CONVERTING PAVED DESERTS INTO SOLAR PARKING LOTS IN URBAN AREAS

(IMPLEMENTING PHOTOVOLTAIC SYSTEMS INTO THE PARKING LOTS

OF THE CITY OF ARLINGTON)

by

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SangChun Ahn, December 4, 2013

ABSTRACT

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SANGCHUN AHN, M.C.R.P.

The University of Texas at Arlington, 2013

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This study presents projected costs and benefits of a carport style photovoltaic (PV) solar energy system, as well as its potential implementation sites in the City of Arlington. The goal was to estimate the amount of electricity generated from converting the existing sites into PV solar parking lots by assessing spatial, locational, and quantitative analysis, utilizing the available data, tools, and techniques in Geographic Information Systems (GIS) and Google Earth Pro. This study applied data from currently installed and active solar energy systems to meet the goal of this study. The findings showed the City of Arlington could generate 218,403 MWh/year, which is equivalent to the benefit of $63,467 per year, and the cost of projected total average solar PV system installation was $429,227,781. The findings showed that the cost of projected total average solar PV system installation would be $429,227,781, whereby the City of Arlington could generate 218,403 MWh/year, which is equivalent to the financial benefit of $63,467 per year. These projections were based on the commonly used 15.7% solar panel

efficiency. With the technological developments in solar PV efficiency, it is likely that electricity produced would exceed the current estimate, leading to even greater benefits of such initiatives.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Dallas-Fort Worth (DFW) is the fourth largest metropolitan area in the United States (US) with a population of 6.5 million, projected to increase further, owing to its notable economic growth. As a result, the overall energy demand is expected to be substantially greater. According to the North Central Texas Council of Governments (2010), the total population of the DFW Metropolitan Planning Area is projected to reach 9.8 million in 2035, corresponding to a 48% increase from 2012 (6.7 million). It is expected that increase in electricity usage and the amount of toxic chemicals released into the air associated with this population growth will be substantial. The Electric Reliability Council of Texas reported that, by 2022, Texas would experience electricity shortages (Searcy, 2012). In 2011, the US Energy Information Administration (EIA) reported that Texas was responsible for 27% of the total daily crude oil capacity and 28% of the US marketed natural gas production (EIA, 2012). As a leader in the US crude oil and natural gas production, Texas has become the biggest carbon-polluting state in the US (Kellison & Pham, 2007; Philips, 2008).

The Environmental Protection Agency (EPA) considers limiting construction of new coal and natural gas fired power plants (Carter, 2012; Valentine, 2013). In September 2013, the EPA proposed carbon dioxide (CO_2) pollution standards for new fossil fuel combusting power plants, responding to "Power Sector Carbon Pollution Standards" from President Obama's Climate Action Plan announced on June 2013 (Valentine, 2013). The background of this proposal can be traced to the *Massachusetts v. EPA* case decision in 2007, when The Supreme Court determined that greenhouse gases (GHG) should be treated as air pollutants under the Clean Air Act and ordered the EPA to assess and determine its impacts on public health and welfare. In December 2009, the EPA discovered that the current and projected GHG emissions were a threat to public health and welfare. Consequently, the EPA announced a proposed settlement agreement to issue rules on GHG emissions from fossil fuel combusting power plants (Valentine, 2013). In 2012, the EPA proposed standards that regulate an output-based limit of 1,000 pounds of CO_2 per megawatt-hour (MW/h) from new power plants. Currently, the EPA is planning to replace their first proposed standard with more effective measures. The EPA's new proposal released in September 2013 addressed:

- "New large natural gas-fired turbines would need to meet a limit of 1,000 pounds of CO_2 per megawatt-hour, while new small natural gas-fired turbines would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour" (Valentine, 2013).
- "New coal-fired units would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour, and would have the option to meet a somewhat tighter limit if they choose to average emissions over multiple years, giving those units additional operational flexibility" (Valentine, 2013).

Based on the new regulations, for Texas, it would no longer be appropriate to maintain the current approach to energy supply, as it would fail to ensure sustainable development for long-term energy demand. Thus, it is evident that the DFW region needs to seek alternative ways to meet its energy demand in near future.

The State of Texas has suitable weather conditions for solar-energy generation (Kellison & Pham, 2007), and benefits from the competitive advantage in the fast-growing solar energy market (State Energy Conservation Office [SECO], 2012). As shown in Figure 1.1, the State of Texas has a substantial solar photovoltaic (PV) resource potential (National Renewable Energy Laboratory (NREL)), and that, in most of its area, including the DFW region, the PV solar resources exceed 5 $kWh/m^2/day$, with even greater potential in the western regions. The PV system produces electricity directly from the sun's energy, whereby a PV solar panel cell converts sunlight into electricity without any pollution (Kellison & Pham, 2007). PV cells are manufactured using layers of semi-conductor material that can be charged (Knier, 2002). These individual units are often interconnected, forming a module and thus increasing their efficiency. Finally, modules are grouped into arrays, which are then placed on locations where solar power could be best utilized (Knier, 2002).

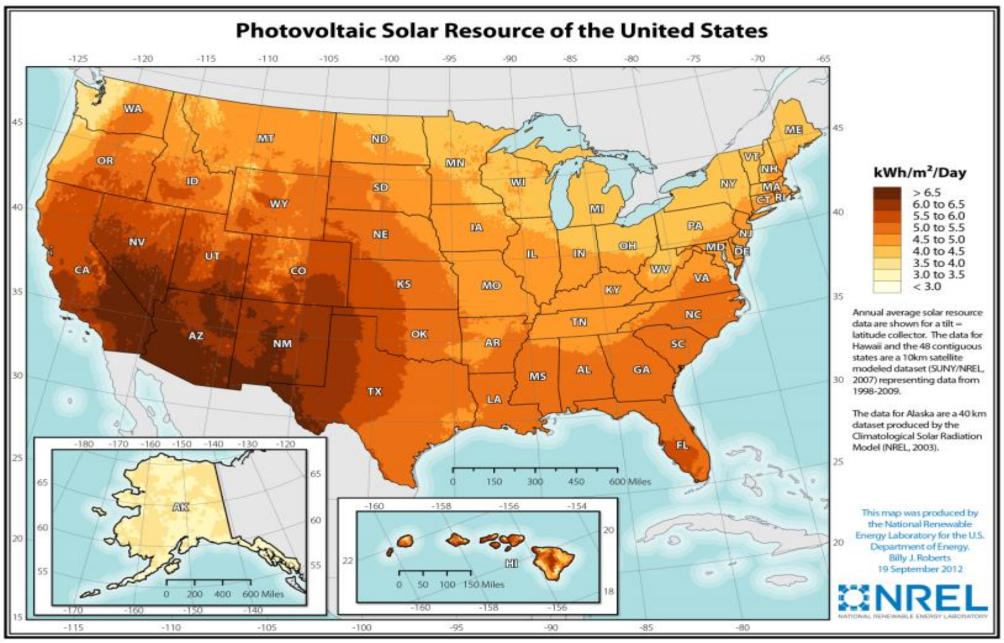

Figure 1.1 Source: NREL PV resource

In spite of its tremendous potential, according to House Research Organization (HRO) from Texas House of Representatives focus report, in terms of its utilization of solar energy, Texas is ranked 13th among the 50 US states, due to its fossil fuel-oriented energy market, conservative politics, and lack of public awareness regarding energy sustainability and environmental protection (House Research Organization [HRO], 2010). Currently, the on-site renewable solar energy generation is still very limited in Texas. Solar energy capacity is significantly lower than wind capacity, with more than 10,648 MWs of installed units (Texas

Coalition for Affordable Power [TCAP], 2013). At present, only 17 MW of solar energy systems are installed in Texas (SunShot, 2013). Texas Coalition for Affordable Power is the nation's largest non-profit corporation organized by cities and other political subdivisions, and is responsible for supporting the members in achieving better electricity acquisition deals. The SunShot is a US Department of Energy (DOE) program created for the integration in solar communities in US.

In addition to its advantageous natural conditions, the sprawling built environment of the DFW area provides numerous sites where solar energy systems could be easily installed. For example, as the roofs of most residential homes and commercial buildings (e.g., big box retails) are flat, they could be used for solar panel installation, while extensive parking lots could be covered using this technology. In particular, installing solar PV systems in parking lots can contribute not only to generating renewable energy on site, but also to solving multiple environmental problems that the DFW area presently encounters.

Impervious covers in suburban parking lots are one of the main contributors to the urban heat island (UHI) effect (Riley, 2002; Stone & Rodgers, 2001). Thus, as solar PVs in parking lots could provide shade to cars and surfaces, this would mitigate the UHI effects and prevent cars from overheating. In addition, solar PVs could support small installation businesses into local areas, serve as electric car charging stations, and public education sites on renewable energy generation.

As in many other cities in the DFW area, the large parking lots in the City of Arlington are already causing environmental problems. More than 31,575,044 m^2 of land is currently occupied by parking lots (based on the Geographic Information System (GIS) analysis conducted by the author) and they are almost fully exposed to sunlight. According to the City's Downtown Master Plan, 30% of downtown land spaces (183 acres) are occupied by parking lots, which is 85% greater than the building footprint within the area (City of Arlington, 2011). These parking lots could be converted into multi-functional spaces, contributing to reducing GHG emissions in the city by implementing the idea of solar parking lots.

Over the past decade, many municipalities across the US have started setting voluntary GHG emission reduction targets and have developed inventories and action strategies to achieve these goals through their Climate Action Plans (CAPs) (Bassett & Shandas, 2010). The latest data reveals that, as most cities in the DFW have not yet released their CAPs, once they attempt to do so, reducing GHG emissions would become very challenging due to their predominantly sprawling urban forms and associated energy demand. Due to the inertia of the built environment, compaction is a gradual process that requires long-term planning and significant effort (Echenique, Hargreaves, Mitchell, & Namdeo, 2012). In this regard, converting the existing parking lots into solar parking lots seems idealistic at this point. Nonetheless, it could become a feasible option for the City of Arlington and other DFW communities in next few decades.

1.2 Purpose of the Study

The study assessed suitable locations and the PV energy potential of the solar parking lots in the City of Arlington, TX. PV system installation on parking lots would be an efficient way to accommodate the energy needs of the current and next generations of city's residents, while yielding environmental benefits through providing shade to reduce UHI effects and to lower CO_2 emissions.

The hypothesis of this study was that solar PV systems utilizing existing parking lots in the City of Arlington could contribute to meeting a significant portion of the increasing electricity demands in the future. This study aimed to measure the amount of electricity generated from solar energy parking system on a local scale by calculating the size of parking lots using GIS and Google Earth. Potential electricity generation was calculated by applying solar PV efficiency data from the currently installed systems, while the solar system installation cost was estimated using average dollar per watt and assumed incentives and rebates. The findings of this study will help the City of Arlington identify the most optimal parking lot sites where urban solar farms could be implemented, as well as quantify the potential electricity production and potential installation cost.

CHAPTER 2

LITERATURE REVIEW

2.1 Why Renewable Energy?

The notable increase in the atmospheric CO_2 concentration is primarily due to human activities (Intergovernmental Panel on Climate Change, 2007) and is related to the expansion of urban development (Ewing, Bartholomew, Winkelman, Walters, & Chen 2008). This issue is becoming increasingly important, as the industrial society had historically been reliant of fossil-fueled energy sources, even though it has long been known that these sources are the main contributors to the CO_2 and other GHG emissions. Population growth implicitly places higher demands on electricity production, thus contributing to the growing GHG emission levels (Holdren, 1991). According to Qader (2009), modern society has become reliant on electrical appliances and devices, as these provide better quality of everyday life. The magnitude of our energy usage and its impact on economic development requires further study. Moreover, given the current population growth pattern, it is evident that we must find alternative ways to meet the growing energy demand (Holdren, 1991).

Today, utilizing fossil fuel is regarded as the most viable and economically effective means of generating electricity and the major resources of this technology are coal, gas, and oil (Qader, 2009). However, in addition to its associated environmental issues, such as air pollution, natural resource depletion, and global warming, these fossil fuel resources are non-renewable and limited. According to Aleklett, a professor of physics at Uppsala University in Sweden and coauthor of the book *Peeking at Peak Oil*, the peak in oil production was reached in 2006, and we are already in the decline phase (Aleklett & Lardelli, 2012). As shown in Figure 2.1, in 1960, the oil well discovery was at its maximum, while the peak of conventional oil production was reached in 2006. Based on this data, the decline of oil production is projected for the period after 2010.

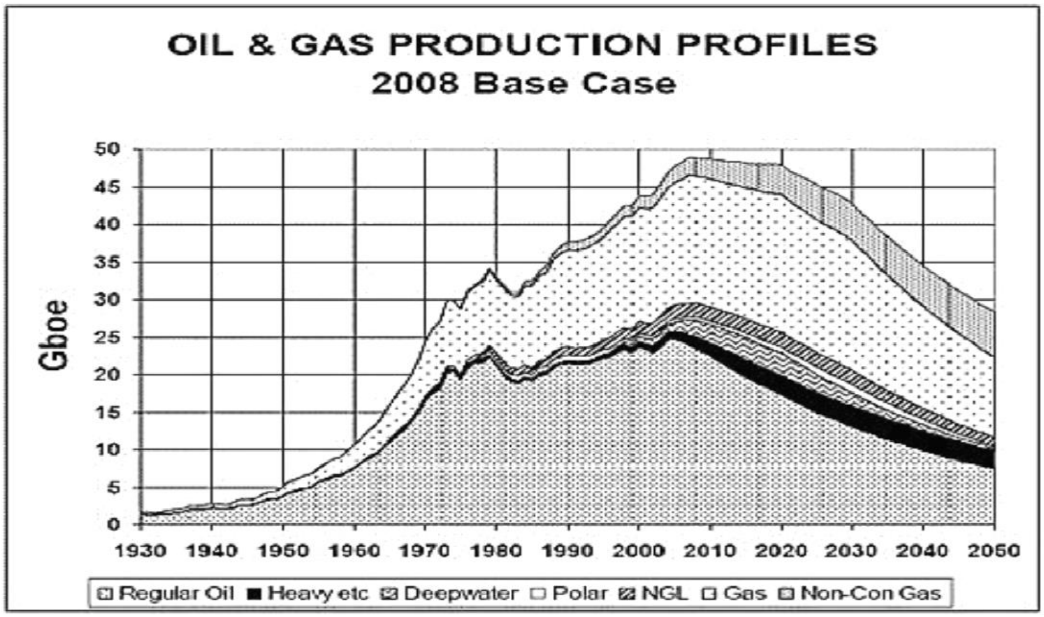

Figure 2.1 Historical oil and gas production trends in the US (Source: ASPO-Ireland Newsletter No. 100 – April 2009)

In the past 30 years, renewable energy resources, such as solar, ocean (currents and tidal waves), wind, and geothermal power, as well as hydroelectricity, bio-fuel, and biomass, have experienced exponential sales growth. Even before the onset of the 21st century, some authors predicted that, starting in 2010, due to its technology development and market growth, renewable energy would become a viable alternative to conventional energy (Girardet, 1999). As shown in Figure 2.2, the increase in the US renewable energy supply was considerable in the 2005 - 2014 period (EIA Short-Term Energy Fuels Outlook, 2013). Moreover, the same graph indicates that the Short-Term Energy Fuels Outlook (2013) projected a 4.4% increase in renewable energy consumption for electricity generation in all sectors by in 2013. The growth is projected to continue to increase at a rate of 2.6%, as a result of a 0.6% increase in hydropower, combined with a 3.7% increase in non-hydropower renewables in 2014 (EIA, 2013).

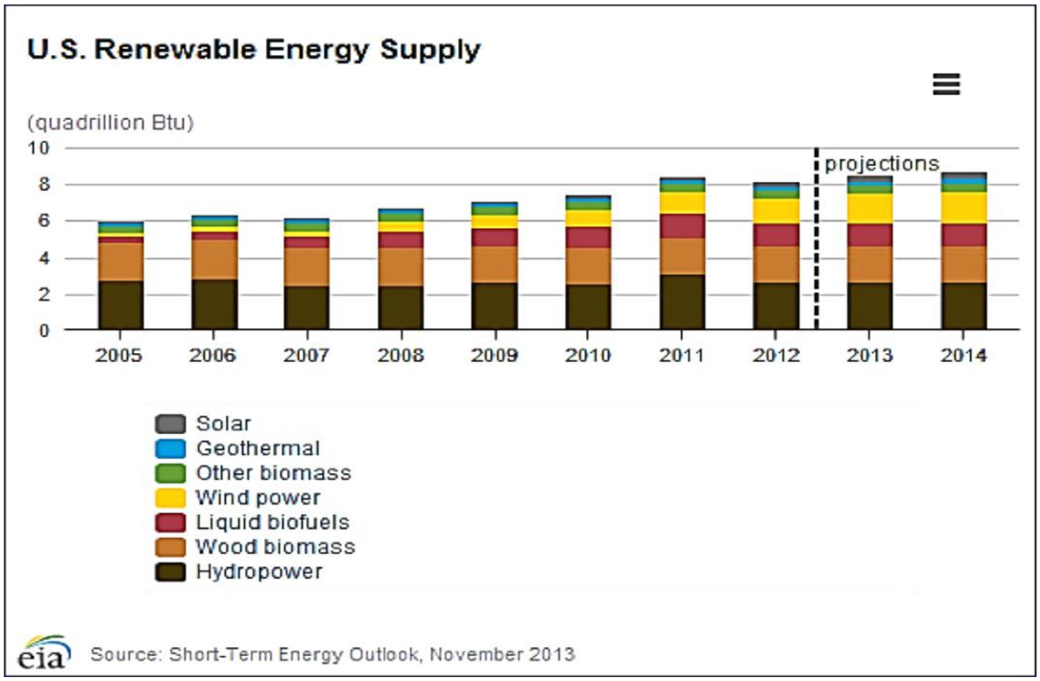

Figure 2.2 US renewable energy supply trends for 2005-2014 (Source: EIA Short-Term Energy Outlook, 2013)

Among various alternative energy sources, solar energy is particularly advantageous, as it is an infinite energy source; thus, it is unlikely that cost associated with solar power would fluctuate considerably (DeGunther, 2011). Like other renewable energy resources, a solar energy system does not require long-range energy source transportation costs to the generator site to generate electricity (DeGunther, 2011). However, compared with other renewable energy resources, solar energy is especially advantageous with respect to meeting the peak hour energy demand due to its maximum outputs of electricity production during peak (day) times (Engineering.com Library, 2013).

Solar energy is becoming more affordable. The Solar Energy Industries Association (SEIA) (2013) reported that the cost of an average PV system has declined by 11% since 2001, when the average system price was around $10 per watt, compared to about $3.05/W in 2013. Given this trend, the PV solar installation capacity is projected to increase to near 10,000 MW in 2016 (Solar Energy Industries Association [SEIA], 2013). Figure 2.3 and 2.4 respectively illustrate the decrease in average PV system price since 2001 to the first half of 2013, and the increase in the US solar installation capacity and its forecast from 2010 to 2016.

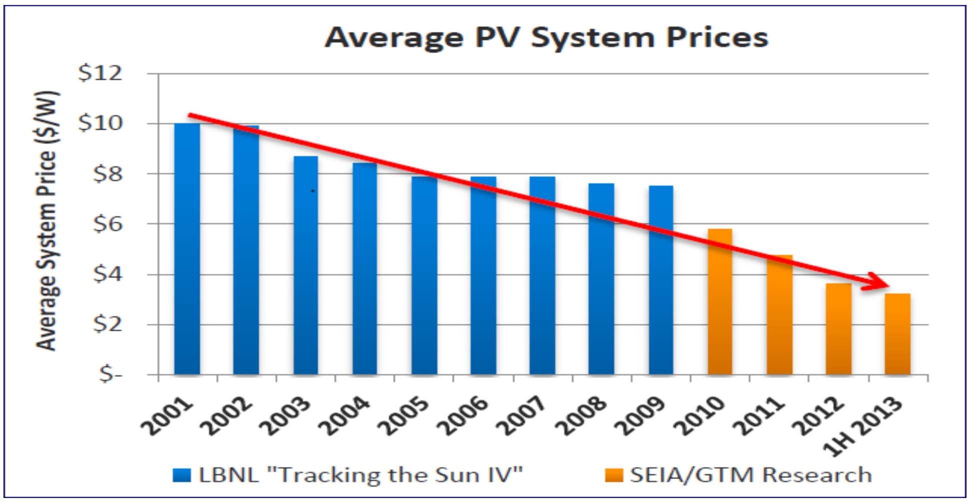

Figure 2.3 Average PV System Prices Trend (Source: SEIA Solar Energy Facts, 2013)

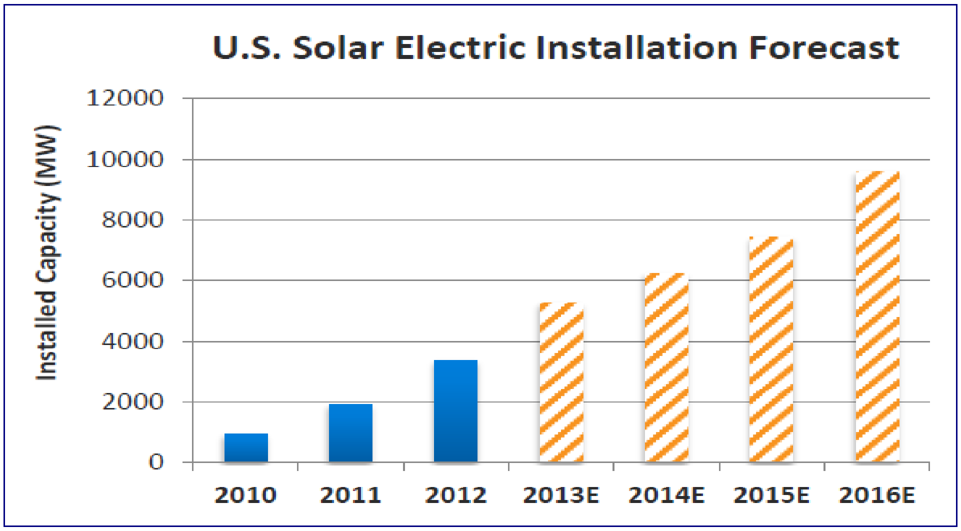

Figure 2.4 US Solar Electricity Forecast (Source: SEIA Solar Energy Facts, 2013)

Solar energy installation is also beneficial to the job market, as it will result in significant job creation, as highly skilled laborers will be in high demand. In particular, new positions for solar technology engineers, assemblers, sales representatives, and solar panel installers, as well as white-collar clerks, will substantially reduce unemployment in the area. Presently, 266 solar companies operate in Texas, employing a 3,200-strong workforce (Solar Energy Industries Association [SEIA], 2013). As shown in Figure 2.5, the solar energy industry benefits the US economy, as the number of individuals working in the solar energy sector will increase with the number of US solar installations. In 2011, the US solar workforce reached 119,000 workers, employed by 5,600 businesses, and in 2012, the solar installations were valued at $11.5 billion (Solar Energy Industries Association [SEIA], 2013).

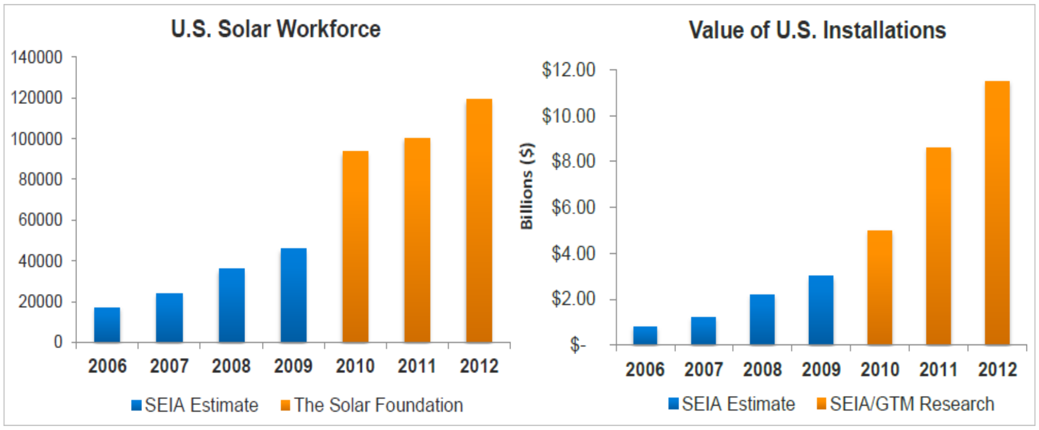

Figure 2.5 Solar job industry growth (Source: SEIA Solar Energy Facts, 2013)

2.2 On-site Solar Energy Generation

The shift towards distributed energy system using renewable resources is expected to create considerable demand for on-site solar energy systems (Bradford, 2006). Owing to their ability to minimize transmission energy loss, distributed systems are more advantageous than utility scale systems. Thus, when considering characteristics of both fuel source and distributed economies, distributed energy system is likely to move towards on-site solar energy (Figure 2.6).

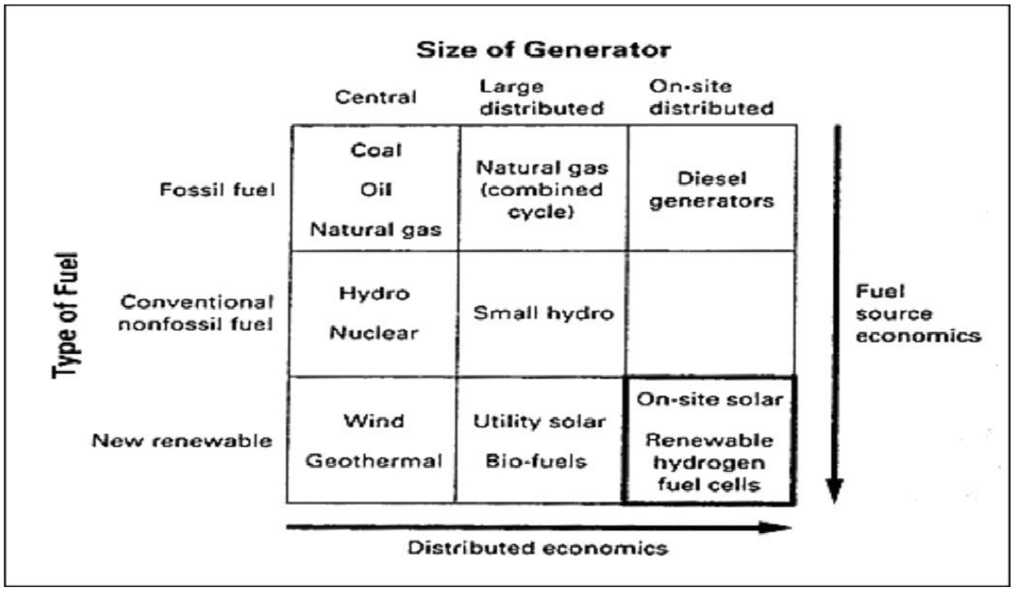

Figure 2.6 Distributed energy systems; Move towards on-site solar energy

(Source: Bradford, 2006)

Figure 2.7 depicts the rapid increase in cumulative US grid-tied PV installations from 2001 through 2010 (Sherwood, 2012). However, it is noteworthy that the 2010 PV capacity was doubled in 2011, and that figure was exceeded for larger systems in both the utility and the non-residential sectors (Sherwood, 2012). The reports from the electric utilities to the EIA (2012) acknowledged that the PV capacity was significantly greater than the utility scale capacity in 2010. According to Interstate Renewable Energy Council report, cumulative grid-connected PV capacity in the US increased to 4 GW DC in 2011 and this trend is expected to continue (Sherwood, 2012).

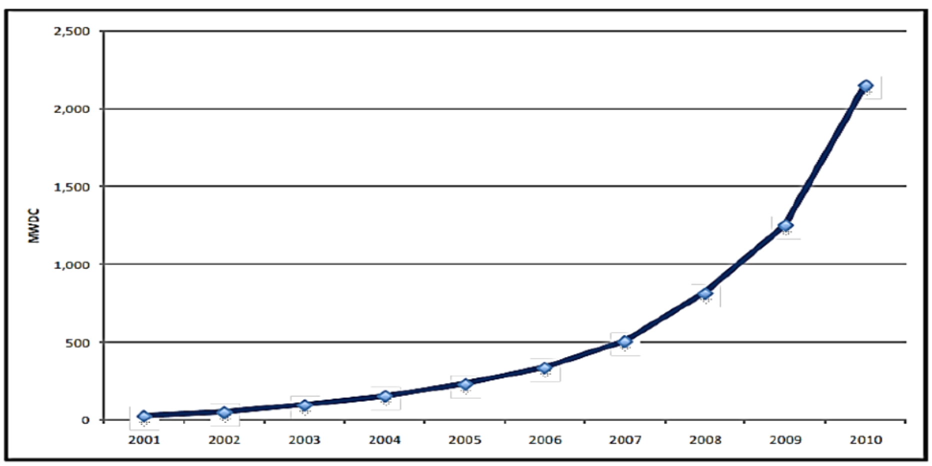

Figure 2.7 Rapid increase in cumulative US grid-tied PV installations from 2001 through 2010

(Source: Sherwood, 2011)

Solar energy production systems, when incorporated into urban design, can supply power to cities where most electric consumption occurs and can comprise a significant component of the urban economy (Beatley, 2008). Such systems can be implemented in urban areas more easily than most other renewable energy generators can, due to the convenience and scale. Solar energy can be integrated into existing urban fabric, utilizing the rooftops of residential, commercial, and industrial buildings, as well as open spaces, such as vacant contaminated sites and parking lots. Figure 2.8 illustrates some examples of a solar PV system installation in urban areas.

Figure 2.8 Examples of a solar PV system installation in urban areas

(Source: PV Database)

Solar parking lots can function as solar energy farms within urban areas. They can utilize paved empty spaces, which typically serve solely as car parking facilities, and are thus a main cause of the UHI problems in urban areas. Converting parking lots into solar farms will generate energy, thus not only meeting the demands of the area, but also bringing considerable environmental benefits. For example, as solar parking lots could provide shade for parked cars, this would prevent the cars from overheating, as illustrated in Figure 2.9.

Figure 2.9 Solar parking lots providing shade for parked cars (Source: beforeitsnews)

2.3 Case Studies

As a part of the present study, several solar parking lot cases in the US were reviewed and analyzed, in order to demonstrate the current trends and the feasibility of expanding this renewable energy production system. In addition, local examples from the DFW municipalities that implement solar PV systems for their municipal use were also reviewed. Although the local examples are not implemented on parking lots, these cases are still significant, as they demonstrate the feasibility of large-scale solar PV installations in DFW cities. As a part of the analysis, their capacity, energy generation, energy and financial savings, GHG emission reduction, and funding sources are compared. In Appendix A and B, the case studies reviewed as a part of this study are summarized.

2.3.1 U.S. Solar PV Systems in Parking Lots

Fresno State University, CA. Responding to the recently revised energy policy of the California State University system, in 2007, the California State University, Fresno (Fresno State), developed a Solar Parking Canopy Project. According to Chevron Energy Solutions (CES)—the company that designed, installed, and commissioned the project— in 2006, Fresno State initiated the development process on $11.9 million of one-MW solar power installation, in cooperation with CES. The system produces more than 1.5 million kWh of energy annually and meets approximately 20% of the university's annual core electrical demand. According to Best Practices 2008, as a result of the implementation of this system, a reduction of around 950 metric tons of GHG emissions is achieved, which is equivalent to planting more than 24,300 trees. Along with these advantages, the system's parking canopies are providing premium shaded parking for vehicles (Best Practices, 2008). Figure 2.10 shows carport style solar energy system in Fresno State.

Figure 2.10 Fresno State University, CA; Solar parking canopy

(Source: Green Building Research Center, at the University of California, Berkeley (Best Practices Case Studies, 2008))

City of Santa Cruz, CA. The City of Santa Cruz implemented a carport style solar energy system on the parking lots of its City Hall and Police Department. The Registry, an integrated Bay Area real estate news company, released a press release about the completion of the project construction in April 2013. This system was developed under the public and private partnership between the Berry Swenson Builder (BSB) solar system development company and the City of Santa Cruz. As a part of this initiative, more than 15,000 solar panels were installed on nine parking lots at government offices, which are projected to save about $18 million in the county's electricity costs over 25 years (City of Santa Cruz, 2012). In addition, utilization of these systems will result in the reduction of more than 4,000 metric tons of GHG emissions each year, which is comparable to over 800 cars being taken off the road or over 9,500 barrels of oil not consumed (City of Santa Cruz, 2012). Figure 2.11 shows an example of the solar panels in a parking lot.

Figure 2.11 City of Santa Cruz, CA; carport style solar energy system

(Source: The Registry News Press Release, 2013)

Cincinnati Zoo Cincinnati, OH. In 2011, the Cincinnati Zoo and Botanical Garden (CZBG) installed most of their main parking lot with more than 6,000 panels of a "carport style" solar energy system. It is the largest publicly accessible "urban" solar energy system in the US. This system is expected to produce about 20% of the zoo's annual electricity needs, which is sufficient to meet the energy demands of 200 homes each year or power 55,000 energy efficient bulbs for a year (CZBG, 2011). Figure 2.12 shows the solar panels in the zoo's car park.

Figure 2.12 Cincinnati Zoo Cincinnati, OH; carport style solar energy system

(Source: Largest Publicly Accessible Urban Solar Array (cincinnatizoo.org, 2010))

Patriot Place, Boston, CT. Patriot Place in Boston, CT initiated the construction of 2,600 PV panels of solar energy system in 2009. The system currently provides approximately 30% of Patriot Place's electricity demand and is expected to produce more than 12 million kWh of electricity over the next 20 years, resulting in reduction of more than 8,800 metric tons of CO_2 emissions. This amount is equivalent to removing more than 1,600 passenger vehicles from the road for a year (NRG energy Inc., 2013). NRG energy Inc. is an official Gillette Stadium and Patriot Place energy provider. Figure 2.13 shows the solar system of Patriot Place, Boston.

Figure 2.13 Patriot Place, Boston, CT (Source: NRG fact sheet (nrgsolar.com, 2013))

2.3.2 DFW Municipal Solar PV Systems

Duncanville, TX. The City of Duncanville, TX, a typical suburb in DFW, is taking the initiative in substituting the current fossil-fuel energy sources with renewable solar energy systems. To date, Duncanville has installed 147.84 kW of three solar PV energy systems on the rooftops of the city hall, a senior center and the library/recreation center. These projects were partly funded by a $1.1 million grant from the Distributed Renewable Energy Technology (DRET) Program (Axium Solar, 2010). Owing to the capacity of these facilities, the city projects at least $26,141 savings annually and anticipates that its $280,000 matching contribution will be recouped in less than one year (Axium Solar, 2010). Duncanville's Assistant City Manager argued that their municipal solar systems would contribute to the reduction of CO_2 emissions by 376,391 pounds annually, which is equivalent to planting trees on 47 acres of land, or removing 33 vehicles from the road annually (Axium Solar, 2010). Figure 2.14 shows the aerial image of Duncanville City Hall.

Figure 2.14 City of Duncanville, TX; rooftop solar PV energy systems

(Source: DFW Solar Tour, 2013)

Cedar Hill, TX._The City of Cedar Hill implemented a solar-powered energy system on its government center, for which it received the joint financial assistance from federal, state, and utility programs. Of the $1.2 million grants received, $952,058 was contributed by the Texas State Energy Conservation Office (SECO), $160,000 by ONCOR, and $26,000 by the City of Cedar Hill. As a part of this project, the city installed 480 rooftop solar panels on its municipal, police, and school district offices, which have the capacity to generate electricity equivalent to powering 14 or 15 average-sized homes (Axium Solar, 2011). Consequently, the city will reduce its net energy consumption by approximately 8%, which is comparable to 279,098 pounds/year of CO_2 emissions (citation). The estimated annual savings are projected to reach $21,000, and the city's $25,933.70 investment is expected to be recovered within less than 18 months (Axium Solar, 2011).

Figure 2.15 City of Cedar Hill, TX; rooftop solar PV energy systems

(Source: City of Cedar Hill real-time monitoring system, 2013)

2.4. Current Solar Energy Policies in Texas

According to the Texas Solar Energy Society (TXSES, 2013), the policies currently in force in the State of Texas are promoting solar energy utilization. In particular, the original

Renewable Portfolio Standard (RPS) is an important regulatory mandate to increase production of energy from renewable sources, third party financing, and guidelines and standards on solar systems. Nonetheless, the state of Texas must work on updating and enhancing its current RPS. Moreover, it is required to adopt the Net Metering law, which provides credits to on-site solar energy system owners (TXSES, 2013). The policy ensures that, in cases where the electricity output of a system exceeds the use, the unused electricity is returned to the grid and system owners receive a financial credit. This is a very useful policy in reducing electricity usage, given that the system owners can see the direct benefits of such initiative, as their electricity bills can be substantially reduced. The SEIA (2013) reported that Net Metering actually increases solar energy system demand (Solar Energy Industries Association [SEIA], 2013) and is an advantageous financial mechanism that could promote more solar energy opportunities in Texas. All case studies presented here indicated substantial advantages of the PV solar system implementations. Based on the facts gathered through these study cases, the next step in this study was the analysis of PV solar system implementation in the City of Arlington.

CHAPTER 3

METHODOLOGY

The aim of the present study was to assess the solar energy generation potential of selected large parking lots in the City of Arlington, TX. The projected electricity production was calculated based on solar monitoring data currently installed in Arlington. Next, the projected amount of electricity from solar parking lots was compared with the actual electricity usage in the area, allowing the evaluation of the ability of the PV installations in selected parking lots to meet local energy demand. The parking lots included in this analysis were selected based on their respective sizes, locations, and land occupancy within the City of Arlington.

3.1 Overview of Data Sources and Analysis

Main Data

In the forthcoming analyses, the data used to generate projections and assessments included:

- Annual electricity generation from a single solar panel that is currently installed in Arlington area
- Information on base solar PV energy system
- Size and location of the selected parking lots (sourced from GIS and Google Earth)
- Current electricity usage for the selected sites in Arlington

The annual electricity generation data of a single solar panel and the PV capacity were obtained from Dr. Yekang Ko’s property in Arlington, TX. This information was used to calculate the potential electricity of the parking lots. For this purpose, the parking lots were grouped into categories based on different land-use types. The City of Arlington provides an Arc GIS shape file that has all Arlington's land-use information data, which was used to generate the map shown in Figure 3.1.

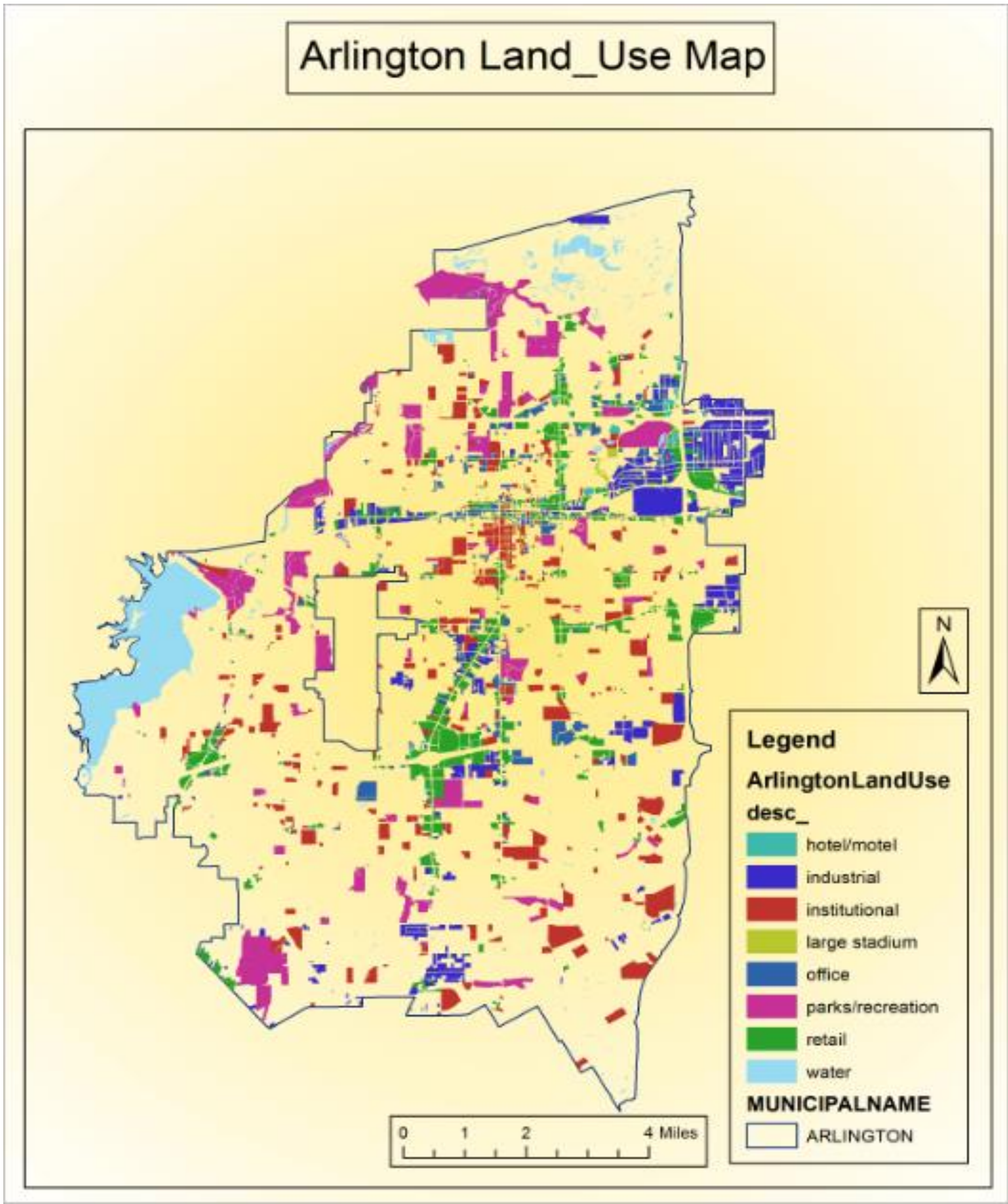

Figure 3.1 Arlington Land-Use Map

The parking lots were selected initially from the visual analysis on Google Earth and the areas confirmed with ArcGIS calculations. In this study, large-sized parking lots (areas were calculated using both Google Earth and ArcGIS) were used, which were classified by different land-use types. For area calculations, the GIS land-use layers were transferred to Google Earth, before creating polygons covering the parking lots in Google Earth. These polygon layers were next transferred into a GIS shape file and their sizes measured in ArcGIS. For this purpose, the parking lot data was combined with the land-use information. This enabled calculation of the potential electricity production on selected parking lots, which was performed by measuring the parking lot size and annual electricity generation from a single solar panel from Dr. Ko's property.

Finally, the number of solar panels that can be installed in selected parking lots was calculated by dividing the potential parking lot size for solar PV installation by the size of a single solar panel. The thus obtained number of solar panels was multiplied by the annual electricity generation capacity of a single solar panel to obtain the amount of the potential electricity generation from the parking lots. This figure was compared with the actual electricity usage data pertaining to the buildings in the City of Arlington in order to finalize the analysis and estimate the projected benefits of this initiative.

Applied Calculation Method

Equation 1.1 and 1.2 show expressions used in estimating the number of solar panels that can be installed and potential electricity production of the parking lot, respectively.

[Potential Parking Lot Size for Solar Panels] /

[Single Panel Size]

=

[The number of solar panels that can be installed]

[Equation 1.1]

[The number of solar panels that can be installed] X

[Annual electricity data from the single solar panel]

=

[Potential electricity production of the parking lot]

[Equation 1.2]

The analysis performed in this phase of the study consisted of five steps, as shown in Figure 3.2. In Step 1, all the input data was reorganized to facilitate the analysis. In Step 2, the parking lots that would be incorporated into the analysis were selected and their respective areas measured using ArcGIS and Google Earth. Steps 3 and 4 pertain to the analyses described above, and include identifying Big Parking Lot (BPL, selected parking lots of this study) locations within the City of Arlington, and calculating the projected solar PV potentials on those BPLs. In Step 5, the results are generated and the outcome of the proposed initiatives defined.

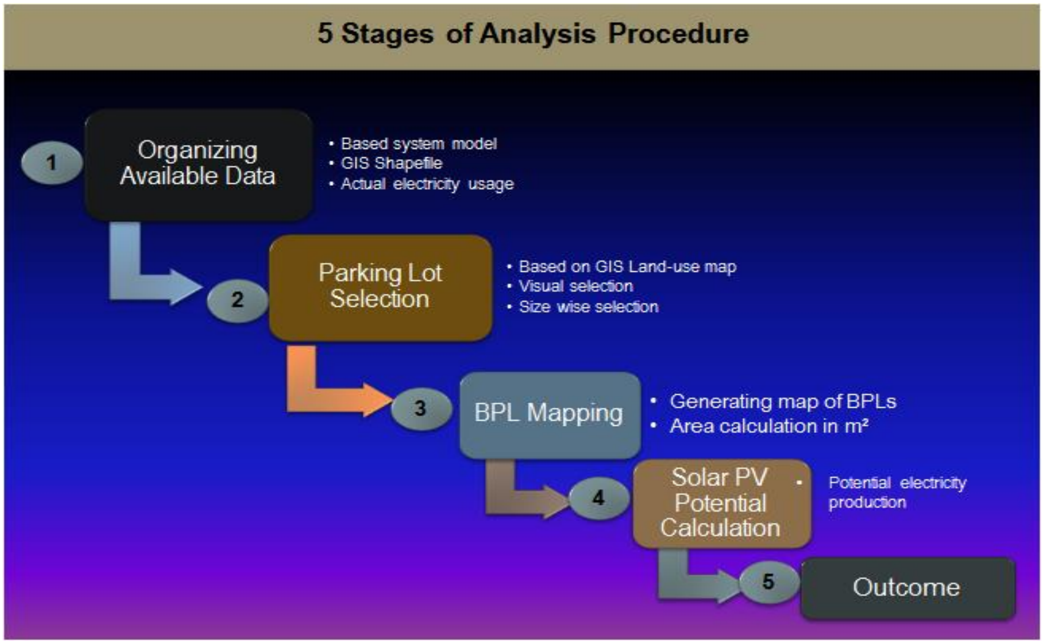

Figure 3.2 Five Stages of Analysis Procedure

3.2 Data Preparation

Prior to commencing the analyses described in the previous sections, both qualitative data and quantitative data were reorganized. Two base PV solar energy systems were used as references, namely (1) annual electricity production and system description data from current installations in Arlington (henceforth referred to as System A), and (2) area measurement data from the system installed on the rooftop of CPC parking garage (System B).

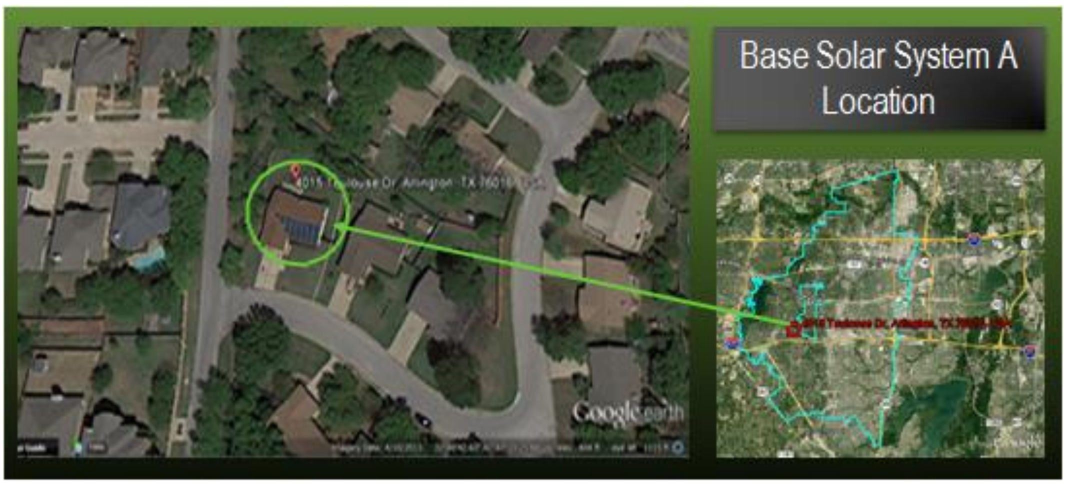

Figure 3.3 Location of the Base Solar System A

Figure 3.3 shows the location of the Base PV Solar System A installed on a south facing rooftop of Dr. Ko's property. This system incorporates an on-line efficiency monitoring program, which yields on-site energy production data, as shown in Figure 3.4.

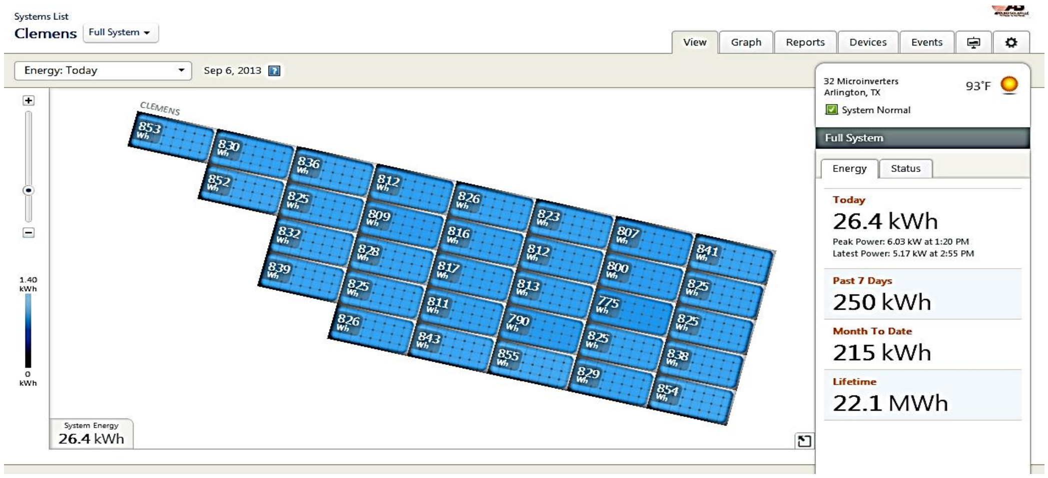

Figure 3.4 Base Solar System A; Data Monitoring

The data from Base Solar System A represents the 2012 annual on-site energy production (expressed in Wh) from the system's 32 solar panels. The size of a single solar panel of this system is 1.6 m^2. Based on the 15.7% PV efficiency, a single panel produced 395,746.125 Wh of electricity in 2012. This data was used as a reference for the solar PV potential in the present analysis. Table 1.1 summarizes the Base Solar System A key characteristics.

Base Solar System A Characteristics (Reference for Electricity Generation) Location: 76016, Arlington, TX	
Capacity (kW)	8.16
Installation date	December 20, 2011
Equipment	32 Siliken 255 watt panels, 32 Enphase M215 inverters, Unirac SolarMount
Single panel size	1.60625 m^2
Total panel size (all 32 panels):	51.4 m^2

Average energy produced from single panel (Wh)	395,746.125 Wh Per Year (2012)
Total energy produced (Wh)	12,663,876 Wh Per Year (2012)

Table 1.1 Base Solar System A Key Characteristics (Reference for Electricity Generation) (Source: DFW Solar Tour)

The Base PV Solar System B is the carport style PV solar energy system that is installed on rooftops of the UT Arlington College Park Center (CPC) parking garage (Figure 3.4). It is currently the largest carport-style PV energy system in the State of Texas (Peterson, 2012). The CPC parking garage covers the area of 8,876 m^2, which was used as a reference to determine a minimum parking lot size for the analysis. This system includes 1,638 carport-mounted PV panels that provide shade for parked vehicles, as well as serve as charging stations for electric vehicles. According to the UTA Office of Sustainability, the energy that this system can produce is equivalent to approximately 30% of the energy use from the mixed-use College Park Development.

Figure 3.5 Location of the Base Solar System B

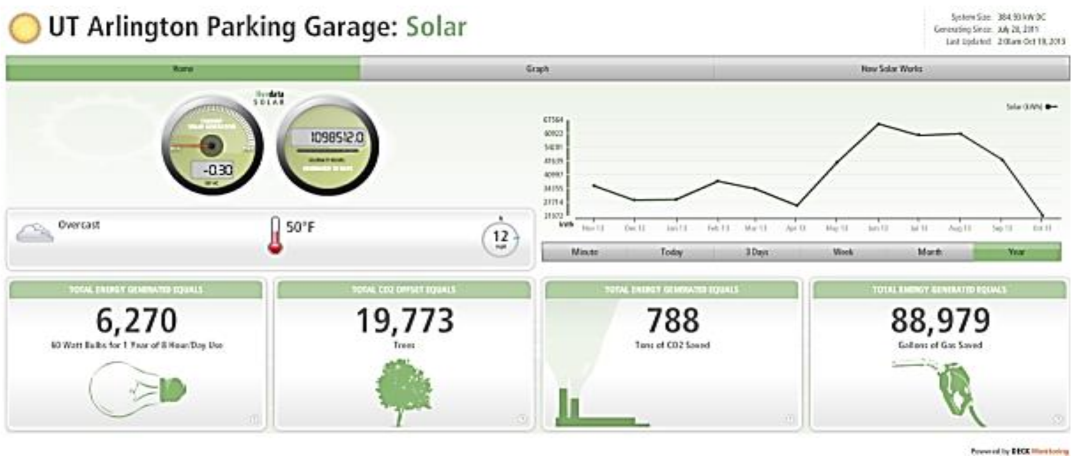

Figure 3.6 An example of real time monitoring system display (Source: UTA Solar Real-Time Monitoring, 2013)

Figure 3.6 shows the site's real time monitoring data, depicting the amount of electricity produced by the panels. Between September 27th, 2011 and October, 2013, the system has generated more than 1,098,512 kWh of electricity, which is sufficient to power 6,270 60-watt light bulbs eight hours a day for a year. A fund and rebate program supported this system financially. More specifically, $1.8 million American Reinvestment and Recovery Act grant, and $390,000 rebate from Oncor contributed to this project (Peterson, 2012). In addition, this system received a rebate from Oncor and recovered UT Arlington's investment of $368,000 on this upper-deck PV energy system. Table 1.2 summarizes the key characteristics of the Base Solar System B.

Base Solar System B Characteristics (Reference for Parking Lot Size)

Energy Generation	▪ Parking Lot Size: 883,010 m^2 ▪ 1,638 photovoltaic panels ▪ The panels had generated more than 473,000 kWh of electricity since September 27, 2011 ▪ Enough to power 2,704 60-watt light bulbs eight hours a day for a year ▪ The energy generated is sufficient to offset an estimated 30% of the energy use at the mixed-use College Park Development
Funding	▪ $1.8 million funded through American Reinvestment and Recovery Act grant ▪ $390,000 rebate from Oncor
Other Information	▪ Largest carport-style photovoltaic energy system in Texas ▪ Provides shade and charging stations for electric vehicles ▪ Provides real-time data about the energy produced by the panels and graphics that explain the process

Table 1.2 Base Solar System B Key Characteristics (Reference for Parking Lot Size)

(Source: UT Arlington News Center, Peterson, 2012)

The energy usage data was obtained for the four city buildings included in the analysis (City Hall, Central Library, Bob Duncan Community Center, and the Parks and Recreation Administration Building). James F. Parajon, Director of Community Development and Planning of the City of Arlington was kind to provide the electricity usage data used for estimating the energy contribution of the PV solar energy parking lot system in relation to the municipal energy use.

3.3 Parking Lot Selection

The parking lots in Arlington used in the analyses were identified based on their designated land use, whereby those covering the area equal or exceeding 8,876 m^2 were chosen. Both Arc GIS and Google Earth were employed in this process, in order to capitalize on the strengths of both software programs. Google Earth Pro provides higher resolution imagery and faster processing than the Bing base imagery layer in ArcGIS, which requires a robust network connection for constant data streaming. Figure 3.7 illustrates the BPL selection and analysis process. As previously noted, BPLs were selected following the interactive analysis that included size calculation, and the map overlays between ArcGIS and Google Earth based on the collected data.

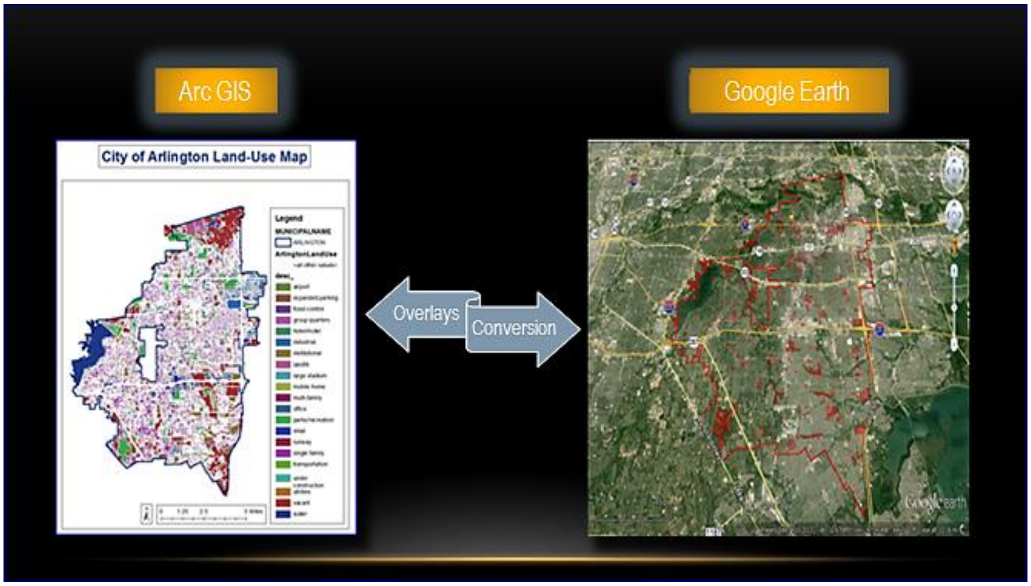

Figure 3.7 BPL Selection Analysis Process

3.4. Selection of Big Parking Lots

Arc GIS and Google Earth facilitated visual analysis that aimed to identify the suitable BPLs within the city. For the purpose of the subsequent analyses, BPLs were defined as parking areas exceeding the total dimensions of the rooftop of CPC parking garage at UT Arlington (Figure 3.8), which was used as the reference site for this study. Since this CPC's system is a successful model in terms of its operation and sustainability efforts, it was appropriate to use it as a benchmark when identifying sites that could be used to install the same system. CPC's 1,638 panels of solar energy system are installed as a roof of two attached parking garages, as shown in Figure 3.7. Out of the total garage area (8,876 m²), the solar panels cover 2,898 m², which is equivalent to 32% of the total rooftop area (Figure 3.8).

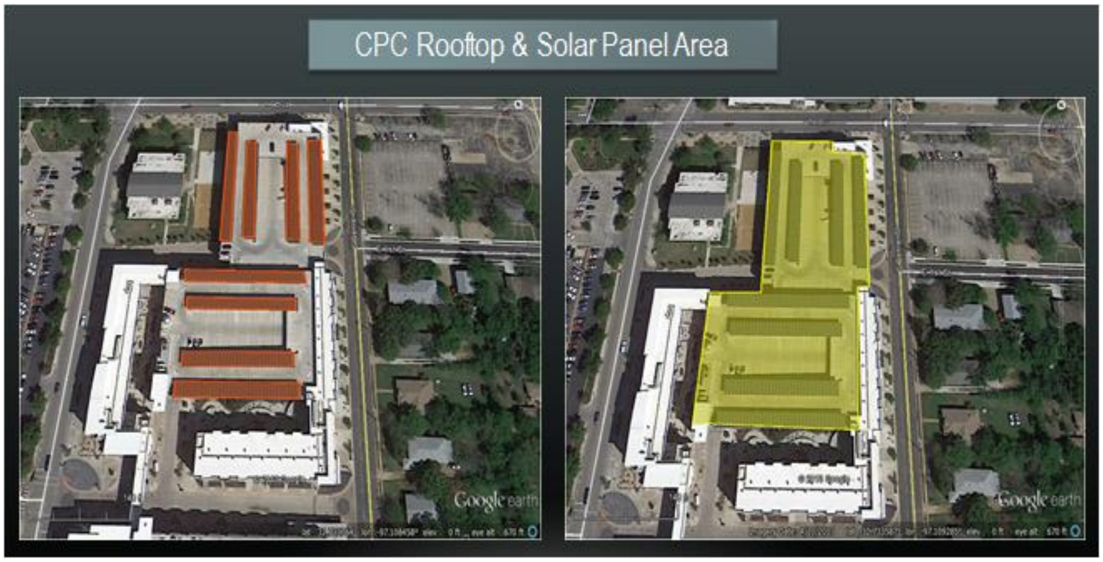

Figure 3.8 CPC Rooftop (Right) and Solar Panels (Left)

Prior to the analysis, the existing parking lots were classified using two main categories—land-use (five types) and size (equal or greater than the CPC parking lot) (Figure 3.9). Since the study is focused on large sized parking lots, areas designated for residential use were excluded from this analysis. The five land use categories included in the study are thus:

- Public: Expanded parking, Parks/Recreation, and Institutional
- Commercial: Hotel/Motel, Office, and Retail
- University: UT Arlington
- Entertainment: Institutional, Large Stadium, and Parks/Recreation
- Industrial: Industrial

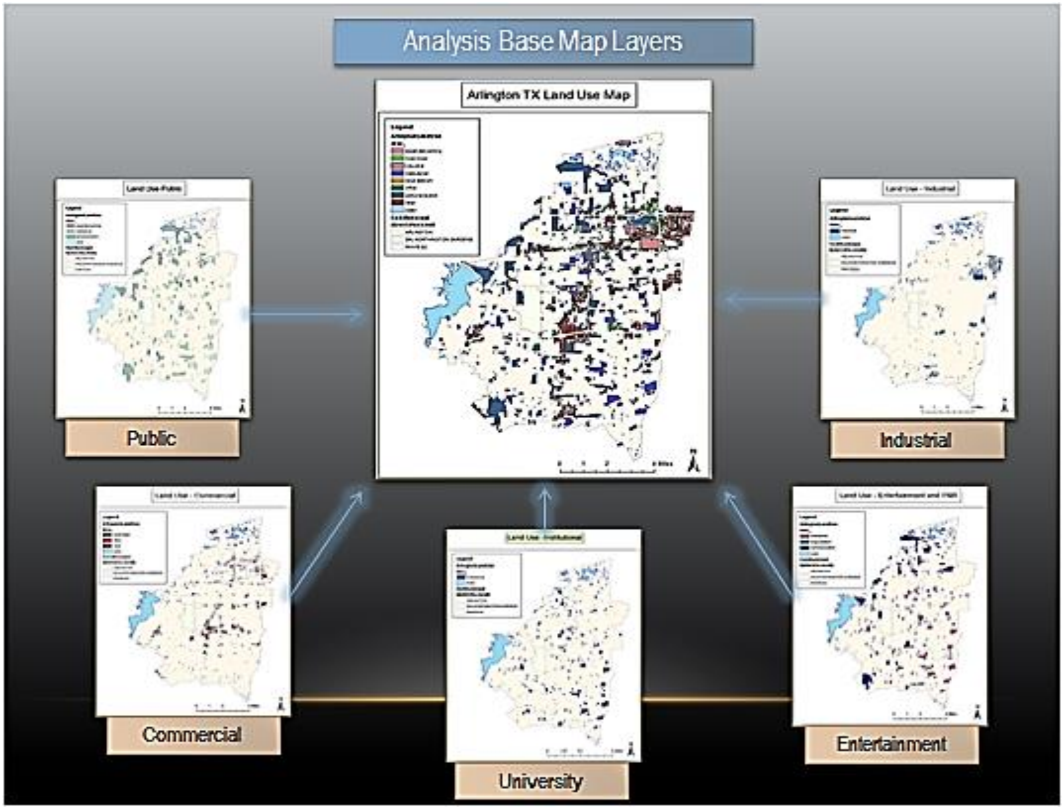

Figure 3.9 Parking Lot Location Map Generation Process

Figure 3.10 displays the BPLs of the Arlington city area in the five land use categories described above. The blue color on the map indicates public BPLs, brown indicates commercial BPLs, University BPLs are displayed in orange (all BPLs in this category are located within the UT Arlington campus), entertainment BPLs are shown with green (mostly located in Arlington's Entertainment District), and industrial BPLs are displayed in two colors—purple and yellow. For the purpose of this study, purple was used to depict the location of the actual BPLs, while yellow indicates the rooftops within the industrial land-use that are of sufficient size to accommodate PV installation. Most industrial buildings in this area are mega-sized warehouses and tend to be of rectangular shape, with flat rooftops, which are very similar to parking lots.

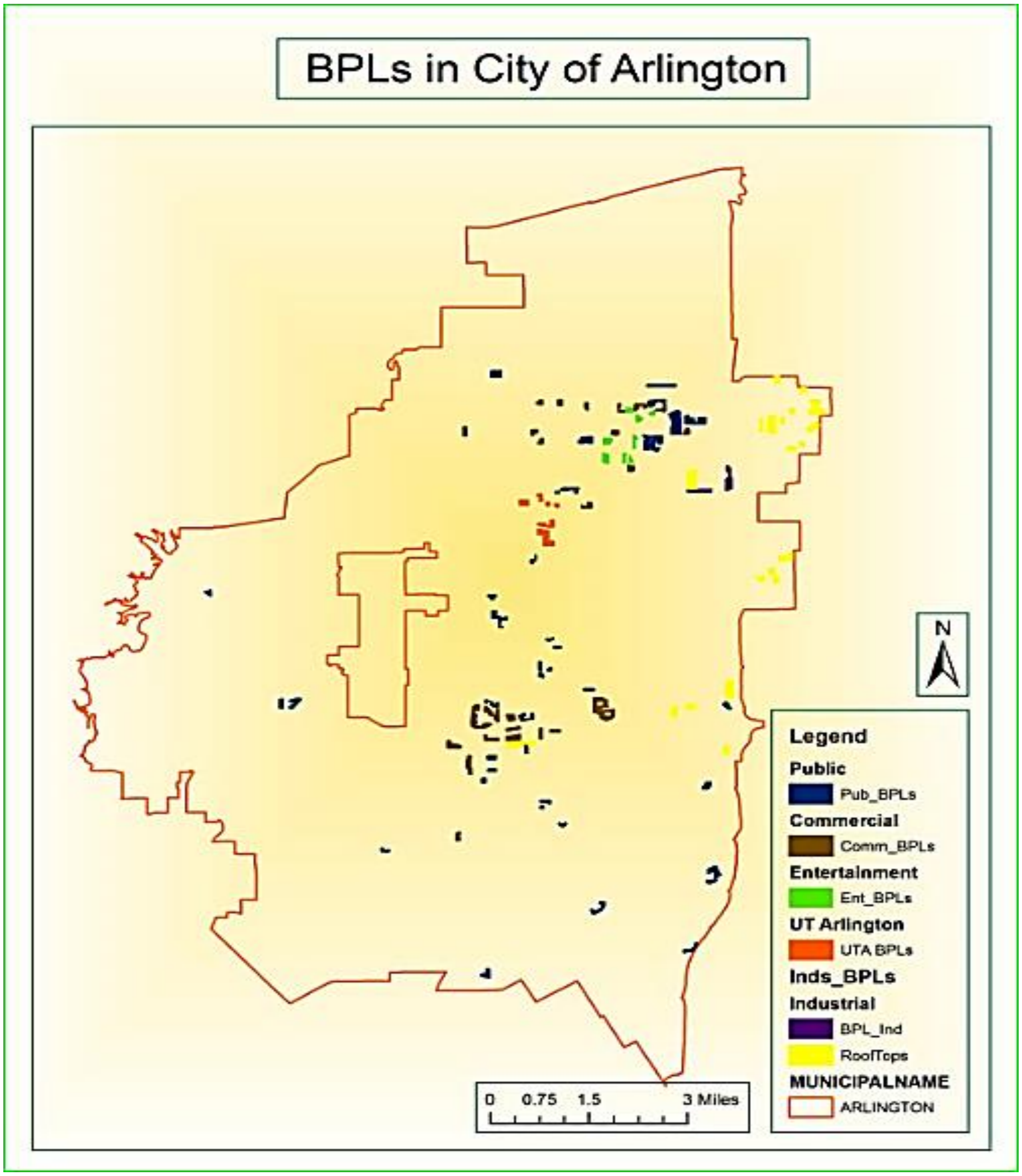

Figure 3.10 Big Parking Lots BPLs in the City of Arlington

3.5 Solar PV Potential Calculation

Once the suitable BPLs were identified, their annual solar energy potential was calculated. To estimate the number of solar panels that can be installed in the BPLs, 32% of each category's parking lot size was determined, in line with the portion in the reference CPC parking garage, and this figure was divided by the base panel size (1.6 m^2). The thus obtained number of required panels was multiplied by the annual electricity generation potential of a base panel, to estimate the total potential electricity production. The results of this analysis are presented in next chapter.

CHAPTER 4

RESULTS

4.1. Potential Electricity Generation from BPLs

Table 1.3 shows the summary of the potential electricity generation capacity of the solar BPLs. Based on these results, Arlington currently has approximately 275,9407 m^2 of 118 BPLs and about 551,884 solar panels could be installed in BPLs, each with about 883,010 m^2 of space (32% of the total area) that could be designated for solar panel installations**.** In Figure 4.1 through 4.4, information pertaining to each category given in Table 1.3 is depicted.

This analysis also projected the potential savings from the on-site electricity generation by applying one of the utility company's solar energy rates. Green Mountain Energy was the first to provide 100% solar electricity in Texas. They offer average Price 11.5¢ per kWh, which includes monthly service charge and is based on usage of 2,000 kWh per month (Green Mountain Energy, 2013). The potential financial savings that could be achieved based on these estimates are given in Table 1.4.

Analysis Outcome				
	Number of BPLs	Total BPL Area (m^2)	Potential PV Area (32% of the total area) (m^2)	Projected Electricity Production (MWh/year)
Public	37	681,961	218,228	53,977
Commercial	29	627,484	200,795	49,664

University	8	58,473	18,711	4,628
Entertainment	15	596,101	190,752	47,180
Industrial	29	795,388	254,524	62,954
TOTAL	118	275,9407	883,010	218,403

Table 1.3 Analysis Outcome

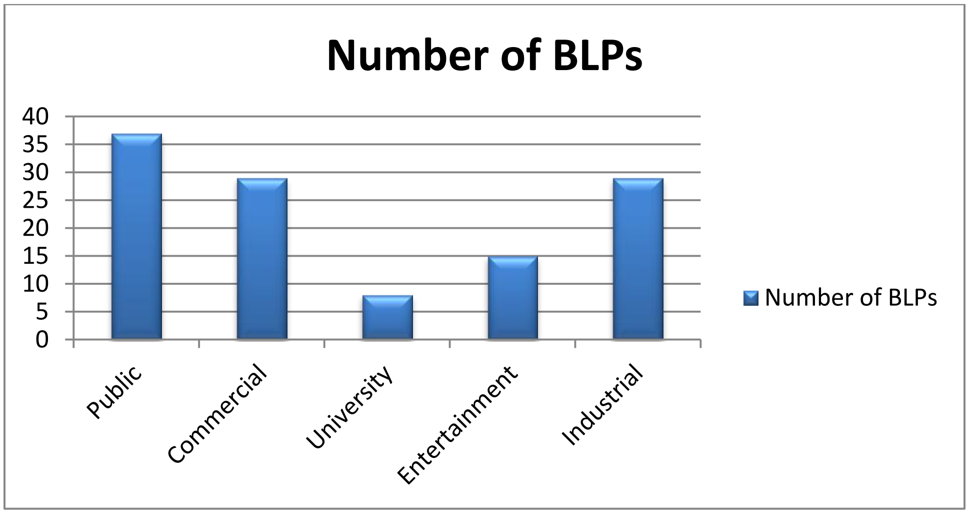

Figure 4.1 Number of BPLs

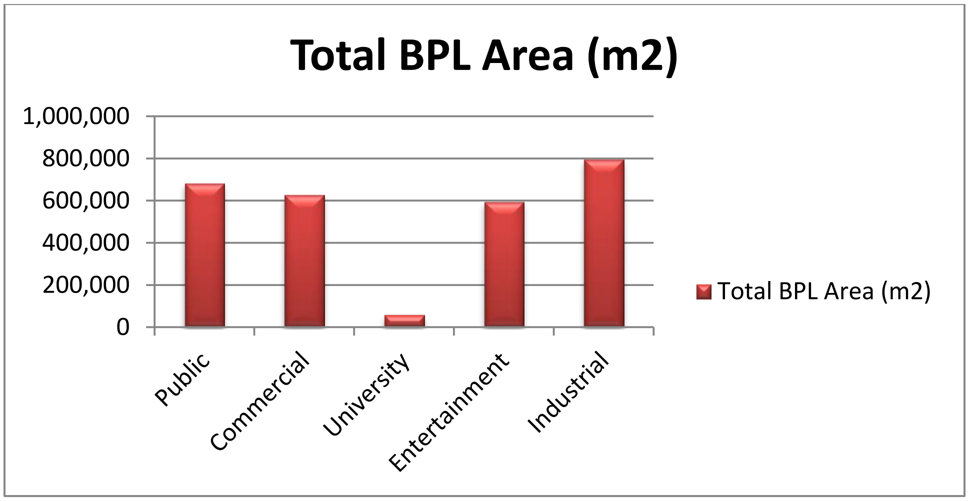

Figure 4.2 Total BPL Area (m^2)

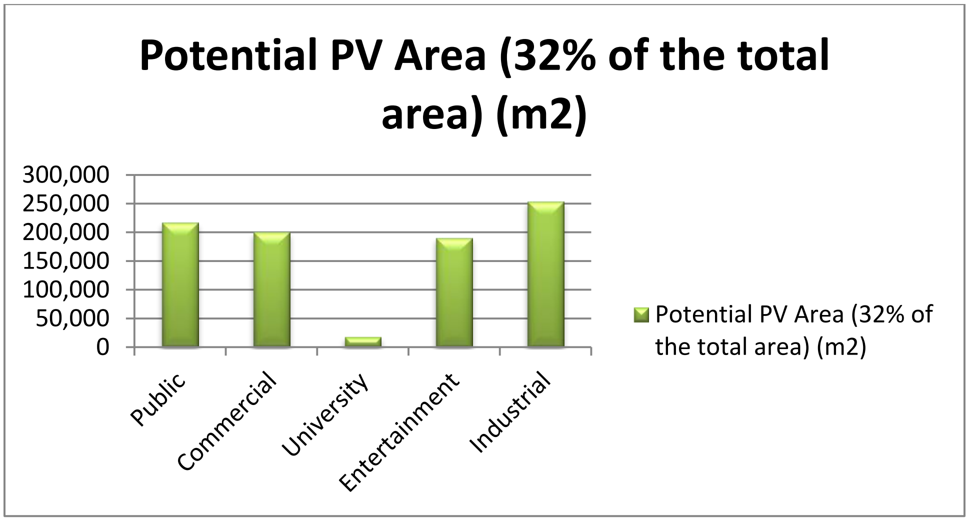

Figure 4.3 Potential PV Area (32% of the total area in m^2)

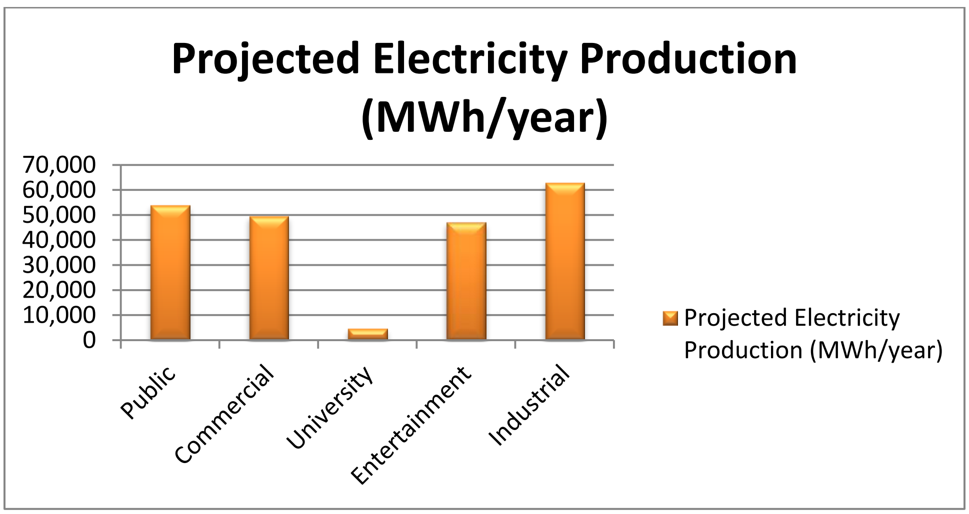

Figure 4.4 Projected Electricity Production (MWh/year)

The results indicate that 218,403 MWh/Yr of electricity could be generated if a PV solar energy system is implemented in all BPLs in the City of Arlington. According to the UT Arlington Parking Garage Solar Monitoring Report published in July 2013 (Figure 3.5), the system has generated 1,043,874 kWh (1,043 MWh) since July 2011, and this amount can power 5,958 60W bulbs for one year, assuming eight hours of use per day. Based on the analysis performed here, if PV solar energy systems were installed in all BPLs, they could collectively produce approximately 200 times more electricity than the reference UT Arlington parking garage. This estimate was obtained by dividing Projected Electricity Production by the amount of electricity generation from the Base Solar System B.

Along with the projected potential electricity generation from Arlington's BPLs, as a part of this study, cost & benefit analysis of PV solar system installation was also performed. As a result, the City's investment recovery time (in years) and the total benefits during the entire lifespan of the solar panels could be projected. As presented in Table 1.1, Base System A is equipped with 32 Siliken 255 watt panels. Thus, the number of panels required to cover 32% of its area was multiplied by 255 watt and $3.05/W (the cost provided by Solar Energy Industries Associations [SEIA], 2013). For instance, based on the 218,403 MWh projected electricity generation capacity of 37 public BPLs, the installation cost was estimated at $106,080,433.50. Moreover, the projected annual benefit from annual electricity generation ($) was $6,207,355.00, and period needed to recover the initial investment was estimated at about 17 years. According to Strecker (2011) from Boston solar Energy Company, the average lifespan of most current solar panel systems is 30-40 years. Thus, in this study, the panels installed in Base System A were assumed to have a lifespan of 35 years. Based on this assumption, the City of Arlington's projected total benefits during the lifespan of the solar panels after recouping their initial investment after 17 years is $111,732,390.

Total projected cost of solar PV System installation in 118 of all BPLs was estimated at $429,227,781, and the projected total benefits after 17 years at $452,094,210. Table 1.4 and Figure 4.5 through 4.7 illustrate summary of the projected solar installation cost & benefit from each category's BPL.

Solar Installation Cost & Benefit Projection on BPL			
	Projected Installation Cost for Solar Panel Installation ($) (Number of panels *255W * $3.05/W)	Projected Annual Benefit from Annual Electricity Generation ($) (Assumption: 11.5¢ /kWh)	Projected total benefits during the entire lifespan of the solar panels ($) (assuming solar panel lifespan of 35 yrs.)
Public	$106,080,433.50	$6,207,355.00	$111,732,390.00
Commercial	$97,605,291.75	$5,711,360.00	$102,804,480.00
UTA	$9,095,786.25	$532,220.00	$9,579,960.00
Entertainment	$92,723,355.00	$5,425,700.00	$97,662,600.00
Industrial	$123,722,914.50	$7,239,710.00	$130,314,780.00
Total	$429,227,781.00	$25,116,345.00	$452,094,210.00

Table 1.4 Solar Installation Cost & Benefit Projection **on BPL**

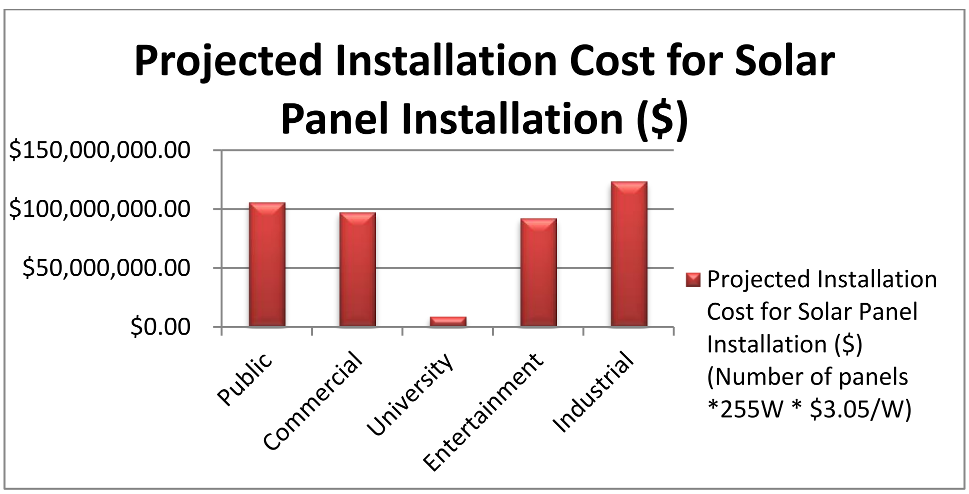

Figure 4.5 Projected Installation Cost for Solar Panel Installation ($)

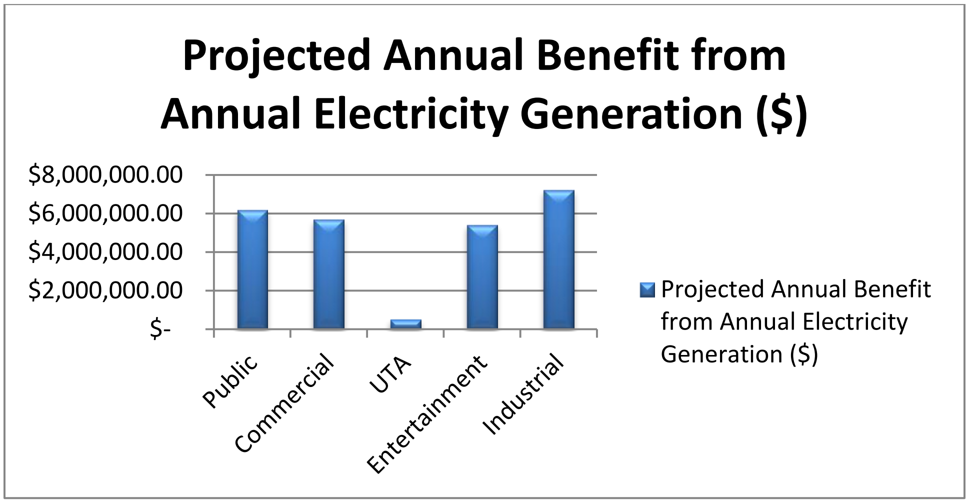

Figure 4.6 Projected Annual Benefit from Annual Electricity Generation ($)

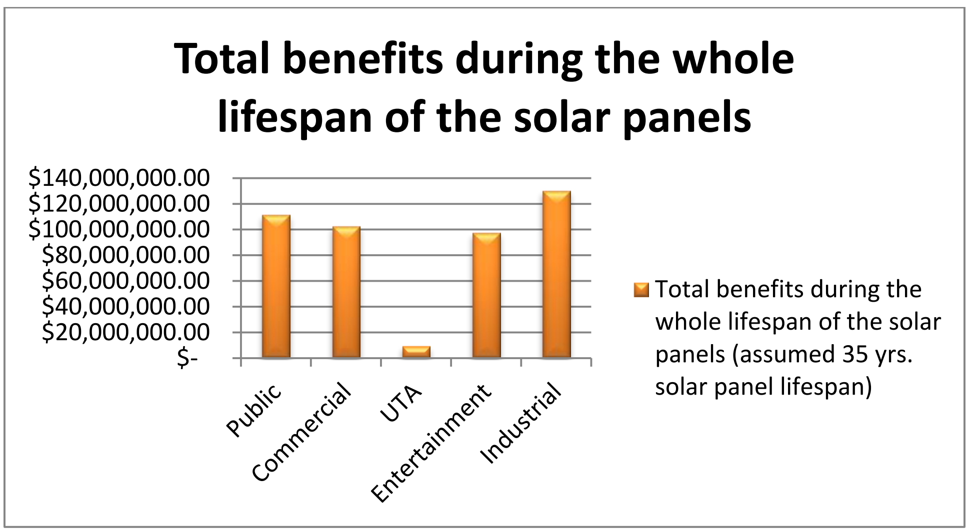

Figure 4.7 Total benefits during the entire lifespan of the solar panels ($)

4.2. Electricity Usage Comparison

The next step in the analysis focused on assessing the capacity of the PV installations in parking lots in terms of their ability to contribute to meeting the local energy demand. Thus, the projected amount of electricity from the solar parking lots was compared to the actual electricity usage in the three municipal demonstration sites: (1) Central Library and City Hall located in Downtown; (2) Bob Duncan Community Center located in Vandergriff Park in Arlington, TX; and (3) the Arlington Parks and Recreation Administration Building located in northeast Lake Arlington.

Figure 4.8 Real World Data Comparison

All sites are categorized as “public” in this study. Figure 4.7 illustrates aerial view and locations of each site. The image in the upper left corner depicts City Hall and Central Library, Bob Duncan Community Center is shown in the upper right image, and the lower left image corresponds to Parks and Recreation Administration Building. Table 1.5 shows a variation in the performances of each of the buildings depending on their electricity use and the size of available parking lots. For instance, in the case of the Central Library and City Hall, when solar PVs are implemented in the parking lots, the potential electricity production is projected to meet approximately 43% of the two building’s combined electricity usage. On the other hand, parking lots in the Bob Duncan Community Center and the Parks and Recreation Administration

Building are projected to generate electricity that exceeds their annual electricity usage. The Bob Duncan Community Center is projected to generate approximately five times more electricity than needed and the Parks and Recreation Administration Building could generate approximately six times more than their annual electricity requirements. The significant differences in the relationships between the amounts of electricity generated and required can be contributed to the different sizes of the parking lots and the electricity usage in each site. Central Library and City Hall can install 6630 solar panels in 10,608 m² of parking lot, with the potential to generate 47% (839,607 kWh) of the actual electricity requirement for 2012. On the other hand, Bob Duncan community center could generate 1,016,133 kWh of electricity, which exceeds its electricity consumption by 472%, and Parks and Recreation Administration building has the potential to exceed its electricity consumption in 2012 by 585% (945,980 kWh).

Comparison Summary (Solar Energy Projection and Percentage (%) by which it exceeds the Consumption)					
	Parking lot Size (m²)	Potential Number of Solar Panels	2012 Electricity Use (kWh)	Potential electricity generation (kWh)	Percentage (%) by which generation exceeds the consumption (Generation/Use*100)
Central Library and City Hall	10,608	6630	3,133,930	134,338 4	43%
Bob Duncan community center	12,838	8023.75	344,788	1,625,788	472%

Parks and Recreation Administration building	11,952	7470	258,540	1,513,586	585%

Table 1.5 Comparison Summary (Solar Energy Projection Amount and the Percentage (%) by which it Exceeds the Consumption)

If Arlington adopts Net-metering law, Bob Duncan community center and Parks and Recreation Administration building could receive energy credits. Bob Duncan community center could generate about 1,016,133 kWh of electricity per year, corresponding to about 671,345 kWh of excess electricity, for which it could receive energy credit. Similarly, Parks and Recreation Administration building could receive energy credit for its excess production of 687,440 kWh.

The present study also projected the solar system installation costs, annual benefits from electricity generation, number of years needed to recover the initial investment, and the total benefits during the entire lifespan of the solar panels. Table 1.6 displays the summary of cost & benefit analysis performed on the three demonstration sites. As can be seen from the results presented in Table 1.6, the projected installation cost of City of Arlington implementing PV solar systems in parking lots of Central Library and City Hall is estimated at $5,156,482.50, and the projected annual benefit from the annual electricity generation is $301,736.63. Moreover, it is estimated that the initial investment will be recovered in about 17 years. Finally, Arlington could receive $5,431,259.39 of the total benefits during the lifespan of the solar panels after recouping their initial investment. The cost & benefit analysis pertaining to all three demonstration sites is summarized in Table 1.6.

Solar Installation Cost & Benefit Projection on Three Demonstration Sites			
	Projected Installation Cost ($) (Number of panels *255W * $3.05/W)	Projected Annual Benefit from Annual Electricity Generation ($)	Projected total benefits during the entire lifespan of the solar panels ($) (assuming solar panel lifespan of 35 yrs.)
Central Library and City Hall	$5,156,482.50	$301,736.63	$5,431,259.39
Bob Duncan community center	$6,240,471.56	$365,167.32	$6,573,011.70
Parks and Recreation Administration building	$5,809,792.50	$339,965.71	$6,119,382.76

Table 1.6 Solar Installation Cost & Benefit Projection on Three Demonstration Sites

CHAPTER 5

CONCLUSIONS

5.1 Summary and Significance of the Study

This study assessed the potential for implementing solar parking lots within the City of Arlington with the aim to generate electricity from a renewable energy source and thus bring significant socioeconomic and environmental benefits. It provides beneficial evidence that supports the viability and profitability of solar parking lot implementation in the future decision-making process for Arlington. The projected amount of electricity generated from all BPLs in Arlington is 218,403 MWh/year, which is equivalent to the benefit of $25,116,345 per year, compared to the cost of projected total average solar PV system installation at $429,227,781. Moreover, the analysis revealed that Arlington could receive $452,094,210 during the entire lifespan (35 years) of the solar panels after the 17 years required to recover the initial investment. The analysis and findings presented here were based on the 15.7% solar panel efficiency, currently in common usage. With the technological developments in solar PV efficiency, it is expected that the electricity production would substantially exceed the levels projected here. Solar PV parking lots will also serve as shades for vehicles, while providing electric car charging stations, thus mitigating UHI effects, improving air quality, and branding Arlington as a new green city in Texas.

5.2 Study Limitations and Future Study

This study did not include data from all available solar panel products on the market. Since data from a specific type of solar panel instrument (15.7% efficiency) was used to generate the current study findings, the results could vary, depending on the levels of PV efficiency currently available on the market and those developed in the future. Thus, in order to examine these effects, future studies of this type could consider various scenarios incorporating different PV efficiency levels.

In the present work, average solar installation cost was estimated at $3.05, based on the SEIA (Solar Energy Industries Association) Q2 2013 solar fact sheet, which could also vary with technology changes and policy updates. A cost-benefit analysis that considers various scenarios would thus yield useful evidence to convince the City officials to consider its implementation. This study used solar energy monitoring data from a particular year, thus limiting the generalizability of its findings. Consequently, future research would benefit from using the monitoring data from multiple years. Finally, as PV solar panel efficiency could also differ across seasons (State Energy Conservation Office [SECO], 2012), estimating seasonal variation in solar energy generation would be also useful.

5.3 Recommendations to Arlington, TX

The decision-makers in the City of Arlington are aiming to achieve sustainability in the city's future development (City of Arlington, 2011). The case studies in the DFW cities presented in the Chapter 2 and the overall study findings demonstrate that the "carport style" PV solar energy supply system implementation in parking lot areas can be considered for the City of Arlington. City of Duncanville, TX has already installed 147.84 kW solar systems and has recovered the $280,000 investment (without 1.1 million grant from DRET) in less than one year (Axium Solar, 2010). Similarly, Cedar Hill, TX, invested 1.2 million dollar in a solar system with assistance of federal, state and utility programs (cost the city $25,933.70). The outcome was a 152 kW solar system installation, which recovered the initial investment within 18 months (Axium Solar, 2011). In the City of Arlington, this study projected that 839,608 kWh of electricity could be generated if Central Library and City Hall parking lots were converted, with projected cost of $5,156,483. It will recoup its investment in 17 years and there will be $5,431,259.39 of total benefits during the life span of the solar panels until 35 years. When we consider more available assistance of federal, state, and utility programs, Arlington would not need to meet the full cost of the installation. Moreover, City of Arlington could consider further cost-benefit analysis with more variable scenarios on ‘carport style’ PV solar energy supply system implementation in parking lot areas.

Arlington could also consider promoting PV solar system implementation through its CAP in the near future. According to International Council for Local Environmental Initiatives (ICLEI, 2009), most major cities in Texas, such as Austin, Dallas, El Paso, Fort Worth, Houston, and San Antonio, comply with CAP and Arlington would benefit from considering joining this group in the near future. Arlington could integrate a solar energy system development into its comprehensive plan. Many DFW cities, including Cedar Hill and Duncanville, are already starting to see the advantages from solar energy. It is evident that, in utilizing its BPLs, the City of Arlington has similar potential.

Following the American Planning Associations (APA) Solar Briefing Paper (2012) recommendation, applying solar community engagement tools and strategies from APA Solar Briefing Paper to promote solar energy opportunities would be highly beneficial for Arlington. First, public education and outreach are instrumental in the success of this initiative (Dillemuth, 2013). Arlington could provide various public outreach workshops and materials, such as solar-related energy system fact sheets, brochures, and/or guides with reliable information, including goals, visions, policies, programs, and reasonable answers to common questions and concerns. Moreover, this approach could inform the local community on the specifics of local solar regulation and permitting, and any solar incentives from federal, state, or local scale (Dillemuth, 2013). The study findings supported the initial hypothesis that solar PV systems utilizing existing parking lots in the City of Arlington will contribute to meeting a significant portion of the increasing electricity demands in the city. Along with the potential to meet the future energy demand, the study also identified many environmental benefits of adopting this strategy. Arlington could consider presenting these PV solar parking lot advantages to the public, using not only the current study findings, but taking advantage of all available sources. Second, solar demonstration projects, such as solar parking lots, can be used effectively for educating the community on the importance of utilizing renewable energy sources, and can be significant asset to the tours of installed solar system sites (Dillemuth, 2013). Cooperating with UT Arlington to provide solar tour program on CPC parking garage to community could be another opportunity for Arlington to consider. Arlington could also benefit from using the installed PV systems to develop recognition and award program for the best performing entities in terms of energy generation, savings, and pollution reduction. According to Dillemuth (2013), creating and providing local solar recognition or award programs to the community is another strategy that would raise solar energy awareness and promote pride in local solar energy installations. This study could thus serve as a useful reference for those in decision-making positions on Arlington's solar energy development. In sum, utilizing PV solar systems in existing parking lots needs to be seriously considered when designing Arlington's future community development plans.

APPENDIX A

SUMMARY OF THE CASE STUDY REVIEWS: U.S. SOLAR PV SYSTEMS IN PARKING LOTS

Appendix A Summary of the Case Study Reviews: US Solar PV Systems in Parking Lot

Case Studies U.S. Solar PV systems						
Solar System	**System Description**				**Benefits**	
	Location	**Capacity**	**Year Build**	**Funding**	**Energy**	**Environment**
Fresno State University Solar Parking Canopy Project	CA	- 1.1 megawatt solar power -3872 panels cover 677 parking spaces	- 2007 Partnership with Chevron Energy Solutions (CES)	- Joint assistance of $1.2 million grants from federal, state and utility programs - $11.9 million total cost and $4.75 million cost to university	- More than 1.5 million kWh of energy production annually - Provides roughly 20% of the university's annual base electrical demand - Will save over $13 million in its 30-year lifespan - 1.525 million kWh of annual energy savings	- Reduces approximately 950 metric tons of GHG emissions - Equivalent to planting more than 24,300 trees and removing more than 200 cars from the road every year * Other Benefits: - Four educational kiosks display real-time

						power production data - Providing premium shaded parking
City of Santa Cruz Solar Carport Project on City Hall and Police Department Parking Lots	CA	- Total 425 kW; 220 kW in City Hall and 245 kW in Police Department site - 835 solar panels at the City Hall and 912 at the Police Department site	- 2012 Partnership with developer Barry Swenson Builder	- Cost: $2.8 million - Loan $1.3 million from city's own investment fund - Guaranteed 4% rate of return on $1.3 million city loan and a 10 year loan payback - Federal energy rebates	- 20 million kWh of generated electricity - Total combined 1,800 kWh of power per day - General fund energy savings of $200,000 a year (in years 16-30) and $2 million over the system's lifespan	- Reduction of more than 5,000 metric tons of GHG emissions each year - Equivalent to over 800 cars being taken off the road * Other Benefits: Landscaped bioswales installed to filter parking lot storm water runoff.

				at $600 K		
City of Cincinnati Cincinnati Zoo & Botanical Gardens "car-port style" solar energy system	OH	- 1.56 megawatt system with 6,400 panels installed on a canopy structure over the Zoo's parking lot	- 2011 Partnership with Melink Corporation And many others -	- The project relies on financing through a combination of federal New Market Tax Credits and federal energy tax credits through PNC Bank - It relies on cash from the tax credits, sales of electricity over	- Meeting about 20% of the zoo's annual electricity requirements - Produced electricity sufficient to power 200 homes each year	- Sufficient to power 55,000 energy efficient CFL bulbs for a year - Reduction of 7,714,876 lbs. of CO_2 emissions * Other Benefits: - Providing shade for nearly 800 of the 1,000 parking spaces -Providing a monitoring web page within its main website

				the next seven years to the zoo and selling the renewal energy credits generated by the investment to Akron-based FirstEnergy		
City of Boston Patriot Place	MA	- More than 2,600 conventional and translucent building-integrated photovoltaic (BIPV) solar energy system	- 2012 Partnership with NRG Energy, Inc. and The Kraft Group	- Federal Stimulus Funds; Department of Energy Resources under the American Recovery and Reinvestment	- 230,243 kWh of electricity, enough to power 19 homes for a full year - Meeting approximately 60% of Patriot Place's electricity demand - Generates more than	- Prevents the release of more than 8,800 metric tons of CO_2 - Equivalent to removing more than 1,600 passenger vehicles from the road for a year - 3,197 gallons of oil,

		- 10% of the NRG Solar Canopy TM panels used are translucent		Act (ARRA)	12 million kilowatt hours of electricity over 20 years	which is enough to heat and cool 16 homes for a full year - 755 gallons of gasoline; enough to drive 21,148 miles - 394 mature trees; enough to produce 4,887,112 sheets of newspaper * Other Benefits: - NRG transformed an open-air retail complex into a state of-the-art, visually stunning retail destination, bringing the entire complex to

						life with infinite-color LED lighting - Serves to shield Patriot Place visitors from the weather by partially covering the site’s outdoor walkways.

APPENDIX B

SUMMARY OF THE CASE STUDY REVIEWS: DFW MUNICIPAL PV SOLAR SYSTEMS

Appendix B Summary of the Case Study Reviews: DFW Municipal PV Solar systems

Case Studies **DFW municipal PV solar systems**						
Solar System	**System Description**				**Benefits**	
	Location	**Capacity**	**Year Build**	**Funding**	**Energy**	**Environment**
City of Duncanville City Hall rooftop	TX	- 147.84 kW of three solar PV energy systems; 53.55 kW from City Hall, 88.2 kW from Library & Recreation Center, and 44.1 kW from Senior Center	- 2010 Installed by Axium Solar, with McKinstry firm acting as Project Manager	- $1.1 million grant from the Distributed Renewable Energy Technology (DRET), administered by SECO for the DOE and a utility rebate provided by Oncor - $26,141 saving	- Produces an estimated 74,970 kWh annually	- Reduces 376,391 pounds of CO_2 emissions annually - Equivalent to planting trees in 47 acres - Equivalent to eliminating 33 vehicles from the road annually

				annually and recovering its $280,000 matching contribution in less than one year		

City of Cedar Hill Solar PV system on the rooftop over the City Hall and Police Department	TX	- 152 kW solar PV system - 496 rooftop solar panels	- 2011 Installed by Axium Solar	-Joint assistance of $1.2 million grants from DFET administered by SECO for the DOE and a utility rebate provided by Oncor - Projected savings of up to $21,000 annually, recovering the city's initial $25,933.70 investment within less than 18 months	- Produces 210,000 kWh of electricity annually - Amount of generated electricity sufficient to power 14 or 15 average-sized homes - Reduces net energy consumption by approximately 8%	- Reduction of 279,098 pounds/year of CO_2 emissions - Equivalent to eliminating 33 vehicles from the road annually

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