Feasibility Analysis of 5, 8 and 10 kW Grid-Connected Photovoltaic Systems in Saudi Arabia

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ABSTRACT

In Recent years, Kingdom of Saudi Arabia (KSA) have shown interest in introducing renewable technologies at a larger scale. Residential sector consumes about 50% of the country's total electricity production. Therefore, introducing PV technology in residential sector could aid the country to tackle its fast growing power demand, and carbon emission problem.

The present study, examines the financial viability of Grid-Connected Residential Photovoltaic (GCPV) systems in the Kingdom of Saudi Arabia. Economic assessment have been carried for several grid-connected PV capacity. We analyze the potential energy generation and cost effectiveness for hypothetical 5, 8, and 10 kWh PV sizes under several financial scenarios. Renewable Energy Project Analysis Software (RETScreen) has been employed to evaluate the PV models. The results show that, residential PV system is infeasible at the current electricity tariff. It has been estimated that electricity tariff has to increase at least by 750%, or by 350% (with 50% of the capital investment provided by government as incentive) for GCPV to be cost effective. However, providing feed in tariff at a rate of 100$/MWh for GCPV owners seems more financially attractive. In addition, installing 5, 8, and 10 kW PV capacity could avoid 6, 10, and 12 tons of CO_2, from being released to the atmosphere, respectively. In general, several economic, political and social issues need to be resolved, in order to create a successful market for PV technology in KSA.

Keywords: Photovoltaic system, Feasibility analysis, RETScreen software

ÖZ

Son yıllarda, Suudi Arabistan Krallığı (SAK) yenilenebilir enerji teknolojilerini daha büyük ölçekte kullanıma sunmak için çaba sarfetmektedir. Konut sektörü ülkenin toplam elektrik üretiminin yaklaşık %50'sini tüketmektedir. Bu nedenle, konut sektöründe fotovoltaik (PV) teknolojisinin kullanılması ülkenin hızlı büyüyen güç talebi ve karbon emisyon problemini çözmeye yardımcı olabilir.

Bu çalışma Suudi Arabistan Krallığındaki Şebekeye Bağlı Konut Fotovoltaik (GCPV) sistemlerinin ekonomik olurluğunu incelemektedir. Şebekeye bağlı ve çeşitli kapasiteye sahip olan fotovoltaiklerin ekonomik değerlendirmesi yapılmıştır. Birkaç finansal senaryoda, varsayımsal 5, 8 ve 10 kW PV sisteminin potansiyel enerji üretimini ve maliyet etkinliği analiz edilmektedir. PV modellerini değerlendirmek için Yenilebilir Enerji Projesi Analiz Yazılımı (RETScreen) kullanılmıştır. Önerilen PV Sistemlerinin uygulanması, gerek hükümet gerekse de ev sahibi açısından incelenmiştir. Sonuçlar, konut PV sisteminin karbon emisyon azaltımına katkıda bulunacağını göstermektedir. Bununla birlikte, SAK'da PV sistemi için başarılı bir pazar oluşturmak ekonomik ve sosyal zorluklarla sınırlandırılmıştır. Yapılan hesaplara göre, GCPV'nin uygun maliyetli olması için elektriğin tarifesinin en az %750 artırılması gerekmektedir. Hükümet bu konuda yatırım yapacaklara %50 katkıda bulunsa bile elektriğin tarifesi en az %350 artırılırsa GCPV sisteminin ekonomik olurluğu olur. GCPV sistemi sahiplerine en cazip gelebilecek uygulama 0.1$/kWh'dan belirlenen şebeke besleme tarifesidir. Ayrıca, 5, 8 ve 10 kW'lık kapasiteli sistemlerin kurulumu yılda sırasıyla 6, 10, 12 tonluk CO2 salınımını azaltmaktadır. Genel olarak,

PV teknolojisi için başarlı bir Pazar oluşturmak için bir çok ekonomik, siyasi ve toplumsal konuların SAK'ta çözülmesi gerekir.

Anahtar Kelimeler: Fotovoltaik sistem, ekonomik analiz, RETScreen yazılım

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LIST OF ABBREVIATIONS

CAGR	Compound Annual Growth Rate
DNI	Direct Normal Irradiance
GCC	Gulf Cooperation Council
GCPV	Grid-Connected Photovoltaic
IRR	Internal Rate of Return
NPV	Net Present Value
PV	Photovoltaic
RE	Renewable energy
SIR	Saving To Investment Ratio
SPP	Simple Payback Period

Chapter1

INTRODUCTION

1.1 Background

Nowadays, many countries are shifting from reliance on hydro-carbon based power generation into more diversified and environmentally friendly energy source with special interest in renewable energy. These energy strategies are mainly motivated by the limitation of fossil fuels and, their adverse impact on the environment. In addition, human population growth have been causing a huge strain on the energy sector, hence now more ever alternative and sustainable energy policy are needed to solve the future energy demand challenges.

Even though, there have been a remarkable achievement in the field of renewable energy development, its full potential has not been met yet. Up until now, there have been a few nations who succeeded to certain degree moving from mainly fossil fuel relied energy sources into more clean and renewable energy sources. This success story predominantly have been bound in couple of developed countries such as Germany, Spain and Italy. However lately there has been relatively developing enthusiasm for inspecting the possibility of sustainable power source in real oil-exporting nations, particularly in those portrayed by intensely oil-subordinate economies (Al-Saleh, Y.M. and Taleb, 2010). In recent years, in the Middle East especially in Gulf Cooperation Council (GCC), there has been growing political commitment to extend their sustainable power source. Not exclusively do these nations require to analyze such maintainable vitality measure to additionally guarantee their monetary prospects, the potential imperative part that these nations could play in accomplishing a more advantageous future eras to come shall not be undermined (Munawwar & Ghedira, 2014).

Kingdom of Saudi Arabia (KSA) is considered to be an oil superpower, with around 267 billion barrels of proved oil reserves which is about 16% of total world share in 2016, and just behind USA. It is also the second biggest petroleum liquid producer in the world pumping around12 million barrel per day. In addition, KSA also holds 5th natural gas proved reserve with 8.3 trillion cubic meters which around 4.4% global total reserve, just behind Russia, Iran, Qatar and United Sates (Petroleum, 2016). Despite KSA huge oil production, 10% of its daily production goes to domestic usage making the country one of the highest oil consumers in the world. The major cause for this high consumption is correlated to the country's high population growth, rapid urbanization and improvement in the living standard (Aljarboua, n.d.).

1.2 Problem Definition

Kingdom of Saudi Arabia's demand for electricity has been increasing at a quick pace. It has been estimated that the electricity's consumption growth to be between 5–8% annually. It reached around 49GW in 2014 (Jeg & Sa, 2015) and it is expected to grow up to 120GW by 2030 (*Natural Gas and the Vision 2030 Summary*, 2016). The peak load has been growing annually at a rate of 7.86% (2013–2014) and standing at 62,260 MW in 2015. The residential sector constitutes approximately 50% of the total power demand of the country(Jun, 2013). Air conditioning and refrigeration section are the leading cause for elevated electricity consumption in residential area. In recent years, the government has recognized that the current energy consumption rate is not sustainable on the long run (Akhonbay, 2012). Therefore, Saudi's authorities have been trying to mandate their energy sector. The kingdom is planning to introduce several renewable energy (RE) technologies in the near in order to reduce its dependence on fossil based energy production. In 2032, about one third of the kingdom's energy need is anticipated to come from renewable energy such solar energy and wind energy, geothermal and biomass energy sources(IRENA, 2015).

Since KSA has high solar radiation, solar technologies are the most convenient type RE for the country. The average annual solar radiation with direct normal irradiance (DNI) in the country reaches around1800 kWh/m2 (Zell et al., 2015). Furthermore, KSA is sparsely populated, leaving large dessert area inhabited. Hence, it could be utilized to harness solar energy by employing variety solar energy technologies. Since 1970^{th} in KSA, numerous researches have been done on solar energy technology. There have been several attempt to evaluate both technical and economic aspect on photovoltaic system. Most of the study concentrates on large scale PV system rather than small residential application.

1.3 Objective and Limitation of the Study

The primary objective of the study is to examine the cost effectiveness of residential Photovoltaic (PV) system in the Kingdom of Saudi Arabia, in particular Jeddah city. Since the country provides high oil subsidy, traditionally electricity generated by burning fossil fuel has been cheaper than electricity produced by renewable energy sources. In addition, the capital cost of PV technologies have been more expensive than conventional electricity generators. However, in recent years PV price have been declining, as result PV technology has become more financially competitive in the energy market. The present study attempts to evaluate the financial feasibility of grid attached residential PV (GCPV) system under several financial scenarios. It has been assessed for three different PV capacity. RETScreen software and Microsoft have been employed to conduct the study.

The present thesis concentrates on residential sector (excluding commercial, and industrial sectors). Also, PV system are categorized into grid-connected system and off-grid system. However, the current work concern mainly with grid-connected PV system. The analysis period assumption is based on economic factor rather than service life of the proposed PV system.

1.4 Thesis Organization

The present thesis is categorized into seven main chapters. The first chapter gives a general background about energy statues. The second chapter presents a brief outline of the solar energy worldwide interest growth, in particular in Saudi Arabia and provide background information necessary to understand the issue involved in the development of energy sector. The third chapter discusses the case study selection, load profile, PV parameter and description. The fourth chapter explains how grid-connected photovoltaic system works for residential application. The fifth chapter presents methodology used to carry out the analysis and provides a systematic description of the case studies. The sixth chapter identifies the main outcome of the examined system. It analysis the case studies and reflect upon possible direction to be taken in the future. The seventh chapter sums up what have been discussed throughout the study, and provide suggestion and recommendation for further studies.

Chapter 2

LITERATURE REVIEW

2.1 Presentation

Utilizing of sustainable power source, which is one of the key preservation strategy in the Kingdom of Saudi Arabia. It offers an incredible favorable position to the country. Since the nation is honored with abundant sunlight, the Kingdom has a choice to minimize its domestic oil consumption and CO_2 footprint. Among the middle- eastern countries, Saudi Arabia became the first gulf country to realize the potential of solar energy. Hence, since 1960th there have been extensive research and development in KSA targeting solar energy application (Almasoud & Gandayh, 2015a). The review uncovered that a decent endeavor has been led to every way i.e. estimation solar radiation, technical, economical investigation, hypothetical displaying and model improvement of sun powered gadgets. The review proposed that more effective, systematic approach should be considered before advancing into development of sun powered energy system in Saudi Arabia.

2.2 Historical Development of Solar Energy

In 1839, A.E. Becquerel became the first person to observe certain materials that produce electric current when they are exposed to light, which is called "photovoltaic Effect" (Treble, Sc, & Eng, 1978). Four decade later, R. Adams and W. Day found the impact of photovoltaic in selenium material (Green, 2002). In spite of a great deal of advances made in solar cell for the next half century, it wasn't until 1950th that solar cell started to emerge at acceptable efficiency rate for electrical production(Hoogwijk, 2004). Oil crisis in the seventies, pushed many developed countries to look for alternative energy source. Hence, large solar energy projects and studies were well funded by governments in order to develop and commercialize energy technologies. Be that as it may, this prime advance of solar oriented industry of the 1970s and mid 80s were stopped in the next decade because of the sensational decrease in oil costs and an absence of political desire on alternative energy (Timilsina, Kurdgelashvili, & Narbel, 2012). Luckily, solar energy development markets have recouped its energy since mid-2000, demonstrating a promising result. The worldwide aggregate limit of sun powered based power era establishment has expanded to more than 40 GW before the finish of 2010 from practically unimportant volume in the previous decade (Ahmed et al., 2011).

There have been an impressive technological progress of solar energy in the past few years. While most early technologies focused in advancements of small size photovoltaic (PV) cells, as of late developing number of sun oriented concentrated power (CSP) and extensive scale PV have brought their piece of the overall industry up in the vitality generation division. In the course of the most recent 3 decade, the cost of sun based vitality innovation have fallen generously. For example, the cost of modules has dropped from around $27,100/kW in the early1980th to around $3900/kW in 2007; the cost of establishment of a PV framework tumbled from $16,500/kW in 1992 to around $5000/kW in 2010(IEA, 2007). The quick development of the sun based vitality market can be credited to various strong approach activity, the expanded unconventionality of petroleum product costs and the antagonistic natural effect of non-renewable energy sources, uniquely ozone depleting gases such as CO^2, NO_2 and SO_2.

2.2.1 Saudi Arabia's Involvement in Solar Energy

Saudi Arabia's solar energy market have been expanding since 1960^{th}. France were the earliest to introduce photovoltaic (PV) system to in KSA. They installed a small PV system in Madinah Airport (Badran, 2001). In 1969, several mini-scale university projects and research activities were carried out on solar energy. Nevertheless, it wasn't until 1977 that a considerable progress started to take place when King Abdul-Aziz City for Science and Technology (KACST) established a structured research center to the development renewable technology. In the last quarter century, Energy Research Institute (ERI) department at KACST has administered a vital research and development projects which contribute to further understanding of solar energy application in the Kingdom (Jamal & Engineering, 2016).

There have been several joint programs carried out in the field of solar energy by ERI and international organizations. KSA and the USA signed a joint contract in the end 1970^{th} to collaborate in the domain of solar energy. The joint collaboration agreement was known as Saudi -United States Program for cooperation in the Field of Solar Energy Program (SOLERAS). The Solar Energy Research Institute (SERI) operated as key player in the partnership between the two countries (Tlili, 2015). "SOLARES" examined technical and economic affairs regarding solar energy. One of the major projects to be achieved were installing two stand-alone PV system in two traditional Saudi rural area which hadn't been linked to the central electric grid. The projects were attained in 1980, where Al-Jubaila and Al-Uyaina became the first two villages to be supplied with solar power. Among Gulf Cooperation Council (GCC) countries as well as in the whole Arab nations, Saudi Arabia was the earliest country to initiate research and development in attempt to electrify rural area without relying on central grid system by deploying solar technologies. After almost two decade research and development, SOLERAS finalized its finding in 1997 (Badran, 2001). In 1980th, Saudi Arabia started to take part in more dynamic way to deal with sun oriented power improvement after the initial trials project that took place earlier to develop solar (Munawwar & Ghedira, 2014).

In 1986, a joint action were signed between Federal Republic Germany and Saudi Arabia to develop and exhibit sun based hydrogen Production (HYSOLAR) and in addition work as power source. In 1991, the first stage of project was concluded, concentrated mainly on inspection, exploration and boosting of hydrogen production technologies, while in the second stage, hydrogen utilization technologies were more emphasized (Alosaimy, Hamed, Balabel, & Mahrous, 2013). The research endeavor in the SOLARES program was an essential collaboration between both the countries. Around $10 million US dollar were invested into the program by both Saudi Arab National base for Science and Technology (SANCST) and The US division of Energy and the, while Research Institute (SERI) in Golden, Colorado, was put in charge of it. The cooperation programs were targeted towards projects that had bilateral benefits to the both pledged participant. The project mainly focused on the application of solar energy such as electricity production, water desalination and other applications (Alawaji, 2001).

In 1994, Saudi Atlas was established to measure actual solar radiation as joint effort between ERI and National Research Energy Laboratory (NREL) in the USA, after it had been realized the importance obtaining solar radiation data. There were twelve cautiously chosen sites from all over the kingdom. In order to obtain an accurate and reliable data, all measurement gadgets were calibrated every 6 months and all of these terminal were linked to a midway data base (Alawaji, 2001). In such manner, it has been wound up to the understanding the convenience of precise surface sun based radiation flux estimation. In addition, the finding affirmed the satellite based radiation flux recording. The information accessible to bolster approval of satellite information comes about identified with the NASA Mission to Planet Earth constituent of the Earth Science Enterprise. Earth Observing System (EOS) venture analyze long haul atmosphere course depended on estimations from EOS Terra Platforms. The information available for the Saudi Network stations was quality assessed and recognized in light of the utilization of a solitary composite adjustment component for the pyrometer situated at each station preceding 2000. Be that as it may, the worldwide even information posted for all of 1998 to date has been changed for the cosine reaction of the individual pyrometer conveyed at each station in in the mid of 2000(Hepbasli & Alsuhaibani, 2011).

In 2008, Saudi's oil minister, Al-Naimi, designated that for the kingdom to fully benefit from its oil industry, it is crucial to enhance its competence in solar energy. Al- Naimi suggested that in the next 30-50 years, Saudi Arabia is hoping to become a major solar energy hub and a megawatt exporter (Al-Ghabban, 2013). In 2010, The Kingdom of Saudi Arabia has started installing water desalinization plant powered by solar system. The primarily move was to grant an important push to the progress of solar energy facility in the kingdom(Munawwar & Ghedira, 2014).

2.3 Solar Energy Studies in Saudi Arabia

PV system has been integrated to Saudi Arabia's electricity network starting from the beginning 1980th. Salim and Eugenio (Abbas A. Salim, 1989) evaluated the execution of a 350 kW PV power system which was built in 1981. In their report, the system procedure in design, fabrication and installation phases, while performance stage was described in more detail, incorporate the challenges and malfunction noticed throughout the 7 years examination time. Also the study pointed out that the concentrator photovoltaic (CPV) system considered to be the biggest in worldwide at that period. The system had performed exceptionally well and had exceeded most of its design objective. It was stated large concentrator PV system were reliable sources of energy based on their long term performance assessment. The examined framework had been kept running in different modes, which comprise of independent and integrated with diesel generators. The framework was connected to the utility and worked in the peak control mode. It was expected that sooner rather than later, the framework would have the extra ability of being straightforwardly coupled to a 350 kW electrolyzer to deliver hydrogen.

Huraib et al. (Huraib, Hasnain, & Alawaji, 1996) reviewed the solar energy projects which were carried out in Saudi Arabia throughout 70^{s}, 80^{s} and 90^{s}. The research was based on the major RD&D exercises at Energy Research Institute (ERI), King Abdulaziz City for Science and Technology (KACST) in the field of solar technology. Several solar technology had been examined such Photovoltaic, solar water heater, solar water purification and others.

Harbi et al. (Al Harbi, Eugenio, & Al Zahrani, 1998) studied the performance photovoltaic-thermal in KSA. It was found in the study, average solar irradiation to be around $1.2kW/m^2$ in summer. In winter time the average solar irradiation for most region was found around $1kW/m^2$. The PV modules were noticed to have more noteworthy effectiveness in cold season than mid high temperature season. Due to high operating temperature of the solar cells in summer time, the PV system were showed to a decrease 30% of their efficiency.

Al-Ajlan et al. (Alajlan, Smiai, & Elani, 1998) conducted an investigation on effective methods toward electrical energy conservation in KSA. The paper focused in three main conservation mechanism; efficiency of electrical apparatuses, vitality protection in structures, rising open mindfulness and data. It was proposed about half of the yearly electricity demand from building can be cut off by simple adding proper insulation. Therefore, the need to install new power stations to meet up with the demand could be reduced in KSA. It has been found in the study, if conservation measure implementation could reduce around 25% of household electricity consumption.

Al-Ajlan et al. (Al-Ajlan, Al-Ibrahim, Abdulkhaleq, & Alghamdi, 2006) look into the major challenges facing KSA in adopting sustainable energy policy. The core discussion of the study revolve around technical, financial and socio-economic issued which prevented the country from introducing a better energy policy measures. It was pointed out that the kingdom's peak electricity demand reached nearly 24GW in 2001 and it is expected to reach around 60 GW by 2023. It was also suggested if energy conservation measure is implemented, additional energy demand is predicted to be decreased by average 5.5% which equivalent to 3.5GW. This could approximately save the kingdom about $1.5–3.0 billion over the next 20 years. Furthermore, if just cooling system are assessed, it is speculation is between o 4100–550MW energy could be saved.

Taleb and Sharples (Hanan M. Taleb & Sharples, 2011) argued that most KSA residential building lack water and electricity efficiency measures. They studied a common KSA residential building. It was observed adding a little modification in the building, would improve the energy efficiency to great extent. In their study work, several conservation mechanism were suggested such improvement thermal insulation, efficient glazing, shading gadgets and fitting fluorescent lighting. It was proposed water preservation mechanism comprises the utilization of low-stream taps, productive clothes washers; and the establishment of a dark water framework. The study claims around 32.4% energy consumption could be minimized if conservation is used. In addition, it was estimated around 32 tons of CO_2 decrease and around 55.4% reduction in water utilization rates.

Baras et al. (Baras, Bamhair, Alkhoshi, & Alodan, 2012) studied the obstacle and chances in the area of solar energy in the kingdom of Saudi Arabia. They found out high temperature of PV could lead to 17% power out reduction in the Riyadh region. However, it was suggested a proper implementation of cooling mechanism would in increase significantly the PV plant power plant efficient. In addition, the paper also demonstrated the financial benefits of the hybrid solar thermal and conventional seawater desalination. It was estimated around $85 million could spare the Kingdom in the water destination sector.

Rehman and El-Amin (Rehman & El-Amin, 2012) evaluated a stand-alone photovoltaic system. The experimental study attempts to evaluate the performance of an off-grid photovoltaic power plant (5.28 kW capacity) installed at King Fahd University of Petroleum and Minerals, Dhahran Saudi Arabia. The analysis demonstrated reduction on the plant's power out due to surface dust collection and high temperature issues. In addition, the PV system execution was analyzed by DC execution proportion variety with PV surface temperature. Energy generation from the PV was observed to be diminishing with expanding PV board surface temperature between July and August. This is due to high weather temperature in those months. The DC execution proportion additionally demonstrated a diminishing course with expanding PV module surface temperature. It was observed also, the maximum energy yield was noticed at around 35°C of PV panel surface temperature.

Hasan and Arif (Hasan & Arif, 2014) studied the effect encapsulate material on the PV module service life. The work examines the correlation of the diverse encapsulants and picking the ideal one in light of different properties, for example, transmittance, UV sturdiness, electrical protection, water vapor transmission rate and price. The basic existence of PV module is additionally analyzed by utilizing these encapsulants. The review utilized beforehand created life-expectation and warm execution system to analyze the effectiveness and life of PV module for each exemplify sort. It was discovered Ionomer to be an ideal encapsulant for PV module, under Jeddah, Saudi Arabia condition.

Ramli et al. (Ramli, Hiendro, Sedraoui, & Twaha, 2015) attempted to identify the ideal photovoltaic module and inverter capacity for a grid-linked PV framework. They considered the constraints of unfulfilled load, surplus power, portion of inexhaustible power, greenhouse gases (GHG) emanations rate are considered so as to gauge ideal capacity of grid-linked PV framework. It was suggested, if the inverter size is reduced by 68%, overall cost of the PV system could be decreased substantially. The result showed that the ideal framework plan, with neglected load and surplus power of zero for supplying power to Makkah with a highest demand reaching at 2200 MW. It was estimated that the ratio between 2200 MW PV capacity and 2200 MW inverter volume.

Khan et al. (Azhar Ali Khan & Muhammad, 2016) explored potential of solar energy at three different location of Saudi Arabia: Riyadh, Mecca and Sharura. It was calculated for direct normal insolation in one-axis tracking surfaces with rotation about

East–West (EW) and North–South (NS) horizontal axes was calculated, a two-axes tracking surface and a fixed surface tilted at the latitude of each sites and facing south The outcomes showed the maximum and minimum solar radiation are observed at the two-axes tracking surface and EW horizontal axis tracking surface, respectively.

2.3.1 Feasibility studies of PV System

There has been numerous studies published investigating the comparative cost effectiveness of PV with regard to conventional power generation system. Rehman et al. (Rehman, Bader, & Al-Moallem, 2007) used monthly solar radiation and daylight period information to evaluate the dissemination of radiation and daylight length over Saudi Arabia. In addition, they conducted an evaluation to explore the energy output and economic viability of a hypothetical 5000kW grid-linked photovoltaic power system for electricity production. RETScreen software was employed to assess energy generation and economic feasibility of the PV power plant. They noticed that the solar radiation fluctuate between 1.63MWh/m2/yr. and 2.56MWh/m^2/yr. at Tavuk and Bishar respectively, while the average stayed as 2.06MWh/m^2/yr. Sunshine duration was noticed on average of 9h per day. The overall results showed that solar radiation vary between 211.4kW/m^2 to 319.2 kWh/m^2 with an average of 260.80 kWh/m2. Annual mean energy production from the PV power plant changed between about 8196 and 12,372MWh while the mean remained around 10,077 MWh/yr. It was found that the maximum and minimum IRR at Bisha and Tabuk were 16.7% and 10.7% respectively, while a mean IRR value of 13.5% was obtained for any location. From environmental perspective, it was estimated around 8182 tons of greenhouse gases emission could be avoided.

Shaahid and El-Amin (Shaahid & El-Amin, 2009) assessed the technical and cost effectiveness of hybrid PV–diesel–battery power systems for off-grid rural application. The month mean daily global solar incident is estimated to fluctuate between 3.05 -7.4 kWh/m2 depending on season. They employed HOMER software to conduct the study. It was estimated from result, the optimal capacity of the hybrid system to be around 2.6 MW PV, 4.6 MW diesel system and one hour worth battery. Also, it was found the cost of producing energy from the proposed system to be 0.18$/kWh under assumption fuel cost of 0.1$/L. It demonstrated as PV capacity increase, the working duration of diesel generators will decline significantly. Meanwhile, the study has emphasized on unfulfilled load, surplus electricity production, proportion energy savings and cutting back of greenhouse gas (GHG) for several scenario. The reduction in GHG by employing the proposed hybrid system was found to be around 25% in contrast to the diesel-only power generation system.

Taleb and Al-Saleh (H.M. Taleb & Al-Saleh, 2010) attempted to study the financial feasibility of utilizing solar PV technology for upcoming new residential houses in KSA. The study aimed to review the possibility of employing the PV technology to supply 1/10 of the electricity consumption in a typical Saudi's house that will be constructed over the period 2010-2025 in the country. They employed RETScreen software for the cost analysis. The study indicated that a considerable amount of financial and health can be gained. Payback period' was estimated to be around 11.8 years at the 2010 and gradually falls down to around 3.7 years due to the decline PV capital cost by 2025. They predicted that between 3.8 and 2.3 billion tons of CO_2 could be reduced depending on different energy management scenarios.

Mutwali and El-Hawary (Mutwali & El-Hawary, 2013) examined the cost effectiveness of residential gied-connected photovoltaic (GRPV) system under the kingdom of Saudi Arabia's condition. In their work, they carried out the investigation by using HOMER software. The major objective of the research was to identify the financial prospect of small-scale Photovoltaic for residential application. The study suggests GRPV could be an alternative energy source for the kingdom if energy policy and PV cost are improved. It was also estimated that 52 -460 barrels could be saved from residential building over the next 25 years (2-18 barrels annually), if GRPV system are implemented. Moreover, despite GRPV system high initial capital cost, it could reduce CO_2 emission footprint and save annual electricity demand from conventional fossil fueled power generation.

Almasoud and Gandayh (Almasoud & Gandayh, 2015b) asserted that the PV technology could be financially competitive with hydro-carbon based energy source if indirect cost such GHG reduction and human wellbeing is considered. In the study, four scenario were evaluated to examine the relation between conventional energy generators and solar PV technology amid 2010–2020: First situation, in respect of electricity cost from conventional fossil fueled power generators, which is 0.15 SR/kWh versus PV plant generated energy cost. This situation showed that the mean cost of solar energy won't be focused with that of ordinary frameworks before 2020; Second situation B considered the non-government-backed energy cost period, which meets 0.45 SR/kWh versus solar energy (SE) frameworks. This cost will be focused with that of SE by 2011; Third situation, expected the utility’s supported cost of ordinary time expenses versus SE. The administration supported cost of ordinary timw with expansion backhanded expenses is evaluated to be around 0.32 SR/kWh and with PV extends by 2015, or by 2020 in the most pessimistic scenario circumstance of high SE costs; Last scenario considered the unsupported price of conventional generation plus indirect costs which is estimated to be around 0.62 SR/kWh in comparison to solar energy cost. This last case showed that solar energy is more cost-effective than conventional energy sources (2010). In addition, it was suggested that the third scenario is the most suitable, since it is similar to the energy policy of Saudi Arabia at the time.

Ramli et al. (Ramli, Hiendro, & Al-Turki, 2016)analyzed the potential of hybrid wind and solar energy system in the west drift zone of KSA. The review concentrated on the energy generation. In addition, the cost of energy from such system was reviewed. It was evaluated for a system where 50% of the energy comes from wind turbine and the rest 50% comes from photovoltaic (PV) system. It was considered the yearly mean solar energy and wind speed to be 6.0 kWh/m2/day and 3.50 m/s, respectively. They used MATLAB and HOMER to study both technical and feasibility analysis of the system. The cost solar energy was assessed around $0.064/kWh which less than the cost of wind energy $0.15/kWh. The energy cost of the mixture framework is to a great extent ruled by wind turbine and battery costs.

Chapter 3

BACKGROUND TO THE CASE STUDY

3.1 Location of the Case Study: Jeddah City

Jeddah city was selected as case study location for the present study. The city is situated on the shore of Red Sea and it is the second largest city in Kingdom of Saudi Arabia. It is also the biggest city in Makkah Province, the biggest marine port on the Red Sea. The chosen residential building site is situated in Jeddah City (latitude 21 and longitude 39), which is quickly developing business city. Jeddah is thought to be a critical portal to the Islamic urban communities of Makkah and Madinah. Residential building that has been selected at a location, where a large construction movement has been seeing in late years.

Figure 1: Jeddah, Saudi Arabia Location (Hepbasli & Alsuhaibani, 2011)

When leading an examination on the PV system, it is valuable to consider the weather conditions of the project. The weather condition in Jeddah between June-august is described by extraordinary high temperature, which have a tendency to be insufferable towards the finish of the season. In winter period Jeddah has a weather condition characterized by average temperature, less humidity and some rain falling from time to time. Itemized data on temperatures and the somewhat high sun powered radiation levels in Jeddah during the time are given in Fig. 2. These found the middle value of levels indicates to daily information for every hour of every month (Hanan M. Taleb & Sharples, 2011).

	Unit	Climate data location	Project location
Latitude	°N	21.7	21.7
Longitude	°E	39.2	39.2
Elevation	m	17	17
Heating design temperature	°C	16.2	
Cooling design temperature	°C	39.6	
Earth temperature amplitude	°C	13.1	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		23.0	60.7%	4.53	96.6	3.7	23.7	0	403
February		23.1	60.3%	5.32	96.5	3.9	24.7	0	367
March		24.9	59.7%	6.18	96.3	4.0	26.5	0	462
April		27.8	56.9%	6.88	96.1	3.8	29.5	0	534
May		30.1	55.9%	7.17	95.9	3.7	32.8	0	623
June		31.0	57.8%	7.12	95.7	3.8	33.9	0	630
July		32.5	53.1%	7.04	95.6	3.6	34.2	0	698
August		32.5	59.1%	6.53	95.6	3.7	34.0	0	698
September		31.4	66.7%	6.17	95.8	3.4	34.0	0	642
October		29.7	66.7%	5.56	96.2	2.9	31.8	0	611
November		27.2	65.2%	4.60	96.4	3.1	27.8	0	516
December		24.7	62.6%	4.15	96.6	3.5	24.8	0	456
Annual		28.2	60.4%	5.94	96.1	3.6	29.8	0	6,638
Measured at	m					10.0	0.0		

Figure 2: Climate Data Jeddah, KSA (Heat, n.d.)

The first step into simulation procedure is to select the intended case study location. In the present thesis Jeddah (specifically Al-Zahraa district) have been selected. Climate data location was referenced from NASA climate database provided by the software. RETScreen. The software gets atmosphere information from ground checking stations and additionally from NASA's worldwide satellite database. NASA climate data was developed based on 22 years of data collection. Solar irradiance values are inferred using satellite observations of the atmosphere and Earth's surface. In the event that atmosphere information is not accessible from a particular site, information is then given from NASA's satellite (Ramli et al., 2015).

3.2 Load Profile

The load profile within the building was adapted from reference (Hanan M. Taleb & Sharples, 2011). The power consumed inside the residential building evaluated for an entire year (8760 hours), utilizing genuine climatic information. The yearly normal power utilization for the building was approximated at around 24,000 kWh every year. The graph demonstrates outstandingly high energy consumption rate in comparison to other countries with comparable climatic conditions. It worth to consider that the electricity demand varies with seasonal weather change throughout the year as can be seen from Fig. 3.

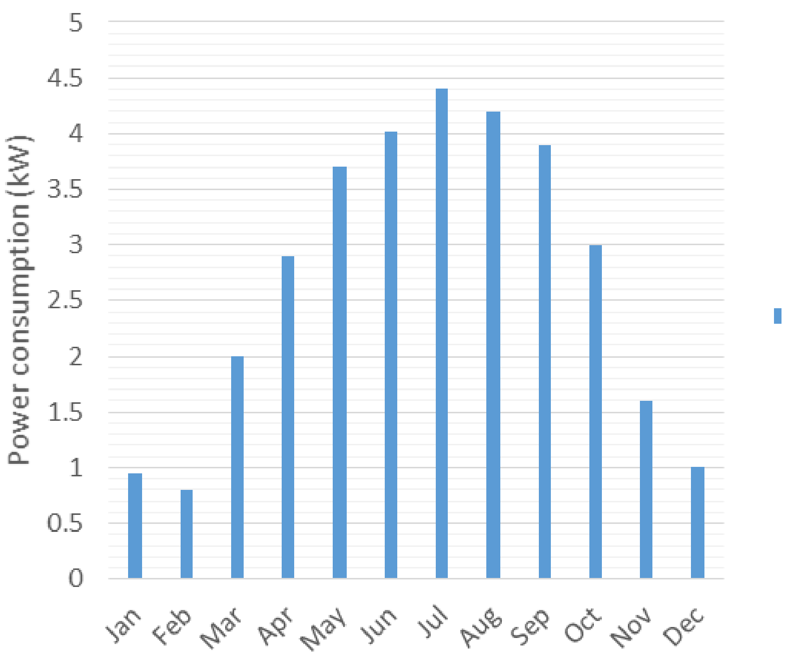

Figure 3: Electricity Consumption per Household in Jeddah (Hanan M. et al., 2011)

3.3 Electricity Tariff

At the outset of a clean energy project, certain information about energy usage is required. First, it was determined the types of fuel and volume which is consumed. Here, electricity supplied by the grid is considered to be generated from fossil fuel.

Second, it was identified the equipment that converts fuel into something more useful energy.

The Saudi power era is intensely depended on fossil fuel, with unrefined oil representing about 30% of power generation, diesel (12%), overwhelming fuel oil (8%) and flammable gas giving the rest 50%.However, since the fuel price highly subsided by the government, Saudi electricity production Company pay only a fraction of the real international oil and gas price.

The average residential electricity tariff for 1-2000kWh consumption rate is around 0.013$/KWh, it is very cheap in contrast to average international price of electricity, which is around $0.1/Kwh. In addition, natural gas and crude oil (which accounts more 80% total electricity production fuel) costs Saudi electricity producers around $\$0.027/m^3$ and $\$0.025/\ m^3$ respectively (Nachet & Aoun, 2015). Detailed electricity tariff is shown Appendix C.

3.4 PV Panel Specification

The PV panel is the main component of the entire PV framework. In the present review we chose the monocrystalline silicon NT-185U1 PV Module which is produced by Sharp Company. We selected this model due to two main reasons: It is widely available in the market: secondly, it has relatively good efficiency comparing to other mono-silicon solar panel. The specification of the module are outlined in Table 1 and more specification of the model can be found in Appendix A. The proposed PV panel has peak power output and efficiency around $185W_p$ and 14.5% respectively.

Table 1: Photovoltaic module Specification [55]

Item description	Item specification
Maximum power (Wp)	185
Open-circuit voltage (V)	44.9
Short-circuit current (A)	5.75
Voltage at point of maximum power (V)	36.2
Current at point of maximum power (A)	5.11
Module efficiency (%)	14.23
Length (mm)	1575
Width (mm)	826
Depth (mm)	46
Weight (Kg)	17
Operating Temperature (°C)	-40 to 90

3.5 Power Inverter Specification

There are several factors which influence in determining power inverter: efficiency, the capital cost, and life service of the inverter gadget. In this study, we selected I-P-HPC-2000W model from I-panda brand (see Table 2). We have selected the model due its high efficiency (95%). Detailed specification are presented in Appendix B.

Table 2: Power inverter specification (*Controller I-P-HPC series*, n.d.)

Inverter Model (HPC-200W)	Specification
Output Power	2000w
DC Input Voltage	24V/48V
AC output Voltage	100/110/220/230/240V

3.6 PV System Input Parameters

RETScreen software employed to estimate annual total energy out and CO_2 reduction from the proposed PV system. Several input parameters are required to simulate the proposed model. Therefore, as demonstrated in Table 3, input parameters were identified in this study. Solar tracking mode is considered to be fixed. The PV panel is assumed to be tilted at optimal angle of 23^o facing south (Azimuth angle $=0^o$). This assumption was based on previous study done by the reference (Ramli et al., 2016). We run simulation for 5kW, 8kW and 10kW PV system capacity. PV system's efficiency in Saudi Arabia is greatly affected due to high temperature and occasional dust storm incident. Hence, we assume the 10% and 5% miscellaneous losses for PV module and inverter respectively. The overnight PV cost (module, installation, and wiring cost) and inverter cost were assumed to be \$2400/kW and \$400/kW respectively.

Table 3: Parameters of the PV system

PV capacity	5kW	8kW	10kW
Solar panel			
Efficiency %	14.2	14.2	14.2
Solar collector area (m^2)	35	56	70
Miscellaneous losses %	10	10	10
Inverter			
Efficiency %	95	95	95
Capacity (KW)	2	5	7
Miscellaneous losses %	5	5	5

3.7 Financial scenarios:

- Scenario A: the current electricity price is considered and the funds are coming solely from the house owner. The contribution of the owner is 100% from the total capital invested with no debt accounted. The electricity produced by grid-connected PV system is consumed internally and surplus electricity is sold to the grid at a rate of 0.10$/kWh. The financial input data are presented in the Table 4. The electricity cost from the grid is assumed to be constant at a rate of 0.013$/KWh for next 20 years.
- Scenario B: the capital of investment is the same. The contribution of the house owner is 50% and while the rest 50% is assumed to be funded by the government or utility company as incentive. The proposed system's electricity price is assumed to be same as the case A as seen in Table 5.
- Scenario C: The house owner receives payment for every electricity produced by PV system known as "feed in tariff". It is assumed the feed in tariff rate to be 100$/MWh. In other word, for every kWh electricity produced by PV system, the owner is paid 0.1$ by utility company. The financial parameter for this Scenario is presented in Table 6.

Table 4: Financial parameters (Scenario A)

PV Capacity	5kW	8kW	10kW
Financial Parameter			
Discount rate %	3	3	3
Inflation ratio %	2	2	2
Project life (yr.)	20	20	20
Debt ratio %	0	0	0
Initial costs			
PV system ($)	12,000	19,200	24,000
Inverter ($)	800	2000	2400
Annual Costs			
M&O costs ($)	40	40	40
Fuel costs ($/kWh)	209	160	130

Table 5: Financial parameters (Scenario B)

PV Capacity	5kW	8kW	10kW
Financial Parameter			
Discount rate %	3	3	3
Inflation ratio %	2	2	2
Project life (yr.)	20	20	20
Debt ratio %	0	0	0
Initial costs			
PV system ($)	12,000	19,200	24,000
Inverter ($)	800	2000	2400
Annual Costs			
M&O costs ($)	40	40	40
Fuel costs ($/kWh)	209	160	130
Incentives ($)	6400	10600	13400

Table 6: Financial parameters (Scenario C)

PV Capacity	5kW	8kW	10kW
Financial Parameter			
Discount rate %	3	3	3
Inflation ratio %	2	2	2
Project life (yr.)	20	20	20
Debt ratio %	0	0	0
Initial costs			
PV system ($)	12,000	19,200	24,000
Inverter ($)	800	2000	2400
Annual Costs			
M&O costs ($)	40	40	40
Fuel costs ($/kWh)	209	160	130
Feed in tariff (($/kWh)	0.1	0.1	0.1

Chapter 4

PHOTOVOLTAIC SYSTEMS

4.1 Overview

The power generation from PV system is developing at fast pace. The increase of PV efficiency and improvement in manufacturing technology are driving down the costs. The interest for sustainable power source is expanding quickly, consequently driving this advancement forward. This section presents the proposed of photovoltaic framework. In addition, it explains the solar radiation and its significance on solar technology.

4.2 Solar PV System

PV system converts solar energy into electrical energy via photovoltaic cell. Usually, PV cells are linked in chain to form PV cell string to achieve high voltage. Several strings are attached to create a PV panel. PV cells generate DC voltage, therefore Inverters are employed to convert DC voltage into AC. PV output is proportional to the solar radiation received and the competence of the PV panel. In many situations, PV systems are linked to central- grid connected, where PV system supply all or partially its power to the electrical grid, so PV system is fully utilized. Proper scheduling between PV and other conventional power plant can ensure full uninterruptible power supply. Residential Grid-connected PV system as shown in figure 4, the solar array is mounted on the rooftop. Residential, grid-connected rooftop systems which have a capacity to meet the load of the consumers and to supply surplus electricity to grid. The excess power feed to the grid is re-supplied to other consumers by grid utility.

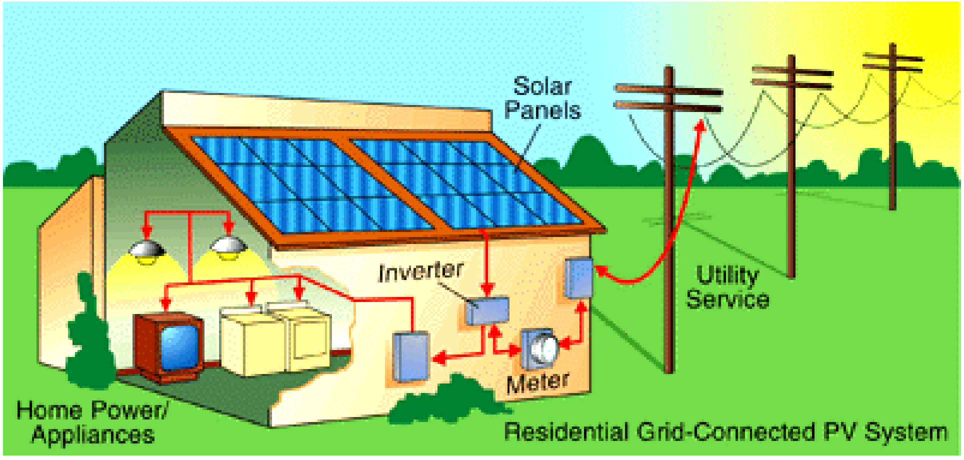

Figure 4: Grid-Connected PV System as shown in Ref. (Sagani, Mihelis, 2017)

The feedback is done via a metering gadget to control power transferred to the grid. If Photovoltaic power generation is not as much as normal utilization, the shopper will bear on obtaining grid power, however a lesser sum than beforehand. For the situation, photovoltaic power generation incredibly surpasses normal utilization, as result the energy generated created by the PV array will be much in abundance of the request. Consequently, the abundance power can create income by pitching the surplus energy to the grid at price contingent upon their concurrence with their nearby utility organization. The client is just required to pay the cost of power expended which is not as much as the estimation of power produced. In the event that more power is created than expended, the vitality bill will be a negative number. Moreover, in some cases, the consumer is paid in cash as incentives by the grid operator (Peerapong & Limmeechokchai, 2015).

Interconnection agreement between the consumer and the utility company is required before installing photovoltaic model system. The agreement presents the various safety standards to be followed during the installation of System (Weida, Kumar, & Madlener, 2016).

4.2.1 Solar Cell

Solar cell is the core power conversion unit of a photovoltaic system. It converts light energy directly into electrical energy and mostly are made from semiconductors such as silicon (see fig. 5). Solar cells have much in the same manner as other strong state electronic gadgets for ex. diodes, transistors and coordinated circuits. Usually, a single solar cell power production isn’t large , therefore several cells are connected together to form modules in order to produce greater power output (Bamisile, 2015).

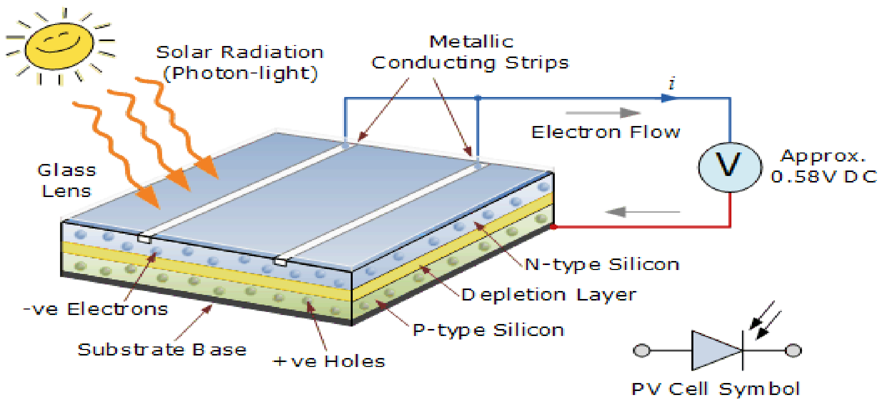

Figure 5: Silicon PV cell taken from Ref. (Mathew, Lim, & Philip, 2013)

In the market, several kind of solar cells exist, however the most widely used category is the silicon based cells. And among silicon cell group, mono-crystalline cell has the highest efficiency. Mono-crystalline atomic structure are situated symmetrically, as result, high efficiency is attained. However it is worth to be noted, the process of manufacturing mono-crystalline cost more than other silicon cell type. In general, Commercial mono-crystalline silicon cells efficiency is between 14 - 17 %. Whereas polycrystalline cell is another alternative silicon cell which cheaper due to less symmetricity and complexity, but the efficiency is around 13 - 15 % (Mathew et al., 2013).

4.2.2 Power Inverter

A power inverter is an electronic gadget that converts direct current to alternating current (AC). Since, Solar panels generate only DC power, inverter is required to convert it to AC power, so that it can be transferred as it is demonstrated in fig 6. The inverter must have the capacity to deal with the normal power level, however should likewise be perfect with the voltage of the supply and load aspect.

Inverters associated with grid-linked are intended to quickly confine from the grid in the case of power blackout. National electric code ought to be stablished to secure conveyance wellbeing in the occasion power goes down. In the event that power is power blackout, the network connected inverter will consequently disengage to keep the energy it produces from making any damage to the grid system.

There are different type of framework associated inverters which are accessible in those days. Depending of the application, inverters may use high-recurrence transformers, low-recurrence transformers, or no transformer by any stretch of the imagination. High-recurrence transformers utilize an automated multi-step system that incorporate changing over the ability to high-recurrence AC and after that back to DC and after that to the last AC yield power (Khalid & Junaidi, 2013).

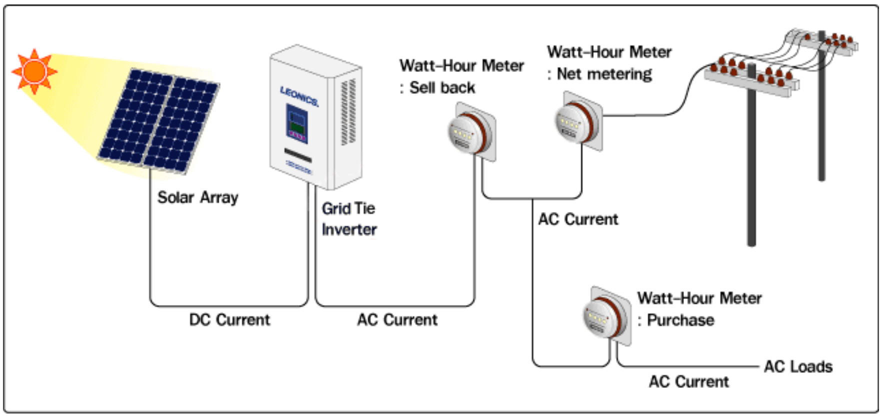

Figure 6: Power Inverter System as explained in Ref. (Dankoff, 2001)

4.3 Solar Insolation

Solar Insolation is the measure of electromagnetic vitality occurrence on the surface of the earth. It is comprised of immediate, diffuse, and reflected radiation. PV cell's assimilation component is defined as the part of sunlight based irradiance episode that is consumed by the cell. The energy of the sun is around 1KW/m2 at high twelve on a cloudless day at the earth equator, on even surface. PV boards can upgrade vitality accumulation by utilizing daylight following framework, however it include additional cost, and require customary upkeep. PV exhibits coordinated toward south in the Northern Hemisphere or toward north in the Southern Hemisphere. The tilt angle of the PV panel from horizontal, can be varied for season to season. However, it is set at fixed optimal angle in the case no tracking system in order to achieve maximum power output during peak electrical demand. Due to of solar flux, soiling, and temperature losses issues, it is difficult to optimize photovoltaic system for a particular region (Zell et al., 2015).

In northern region such as USA, Canada and Europe, solar insolation varies between around 4.1 kWh/m²/day and 6.5 kWh/m²/day (IEA, 2007). A typical photovoltaic installation in the southern regions of Europe and the United States is estimated to produce around 1 $kWh/m^2/day$. In contrast, depending of the location, solar insolation, title angle, a typical 1 kW photovoltaic installation in Australia, the southern latitudes of Europe or United States, may generate between 3.6–7 kWh/day. In the Sahara desert due to high solar insolation, ideally 8.3$KWh/m^2/day$ can be obtained by PV panel at optima angle. The area of the Sahara desert is about 9 million km^2. It estimated 1% of the total area of Sahara desert could supply electricity to the entire global energy demand (Zell et al., 2015).

Chapter 5

SIMULATION FOR ECONOMIC ANALYSIS BY USING RETSCREEN SOFTWARE

5.1 Introduction

This chapter presents the procedure followed in the study. It explains the approaches which were taken to evaluate both energy production and cost effectiveness of the residential PV system in the kingdom of Saudi Arabia. The amount energy production and CO_2 of the system is estimated using RETScreen software (RETScreen International., n.d.). The software is open source given by Natural Resources Canada and has been created with the commitment of a few specialists from government, industry and the scholarly community. It was created in a joint effort with NASA, REEEP, the United Nations and the World Bank.

RETScreen is well-recognized renewable energy software throughout the globe. It is very effective tool to study the feasibility of a potential renewable energy project. The software allows the user to model, simulative and analysis different type renewable technology. It considers the innovation, business, and fund of clean vitality in an incorporated manner, which aids in creating suitable and fruitful approaches. RETScreen software is employed by many research centers and universities all over the world. It has been utilized by more than half millions users worldwide, instructed in more than 800 colleges and schools, accessible in several languages (Heat, n.d.).

5.2 Simulation Procedure

The section describes the simulation procedure in RETScreen software. In the present study, RETScreen4 version was employed to carry out the simulation. It can simulate for several renewable energy technologies such solar energy, wind turbine, fuel cell, photovoltaic, solar thermal power, wave power, and others. However, this section demonstrets how residential grid-connected PV model is simulated in RETScreen4 for Jeddah, Saudi Arabia location.

5.2.1 Start Interface

The first step in RETScreen4 software is to specify project information and site reference conditions (see fig. 7). In The section project type, technology, and grid type are specified. In addition, selected location climate data are determined. RETScreen provide climate data for several site around the world. This section is critical, since further steps rely on it.

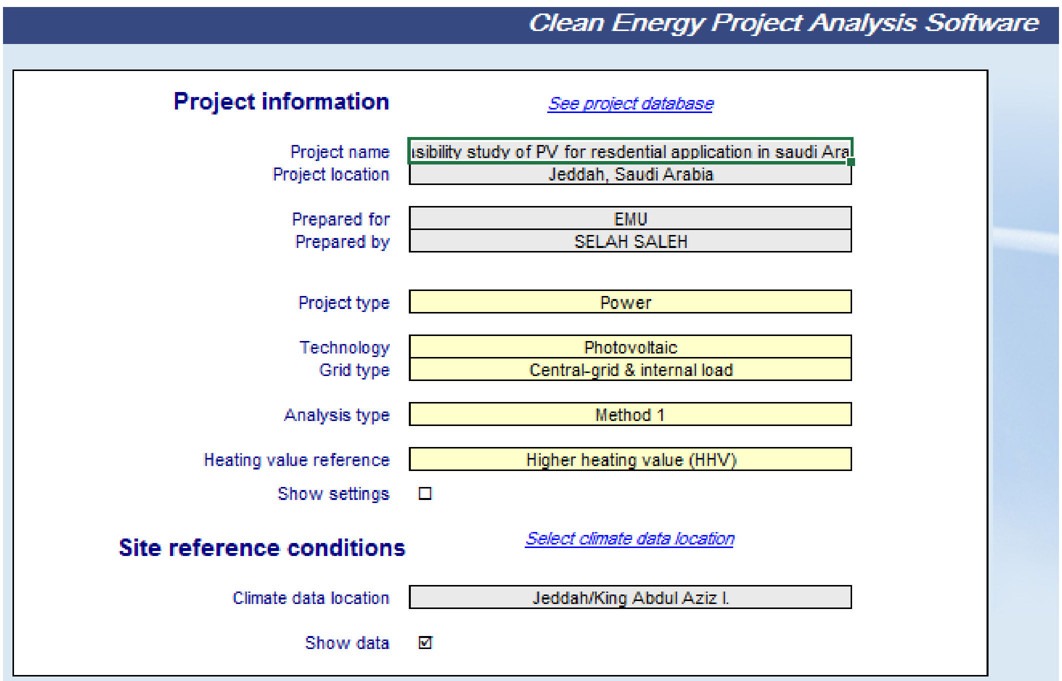

Figure 7: Start Interface in RETScreen

5.2.2 Identifying Load

In this part monthly electricity load per presidential building is specified. In addition, the electricity rate in the base case is identified as shown in fig. 8.

Power project	Unit	
Base case power system		
Grid type		Central-grid & internal load
Base case load characteristics		
Month		**Power gross average load kW**
January		1
February		1
March		2
April		3
May		4
June		4
July		4
August		4
September		4
October		3
November		2
December		1
System peak electricity load over max monthly average		22.0%
Peak load - annual		5
Electricity	MWh	24
Electricity rate - base case	$/kWh	0.013
Total electricity cost		$ 314

Figure 8: Load Profile Specification in RETScreen

5.2.3 Energy Model

The third requires to specify solar tracking mode, slope, and azimuth angle of the solar panel (see fig. 9). Moreover, electricity export rate to the grid in the case surplus electricity is produced determined. In addition, PV and inverter model specification are selected.

Analysis type		○ Method 1
		⦿ Method 2

Resource assessment

Solar tracking mode		Fixed
Slope	°	23.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	4.53	5.67	100.0	0.007
February	5.32	6.20	100.0	0.007
March	6.18	6.61	100.0	0.008
April	6.88	6.74	100.0	0.008
May	7.17	6.58	100.0	0.008
June	7.12	6.33	100.0	0.008
July	7.04	6.35	100.0	0.008
August	6.53	6.23	100.0	0.008
September	6.17	6.36	100.0	0.008
October	5.56	6.30	100.0	0.008
November	4.60	5.57	100.0	0.007
December	4.15	5.28	100.0	0.007
Annual	**5.94**	**6.18**	**100.00**	**0.091**

Annual solar radiation - horizontal	MWh/m²	2.17
Annual solar radiation - tilted	MWh/m²	2.26

Photovoltaic			
Type		mono-Si	
Power capacity	kW	5.00	
Manufacturer		Sharp	
Model		mono-Si - NT-185U1	27 unit(s)
Efficiency	%	14.2%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	35	
Miscellaneous losses	%	10.0%	
Inverter			
Efficiency	%	95.0%	
Capacity	kW	3.0	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	18.8%	
Electricity delivered to load	MWh	8.117	
Electricity exported to grid	MWh	0.091	

perating strategy - base load power system		
Electricity rate - base case	$/MWh	13.00
Fuel rate - proposed case power system	$/MWh	0.00
Electricity rate - proposed case	$/MWh	13.00

Figure 9: Energy Model in RETScreen

5.2.4 Emission Analysis

The software also allows the user to estimate greenhouse gas (GHG) specifically CO_2 emission reduction. The software predicted how much CO_2 could be avoided from being released to the atmosphere if the proposed renewable technology is implemented. It evaluates the emission quantity base on conventional fossil fueled power plant. Since, emission tariff is paid to international environmental organization, transaction feed has to be specified. Moreover, reduction credit rate, duration period, and escalation is required as demonstrated in fig. 10 in the following.

Emission Analysis

Base case electricity system (Baseline)		GHG emission factor (excl. T&D)	T&D losses	GHG emission factor
Country - region	**Fuel type**	**tCO2/MWh**	**%**	**tCO2/MWh**
Saudi Arabia	All types	0.737		0.737
Electricity exported to grid	MWh	0	T&D losses	0.0%
GHG emission				
Base case	tCO2	17.9		
Proposed case	tCO2	11.8		
Gross annual GHG emission reduction	tCO2	6.0		
GHG credits transaction fee	%	5.0%		
Net annual GHG emission reduction	tCO2	5.7	is equivalent to	1.1
GHG reduction income				
GHG reduction credit rate	$/tCO2	24.00		
GHG reduction credit duration	yr	20		
GHG reduction credit escalation rate	%	5.0%		

Figure 10: Emission Analysis in RETScreen

5.3 Modeling

This section presents briefly the different mechanisms used to calculate the energy generation of the proposed system in RETScreen. The software estimates solar radiation from given month to month mean day by day sun powered radiation on a flat surface. What's more, it figure out the effectiveness of PV given encompassing temperature and accessible sun based radiation. The evaluation methods used in this section was adopted from reference (Thevenard, Leng, & Martel, 2000).

5.3.1 Solar Radiation

In PV systems the energy output greatly rely on the average daily solar radiation, and the orientation and angle of the solar panel. However, usually the solar radiation values presented for horizontal surfaces, ex. on-line weather database of RETScreen. Hence, the first task encounters by the program is changing over monthly mean horizontal radiation values to their surface of array equivalent. RETScreen confront extra difficulties because of the way that both tracking and fixed arrangements are considered. Therefore, an algorithm developed by Klein and Theilacker was adopted in RETScreen software to estimate the solar radiation incident on tilted surface from given horizontal radiation as follows (Duffie & Beckman, 2013).

$$I_T = \left(1 + \frac{I_d}{I_0}\right) I_b R_b + I_d \left(1 - \frac{I_b}{I_O}\right)\left(\frac{1+cos\beta}{2}\right)\left(1 - \sqrt{\frac{I_b}{I}} sin^3 \frac{\beta}{2}\right) + \rho_g \left(\frac{1-cos\beta}{2}\right) I \qquad (1)$$

Where:

I = the global horizontal radiation (kW/m^2)

Io = the extraterrestrial horizontal radiation (kW/m^2)

I_b = the direct beam radiation on a horizontal surface (kW/m^2),

I_d = the diffuse radiation on a horizontal surface (kW/m^2),

ρ_g = the ground reflectance (%)

β = the tilt angle of the surface

R_b = the ratio of beam radiation on the tilted surface to beam radiation on the horizontal surface (unite-less)

5.3.2 PV power output

The power output of the PV array, P_{PV}, in RETScreen is evaluated by the following expression (Ramli et al., 2016):

$$P_{PV} = P_{PV,STC} \times F_{PV} \times F_{temp} (\frac{I_T}{I_{T,STC}}) \qquad (2)$$

Where:

$P_{PV, STC}$ = rated capacity of PV array under standard test conditions (kW)

F_{PV} = PV derating factor (%),

F_{temp} = temperature derating factor (dimensionless)

I_T = solar radiation incident on a tilted surfaced of PV array (kW/m_2)

$I_{T, STC}$ = incident radiation at standard test conditions (1 kW/m_2)

5.3.3 Array Model

The PV array model in RETScreen is based on work done by reference(Evans, n.d.).

The array efficiency, η_P (%), is calculated by the following equation:

$$\eta_P = \eta_r[1 - \beta(T_c - T_r) \quad (3)$$

Where:

η_r = nominal efficiency (%)

T_r = measured at a reference temperature = 25 ^oC

β = temperature coefficient for module efficiency

T_C= the module temperature and the mean monthly ambient temperature Ta as can from, the following equation:

$$T_c - T_a = (219 + 832K_t)\frac{N_{OCT} - 20}{800} \quad (4)$$

Where:

K_t = the clearness index

N_{OCT} = Nominal Operating Cell Temperature

5.3.4 Array Power available to Load

The array Energy available (E_A) to the load can be evaluated as following:

$$E_A = H_t\, \eta_p (1 - \lambda_p)(1 - \lambda_c) \text{ (kJ)} \tag{5}$$

Where:

λ p= miscellaneous array losses such as dirt or snow covering the modules

λc = various power conditioning losses such as DC to AC conversion losses

H_t = solar radiation incident upon the array

5.3.5 Model for PV array connected to grid systems

The grid-linked model is less complex than off-grid model. The energy accessible to the grid is what is generated by the array and minimized by inverter losses:

$$E_{grid} = E_A\, \eta_{inv} \text{ (kJ)} \tag{6}$$

Where:

η_{inv} = inverter efficiency

Contingent upon the framework design not this energy might be consumed by the grid. The energy really conveyed E_{dlvd}:

$$E_{dlvd} = E_{grid}\, \eta_{abs}$$

η_{abs} is the PV energy absorption rate, for large grids = 1, and for small grids ranges between 0.95 and 0.98.

5.4 Economic Analysis

The calculation is performed concerning PV system for residential application. The economic analysis have been evaluated using simple payback time (SPP), saving to investment ratio (SIR), Internal Rate of Return (IRR) and Net present esteem (NPW). All parameters are assessed with regards to 3 scenario as mentioned in section 5.6.

5.4.1 Net Present worth (NPW)

Net Present Value (NPW) is the difference between the present value of cash inflows (saving) and the present value of cash outflows (investment).Net present worth greater than zero demonstrates that the anticipated profit produced by a venture surpasses the expected expenses. For the most part, a venture with a positive NPW is considered to be profitable and one with a negative NPW indicates the project might not to be financial profitable.

$$NPW = \sum PW_{AS} - \sum PW_{LCI} \tag{7}$$

Where:

PW_{AS} = present worth of annual saving

PW_{LCI} = present worth of life cycle investment

Present worth (PW) can be defined as the future cash worth at the present time, and it is calculated by the following formula:

$$PW = \frac{FW}{(1+i)^n} \tag{8}$$

Where, FW is the future value, **i** is the interest rate, and **n** is analysis period.

PW_{AS} includes the worth of annual saving (electricity exported + avoided fuel cost + GHG reduction income + feed in tariff) of the project. **PW_{LCI}** considers the value of life cycle investment (purchase cost + M&O cost + imported electricity cost) of the project.

5.4.2 Saving to Investment Ratio (SIR)

The savings-to-investment ratio (SIR) is the ratio between net present worth net savings to the present worth net costs of a project. In general, if SIR is greater than 1, the intended project or investment is considered to be profitable.

$$SIR = \frac{\sum PW_{AS}}{\sum PW_{LCI}} \tag{9}$$

5.4.3 Internal Rate of Return (IRR)

Internal rate of return (IRR) is just simply the interest rate at which the net present value of all the cash flows from a project equal zero. The investment is indicated to be feasible if the IRR is greater than discount rate.

5.4.4 Simple Payback Period (SPP)

Simple payback period (SPP) is the ratio between initial investment (IC) and annual saving (AS). It provide a rough estimation how long it will take a project to recover the initial investment. This method ignores inflation rate, so cautious should be taken when considering SPP to determine whether to undertake a project or not. Shorter SPP period desirable, since longer payback periods are typically not desirable for financer investors.

$$SPP = \frac{IC}{AS} \tag{10}$$

Chapter 6

RESULTS AND DISCUSSION

6.1 Simulation Results

The annual average solar radiation per m^2 on horizontal and tilted surface were found 2.17MWh and 2.26MWh respectively. 5kW PV capacity as expected delivered the least electricity to the load which is 8.117MWh annually, while the maximum electricity delivered to the load was by 10kW PV capacity which was obtained to be 14.195MWh every year as seen in Table 8. Electricity delivered to grid was found to be 0.091MWh, 1.215 MWh and 2.22 MWh for 5kW, 10kW and 10kW PV capacity respectively.

Table 7: Simulation results

PV Capacity	5kW	8kW	10kW
Annual solar radiation - horizontal (MWh/m^2)	2.17	2.17	2.17
Annual solar radiation - tilted (MWh/m^2)	2.26	2.26	2.26
Annual Electricity delivered to load (MWh)	8.117	11.852	14.195
Annual Electricity exported to grid (MWh)	0.091	1.215	2.220
PV penetration rate %	33	50	58
Electricity export rate ($/KWh)	0.1	0.1	0.1
Annual Electricity export income ($)	9	122	222
Avoided annual energy cost ($)	105	154	184

6.2 Estimation of CO_2 Emission Reduction

To compute the amount of CO^2 emission reduction, the net measure of yearly power delivered from the PV system (given the 10% miscellaneous loss) should be considered. The base case power system is figured by contributions of the power source blend by fuel type and benchmark transmissions and distribution (T&D) loss. For the sake of simplicity, RETScreen's default emissions factors for these fuels mix types are employed in the analysis as listed in Table 9. The highest gross CO2 reduction as can be seen from Table 8 was achieved by 10kW PV size at 12.1 tons every year.

Table 8: Estimation CO_2 reduction annually

PV Capacity	5kW	8kW	10kW
GHG emission factor (tCO^2/MWh)	0.737	0.737	0.737
GHG credit transaction fee %	5	5	5
GHG reduction income			
GHG reduction credit rate ($/$tCO^2$)	24	24	24
GHG reduction credit duration (year)	20	20	20
GHG reduction credit escalation rate %	3	3	3
Gross annual emission reduction (tCO^2)	6.0	9.6	12.1
Annual CO^2 reduction income ($)	138	220	276

6.3 Financial Analysis Results

The financial analysis were carried in Microsoft excel sheet. The evaluated net present value (NPV), saving to investment ratio (SIR), simple payback period (SPP) and internal rate of (IRR). In the present work, RETScreen was employed only for energy and Carbon emission analysis. Excel sheet was employed to calculate the financial analysis and the full excel sheet method present appendix C and D. In scenario A, as it was mentioned, we assume the current electricity price will be remained constant in Saudi Arabia for the next 20 years and the project fund only comes from the house owner, with no debt inquired. In scenario B, we assumed 50% of the fund comes from the government as incentive to the owner. In scenario C, we supposed the utility company pays $100 to the owner for every megawatt electricity generates from an installed PV system.

Table 9: Financial results for Scenario A (at current electricity price)

PV capacity	5kW	8kW	10kW
Net Annual Saving	461	655	812
NPV ($)	-9,133	-13,375	-16,078
SIR	0.4	0.4	0.4
SPP (Yr.)	28.6	32.4	33
IRR (%)	-6	-6	-5

Table 10: Financial results for Scenario B (with 50% incentive)

PV capacity	5kW	8kW	10kW
Net Annual Saving	461	655	812
NPV ($)	-2,533	-2,775	-2,678
SIR	0.8	0.8	0.8
SPP (Yr.)	14.3	16.2	16.5
IRR (%)	-1	0	0

Table 11: Financial results for Scenario C (at $100/MWh feed in tariff rate)

PV capacity	5kW	8kW	10kW
Net Annual Saving	1,261	1,855	2,212
NPV ($)	3,338	5,332	5,747
SIR	1.2	1.2	1.2
SPP (Yr.)	10.5	11.4	12.1
IRR (%)	5	5	5

6.3.1 Owner's Perspective

The financial results shows that residential PV are not cost effective under scenario A and B as it is observed Table 9 and Table 10. For scenario A and B saving to investment ratio (SIR) and internal rate of return (IRR) were found to be very poor, which indicates the systems are not financial beneficial for the customers. The main reason for this disparity is the low energy price in the kingdom of Saudi Arabia relative to international price. In general PV systems yield good saving if energy price is high.

Scenario A results shows that the optimal SIR, SPP and IRR to be 0.4, 14years, and -5% respectively (see Table 9). Hence, considering high initial cost, and with no incentive or feed in tariff the PV system seems financially unattractive to customers.

Scenario B presents that the optimal SIR, SPP and IRR to be 0.8, 14years and 0% respectively (see Table 10). Again this scenario seems to not designate the financial viability of PV system in residential application from house owner's point of view.

Scenario C seems the only scenario that has promising results from viability standpoint. The optimal SIR, SPP, and IRR were found to be 1.2 and 10.5years and

5% respectively (see Table 11). However, we should bear in mind, it was assumed the feed in tariff rate to be $0.1/kwh which currently no clear policy about this issue exists in Saudi Arabia.

6.3.2 Government's Perspective

As mentioned above, the government losses millions dollars in subsidizing fuel and electricity every year. The energy subsidies in KSA represent undoubtedly a tremendous burdens for the economy. According to reference (Nachet & Aoun, 2015) the average subsidization rate is estimated 77.3% in Saudi Arabia (annually $18 billion loss in energy sector subsidy). The average annual cost of electricity with subsidy per household per year is around $312, but if actual end user cost without subsidy was considered, the average annual cost would have been around $2400. Hence, it is estimated that the government loss in subsidizing for each residential building up to $1848 each year. That is approximately equivalent to 36 barrel of oil per each household at the current price $50/barrel (EIA, 2017). If GCPV is implemented, 30-60 percent of the electricity consumption could be reduced (saving the government $550-$1100 per household). In addition, 6-12 ton of CO_2 could be avoided from releasing to the atmosphere. The cost of CO_2 is assumed $24/ton, so additional saving ($144-$288) could be gained annually per building by just carbon emission reduction.

GCPV can also be utilized to tackle peak electricity demand in Saudi Arabia. Due to the heavy use of air conditioners, peak load demands take place on sunny days. Fortunately, the peak load matches with the most noteworthy occurrence solar incident, and subsequently PV frameworks yields the greatest power. Load profiles in top energy demand in Jeddah lies for the most part from mid-day to 5 in the afternoon. Correspondingly, PV may add to expand peak energy demand capacity and reduce load consumption of power which is called peak saving. Therefore, general power request from customary sources in Saudi Arabia might be limited specifically at peak time, and the highest saving example demonstrates the sum required from traditional generation. Solar radiation are generally accessible between 6.00-18.00, while electrical burdens increment from 7 in the morning and, goes down from 18 in the afternoon., particularly amid workdays. Top loads in Saudi Arabia are generally seen amongst May and September, when the month to month pattern of daylight length corresponds that of highest in electrical burdens (Almasoud & Gandayh, 2015a).

6.4 Acceptability of the Proposed System

In this section, we analyzed the proposed system under different input parameter as described in the Table 12, 13 and 14 below. Each table shows what happens to the selected financial indicator (SPP, SIR and IRR) when two parameters (electricity cost and feed in tariff) are varied for different PV capacity.

6.4.1 Acceptability analysis of Scenario A

In this scenario, it has been observed that the proposed GCPV is not good option for the kingdom based on today's energy price as presented in Table 12. The electricity price would have to increase by 750% in order the proposed PV system to have SIR greater than 1, IRR greater than the discount rate, and SPP to be less than 10 years. This may seem hard to fetch at the current energy policy, however with recent initiation from government to mandate the country's energy sector, it may be possible the electricity price to increase drastically in the near future making PV system more attractive financially.

6.4.2 Acceptability analysis of Scenario B

In the case the 50% of the initial cost funded by the government or utility company, the electricity has to be raised only by 375% (see Table 13) for the PV system to be economically feasible for house owners, which is better than the previous scenario.

6.4.3 Acceptability analysis of Scenario C

Perhaps, this scenario the most reasonable approach at the current electricity price. It only required the feed in tariff to be greater than $0.1/kwh for the GCPV financial to be acceptable as illustrated in Table 14.

Table 12: Acceptability Analysis of Scenario A

PV Capacity	5kW			8kW			10kW		
Price of electricity ($/kWh)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)
0.013	28.6	0.4	-6	32.4	0.4	-6	33	0.4	-5
0.03	15.1	0.7	-3	19.9	0.6	-3	21.9	0.6	-3
0.05	9.7	0.8	-1	13.7	0.8	-1	15.7	0.8	-1
0.07	7.2	1	2	10.4	0.9	1	12.2	0.9	1
0.10	5.1	1.1	4	7.7	1.1	4	9.2	1.1	4

Table 13: Acceptability analysis of Scenario B

PV Capacity	5KW			8KW			10KW		
Price of electricity ($/kWh)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)
0.013	14.3	0.7	-1	16.2	0.8	0	16.5	0.8	0
0.03	7.6	1	2	9.9	1	3	11	1.1	3
0.07	3.6	1.2	9	5.2	1.3	9	6.1	1.4	9
0.10	2.6	1.3	13	3.8	1.5	13	4.6	1.6	13

Table 14: Acceptability analysis of Scenario C

PV Capacity	5kW			8kW			10kW		
Feed in tariff ($/kWh)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)	SPP (yr.)	SIR	IRR (%)
0.05	15.4	0.8	0	17.7	0.8	0	19.1	0.8	0
0.07	13	1	2	14.5	1	2	15.5	1.1	2
0.1	10.5	1.2	5	11.4	1.2	5	12.1	1.3	5
0.12	9.3	1.4	7	10	1.4	7	10.6	1.4	6
0.15	7.9	1.6	9	8.4	1.7	9	8.9	1.6	9

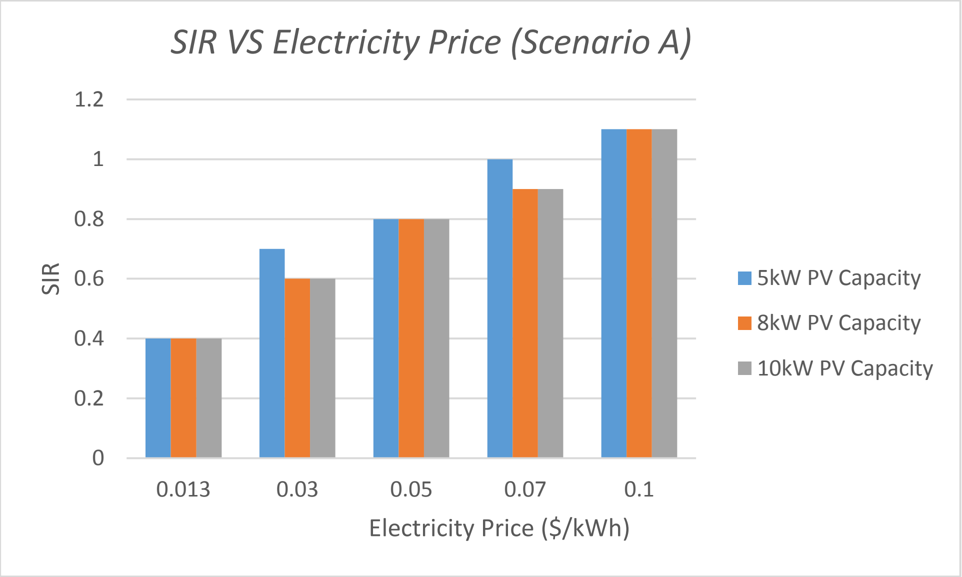

Figure 11: SIR VS Electricity Price (Scenario A)

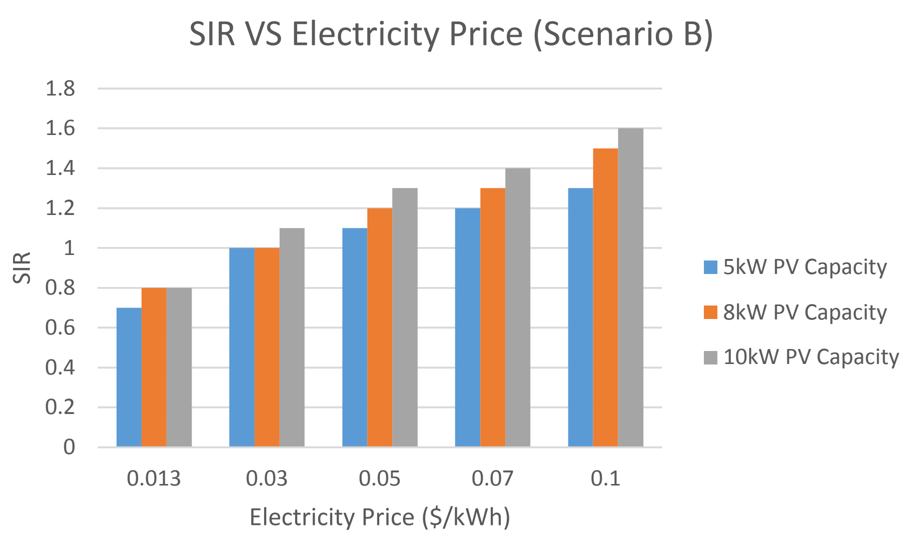

Figure 12: SIR VS Electricity Price (Scenario B)

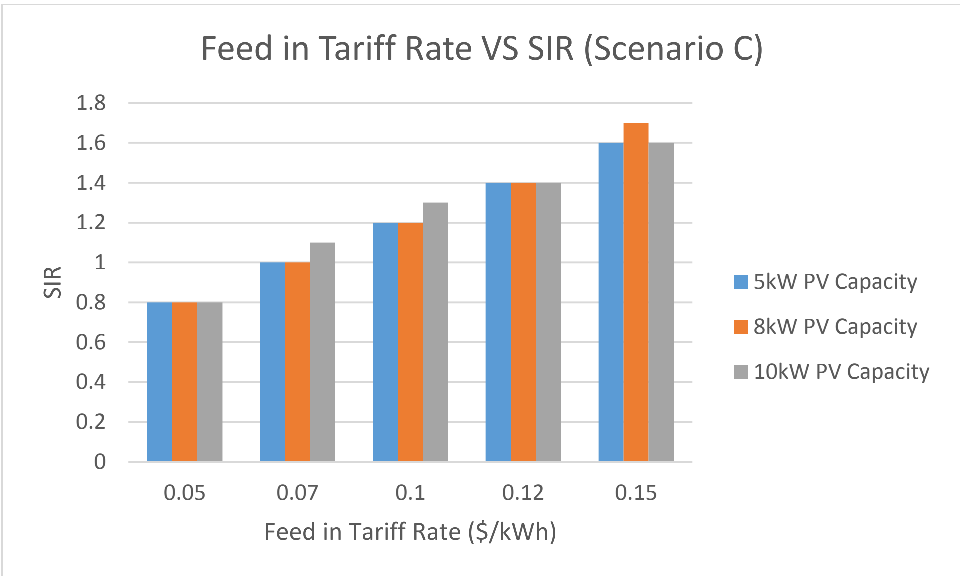

Figure 13: Feed in Tariff Rate VS SIR (Scenario C)

Chapter 7

CONCLUSION

Around the globe, particularly in developed countries, minimizing domestic energy consumption can lead to financial and environmental benefits. Hence, many countries are putting great efforts to shift into renewable energy based economy for a sustainable future. Among the Middle Eastern countries, Kingdom of Saudi Arabia has the most ambitious plan to introduce renewable technology. The kingdom aims 30% of its energy mix to come from renewable energy source by 2032. However, for that to happen, the country needs to solve several economic, social and environmental barriers.

The present study examines the proximity of implementing grid-connected PV system in a typical Saudi residential building. The main focus of the work is to examine grid-connected PV (GCPV) system from economic perspective. RETScreen software and Microsoft Excel have been employed to simulate and analysis the proposed 5kW, 8kW, and 10kW PV system for residential application in Jeddah, KSA. The results of the study shows that GCPV are not financially viable for residential application in KSA at the present time, unless the current price of electricity increases by 750%, or providing 50% incentive plus increase in electricity price by 375% . Moreover, if feed in tariff are set at a rate of greater or equal to 0.1/kWh, GCPV technology might be more financially attractive. In addition, implementing the GCPV system, could be avoid 6, 10, 12 tons of CO_2 from 5kW, 8kW, and 10kW PV sizes, respectively.

The study demonstrates that the potential of solar energy cannot be overlooked. The observations of the present work might not be convenient for evaluating GCPV application, but it may contribute to initial assessment for further study. In addition, it demonstrates that GCPV frameworks requires various issues to be settled before they can be used in KSA. Most importantly there is no clear regulation regarding GCPV system in the country. For example, there is no feed in tariff or any other incentive means which is giving to PV owners. Moreover, KSA has one of the lowest electricity price in the world. The kingdom, needs to rise the electricity tariff, for PV system to be more profitable and competitive in the market. Last but not least, Government is expected to address the investors about the advantages of using sustainable power sources. Furthermore, at present Saudi government's subsidy covers just for the generation of energy from oil and gas, there is subsidy for renewable power sources. Subsequently, as of now GCPV frameworks are neither socially nor financially practical in KSA. All things considered, and in spite of its high capital cost, renewable technology has noteworthy points of interest. It can add to lessening in both CO_2 discharges and the amount of oil barrels that are devoured to deliver power. It likewise PV system could supply energy to the grid during peak period. Subsequently, although costly at the beginning, GCPV system stay a standout amongst the most environmentally friendly energy resources, which lights up the potential for their future deploy in in the country.

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APPENDICES

Appendix A: PV Module Description

NT-185U1 **MULTI-PURPOSE MODULE**

185 WATT

ELECTRICAL CHARACTERISTICS

Cell	Single crystal silicon
No. of Cells and Connections	72 in series
Open Circuit Voltage (Voc)	44.9V
Maximum Power Voltage (Vpm)	36.2V
Short Circuit Current (Isc)	5.75A
Maximum Power Current (Ipm)	5.11A
Maximum Power (Pm)*	185W
Minimum Power (Pm)*	166.5W
Encapsulated Solar Cell Efficiency (ηc)	17.48%
Module Efficiency (ηm)	14.23%
PTC Rating (W)**	162.43
Maximum System Voltage	600VDC
Series Fuse Rating	10A
Type of Output Terminal	Lead Wire with MC Connector

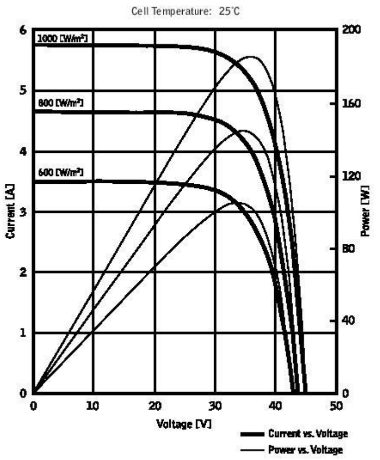
MECHANICAL CHARACTERISTICS

Dimensions (A x B x C below)	62.01 x 32.52 x 1.81" / 1575 x 826 x 46mm
Weight	37.485lbs / 17.0kg
Packing Configuration	2 pcs per carton
Size of Carton	66.93 x 38.19 x 5.12" / 1700 x 970 x 130mm
Loading Capacity (20 ft container)	168 pcs (84 cartons)
Loading Capacity (40 ft container)	392 pcs (196 cartons)

ABSOLUTE MAXIMUM RATINGS

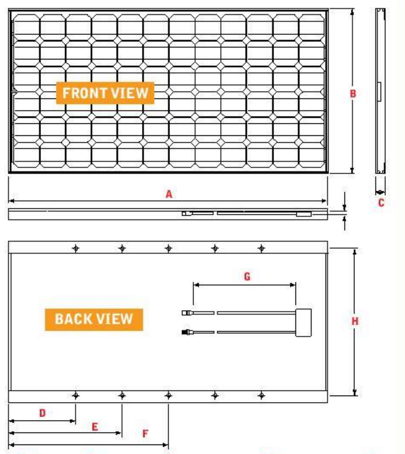
Operating Temperature	-40 to 194°F / -40 to +90°C
Storage Temperature	-40 to 194°F / -40 to +90°C
Dielectric Isolation Voltage	2200 VDC max.

IV CURVES



Current, Power vs. Voltage Characteristics

DIMENSIONS



D	E	F	G	H
7.3"/185.5mm	19.42"/485.5mm	30.93"/785.5mm	51.2" +/- 2"/1300mm+/-50mm	30.43"/773mm

Specifications are subject to change without notice.

* (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5
** (PTC) Pacific Test Conditions: 20°C, 1 kW/m², AM 1.5, 1 m/s wind speed

In the absence of confirmation by product manuals, Sharp takes no responsibility for any defects that may occur in equipment using any Sharp devices. Contact Sharp to obtain the latest product manuals before using any Sharp device.

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Cover photo: Solar installation by Pacific Power Management, Auburn CA SSD-03-007 Printed in the USA

Appendix B: Power Inverter Module Description

Parameter / Model		1000W	1500W	2000W	3000W	4000W	5000W
Rated Output Power		1000W	1500W	2000W	3000W	4000W	5000W
Peak Power		2000W	3000W	4000W	6000W	8000W	10000W
Battery (Lead-acid battery)		24V	24V/48V(optional)			48V	
Charging Parameter							
Charge Mode（setting）		PV charge					
		PV charge + utility charge					
MPPT Solar Controller	Voltage	24V	24V/48V			48V	
	Current	20A	25A	30A	40A	40A	40A
	Max PV Input Voltage	100V					
	PV Charge Efficiency	95%~99%					
	Max PV Input Power	568W	24V: 710W 48V1420W	24V: 852W 48V: 1704W	24V:1136W 48V: 2272W	2272W	2272W
Utility	AC Charge Current	0~15A					
	Charge Mode	3-Stage Charging					
Inversion parameter							
AC Output	Voltage	220V±3% or 230V±3 or 240V±3% or 100V±3% or 110V±3% (optional)					
	Frequency	50Hz±0.5 or 60Hz±0.5 (optional)					
Output wave type		Pure sine wave output, Total Harmonic Distortion THD≤3					
Overload ability		>120% 1 min, >130% 10s					
Power Consumption		0.4A	24V: 0.5A	24V: 0.7A	24V: 0.7A	0.6A	0.65A

Appendix C: Current Electricity tariff in Saudi Arabia

<table>
<tr><th>Consumption categories (in Kwh)</th><th>Residential</th><th>Commercial</th><th>Governmental</th><th>Private educational establishments</th><th>Private Health establishments</th><th>Agriculture</th><th>Charities</th></tr>
<tr><td>1-2000</td><td>0.013</td><td>0.032</td><td rowspan="9">0.069</td><td rowspan="9">0.032</td><td rowspan="9">0.032</td><td>0.013</td><td>0.013</td></tr>
<tr><td>2001-4000</td><td>0.027</td><td>0.032</td><td>0.027</td><td>0.027</td></tr>
<tr><td>4001-5000</td><td>0.032</td><td rowspan="4">0.053</td><td>0.027</td><td>0.027</td></tr>
<tr><td>5001-6000</td><td>0.032</td><td rowspan="6">0.032</td><td rowspan="6">0.032</td></tr>
<tr><td>6001-7000</td><td>0.040</td></tr>
<tr><td>7001-8000</td><td>0.053</td></tr>
<tr><td>8001-9000</td><td>0.059</td><td rowspan="3">0.069</td></tr>
<tr><td>9001-10000</td><td>0.064</td></tr>
<tr><td>>10000</td><td>0.069</td></tr>
</table>

Appendix D: Excel Inputs worksheet

Input in BLUE cells only.

TABLE 1

Life Cycle Investment Schedule, from Steps 1, 2, and

Year	New	Old	Net Amount
0			$0
1			$0
2			$0
3			$0
4			$0
5			$0
6			$0
7			$0
8			$0
9			$0
10			$0
11			$0
12			$0
13			$0
14			$0
15			$0
16			$0
17			$0
18			$0
19			$0

TABLE 2

Annual Savings		(from Step 3)
Discount Rate		(from Step 4)
Analysis period (years)		(from Step 5)
Residual value		(from Step 6)

Appendix E: Excel outputs worksheet

TABLE 3: Savings Calculations   Formula: PV Annual Savings = Annual Savings / (1 + Discount Rate)^{year} (from Step 7)

Year	0										
Annual Savings	$0										
PV Annual Savings	$0										
□ PV Annual Savings	$0										

TABLE 4: Investments   Formula: PV Life Cycle Investment = Life Cycle Investment / (1 + Discount Rate)^{year} (from Step 8)

Year	0										
Net Life Cyle Investments	$0										
PV Life Cycle Investments	$0										
□ PV Life Cycle Investments	$0										

Net Cash Flows	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

TABLE 5: Results	OUTPUTS	
Net Present Value (NPV)	$ 0	(from Step 9)
Savings-to-Investment Ratio		(from Step 10)
Internal Rate of Return (IRR)		(from Step 10)
Simple Payback (years)		