THE COSTS AND BENEFITS OF LARGE SCALE SOLAR PHOTOVOLTAIC POWER PRODUCTION IN ABU DHABI, UAE

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ABSTRACT

ELIZABETH S. HARDER: The Costs and Benefits of Large Scale Solar Photovoltaic Power Production in Abu Dhabi, UAE
(Under the direction of Dr. Jacqueline MacDonald-Gibson)

The potential for a 10 MW photovoltaic power plant in Abu Dhabi is examined in this paper, using RETScreen modeling software to predict energy production, financial feasibility and GHG emissions reductions. Initial results show a high energy production potential, generating 24 GWh and saving over 10,000 tons of GHG emissions annually, but a poor financial analysis yielding a net present value (NPV) of negative $51 million. Benefits of reducing GHG and air pollution emissions by replacing natural gas with PV generation are calculated to have a net present value of $44 million, with a large range of possible values. Results show that the high initial costs and low expected price for electricity generated are driving reasons why photovoltaic systems are not being implemented in Abu Dhabi. A feed-in-tariff rate of $0.16/kWh is recommended to make large scale PV systems profitable.

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INTRODUCTION

The United Arab Emirates has an abundance of natural resources, containing 9.3 percent of the world's proven oil reserves and 4.1 percent of the world's proven gas reserves (Cordesman, 1999). These fossil fuel resources helped the country evolve from a rural undeveloped land populated by nomadic people to an industrial world leader, experiencing unprecedented growth in the last four decades. Abu Dhabi, the largest and richest of the seven emirates, has the majority of these natural resources in the UAE, with 95 percent of the oil and 92 percent of the natural gas reserves (Oxford Business Group, 2008).

Looking forward, Abu Dhabi has begun investing in renewable energy technologies (RETs), hoping to continue being an energy world leader, but with clean renewable energy. Growing concern over global climate change, escalating air pollution, and decreasing fossil fuel reserves have driven RETs to be increasingly used for power production. Abu Dhabi has shown mounting support for clean energy. As the UAE invests in more RETs, it can serve as an example for other oil-producing countries as it moves towards a more sustainable future.

Objectives

This research examines the costs and benefits associated with constructing a 10 MW photovoltaic (PV) power plant in Abu Dhabi. The energy production capabilities, economic costs and benefits, and GHG emissions reductions associated with this plant are estimated using RETScreen software. RETScreen was developed by Natural Resources Canada to help decision makers conduct preliminary assessments of RET projects worldwide. Benefits of avoided air pollution and GHG emissions are then calculated using emissions data from the Umm Al Nar power plant in Abu Dhabi and monetary estimates for marginal damages for various pollutants.

This research is the first use of RETScreen to assess large-scale PV production in the UAE. In addition, this study goes beyond previous RETScreen studies by monetizing the benefits of avoided air pollution and GHG emissions. This research is especially important as Abu Dhabi's increasing energy demand, high solar radiation levels, and goal to be a clean energy leader make the Emirate an optimal candidate for increased use of PV energy.

Electricity Production

Electricity production in the UAE is predominantly from natural gas-fired power plants, comprising 98 percent, while the remaining 2 percent is from oil (International Energy Administration, 2006). Oil-fired power plants are rarely used and only to meet times of peak demand. In Abu Dhabi, most power plants are independent water and power projects (IWPPs), which are cogeneration facilities that desalinate water and produce electricity simultaneously. These IWPPs provided an estimated 84.4 percent, 24.5 annual GWh, of total electricity generation for Abu Dhabi in 2006 (Abu Dhabi Water and Electricity Company, 2009).

Electricity Demand

Energy consumption per capita in the UAE in 2005 was the fifth highest in the world (Buurma, 2009). Heavy air conditioner usage as well as low electricity prices caused this high per capita energy consumption. The government heavily subsidizes energy use; the average annual figure for UAE power subsidies is estimated to be more than $270 million (Al-Iriani, 2005). Table 1 shows rate for electricity from the Abu Dhabi Electricity and Water Company (ADWEC), the state-run utility company for the emirate of Abu Dhabi. ADWEC charges just 3 fils/kWh for UAE nationals in rural areas, equivalent to approximately US 0.816 cents/kWh (Regulation and Services Bureau, 2009). The cost to UAE nationals in urban areas is 5 fils/kWh, equivalent to US 1.36 cents/kWh. The cost of electricity production is estimated at around 30 fils/kWh (US 8.16 cents), meaning that only 17 percent of the production cost is paid by a customer classified as an urban national (Al-Iriani, 2005). These numbers are considerably low when considering the average US price per kilowatt in 2008 was about US 9.82 cents/kWh, meaning that Americans pay, on average, seven times as much for a kWh of electricity as an urban UAE national (Energy Information Administration, 2009a).

Customer	Charge	Charge/(UAE) Production Cost*
Expatriates, Commercial, and Industrial sectors	15 fils/kWh (US $0.0408)	50%
UAE national (urban)	5 fils/kWh (US 0.0136)	17%
UAE national (rural)	3 fils/kWh (US 0.0082)	10%

Table 1: Electricity charges for various ADWEC customers.

Electricity Trends and Forecasts

Electricity use in UAE has exponentially increased in the three decades (Figure 1). Abu Dhabi’s annual electricity demand, specifically, has increased steadily over time. Total annual electricity usage in 1998 was 16,104 GWh. Demand rose to 20,649 GWh in 2001 and 27,323 GWh in 2006. This equates to an increase of over 8 percent each year and a total increase from 1998 to 2006 of approximately 70 percent (Abu Dhabi Water and Electricity Company, 2009).

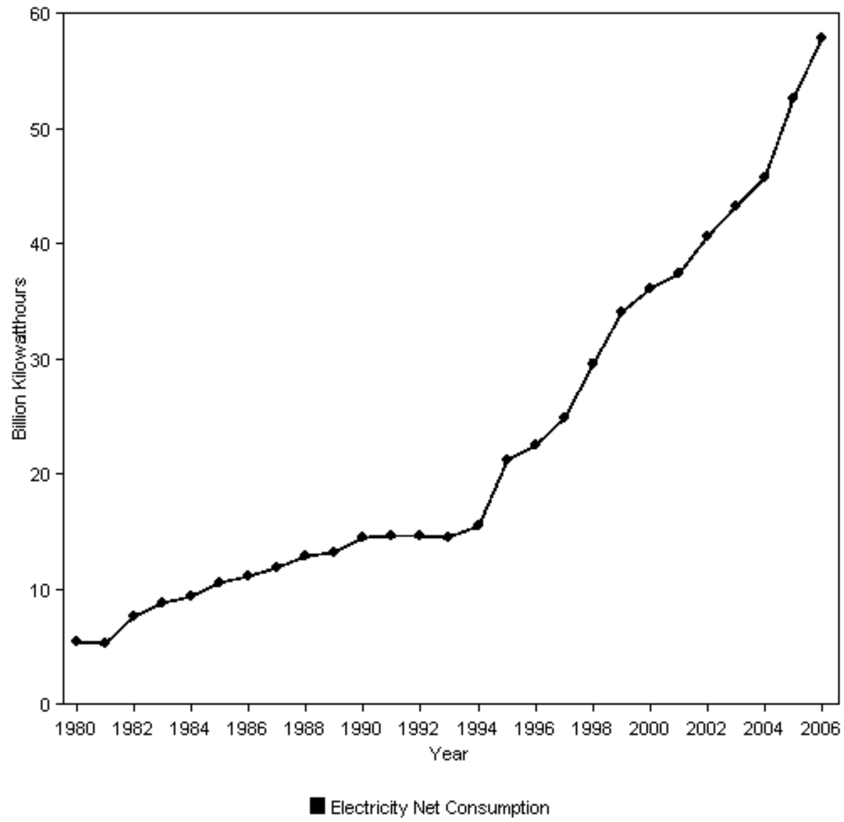

Figure 1: Trend of UAE electricity consumption over time (Energy Information Administration, 2010).

Looking forward, the electricity peak demand in Abu Dhabi is expected to increase more than four-fold in just two decades, from 5,616 MW in 2008 to 25,530 MW in 2028, largely attributable to a booming real estate market in Abu Dhabi and expected construction of mega projects (Miller, 2009). This predicted increase in energy demand is so large that natural gas-fired power plants would have to greatly ramp up power production to meet the rising demand, a potentially costly operation. In fact, the UAE became a net importer of natural gas in 2007 as a result of high per capita energy consumption (Energy Information Administration, 2009b). This need for increased power generating capacity has created a window of opportunity to have renewable energy (RE) sources integrated into Abu Dhabi's electricity generation mix.

Renewable Energy in Abu Dhabi

Abu Dhabi has already begun supporting clean energy technologies with a long-term goal to be a world-leader in RETs. The emirate hosted the World Future Energy Summit in January 2009, developed a renewable energy target of 7 percent by 2020 for the Abu Dhabi Energy Plan (Naidoo, 2009), and called for a 10% renewable portfolio standard by 2030 in the Abu Dhabi Climate Change Policy Plan (Environment Agency Abu Dhabi, 2009). In June of 2009, the Abu Dhabi-based company Environmena completed construction of a 10MW PV power plant outside the city of Abu Dhabi, the largest of it kind in the Middle East. This plant will provide power for the construction of Masdar City and attract more investment in Abu Dhabi's clean energy industry (Walsh, 2009).

The government-owned Abu Dhabi Future Energy Company runs the Masdar Initiative, a multi-billion dollar program to spur innovative technology growth in RETs. In 2008, the government of Abu Dhabi invested US $15 billion in the Masdar Initiative, the largest single government investment of its kind. The main project for this initiative is to build Masdar City, a novel ultramodern zero-waste, carbon neutral, car-free city for 50,000 people eleven miles outside the city of Abu Dhabi. The city will also include unique zoning for companies specializing in renewable and alternative energy technologies, hoping to attract innovative industries to the emirate. Masdar City is meant to serve as an example of the potential for RE in Abu Dhabi and also as a sign to the international community that Abu Dhabi is not only progressive, but also environmentally conscientious (Craft, 2008).

PV Power Production Potential

Abu Dhabi's high solar insolation rates, large capital resources, beneficial timing synergy, and air pollution health impacts are all compelling reasons to invest in PV energy.

Solar energy holds tremendous potential in Abu Dhabi. One study collected solar data for Abu Dhabi (24.43°N, 54.45°E) for an entire year and found that Abu Dhabi's annual mean global radiation is the highest among Arab state capitals (see Table 2) (Islam et al., 2009).

States	January	February	March	April	May	June	July	August	September	October	November	December	Annual (Average)
Monthly and annual mean global radiation in MJ/m^2/day													
Abu Dhabi	15.48	18.0	20.52	24.12	28.08	27.36	25.2	24.12	23.4	20.52	17.28	14.4	21.6
Amman	9.72	13.32	18.0	20.88	28.08	30.24	29.52	27.0	23.04	17.28	13.68	9.72	20.16
Bahrain	12.96	17.28	17.28	21.96	24.84	26.64	28.44	22.68	20.88	17.64	14.04	10.8	19.62
Tunis	8.64	11.16	15.84	20.52	23.4	26.28	26.64	22.68	19.08	14.40	10.44	8.28	17.28
Alger	7.92	10.8	14.76	17.64	21.6	22.32	25.2	23.04	18.36	11.88	9.72	10.8	15.84
Riadh	12.6	16.56	18.36	19.8	20.16	21.96	21.96	21.24	20.52	19.08	16.56	12.96	18.36
Baghdad	10.8	13.68	17.28	20.52	23.4	26.28	25.92	23.76	20.52	15.84	11.88	9.72	18.36
Sala (Oman)	16.56	17.64	20.16	20.88	21.96	18.72	11.88	10.80	16.56	19.44	17.28	15.84	17.28
Doha	13.32	15.84	17.64	20.52	22.32	23.4	21.6	20.88	19.8	15.12	14.76	12.6	18.36
Casablanca	9.72	11.88	16.2	19.44	22.68	23.4	23.04	21.24	18.0	13.68	9.72	8.64	16.56
Sana	14.4	15.84	17.28	15.84	20.88	19.08	19.62	16.56	18.72	14.4	14.4	14.04	16.56
Mosul	7.2	8.28	12.96	16.2	19.8	22.68	22.68	20.16	17.28	12.96	8.28	6.48	14.76
Damas	11.16	12.6	16.56	19.08	26.64	28.8	26.28	25.92	21.96	16.56	10.8	8.28	18.72
Jerusalem	9.72	12.24	18.0	21.6	24.84	27.36	27.36	25.92	21.96	17.28	12.6	9.36	19.08
Kuwait	11.16	14.76	19.8	22.32	25.56	28.44	27.0	25.56	22.32	17.28	12.24	10.44	19.8

Table 2: Monthly mean daily values of global solar radiation for Abu Dhabi and other cities in the Middle East, taken from Islam et al. (2009).

Furthermore, as a wealthy emirate, Abu Dhabi will be able to afford to pay the large upfront capital investment costs typical of solar energy projects. Abu Dhabi began privatizing its power sector in 1999 to encourage new foreign investment in power capacity to meet its growing energy needs, creating a larger potential supply of capital to fund RETs (Al-Iriani, 2005). Large-scale PV plants will draw more international attention to Abu Dhabi's development of RETs, one of the government's goals. Abu Dhabi has reaped the economic benefits of its fossil fuel resources and can now use those profits to procure the prestigious position of leading the world in energy once again, this time on the cutting edge of RETs.

Moreover, the energy grid benefits from solar energy, as a synergy exists between peak energy demand and peak solar energy production. This is especially important for Abu Dhabi, as its peak annual energy demand is always in the daytime in August or September, corresponding to the Emirate's hottest time of the year, when air conditioning use is high (Abu Dhabi Water and Electricity Company, 2009). Daytime summer sunshine provides the most solar radiation in

Abu Dhabi, maximizing solar energy production. Thus, the PV power plant peak electricity generation will coincide with the time when electricity demand is highest (Borenstein, 2008).

Lastly, Abu Dhabi faces high levels of air pollution, which pose increased health risks to Abu Dhabi residents. It is estimated that approximately 23,000 health-care facility visits and 600 premature deaths each year, due to respiratory diseases, cardio vascular diseases, and chronic obstructive pulmonary disease, are potentially attributable to anthropogenic ambient air concentrations of ozone and particulate matter in the UAE (University of North Carolina at Chapel Hill: Environmental Burden of Disease Study, 2010). Solar energy has numerous benefits for air quality as it avoids the air pollution emissions from conventional power plants. The U.S. National Renewable Energy Laboratory has estimated that "Typically, on an annual 'per kilowatt' basis, PV offsets or saves up to 16 kilograms of nitrous oxides (NOx), 9 kilograms of sulfurous oxides (SOx), and 0.6 kilogram of other particulates. In addition, one kilowatt of PV typically offsets between 600 and 2300 kilograms of carbon dioxide ($C0_2$) per year" (National Renewable Energy Laboratory, 2003). The second part of this research focuses on monetizing the potential air quality benefits from reducing the emissions of conventional power plants due to the addition of clean photovoltaic power capacity.

Energy Models

Numerous studies have been conducted and models developed that calculate the optimal way to incorporate renewable energy into the energy generation mix. Some models are capable of finding the optimal solutions to incorporate RETs on a national scale; examples include the Optimal Renewable Energy Mathematical (OREM) model used in India (Iniyan and Sumathy, 2003); MARKet Allocation (MARKAL) model developed by the International Energy Agency and used in Japan, Finland, and other countries (Endo and Ichinohe, 2006; Lehtilä and Pirilä, 1996; Seebregts et al.,); and Energy Flow Optimization Model (EFOM) developed by the Commission of European Communities to evaluate distributed energy potential (Cormio et al., 2003; Dicorato et al., 2008). Smaller-scale models include the MetaNet Model to study the rural Japanese Energy mix (Nakata et al., 2005) and the Inexact Community Scale Energy Model (Cai et al., 2009). These models, however, require a great deal of data on the current power grid, which was unavailable for Abu Dhabi, mandating that this study examine electricity potential on a smaller scale.

RETScreen Overview

RETScreen was created in 1996 by Natural Resources Canada's Canmet Energy Research Center and is available free of charge. This user-friendly software enables decision makers to weigh the costs and benefits of installing RE projects. RETScreen is available in 35 languages and is used worldwide by universities, colleges, private firms, and consultants for evaluating RE projects. A 2003 independent survey of RETScreen users found that RETScreen had facilitated ten 250kW PV projects in Denmark, an 89 kW project in India, and an estimated 1,000 MW of installed RE capacity worldwide in 2004. The software is estimated to help the installation of 24 GW worldwide by 2012 (Graham and Higgins, 2004)

RETScreen software consists of user-friendly Excel worksheets standardized to provide a low-cost preliminary assessment of RE projects. The software has flexibility options allowing users to select more complex frameworks, which require more information but have more accurate and detailed results, or basic frameworks for quick, inexpensive calculations. RETScreen uses built-in calculations to make the program more user-friendly, requiring less detailed information and less computational power. For instance, other models, like HOMER, use hourly global solar radiation (GSR) levels for an entire year, totaling 8760 individual values, for an in-depth project assessment, while RETScreen uses the monthly average GSR levels, only 12 values.

Independent reviews of RETScreen software and comparisons with other software packages report accurate results from RETScreen. A comparison between the RETScreen model and more in-depth models using hourly values showed that they have roughly the same results, with an annual difference of less than 5 percent for projected energy production (RETScreen International, 2001-2004). One study (Bekker and Gaunt, 2008) explored the accuracy of the RETScreen and HOMER models compared with MATLAB-based software called SunSim that was developed to simulate a best-case scenario for modeling, with 5-minute weather data as inputs using data from South Africa. The study found that RETScreen underestimated energy output (kWh/m^2/year) by 0-6%, while HOMER underestimated the output by 6-9%. The study also found that RETScreen's monthly weather data calculation overestimated energy output, while the tilted surface modeling algorithm in RETScreen underestimated energy output, resulting in a fairly accurate overall estimate that was superior to HOMER's estimate. Another study (Gilman, 2007) compared RETScreen with two other popular software RE modeling packages, HOMER and Hybrid2, for a fictitious location in California. The study estimated annual energy production for a grid-connected PV system with each software package of 4,011 kWh; 3,930 kWh; and 3,616 kWh for HOMER, Hybrid2, and RETScreen, respectively. Gilman attributed RETScreen's estimate to be the lowest because it accounted for ambient temperature's effect on PV efficiency.

Previous RETScreen Assessments

Three recent studies, discussed below, have used RETScreen software to examine large-scale PV grid-connected power plants in the Middle East and assess their energy production potential, financial feasibility, and GHG emissions reductions. All three studies examined a number of potential sites for the proposed PV plant and conducted a RETScreen analysis for each site, determining the optimal location for the power plant. Table 3 summarizes some of the information from these studies, including RETScreen estimates of financial costs and benefits, as well as predicted GHG reductions.

	Saudi Arabia (Rehman et al, 2007)	Egypt (EL-Shimy, 2009)	Jordan (Hrayshat, 2009)
Capacity (MW)	5 MW	10 MW	5 MW
Location	Bishah, S.A.	Wahat Kharga, Egypt	Talifa, Jordan
Global Solar Radiation	2.56 ($MWh/m^2/year$)	2.13 ($MWh/m^2/year$)	2.46 ($MWh/m^2/year$)
Daily Sunshine Duration	9.2 hrs	12.1 hrs	9.6 hrs
Converter (efficiency)	4750 kW (95%)	4750 kW (95%)	4750 kW (95%)
Module Type	BP 90 W	Sanyo 205 W	BP 90 W
Internal Rate of Return	16.7 %	24.9 %	20.1 %
Net Present Value	$74 million (US)	$ 144.3 million (US)	$40.5 million (US)
Cost of Energy	20 cents/kWh	20 cents/kWh	123 cents/kWh
GHG Reduction	10,007 tons/year	14,538 tons/year	9,317 tons/year
Total Area	35,000 m^2	57,562 m^2	34,965 m^2

Table 3: Summary of three RETScreen studies for large-scale grid-connected PV power plants; values shown are results from the study-determined optimal location for each country.

Rehamn et al. (2007) examined the potential production, cost, and GHG emissions reduction of installing a 5 MW PV system in Saudi Arabia. The study looked at 41 different locations in Saudi Arabia for global solar radiation (GSR) levels and sunshine duration (SSD) values, finding the optimal location for the PV plant in Bishah. The article highlighted that maximum GSR levels were recorded in summer months, matching the time when electricity demand were highest in the country. The study conducted a RETScreen analysis for each of the 41 locations, showing various energy output factors. The RETScreen model also used input of cost escalation, avoided costs of conventional energy generation, project life, and initial costs of the PV plant to find the financial feasibility of the project. The net present value (NPV) for installing a 5 MW PV plant in Bishah was estimated to be US $74 million, having a simple payback period of approximately 7.6 years. The GHG emissions analysis reported that if each of the 41 locations had a 5 MW power plant installed, Saudi Arabia would have a reduction of 335,455 CO_2 tons/year (Rehman et al., 2007).

The second study, by El-Shimy (2009), examined 29 potential sites for a 10 MW PV grid-connected power plant in Egypt, which has established a target to produce 3 percent of its energy from RE sources by 2010. El-Shimy calculated the energy production for each site based on NASA's Surface Meteorology and Solar Energy database. The study examined a number of different solar PV module types and selected the model with the highest ratio of capacity/area, the mono-Silicon 205 W Module from SANYO. The study assumed the modules were on a two-axis tracker system to maximize the potential energy output from the plant. RETScreen was used to perform an economic feasibility assessment as well as determine the GHG emissions reductions. The study concluded with recommending a new 10 MW plant be built in Wahat Kharga, Egypt, which RETScreen determined to be the most profitable location with a NPV of US $144.3 million (El-Shimy, 2009)

The third study, by Hrayshat (2009), used measurements for global solar radiation and sunshine duration for 10 years for 24 locations in Jordan to determine the best location for a 5 MW grid-connected PV power plant. RETScreen was used to determine the energy output, financial costs, and GHG emissions reductions associated with the PV plant for each location. Table 3 shows predicted values for the optimal site in Talifa. This location has an estimated NPV of 28.65 Jordanian Dinars (US $40.5 million). The RETScreen GHG emission mitigation analysis found a savings of 9,327 tons of CO_2 equivalents per year. The article ended by recommending a pilot 5 MW power plant to be installed in Talifa (Hrayshat, 2009).

All three RETScreen studies found the PV projects to have a positive net present value, making all of the projects financially feasible.

METHODOLOGY

This study has two main components in its analysis, shown in Figure 2. First, a RETScreen study is conducted to estimate energy production, financial feasibility and GHG emissions reductions. Second, benefits of avoided air pollution and GHG emissions from the Umm Al Nar power plant is monetized given the energy production estimate from RETScreen, emissions data from the Umm Al Nar power plant, and cost estimates of air pollutants from previous studies.

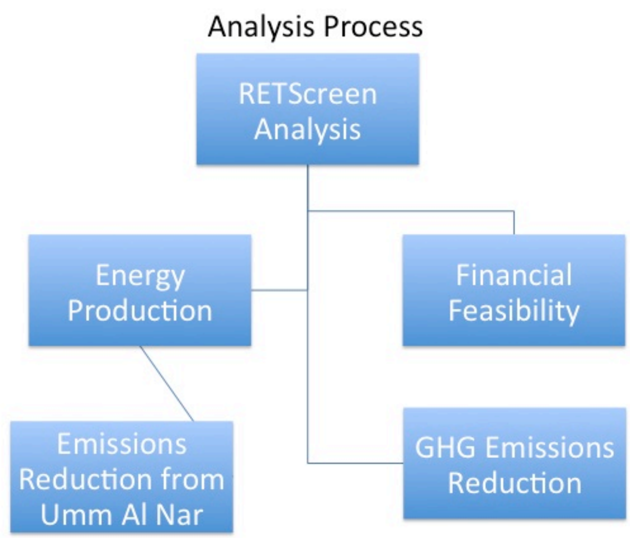

Figure 2: Flow Diagram of Research Steps and Process

RETScreen Model

The RETScreen model calculates three different estimates for this PV project: energy production, financial feasibility, and GHG emissions reduction. The modeler provides inputs like PV module type, location of the PV plant, a variety of costs, electricity transmission, and more, which are then used in calculations. The following sections will discuss the various user-defined inputs selected for the model's worksheets. For a more detailed introduction to the RETScreen program, see www.retscreen.net or Thevenard et al. (2000).

Energy Production Estimation

RETScreen uses a number of built-in algorithms in combination with user-provided data, such as monthly solar radiation values, temperature, and PV module specifications, to calculate expected energy production from the PV power plant. The energy production estimation is then used to determine the financial feasibility as well as the GHG emission reduction prediction of the proposed PV project. Location, global solar radiation, weather, PV module type, as well as miscellaneous energy loss data are discussed below.

The location of the PV plant is used to find exact weather information and solar radiation at that specific site. The 10 MW power plant is assumed to be located at 24.43°N, 54.45°E, near the Abu Dhabi International Airport.

In order to accurately predict the electricity generation from the solar module, RETScreen must have site-specific global solar radiation (GSR) values. GSR values represent the energy from the sun striking a horizontal surface. The GSR values from NASA's Surface Meteorology and Solar Energy database as well as measured values for 2008 from Islam (2009) are shown in Table 4. The GSR data have higher values in summertime months, when electricity demand is highest due to heavy air conditioning use, providing a beneficial synergy. The model uses NASA's 22-year average GSR data as inputs in the model as this has less uncertainty due to temporal variability rather than the 2008 estimates from Islam (2009).

Global Solar Radiation (kWh/m^2/day)		
Month	**2008 values** (Islam et al., 2009).	**22 year average** (NASA)
January	3.91	4.30
February	4.84	5.00
March	5.73	5.70
April	6.33	6.70
May	6.96	7.60
June	6.84	7.60
July	6.81	7.00
August	6.53	6.70
September	6.20	6.50
October	5.39	5.70
November	4.24	4.80
December	3.14	4.00
Annual	**5.58**	**5.97**

Table 4: Monthly average GSR values for Abu Dhabi. *Table format taken from table 1 in (Islam et al., 2009).

Weather data input in the model are used to calculate the module efficiency. RETScreen adjusts the energy output given the temperatures in exceedance of the nominal operating cell temperature (NOCT). The NOCT is defined as the temperature of the solar cell with 800 w/m^2 solar radiation, 1 m/s wind speed, and ambient temperature of 20° C (RETScreen International, 2001-2004). This is especially important in the UAE as hot summer temperatures decrease energy output significantly. The model assumes the PV cells lose approximately 0.4% efficiency for every degree Celsius above 45° C, the NOTC. RETScreen has a database of ground monitoring stations worldwide with the required weather information for the model. The model uses the Abu Dhabi International Airport weather information from the RETScreen database.

RETScreen requires information about the specific PV module used to calculate energy production. PV modules consist of collections of cells that convert the sun's energy into direct current (DC) electricity. A group of modules together form an array. The number of modules in the system is selected to provide the desired energy production. This PV system uses 111,111 modules for a total area of 69,980 square meters or 17.3 acres. RETScreen has an existing database of module brands with associated input data required to run RETScreen. We assume the proposed PV power plant uses mono-silicon BP Solar 90 watt modules, outlined in detail in Table 5. This module was used by similar studies in Jordan and Saudi Arabia (Alawaji, 2001; Hrayshat, 2009).

Module Specifications	
PV Type	Mono-Si
Power Capacity	90 watt
Manufacturer	BP Solar
Model	BP 590 F
Efficiency	14.3%

Table 5: Detailed specifications of the PV module.

Power production of photovoltaics can decrease significantly with the accumulation of dust or sand on the surface of the PV cell, often called “soiling.” There have been numerous studies of the soiling effect on PV cells (El-Nashar, 2003; Kimber et al., 2006; Kurokawa, 2003; Meyer and Van Dyk, 2004; Tang et al., 2006; Thornton, 1992). The soiling effect is especially important in the desert conditions of Abu Dhabi, where sand storms can deposit large amounts of dust and sand on the PV cell. This loss of energy production is input into the model as “miscellaneous losses,” representing the percentage decrease in production.

A 2003 study by El-Nashar examined the energy production of a solar desalination plant in Abu Dhabi for one year, comparing energy received in solar evacuated tube collectors for sections of the plant that were cleaned of dust accumulation to other sections that were not cleaned. A solar evacuated tube collector is a device that heats a liquid inside an evacuated glass tube, normally used for water heating. While an evacuated tube collector is different from a photovoltaic panel, the solar energy transmittance reported in this study is pertinent as the solar collectors were located in the same region as the proposed PV plant. The study showed noticeable decreases in transmittance in the months of June, July, and August, when the sand storms are most prevalent (Figure 2). Moreover, the collected heat ratio, which compared solar collection of tubes with no maintenance for the year (numerator) to tubes that were cleaned daily (denominator), decreased from 0.98 at the beginning of the year to a minimum value of 0.65 during summer months (El-Nashar, 2003). Reported losses from the solar evacuated tube collectors in Abu Dhabi are not applicable for simulating PV losses in RETScreen but are reported instead to convey the general trend of the soiling effect given dust storms in the UAE.

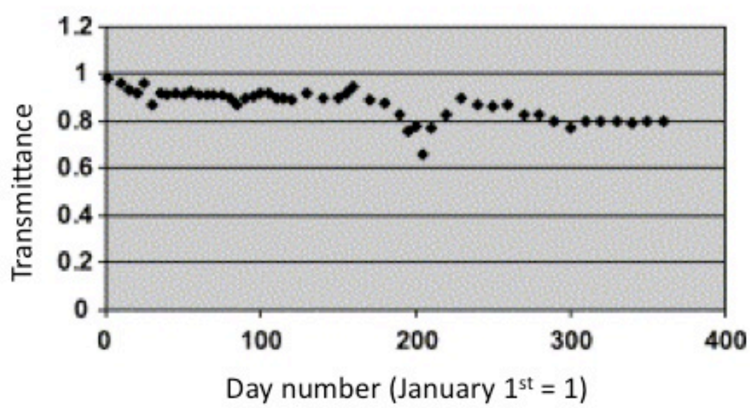

Figure 3: Effect of dust deposition on an evacuated tube collector in Abu Dhabi. The vertical axis represents the ratio of transmittance of a regularly cleaned collector to a collector which has no cleaning (El-Nashar, 2003).

Another study (Kimber et al., 2006) examined the performance of over 250 PV systems in order to develop an accurate model for predicting losses due to the soiling effect. The study found that in desert regions, the soiling effect was highly correlated with rainfall. A single axis tracking PV system in a desert region in the southwestern United States, which has climatic conditions similar to those in Abu Dhabi, found that average annual soiling losses for a typical year were about 4.2%, (Kimber et al., 2006). The study also found that a rainfall of 0.2-0.3 inches over one day results in an increase of 6% in efficiency on average (see Table 6). Thus, the panels will be naturally cleaned from rain throughout the year.

PV Efficiency increase from a rainfall event of 0.2-0.3 inches over one day			
Average	Min	Max	Std. Dev.
6%	-8*	56%	14%

Table 6: Projected PV efficiency increase from natural cleaning of modules from rain precipitation.

The proposed PV system utilizes a one-axis tracking system, which will experience fewer production losses as compared to a stationary solar collector, such as the evacuated tubes studied in Abu Dhabi. Solar tracking systems maximize electricity production by rotating the PV module throughout the day to follow the suns path to increase the direct sunlight received by the panel. Tracking arrays can be useful to protect against destructive sandstorms, often higher above ground and movable to decrease wind load, rotating the face of the PV cell away from the dust and wind (Thornton, 1992). There are many ways to reduce the effect of soiling on PV power production. Increased cleaning can occur in the summer months and after dust storms when it is needed most (El-Nashar, 2003).

In our model, we assume that dust and soiling will decrease annual production by 5 percent. A study conducted by the US National Renewable Energy Laboratory of derate factors, the percentage decrease in output, in the US reported an average derate factor rating of 0.95 (range of 0.75-0.98) for soiling among 24 PV system studies, equivalent to an average annual loss of 5% (Marion and Anderberg, 2000). Table 7 summarizes the input values used to estimate the energy production potential of the PV plant.

Input	Description	Input Value
Solar Tracking Mode	The tracking mode can be fixed (stationary) or on a one axis, two axis, or azimuth tracking system to maximize direct sunlight hitting the PV module.	One-Axis
Azimuth	The orientation of the PV module. If facing directly south, azimuth is zero.	0.0
Annual solar radiation – horizontal	The amount of solar radiation (MWh/m^2) striking a horizontal surface in one year.	See Table 4
Miscellaneous losses	This input is used to represent the losses from dust accumulation and sand storms.	5%
Inverter Efficiency	The percentage of electricity the inverter successfully converts from DC to AC.	95%
Inverter Capacity	The output of the inverter in AC kW.	9,500
Inverter Misc. Losses	Any miscellaneous losses from the inverter or other power conditioning.	0%

Table 7: Input values for RETScreen's energy production worksheet.

Financial Feasibility Assessment

RETScreen's financial analysis accounts for the benefits of the electricity produced and the costs of the PV power plant. These estimates are then used to show financial statistics, like net present value (NPV), simple payback period (SPP), and internal rate of return (IRR) of the project.

The cost estimate is made up of the initial costs, annual costs, periodic costs, and end-of-life costs. Numerous studies and reports were consulted to develop estimates of these costs (International Energy Agency, 2009; Kurokawa, 2003; Maruoka, 2008; Mitchell et al., 2002; Moore et al., 2005; Raugei and Frankl, 2009; Skyline Solar, 2009), as the economics of photovoltaics is constantly changing and differs in different parts of the world.

The module price is assumed to be \$5.50/watt, for total equipment costs of \$55.5 million. The estimate is taken from the RETScreen User Manual which states that current cost are between \$5.50/watt to \$8.00/watt with lower range of costs for PV projects larger than 20 kWp

(RETScreen International, 2001-2004). The feasibility study, development, and engineering estimates follow predicted values in previous studies (Alawaji, 2001; Hrayshat, 2009; Rehman et al., 2007). The balance of system (BOS) costs are estimated to be \$36.5 million. BOS costs include the tracking system, inverter, electrical components, and installation, which are assumed to cost US \$300/m^2, \$1,000/kW, \$700/kW, and \$900/kW respectively (RETScreen International, 2001-2004). The total initial cost is predicted to be \$92 million (Table 8).

Annual costs consist of operating and maintenance and periodic costs, such as replacing inverters. Operating and maintenance costs are relatively small as PV systems are low maintenance, estimated to be \$334,500 annually (Alawaji, 2001; Hrayshat, 2009; Rehman et al., 2007). Periodic costs are fairly low as PV modules themselves are very durable and often come with 20 year guarantees. Inverters, however, have a shorter lifetime and are estimated to cost approximately \$2 million every 5 years for replacement of one of the two inverters (El-Shimy, 2009.

RETScreen also calculates the end-of-life cost, which can be positive, representing the salvage value of the PV equipment after its predicted lifetime. A recent study examining the financial aspect of very large solar power project estimated a PV system would be worth 10% of its original value after 30 years (Komoto et al., 2009). Using this assumption, we assume the PV system's end-of-life worth to be approximately \$9 million. A summary of the values input to RETScreen to compute the expected cost for the PV power plant is shown below in Table 8.

Type of Cost	$ USD (in thousands)	% of Initial Costs	Reference
Feasibility study	$200	0.22%	(Alawaji, 2001; Hrayshat, 2009; Rehman et al., 2007)
Development	$165	0.18%	
Engineering	$150	0.16%	
Equipment	$55,000	59.77%	(RETScreen International, 2001-2004)
Balance of Plant Costs	$36,500	39.67%	(RETScreen International, 2001-2004)
Tracking System	$10,500		
Inverters	$10,000		
Electrical Components	$7,000		
Installation	$9,000		
Total Initial costs	**$92,015**	**100.00%**	**-**
Inverter Replacement Costs	$2,000	Every 5 years	(Alawaji, 2001; Hrayshat, 2009; Rehman et al., 2007)
Operation and maintenance	$335	Annually	
Salvage Value	$9,202	10%	(Komoto et al., 2009)

Table 8: Initial, periodic, and end of life cost for the PV power system

RETScreen's financial feasibility estimate includes the cost estimate as well as calculations to account for the avoided cost of conventional energy; expenses for loans for the project; and tax expenses. The annual conventional energy savings due to PV-generated electricity entering the grid is calculated by multiplying the electricity export rate by the net energy production from the PV plant. The electricity export rate is the price paid by the utility for electricity from the PV plant that is dispatched to the power grid to serve elelctricirty needs in Abu Dhabi. This rate is assumed to be equivalent to the cost of electricity production, which is estimated in the UAE to be 30 fils (equivalent to US $0.082) per kWh (Al-Iriani, 2005). RETScreen has a built-in function to account for increasing energy prices over time, assumed to be escalating at a 4% rate annually.

RETScreen also can account for the monetary value of GHG emission reductions. However, our baseline assumption is that these external benefits will not be included, as the UAE currently has no monetary incentives in place for GHG emissions reduction. Thus, this proposed PV project is assumed to receive no GHG emissions credits; however, one sensitivity analysis scenario discussed later assumes GHG emissions credits are received for the plant.

All taxes are assumed to be zero, since the UAE does not have a tax system. (The UAE government does not charge taxes, since it receives its revenue from sales of oil and gas, as well as return on other assets.) We also assume that there are no government incentives for the plant. We assume that foreign direct investment and the government of Abu Dhabi fund the PV plant, without the need for a loan. The inflation rate, discount rates, and other financial indicators are shown in Table 9.

Financial Parameter Inputs			
Input	**Description**	**Input Value**	**Reference**
Electricity Export Rate	The price the utility pays for electricity generated by the PV exported to the power grid.	\$0.0816 /kWh	(Al-Iriani, 2005).
Electricity Cost Escalation Rate	The assumed escalation in electricity prices per year over the lifetime of the PV plant.	4%	(Alawaji, 2001; Hrayshat, 2009; Rehman et al., 2007)
Inflation Rate	Annual rate of increase in the price of goods /services	2.5 %	
Discount Rate	Rate used to discount future cash flows	5.0%	
GHG emissions reduction	The expected revenue from GHG emission reduction credits.	\$0/ ton CO_2 eq.	-
Project Life Time	Estimated project life time	30 years	(Komoto et al., 2009)

Table 9: Input values for financial feasibility analysis

GHG Emissions Analysis

To calculate GHG emissions reductions, the net amount of annual energy produced from the 10MW power plant (given the GSR level and miscellaneous losses) is assumed to represent an equivalent amount of conventional electricity that no longer needs to be produced. The base case electricity system is calculated by inputs of the electricity source mixture by fuel type and baseline transmissions and distribution (T&D) losses. Losses from transmissions and distribution are reported to be 2% and 8%, respectively (Miller, 2009). The existing emission rates for GHGs from the Umm Al Nar power plant are input into RETScreen to simulate the baseline GHG emissions. In 2003, the Umm Al Nar power plant consumed 99.93 percent natural gas fuel with traces of other fuels. RETScreen's default emissions factors for these fuels types are used in the analysis and listed in Table 10.

Fuel	2003 Fuel Consumption	Percentage of Fuel Consumed	CO_2 Emission Factor (kg/GJ)	CH_4 Emission Factor (kg/GJ)	N_2O Emission Factor (kg/GJ)	Fuel conversion efficiency
Natural Gas	129,343,968.54	99.93%	56.1	0.003	0.001	45%
Crude Oil	74,008.63	0.057%	77.4	0.0030	0.0020	30%
Gas Oil	1,675.14	0.001%	63.1	0.0010	0.0010	45%
Fuel Oil	15,171.42	0.012%	74.1	0.0020	0.0020	30%

Table 10: Baseline composition of emissions from the Umm Al Nar power plant. Fuel consumption (Abu Dhabi Water and Electricity Company, 2009) as well as emission factors for various fuels (RETScreen International, 2001-2004) are reported. Fuel consumption data is taken from 2003, which is the most recent year with emissions data for the Umm Al Nar power plant.

RETScreen compares this baseline GHG emissions case with the proposed new electricity system, which has integrated the 10MW power plant into the electricity grid. The PV plant is 100% powered by solar radiation and emits no GHGs. It is important to note that the full life cycle analysis of the PV power plant does have GHG emissions from resource extraction of silicon, equipment manufacturing, transportation, and more. A comprehensive study comparing the full life cycle emissions of various electricity power sources by Weisser (2006) estimated natural gas combustion, the typical power plant type in Abu Dhabi, to release of 440 to 780 g $CO_{2-eq.}$/kWh while PV power production released between 43 to 73 g $CO_{2-eq.}$/kWh. However, the calculations in the model do not account for full life cycle emissions of any of the conventional electricity supply, so the PV life cycle emissions are also omitted. The transmission and distribution (T&D) losses for the proposed new electricity system are assumed to be 10% as well. The input values for the GHG emissions analysis are listed in Table 11.

Input	Descriptions	Input Value	Reference
Baseline Electricity Systems	The current makeup of electricity sector in Abu Dhabi	See Table 7	-
Baseline T & D Losses	The losses of electricity from transmission and distribution.	10%	(Miller, 2009)
PV Emissions	The PV project is 100% solar, and does not emit GHG.	0%	-
Proposed system T&D Losses	Transmission and distribution losses in the proposed electricity system, which the PV plant integrated in it.	10%	(Miller, 2009)

Table 11: Inputs for the GHG emissions reduction analysis.

RETSCREEN RESULTS

Projected Energy Production

The proposed power plant is projected to produce approximately 24.4 GWh annually of (alternating current) electricity available for export to the electricity grid. This number takes into account losses from sand and dust, as well as the effects of inverter efficiency and outside temperatures on performance of the PV system. Per-capita electricity consumption in the UAE is 12,375 kWh per year (CIA, 2010). Thus, this plant could meet the needs of about 1,975 people. Total gross electricity generation in Abu Dhabi in 2008 was approximately 34,500 GWh (Abu Dhabi Water and Electricity Company, 2009). Given this information, the 10MW power plant would account for 0.07% of total generation.

The power plant capacity represents the ratio of actual energy output compared with the plant's optimal nameplate capacity. The PV power plant capacity is estimated to be 28%. The specific yield is 350 kWh/m^2, representing the total annual energy delivered by the PV plant divided by the area of the plant. The peak electricity export occurs in the month of May, when production is 2,500 MWh (see Figure 3). The decrease in electricity production from May to August is likely due to the fact that extreme high summer temperatures decrease the efficiency of the solar cells.

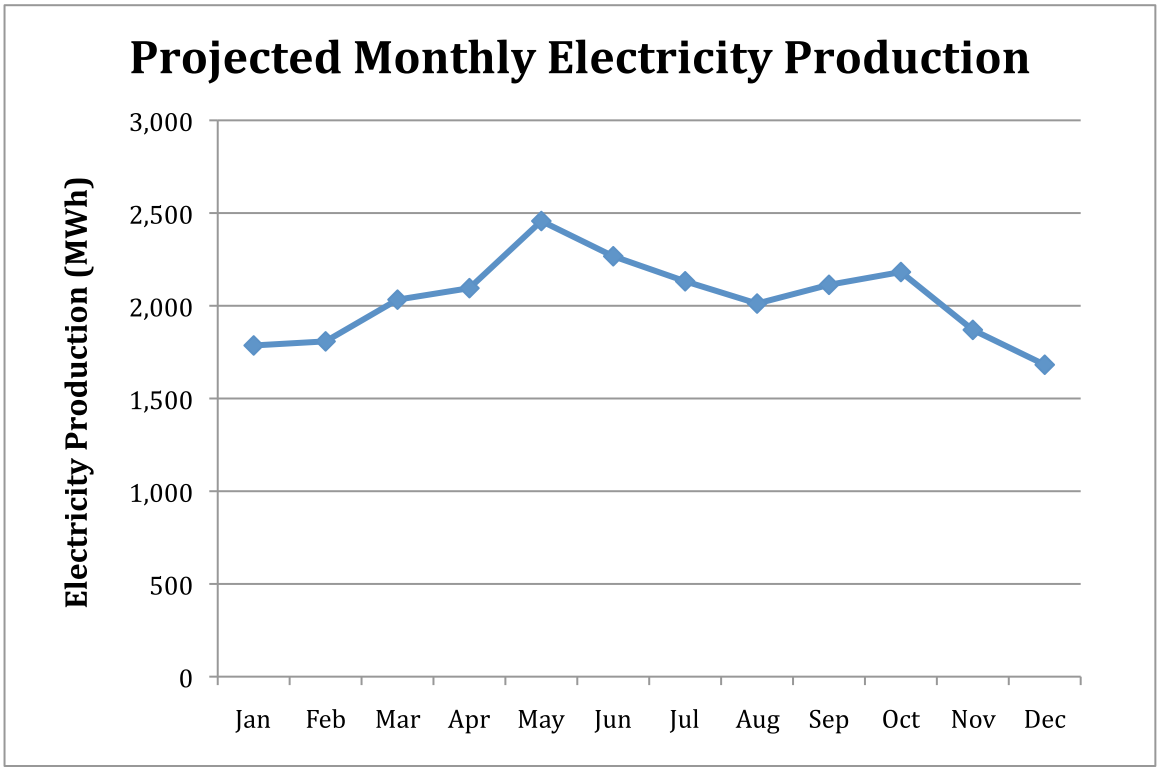

Figure 4: RETScreen's monthly projected electricity production.

Financial Analysis Results

RETScreen calculates numerous financial indicators, enabling comparisons among other investment projects and reflection on the economic feasibility of any project. The main financial indicators are reported in Table 12 and further discussed in the following paragraphs.

The net present value (NPV) for the project compares the total cash inflows discounted to present value against all costs for the project. The NPV for this project is shown in Equation 1. Positive values for the NPV indicate a financially feasible project.

$$\text{NPV} = -\begin{matrix}\text{Initial}\\\text{Costs}\end{matrix} + \text{PV}\left[\begin{matrix}\text{Electricity}\\\text{Income}\end{matrix} - \begin{matrix}\text{Operating and}\\\text{Maintenance Cost}\end{matrix} - \begin{matrix}\text{Inverter}\\\text{Replacement}\end{matrix} + \begin{matrix}\text{Salvage}\\\text{Value}\end{matrix}\right]$$

Equation 1: The calculation for the net present value of the PV project.

$$NPV = -92{,}015{,}000 + PV\ [(24{,}436 * (\sum_{t=1}^{30} 81.67 * 1.04^{t})) - (\sum_{t=1}^{30} 334{,}500 * 1.025^{t}) - (\sum_{t=1}^{6} 2{,}000{,}000 * 1.025^{5t}) + (9{,}201{,}500 * 1.025^{30})]$$

$$NPV = -92{,}015{,}000 + PV\ (24{,}436 * (\sum_{t=1}^{30} 81.67 * 1.04^{t})) - PV(\sum_{t=1}^{30} 334{,}500 * 1.025^{t}) - PV(\sum_{t=1}^{6} 2{,}000{,}000 * 1.025^{5t}) + PV(9{,}201{,}500 * 1.025^{30})$$

$$NPV = -92 + 51.8 - 7.1 - 8.0 + 4.5 = -50.8 \text{ (\$ US million)}$$

Equation 2: Values of the various components of the net present value equation.

The NPV for the PV plant with a 30-year assumed lifetime is $ -51 million. Equation 2 shows that components of the NPV equation. The initial cost and the present value of the income from exported electricity are two most influential factors in this equation. In order to have a positive NPV, the electricity export rate, the price paid by the utility company for electricity exported to the power grid, would have to be $0.16/kWh or greater. Similarly, the NPV could also be positive if initial cost were decreased from $92 million to below $41 million. In other words, the technology needs to be about half its current costs to be economically feasible, if the all else remains the same.

The energy production cost measures the total cost for producing one kWh of electricity and is estimated to be 16.18 cents/kWh. The net benefit-cost (BC) ratio compares the cost of the project's equity to the benefits of all income over the 30-year lifetime in present value. The net BC ratio is projected to be 0.45. Ratios larger than 1 are desired for projects, as the benefits would be greater than the costs. Annual life cycle savings (ALCS) represents the yearly benefit of the PV plant, taking into account net present value, project lifetime, and the discount rate. The ALCS for the project is projected to be $-3.3 million annually.

The internal rate of return on investment (IRR) represents the interest earned by the project over its lifetime. The IRR is projected to be 0.5 %. If the IRR is greater than the investor's required return on investment, then the project is financially worthwhile. The simple payback period indicates how many years it takes to recoup the initial and annual costs given positive annual income from the PV system. This PV power plant has a payback period of 55.4 years. Similar to the simple payback period, the years to positive cash flow indicates how long it takes to recoup the initial investment only, excluding periodic investments. The project has an anticipated 29.5 years to positive cash flow.

Financial Indicators for PV Power Plant	
Net Present Value	$ -50.8 million
Energy Production Cost	16.18 cents/kWh
Benefit-Cost Ratio	0.45
Annual Life Cycle Savings	$-3.3 million
Internal Rate of Return	0.5 %
Simple Payback Period	55.4 years
Years to Positive Cash Flow	29.5 years

Table 12: RETScreen's projected values of various financial indicators.

The results summarized in Table 12 do not include estimates of GHG and air pollution reduction benefits. The current negative NPV demonstrates that without including the benefits of reduced GHG and air pollutant emissions, solar power is too expensive to be justified economically. However, the conclusion may be different if the benefits of avoiding environmental damages are taken into account.

GHG Emissions Reductions

The current GHG emissions factor from the Umm Al Nar power plant, given the amounts and type of fuel consumption of the plant, is calculated to be 0.488 tons of CO_2 per MWh. This emissions rate is compared with the proposed PV power plant, which has a GHG emissions factor of zero. The model estimates that the PV plant will reduce GHG emissions by 10,732 tons of $CO_{2\ eq.}$ annually. Assuming a 30-year lifetime for the plant, approximately 320,000 tons of CO_2 emissions will be avoided as the PV power plant replaces the need of some electricity from the existing power grid (see Table 13).

Estimated GHG Emissions Reduction	
Annual GHG Emissions Savings	10,732 tons CO_2 eq./year
Lifetime GHG emissions saving	320,000 tons CO_2 eq.

Table 13: RETScreen's predicted GHG emissions reduction given the construction of the 10 MW PV power plant in Abu Dhabi.

RETSCREEN SENSITIVITY ANALYSIS

RETScreen's predicted values change with modifications to various inputs factors. This sensitivity analysis examines the effect of altering the global solar radiation, electricity export rate, electricity escalation rate, energy losses from sand and dust, initial costs, and GHG emission reduction credits, while holding all other inputs constant. Results are shown in Table 14 and discusses in detail below.

Sensitivity Analysis Results for RETScreen Estimates					
Input Variable	**Value Change**		**Results (% Chance from Original)**		
	Original Value	**New Value**	**Net Energy Production (GWh)**	**Production Cost (cents/kWh)**	**NPV (US $ Million)**
Global Solar Radiation	Avg. = 5.97 ($kWh/m^2/day$)	Avg. = 5.58 ($kWh/m^2/day$)	22.3 (-7.8%)	16.9 (-4.4%)	-53.2 (-4.6%)
Electricity Export Rate	8.16 (cents/kWh)	42 (cents/kWh)	No change	No Change	163.7 (+421.9%)
Electricity Escalation Rate	4%	8%	No change	8.8 (-45.6%)	-7.2 (+85.8%)
Losses from Dust and Sand	5%	10%	23.2 (-4.5%)	17.1 (+5.7%)	-53.6 (-5.1%)
		2%	25.2 (+4.0%)	15.7 (-3.0%)	-49.2 (+3.2%)
Initial Costs	$92 million	$65.5 million	No change	12.0 (-25.8%))	-24.4 (+52.1%)
GHG Emissions Reduction Credit	$0	$16/ton	No change	15.6 (-3.6)	-47.4 (+6.8%)

Table 14: Results for sensitivity analysis with changing various inputs and assumptions in the RETScreen Model.

Global Solar Radiation

The current global solar radiation (GSR) values reflect the 22-year averaged insolation data from NASA. However, a recent study (Islam et al., 2009) produced GSR values for the entire year of 2008 that were lower than the NASA data (see Table 4). The difference in GSR values are likely due to the fact that the locations of GSR records are slightly different, and the year 2008 was a time of low solar radiation during the sun's 11 year solar cycle. If these records were used, RETScreen predicts a less favorable situation. The annual electricity production is estimated to decrease to 22.3 GWh/year. Given the decrease in projected energy production, electricity production costs increase to 17.0 cents/kWh, and NPV decreases to $-53.2 million. These changes show that site specific GSR values are important to accurately predict energy production potential at any location.

Electricity Export Rate

The electricity export rate is the price paid by the utility company for electricity produced by the PV plant. This rate is multiplied by the annual electricity exported to the grid to estimate the total annual income from exported electricity. The current electricity export rate is $0.082/kWh (30 fils/kWh) which is the estimated actual cost of electricity production in the UAE (Al-Iriani, 2005). However, other similar RETScreen studies in Egypt and Jordan have assumed an electricity export rate of $0.42/kWh (El-Shimy, 2009; Hrayshat, 2009) and another RETScreen study for Saudi Arabia used an electricity export rate of $0.50/kWh (Rehman et al., 2007). These higher estimates are likely a result of assuming a premium will be paid for electricity generated by renewable sources. A feed-in-tariff is a policy tool that essentially guarantees that a utility will purchase all of the electricity generated at a predetermined price, often at a premium. Many countries have feed-in-tariffs for renewable energy sources in place, most notably: Germany ($0.68/kWh), Spain ($0.49/kWh), Portugal ($0.67/kWh), where high tariff rates that have resulted in now sizable RE generation capacity (Rowlands, 2005). It is likely that these previous RETScreen studies assumed that a feed-in-tariff would be established for the PV plant while this study's electricity export rate is more conservative.

If we assume the electricity export rate to be $0.42/kWh we find the same energy production and GHG emissions reduction but a vast difference in financial feasibility. The NPV increases to $163.7 million. The ALSC, IRR, and CB ratio each increase to $10.6 million, 1.4%, and 2.78, respectively. The predicted time to positive cash flow is just 7.9 years. In effect, the project is now projected to be profitable and a sound financial investment. Thus, it is essential to further evaluate the export rate to ensure the project will be profitable. Any export rate above $0.16/kWh would result in a positive NPV, making a feed in tariff of at least $0.16/kWh highly effective.

Electricity Escalation Rate

The electricity escalation rate reflects the projected amount of annual increase in the electricity export rate over the lifetime of the project, currently assumed to be 4 percent. However, the escalation rate could be substantially higher. The UAE became a net importer of natural gas in 2007 (Energy Information Administration, 2009b). The country has an existing agreement with Qatar for a predefined purchased price for natural gas, but new purchasing contracts between Qatar for additional gas supply will face the possibility of purchasing gas at significantly higher prices (Remo-Listana, 2008). In addition, the rapid growth in electricity demand expected in the next decade in Abu Dhabi could also increase electricity prices, resulting in significantly higher profits from electricity exported to the grid. Thus, a second scenario is considered which incorporates higher electricity escalation rate of 8 percent. Again, we find the same energy production and GHG emissions reduction, but the NPV increases to $-7 million, an improvement of $44 million, while the electricity production costs decreases to 8.79 cents/kWh.

Losses Due to Sand and Dust

There is a wide range of possible percentage losses in the energy production due to sand and dust on the PV panel. The value for miscellaneous losses was changed from its original value of 5% to 2% and 10% in order to examine effects on resulting values. If the PV panel had losses of 2 percent due to sand and dust, the resulting energy production would increase to 25.2 GWh, with a capacity factor of 28.8%. The NPV would increase to $-49.2 million and electricity production cost decreases to 15.7 cents/kWh. Conversely, if PV losses were projected to be 10 percent, the energy production would be 23.1 GWh, with a capacity factor of 26.4%. The NPV would decrease to $-53.3 million and electricity production cost increases to 17.1 cents/kWh.

Initial Costs

The initial cost of the project may also vary. Equipment costs are almost continuously decreasing cost in the PV industry. Average costs for PV modules were only $3.70/watt in the US in 2009 (International Energy Agency, 2009), in contrast to our assumed module price of $5.50/watt. One 3.5 MW PV power plant in Tucson, Arizona reported costs of modules at $3.33/watt and total system cost of just $6.50/watt (Moore et al., 2005). Assuming these same costs, a price of $65 million is assumed for all equipment and balance of system costs, for a total initial cost of $65.5 million. The resulting financial indicators show an improvement. The NPV increases to $-24.4 million, while the electricity production cost decreases to 12.01 cents/kWh.

Income from GHG Emissions Reduction Credit Trading

It is currently assumed that the PV project receives no benefit from GHG emissions reduction, with GHG emissions reduction credits valued at $0/ ton CO_2 eq. However, financial indicators would improve when including GHG credits trading. Carbon trading schemes attempt to internalize the externalities of GHG emissions by putting a price on emitting CO_2. Clean energy projects in the UAE are eligible for Clean Development Mechanism (CDM) funding. The CDM was established under the Kyoto Protocol as a way for developed countries to fund GHG emissions reductions projects in other countries, where projects are potentially less expensive. There are currently two solar projects in Abu Dhabi, funded by MASDAR, that are registered for CDM funding (UNFCCC, Feb 2010). The average price in January 2010 for a certified emissions reduction on the European Union's Emissions Trading Scheme was €11.57/ton CO_2 eq., approximately equivalent to US $15.80/ ton CO_2 eq. (European Climate Exchange, 2010). Thus, a RETScreen analysis was conducted that assumed to the PV plant would receive GHG emissions credits of $16/ton, with a 5% escalation rate for 20 years. The benefit from this income has a present value of $3.4 million; however, this benefit is not enough to make the project profitable with the NPV only increasing to $-47.4 million.

BENEFITS OF AVOIDED EXTERNALITIES

Environmental and societal damages often occur because they are not accounted for in cost evaluations and instead are negative external cost born by society. If our project were to look at these externalities there would be a benefits from avoided damages from both GHG emission and air pollution.

RETScreen has estimated that the PV plant would reduce GHG emissions by an estimated 10,732 tons CO_2 eq./year. Emissions rates for the Umm Al Nar plant were calculated to provide an example of potential air pollution emissions reductions with the additional of PV power plants instead of conventional power plants. Emissions rates were determined by dividing total annual emissions (Abu Dhabi Environment Agency, 2010) by gross electricity production for the Umm Al Nar power plant in 2003. The resulting emissions rates are shown in Table 15. With the construction of the PV plant, an estimated 372.9 tons of NOx, 0.15 tons of SO_2, and 1.72 tons of total suspended particulates would be reduced from the Umm Al Nar plant's annual emissions.

Pollutant	**2003 Reported Annual Emissions** (tons/yr)	**Emissions Rate** (grams/ kWh)	**Emissions savings** (tons/yr)
NOX	86,483.40	15.26	372.85
SO2	34.16	0.01	0.15
TSP	398	0.07	1.72
GHG	-	-	10732

Table 15: The avoided emissions from the Umm Al Nar power plant with the addition of the PV power plant.

Avoided GHG Emissions

The previous scenario examined benefits for this GHG emissions reduction valued at \$16/ton, the market price for a carbon reduction credit. However, this represents the marginal *abatement* cost of carbon emissions. In other words, the cost of reducing existing carbon emissions by 1 ton is approximately \$16, but this is not the price of *damages* caused by 1 ton of GHG emissions. There is significantly more uncertainty in estimating the marginal damages of GHG emissions as future climatic conditions and human adaptation is highly uncertain. Tol et al (2005) reviewed 103 cost estimates of damages from GHG emission and found that for probability density functions generated for peer reviewed marginal cost estimates; damages had a mean of \$50/ton with a minimum value (5% probability) of \$-9/ton and a maximum (95% probability) value of \$245/ton. This estimate is used to determine present value of benefits from avoided GHG emissions damages.

Avoided Air Pollution

There is also a benefit from producing electricity with less air pollution emissions. In order to include this benefit of reduced air pollution, monetary values must be assigned to these pollutants. There have been numerous studies and a growing area of research on quantifying the external cost of air pollution ((Bozicevic Vrhovcak et al., 2005; Kudelko, 2006; Matthews and Lave, 2000; Zhang et al., 2007)). One study by Matthews and Lave (2000) examined a number of economic valuation studies around the world and summarized their cost estimates for various pollutants. The studies used a number of different economic valuation techniques including: damage functions, willingness to pay, and externality adders. The damage function monetizes the damages caused by air pollution such as effects on human health, visibility, the environment, and more. Willingness to pay (WTP) studies ask people what they would be willing to pay for something. Air pollution WTP studies often find the WTP for avoiding death to generate a value of a statistical life that is then used with estimated premature deaths from air pollution to find total costs. Externality adders studies add the estimated social damage estimates of air pollution to market costs of new power plant for better societal optimization when choosing future investments in power plants (Matthews and Lave, 2000).

The mean, minimum, and maximum cost estimates of numerous social damage estimate studies for NOx, SO2, and PM_{10} are scaled up from $1992 to current $2010 and reported in Table 16. It is important to note that these estimates are not specific to the UAE and are also highly variable. The majority of studies reported by Matthews and Lave (2000) are from the United States, which is assumed to be roughly comparable to Abu Dhabi as they have similar economic status. However, the exact monetary value for external costs of air pollution is highly debated and still uncertain.

Pollutant	Minimum ($/ton)	Mean ($/ton)	Maximum ($/ton)	Reference	No. of Studies
NOx	$4,396	$345	$14,915	Matthews and Lave (2000)	9
SO_2	$3,140	$1,208	$7,379		10
PM_{10}	$6,751	$1,491	$25,434		12
GHG*	$-10	$57	$277	Tol et al (2005)	28

Table 16: Summary of social damage estimates from a variety of air pollution valuation studies worldwide. Estimates scaled up to present 2010 dollars.

The mean cost of each pollutant is used to quantify the benefit of avoided air pollution from conventional energy sources like the Umm Al Nar power plant. Total suspended particulates are assumed to be equal to PM_{10}, consistent with the US EPA's PM emissions factor estimates which assumes all PM emissions from natural gas combustion is less than 10 micrometers in diameter (Eastern Research Group, 1998).

Pollutant	Emissions Savings (tons/yr)	Mean Damage Cost ($/ton)	Annual Benefit ($ thousands)	Present Value of Benefits ($ thousands)
NOX	372.85	$4,396	1.639	$32,126.1
SO2	0.15	$3,140	0.5	$9.2
TSP	1.72	$6,751	11.6	$227.6
GHG	10732	$57	611.7	$11,990.1
	TOTAL BENEFIT	$14,344	$2,262.9	**$44,353.0**

Table 17: Calculation of the monetary benefit of reduced air pollution emissions with addition of a 10 MW PV power plant instead of conventional power production from plants like the Umm Al Nar power plant.

The benefits are calculated and shown in Table 17. The total present value of all air pollution savings benefits for the 30 year PV plant lifetime, with a 3% discount rate, is estimated to be $44.4 million, with a range of $0.4 million to $221 million. When the mean present value of these benefits is included in the financial analysis the project's overall NPV increased to $-6.5 million. If initial costs decreased to $65 million, as suggested in the sensitivity analysis, then NPV increases to $20 million, making the project financially feasible.

AIR POLLUTION BENEFITS SENSITIVITY ANALYSIS

It is important to note that the discount rate is very important in calculating the future benefits of air pollution reduction. The discount rate of 3 percent was chosen because otherwise the benefits of better air quality to future generations would be severely devalued (Pearce et al., 2003). The impact of changing the discount rate is shown below in Figure 4. The ranges of damage cost estimates for the air pollutants greatly impact the value of air quality benefits as well. Results in Figure 4 show the calculated present value of air quality benefits for the minimum, mean, and maximum values reported by Matthews and Lave (2000) and Tol (2005).

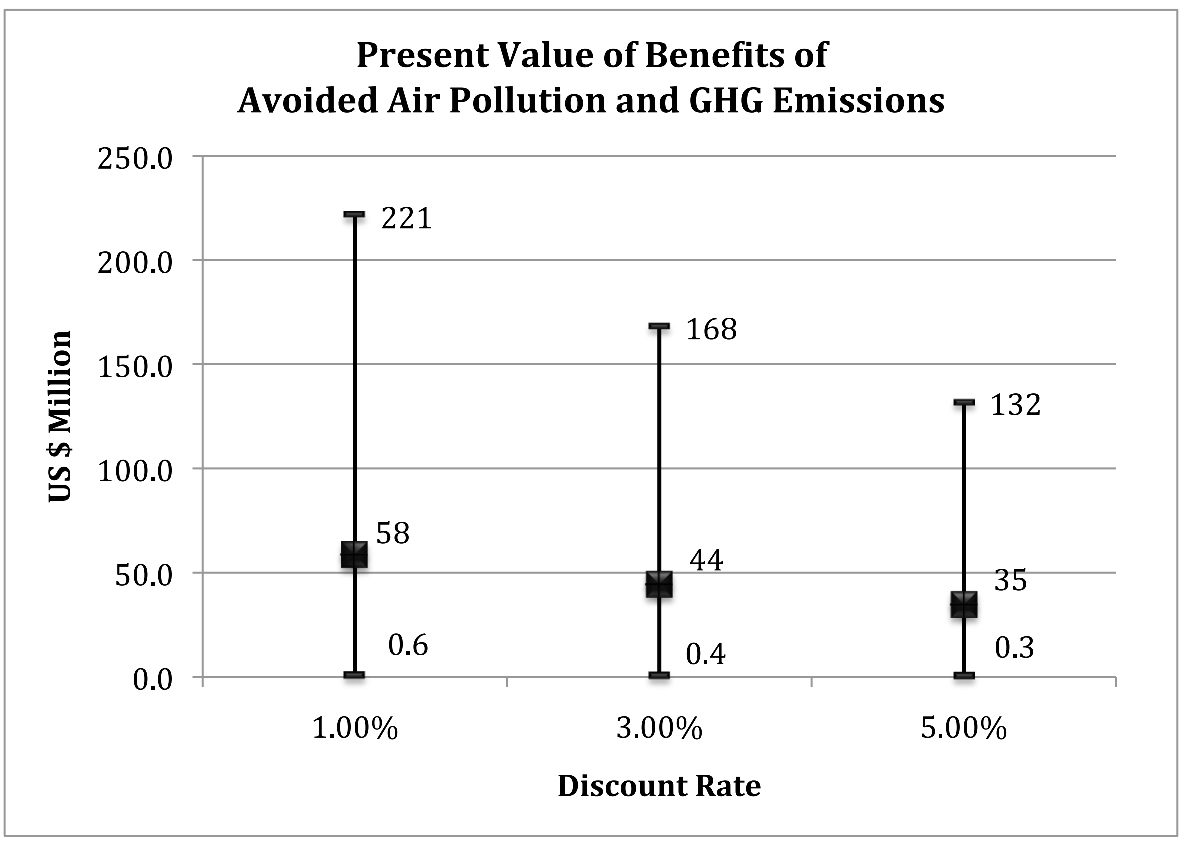

Figure 5: Sensitivity analysis results of the predicted monetary benefits of avoided air pollution given changes in discount rate and damage estimates.

CONCLUSION

The energy production potential for large scale PV power plants in Abu Dhabi is extremely high, with a capacity factor of 27.9%. A 10 MW power plant close to Abu Dhabi city is predicted to generate 24.4 GWh of electricity each year. However, large-scale PV power plants are currently not profitable in Abu Dhabi, with an estimated NPV of $-50.8 million for a 10 MW facility. This negative NPV demonstrates why solar power is not being implemented on a wide scale around the world: the costs are still too high.

Conclusions would be different if environmental damages were taken into account. . Improved air quality will likely decrease hospital visits for respiratory ailments, cardiovascular disease, asthma, and more. There is a potential replacement of 24.4 GWh of conventional thermal power production annually with the construction of each 10 MW PV power plant built, saving an estimated 10.732 tons CO_2 eq., 372.8 tons of NOx, 0.15 tons of SO_2, and 1.7 tons of total suspended particulates annually. Rough calculations of these benefits o are estimated to have a present value of approximately $44.4 million, with a large range from $0.3 million to $221 million for damage cost estimates, increasing the project's NPV to an estimated $-6.5 million. It is important that these benefits are taken into account by decision makers choosing how to meet Abu Dhabi's rising demand for new power capacity.

There are also numerous intangible benefits for Abu Dhabi by investing in PV now. The Emirate will be have a first mover advantage in the PV industry, being ahead of the world in PV technology. Abu Dhabi can further develop its image as an environmentally aware state. Investments in PV technology now will help reduce Abu Dhabi's carbon footprint, decreasing future climate change mitigation requirements. These findings confirm the need to support PV projects with subsidies to account for the long-term benefits they provide to society at large. Without subsidization, PV projects will not be implemented, as utility companies will not account for these positive externalities.

The financial feasibility of the project is highly dependent on the electricity rate the PV plant owner will receive for power delivered to the grid. The current expected price per kWh of 8.2 cents is simply too low to make the project profitable. In order to have a positive NPV, the electricity export rate would have to be 16 cents per kWh or greater. Thus, the PV project would be profitable if a feed-in-tariff was established that guaranteed a purchase price of the electricity generated. This highlights the importance of government incentives to spur the increase RE investments. Incentives such as feed-in tariffs, renewable portfolio standards, government investments in research and development for PV, and more, can be essential toward spurring RE development in Abu Dhabi.

Additional research is highly recommended, as there are limitations to the RETScreen model. This analysis examined the feasibility of only PV energy and not other RE source like wind, concentrated solar, and geothermal. In addition, RETScreen requires fixed values for inputs while a range of possible values could be more appropriate in cases where uncertainty exists such as imputing GSR values, the electricity export rate, and initial costs values. RETScreen did not account for the intangible benefits of the PV power plant. While RETScreen estimates financial and technical feasibility of the project, the political feasibility is not examined.

Future research for PV power generation in Abu Dhabi should examine the political feasibility of installing RE sources and possible establishing a premium for power produced by

RE sources. The calculation of benefits of reduce air pollution should replace global damages estimate with Abu Dhabi specific values by modeling the health benefits of reduced emissions from existing power plant in Abu Dhabi, specifically. Lastly, other RE energy sources should also be studied to see what energy source would be the most beneficial economically and environmentally.

Abu Dhabi currently has a window of opportunity to invest in RE sources. The Emirate's clean energy goals, needs for new power generation capacity, substantial cash reserves, and high GSR levels make RE projects ripe for development. This study shows, however, that government incentives are needed to make these projects profitable and prompt PV power plant construction in Abu Dhabi.

APPENDIX I: ENERGY PRODUCTION ESITMATION

GSR Calculations

RETScreen uses a built in algorithm to covert the GSR data to apply to tilted surfaces, such as PV modules on a tracking axis. The hourly irradiance in the plane of the PV array is shown in the following equation:

Equation 3: Hourly irradiance in PV plane:

$$H_t = H_b R_b + H_d ((1+\cos\beta)/2) + H_\rho ((1-\cos\beta)/2)$$

where ρ = the ground albedo (reflection) and β = the slope of the PV module (RETScreen International, 2001-2004). RETScreen alters the value of β to simulate a tracking PV array.

Weather Calculations in RETScreen

The efficiency of the module (η_p) is calculated by

Equation 4: Calculation for module efficiency:

$$\eta_p = \eta_r [1- \beta_p (T_c - T_r)]$$

"where η_r is the PV module efficiency at reference temperature T_r (=25°C), and β_p is the temperature coefficient for module efficiency. T_c is related to the mean monthly ambient temperature T_a" (RETScreen International, 2001-2004).

APPENDIX II: COST ESTIMATION

Feasibility Study, Development, Engineering Design Cost Estimates

A feasibility study is important to ensure that the potential project is worthwhile. While RETScreen provides a preliminary assessment, a more detailed study is needed to narrow the uncertainty in production and cost estimates. This in-depth study is quintessential for large-scale projects, such as this proposed 10 MW PV plant. This study often includes preparing design plans for the power plant and investigating the site. A site investigation is important to ensure that the location will receive the proper solar radiation and to evaluate the slope of the ground, etc. Engineering design costs include the PV system design, structural design, and electrical designs (RETScreen International, 2001-2004). The proposed 10 MW plant is grid connected, which typically requires more time for the PV system design and electrical design. The PV design deals mostly with the placement of each module in detailed drawings while the electrical design lays out how the system will be connected to the existing power grid. The structural design typically cost more when the PV system is on a tracking system, as the one-axis tracking system designed for this PV power system. Many of the cost estimates are adopted from three previous RETScreen studies, shown in the table below.

Inputs from Similar RETScreen Studies

Input	Jordan Study (5MW) $	%	Saudi Arabia (5MW) $	%	Egypt Study (10MW) $	%
Feasibility study	$80,1123	0.20%	$80,000	0.20%	$207,482	0.20%
Development	$70,099	0.18%	$70,000	0.18%	$207,482	0.20%
Engineering	$62,588	0.16%	$62,500	0.16%	$207,482	0.20%
Equipment	$28,208,970	70.63%	$27,750,000	69.61%	$73,033,539	70.40%
Balance of Plant Costs	$10,698,302	26.79%	$11,094,003	27.83%	$24,897,797	24.00%
Misc	$818,368	2.05%	$806,130	2.02%	$5,187,041	5.00%
Total Initial costs	$39,938,440	100.00%	$39,864,634	100.00%	$103,740,822	100.00%
Inverter Replacement Costs	$987,306	Every 5 yrs	$1,000,000	Every 5 yrs	$2,000,000	Every 5 yrs
Operation and maintenance	$336,473	Annually	$334,500	Annually	$334,500	Annually

Module Price

Equipment and installation costs include the costs for the PV modules and their delivery, the structure support for the system, the inverters, as well as system installation. The PV module costs will makeup the majority of the costs of the system. Typically, a PV module for a large-scale project costs $5.50/watt (RETScreen International, 2001-2004). Similar RETScreen studies that use the BP Solar PV module have assumed this $5.50/watt price (Alawaji, 2001; Hrayshat, 2009). Other studies have reported a wide range of module cost from $2.33/watt to $4.16/watt, shown in the Table below.

Reported Costs ($/watt) for PV modules and total PV system					
	Raugei (2009)	Moore (2005)	IEA PVPS (2009)	Maruoka (2008)	Skyline Solar (2010)
PV Module	$4.16/watt	$3.33/watt	$3.7/watt	n/a	$2.33/watt
Total Equipment Costs	$6.52/watt	$5.40/watt	$6.5/watt	$6.13/watt	$4.44/watt

Operating and Maintenance:

A 2005 report on the performance of a 3.5 MW power plant in Arizona documented every maintenance cost for three years, including unscheduled maintenance and general maintenance and upkeep, and found average annual cost to be 0.16% of initial installation cost (Moore et al., 2005). Applying this 0.16% cost assumption, the PV plant in Abu Dhabi would have an estimated $144,000 annually for maintenance. Operating cost values are often shown as cost coupled with maintenance. Operating and maintenance cost for other similar RETScreen studies (Rehman et al., 2007; Hrayshat, 2009; Alawaji, 2001) were all approximately $334,500 and were adopted for use in this analysis as well.

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