containing the image of the graph.
 * @param file  Name of the file to where we want to write.
 * @return Success: 1, Failure: -1
 */
public int writeGraphToFile(byte[] img, String file)
{
    File to = new File(file);
    System.out.println(to.exists());

    return writeGraphToFile(img, to);
}

/**
 * Writes the graph's image in a file.
 * @param img   A byte array containing the image of the graph.
 * @param to    A File object to where we want to write.
 * @return Success: 1, Failure: -1
 */
public int writeGraphToFile(byte[] img, File to)
{
    try {
        FileOutputStream fos = new FileOutputStream(to);
        fos.write(img);
        fos.close();
    } catch (java.io.IOException ioe) { return -1; }
    return 1;
}

/**
 * It will call the external dot program, and return the image in
 * binary format.
 * @param dot Source of the graph (in dot language).
```

```
     * @param type Type of the output image to be produced, e.g.: gif, dot, fig, pdf, ps, svg, png.
     * @param representationType Type of how you want to represent the graph:
     * <ul>
     *    <li>dot</li>
     *    <li>neato</li>
     *    <li>fdp</li>
     *    <li>sfdp</li>
     *    <li>twopi</li>
     *    <li>circo</li>
     * </ul>
     * @see http://www.graphviz.org under the Roadmap title
     * @return The image of the graph in .gif format.
     */
    private byte[] get_img_stream(File dot, String type, String representationType)
    {
      File img;
      byte[] img_stream = null;

      try {
        img = File.createTempFile("graph_", "." + type, new File(this.tempDir));
        Runtime rt = Runtime.getRuntime();

        // patch by Mike Chenault
        // representation type with -K argument by Olivier Duplouy
        String[] args = { executable, "-T" + type, "-K" + representationType, "-Gdpi=" +
dpiSizes[this.currentDpiPos], dot.getAbsolutePath(), "-o", img.getAbsolutePath() };
        Process p = rt.exec(args);
        p.waitFor();

        FileInputStream in = new FileInputStream(img.getAbsolutePath());
        img_stream = new byte[in.available()];
        in.read(img_stream);
        // Close it if we need to
        if( in != null ) {
          in.close();
        }

        if (img.delete() == false) {
          System.err.println("Warning: " + img.getAbsolutePath() + " could not be deleted!");
        }
      }
      catch (java.io.IOException ioe) {
        System.err.println("Error:    in I/O processing of tempfile in dir " + tempDir + "\n");
        System.err.println("       or in calling external command");
        ioe.printStackTrace();
      }
```

```
    catch (java.lang.InterruptedException ie) {
        System.err.println("Error: the execution of the external program was interrupted");
        ie.printStackTrace();
    }

    return img_stream;
}

/**
 * Writes the source of the graph in a file, and returns the written file
 * as a File object.
 * @param str Source of the graph (in dot language).
 * @return The file (as a File object) that contains the source of the graph.
 */
private File writeDotSourceToFile(String str) throws java.io.IOException
{
    File temp;
    try {
        temp = File.createTempFile("graph_", ".dot.tmp", new File(tempDir));
        FileWriter fout = new FileWriter(temp);
        fout.write(str);
        fout.close();
    }
    catch (Exception e) {
        System.err.println("Error: I/O error while writing the dot source to temp file!");
        return null;
    }
    return temp;
}

/**
 * Returns a string that is used to start a graph.
 * @return A string to open a graph.
 */
public String start_graph() {
    return "digraph G {";
}
public String start_unDirectionalGraph(){
        return "graph G{";
}

/**
 * Returns a string that is used to end a graph.
 * @return A string to close a graph.
 */
public String end_graph() {
```

```
    return "}";
}

/**
 * Takes the cluster or subgraph id as input parameter and returns a string
 * that is used to start a subgraph.
 * @return A string to open a subgraph.
 */
public String start_subgraph(int clusterid) {
    return "subgraph cluster_" + clusterid + " {";
}

/**
 * Returns a string that is used to end a graph.
 * @return A string to close a graph.
 */
public String end_subgraph() {
    return "}";
}

/**
 * Read a DOT graph from a text file.
 *
 * @param input Input text file containing the DOT graph
 * source.
 */
public void readSource(String input)
{
    StringBuilder sb = new StringBuilder();

    try
    {
        FileInputStream fis = new FileInputStream(input);
        DataInputStream dis = new DataInputStream(fis);
        BufferedReader br = new BufferedReader(new InputStreamReader(dis));
        String line;
        while ((line = br.readLine()) != null) {
            sb.append(line);
        }
        dis.close();
    }
    catch (Exception e) {
        System.err.println("Error: " + e.getMessage());
    }

    this.graph = sb;
```

```
    }

} // end of class GraphViz
```

6. Hierarchy Graph

```
import java.awt.Desktop;
import java.util.Arrays;
import java.io.File;
import java.io.IOException;
import java.util.LinkedList;


public class HierarchyGraph {
	int identifier;
	public HierarchyGraph(String filePath){
		identifier = 0;
		createGraphFile(filePath,"pdf");
	}
	private void createGraphFile(String filePath, String type){
		GraphViz graph = createGraphViz(filePath);
		String fileName = "analysis";
		String repesentationType= "dot";// can be changed to neato, fdp, sfdp, twopi,
circo.
		File out = new File(fileName + "." + type);    // change export location here
		graph.writeGraphToFile( graph.getGraph(graph.getDotSource(), type,
repesentationType), out );
		try {
			Desktop.getDesktop().open(out);
		} catch (IOException e) {
			System.out.println("Couldnt open file");
			e.printStackTrace();
		}
	}
	private GraphViz createGraphViz(String filePath){
		GraphViz graph = new GraphViz();
		StatsWork analysis = new StatsWork();
		graph.addln(graph.start_unDirectionalGraph());
		ExcelReader excel = new ExcelReader();
		try{
			graph.addln("splines=line;");
			for(int i = 0; i < excel.getColCount(filePath); i++){
				System.out.println(excel.getColumnName(filePath, i));
				if(excel.isColNumeric(filePath, i)){
					LinkedList<Double> colList = excel.getColumn(filePath,i);
					double[] colArray = listToArray(colList);
					colArray = Arrays.stream(colArray).distinct().toArray();
```

```
                    Arrays.sort(colArray);
                    String colName = excel.getColumnName(filePath , i);
                    graph.addln("subgraph \""+colName+"\"{ ");
                    firstLayer(graph, colName, colArray);
                    secondLayer(graph, colArray);
                    graph.addln("}");
                    }
                identifier++;
            }
        }
        catch(IOException e){
            System.out.println(":/");
            graph.addln(graph.end_graph());
            graph.increaseDpi();   // 106 dpi from java api
            return graph;
        }
//      graph.addln("{ rank=same, \"Cost\", \"Capacity\", \"Production\" }");

        graph.addln(graph.end_graph());
        //System.out.println(graph.getDotSource());//testing purposes
        graph.increaseDpi();   // 106 dpi from java api
        return graph;
    }
    private void firstLayer(GraphViz graph, String source, double[] column){
        addNodesToGraph(graph, source, Double.toString(column[0]) );
        double mid = ( column[0] + column[column.length-1] ) / 2;
        addNodesToGraph(graph, source, Double.toString(mid) );
        addNodesToGraph(graph, source, Double.toString(column[column.length-1]) );

    }

    private void secondLayer(GraphViz graph, double[] column){

        for(int i = 1; i<4 && i<column.length; i++){
            addNodesToGraph(graph, Double.toString(column[0]),
Double.toString(column[i]) );
            double mid = ( column[0] + column[column.length-1] ) / 2;
            addNodesToGraph(graph,
Double.toString(mid),Double.toString(column[((column.length-1) / 2) + i]));
            addNodesToGraph(graph, Double.toString(column[column.length-1]),
Double.toString(column[column.length-5+i]) );

        }
    }
    private void addNodesToGraph(GraphViz graph, String sourceName, String
targetName){
```

```
		if(targetName!=null){
			graph.addln("\""+sourceName+""+identifier+"\""+"--
"+"\""+targetName+""+identifier+"\"");

	graph.addln("\""+targetName+""+identifier+"\""+"[label=\""+targetName+"\"]");

	graph.addln("\""+sourceName+""+identifier+"\""+"[label=\""+sourceName+"\"]");
		}
		else{
			graph.addln("\""+sourceName+""+identifier+"\"");

	graph.addln("\""+sourceName+""+identifier+"\""+"[label=\""+sourceName+"\"]");
		}
	}
	private double[] listToArray(LinkedList<Double> column){
		double[] array = new double[column.size()];
		for(int i = 0; i<array.length;i++){
			array[i] = column.get(i);
		}
		return array;
	}
}
```

7. Interface

```
import java.awt.Dimension;
import java.awt.event.*;
import java.awt.image.BufferedImage;
import java.io.File;
import java.io.IOException;

import javax.imageio.ImageIO;
import javax.swing.*;
import javax.swing.filechooser.FileNameExtensionFilter;
public class Interface extends JFrame implements ActionListener{
	ButtonInterface analysisButs;
	AnalysisInterface analInt;
	String excelPath;
	public Interface(){
		super("Dashboard");
		addFeatures();
		setSize(850,550);
		setResizable(false);
	   setVisible(true);
	}
	public void addFeatures(){
		JTabbedPane tabbedPane = new JTabbedPane();
		analysisButs = new ButtonInterface();
```

```
		analInt = new AnalysisInterface();
		//add(analysisButs.getPicturePanel());
		tabbedPane.addTab("Map", analysisButs.getPicturePanel());
		tabbedPane.addTab("Quantitative", analInt.getPanel());
		add(tabbedPane);
		analysisButs.getStartAnal().addActionListener(this);
		analysisButs.getReadExcel().addActionListener(this);
		analInt.getStart().addActionListener(this);
	}
	public static void main(String[] args){
		new Interface();
	}
	@Override
	public void actionPerformed(ActionEvent e) {
		 if (e.getSource() == analysisButs.getReadExcel()) {
			   JFileChooser chooser = new JFileChooser();
			   chooser.setCurrentDirectory(new java.io.File("."));
			   chooser.setDialogTitle("Select Excel File");
			   FileNameExtensionFilter filter = new FileNameExtensionFilter("EXCEL
FILES", "xlsx", "excel");
			   chooser.setFileFilter(filter);

			   if (chooser.showOpenDialog(null) ==
JFileChooser.APPROVE_OPTION) {
				      System.out.println("getCurrentDirectory(): " +
chooser.getCurrentDirectory());
				      System.out.println("getSelectedFile() : " +
chooser.getSelectedFile());

				      excelPath=chooser.getSelectedFile().getPath();
			   } else {
				      System.out.println("No Selection ");
			   }
		  }
		if(e.getSource()==analInt.getStart()){
			if(excelPath==null){
				JOptionPane.showMessageDialog(null, "No excel selected");
				return;
			}
			HierarchyGraph graph = new HierarchyGraph(excelPath);
		}
	}

}
```

8. Analysis Interface

```
import javax.swing.BoxLayout;
```

```
import javax.swing.JButton;
import javax.swing.JCheckBox;
import javax.swing.JPanel;
import javax.swing.JRadioButton;


public class AnalysisInterface {
	JPanel number;
	JPanel yearSelect;
	JPanel cost;
	JPanel capacity;
	JPanel production;
	JPanel numPanels;
	JPanel efficiency;
	JPanel analysisInt;
	JButton start;
	public AnalysisInterface(){
		initializeButtons();
		createInterface();
	}

	public JPanel getPanel(){
		return analysisInt;
	}
	private void createInterface(){
		JPanel topPan = new JPanel();
		JPanel botPan = new JPanel();
		JPanel vertBox = new JPanel();
		JPanel startPan = new JPanel();
		startPan.add(start);
		vertBox.setLayout(new BoxLayout(vertBox, BoxLayout.Y_AXIS));
		topPan.add(number);
		topPan.add(yearSelect);
		topPan.add(cost);
		topPan.add(capacity);
		botPan.add(production);
		botPan.add(numPanels);
		botPan.add(efficiency);
		vertBox.add(topPan);
		vertBox.add(botPan);
		vertBox.add(startPan);
		analysisInt.add(vertBox);
	}
	private void initializeButtons(){
		number = new NumericalPanel("#");
		yearSelect = new NumericalPanel("Year");
```

```
		cost = new NumericalPanel("Cost");
		capacity = new NumericalPanel("Capacity");
		production = new NumericalPanel("Production");
		numPanels = new NumericalPanel("Panels");
		efficiency = new NumericalPanel("Efficiency");
		analysisInt = new JPanel();
		start = new JButton("Start analysis");
	}
	public JButton getStart(){
		return start;
	}
	public int getRadioStatus(JPanel panel){
		return 0;
	}
}
```

9. Button Interface

```
import java.awt.image.BufferedImage;
import java.io.File;
import java.io.IOException;

import javax.imageio.ImageIO;
import javax.swing.ImageIcon;
import javax.swing.JButton;
import javax.swing.JLabel;
import javax.swing.JPanel;
import javax.swing.JTextField;


public class ButtonInterface {
	JPanel analysisSelection = new JPanel();
	JButton readExcel = new JButton("Select Excel");
	JTextField cost = new JTextField("$999");
	JTextField capacity = new JTextField("100");
	JTextField production = new JTextField("100");
	JButton startAnal = new JButton("Start Analysis");
	JPanel picturePanel;

	public ButtonInterface(){
		initializeButtons();
	}
	public void initializeButtons(){
		analysisSelection = new JPanel();
		readExcel = new JButton("Select Excel");
		cost = new JTextField("$999");
		capacity = new JTextField("100");
		production = new JTextField("100");
```

```
		startAnal = new JButton("Start Analysis");
	BufferedImage Img = null;
		try {
			Img = ImageIO.read(new File("us_map.png"));
		} catch (IOException e) {
			e.printStackTrace();
		}
		JLabel picLabel = new JLabel(new ImageIcon(Img));
		picturePanel = new JPanel();
		analysisSelection.add(readExcel);
		analysisSelection.add(new JLabel("Minimum cost:"));
		analysisSelection.add(cost);
		analysisSelection.add(new JLabel("Minimum capacity:"));
		analysisSelection.add(capacity);
		analysisSelection.add(new JLabel("Minimum production value:"));
		analysisSelection.add(production);
		analysisSelection.add(startAnal);
		picturePanel.add(analysisSelection);
		picturePanel.add(picLabel);
	}
		public JPanel getPicturePanel(){
			return picturePanel;
		}
		public JButton getStartAnal(){
			return startAnal;
		}
		public JButton getReadExcel(){
			return readExcel;
		}
}
```

Vita

Diane N. De Hoyos holds a Bachelor of Science degree in her own designed plan - Comprehensive Science receiving a second degree is Spanish which included a summer study in Madrid, Spain from Bowling Green State University in Bowling Green, Ohio. In 1994 she received a Master's Degree in Manufacturing Engineering from the University of Texas at El Paso.

Diane has worked in the private sector since 1981 including global organizations such as Cooper Tire, Allied Signal, Outboard Marine Corporation and The General Motors Corporation. Her tenure management experience included assignments both domestic and international in the areas of: Purchasing, Advanced Supplier Quality, Cost Reduction and Supplier Diversity. Twelve years of her professional tenure were in the Maquiladora Industry where she completed a thesis entitled ***"A Study of the Factors Influencing Productivity In a U.S and Maquila Manufacturing Operation"*** at the University of Texas at El Paso. Diane has been an invited lecturer and speaker in the areas of Science and Engineering for the past 25 years.

Diane currently serves in the capacity of Assistant Vice President of Purchasing and General Services at the University of Texas at El Paso. She was awarded the prestigious HENAAC award in 1999. She was the first female recipient of the "Golden Nugget" award for the College of Engineering at UTEP in 2003. Diane is a graduate of Leadership El Paso and currently a member of Leadership Texas having served on the University of Texas Alumni Board. Diane has distinguished herself and has been the recipient of numerous awards locally and nationally for outstanding leadership and contributions to the Hispanic community throughout her notable career.

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