Techno-Economic Comparison between Building Sector Distributed Generation and Large Scale PV-Farm Based Generation in Saudi Arabia

BY

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To my parents and my brother Abdulmajeed and my cousin Ayed and all friends who supported me to write this book

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LIST OF ABBREVIATIONS

AC: **Alternative current**

DC: **Direct current**

CSP: **Concentrated Solar Panel**

CF: **Cash flow**

CC: **Capital cost**

DNI: **Direct normal irradiance**

DHI: **Diffuse horizontal irradiance**

ECRA: **Electricity & Cogeneration Regulatory Authority**

EUI: **Energy unit index**

EPA: **Environmental Protection Agency**

EIRP: **Electricity Industry Restructuring Plan**

GHI: **Global horizontal irradiance**

GHGs: **Green House Gases**

HOMER: **Hybrid Optimization of Multiple Electric Renewables**

KAPSARC: **King Abdullah Petroleum Studies and Research Center**

KACST: **King Abdul-Aziz City for Science & Technology**

KAUST: **King Abdullah University of Science and Technology**

KACARE: **King Abdullah City of Atomic & Renewable Energy**

LEC: **Levelized energy cost**

LCC: Life cycle cost

NPW: Net present worth

PCU: Power Conditioning unit

PV: Photovoltaic

SA: Saudi Arabia

SEC: Saudi Electricity Company

US: United Stat

ABSTRACT

This thesis discusses the PV output potential from the Saudi building sector and determine the impact of PV generation from the building sector on peak load shaving in SA then compare the building sector distributed generation with large scale PV-farm based generation in terms of techno-economics. The thesis develops Models to determine the potential of PV power output from typical sample buildings and extrapolate the modeling results to estimate the overall building sector potential then matches the power generation and load profiles at regional and national levels to determine the scope for peak load shaving. Finally, it compares the technical, regulatory, environmental and socio-economic aspects of distributed generation against the large-scale PV farm-based generation in Saudi conditions. The study will apply on the residentials buildings in Dhahran city in the eastern region of SA. Also, we chose Dhahran city to be the location of the site of the solar farm.

The results show that the distribution building PV system is better than the solar farm and that due to a number of issues. The cost of the solar farm is higher than the cost of the PV system in building and that because of the additional cost of adding substation and addition cost of the transmission and distribution. The results show that the generation of energy from the PV system of the residentials buildings is about 34% of the total energy consumption of the buildings and if only 20% of the residentials buildings in SA use the PV system then that will shave the peak load of Saudi Arabia by 3.4%. The solar farm can reduce the emission of CO2 much more than the buildings PV system but the PV system of buildings can help people to have there own sources of energy.

ملخص الرسالة

الاسم الكامل: خالد سعد دليم فردان القحطاني

عنوان الرسالة: مقارنة فنية واقتصادية بين الطاقة الشمسية المنتجة من قطاع المباني والتوليد الواسع النطاق من حقول الخلايا الشمسية في المملكة العربية السعودية.

التخصص: هندسة معمارية

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الدراسة تحقق في الطاقة الشمسية المنتجة من قطاع المباني في المملكة العربية السعودية ومدى أثرها في تغطية الاستهلاك المحلي من الطاقة الكهربائية وسد الاحتياج المتزايد للكهرباء وخاصة في فصل الصيف. وكذلك دراسة أثر الطاقة الشمسية على الجانب الاقتصادي والبيئي. وتقوم الدراسة بعمل دراسة جدوى التوليد الواسع النطاق أو حقل (مزرعة) الخلايا الشمسية لإنتاج الطاقة الشمسية ومن ثم مقارنة نتائج قطاع المباني بنتائج حقل الخلايا الشمسية من حيث انتاج الطاقة والتكلفة والأثر البيئي.

والنتائج تشير إلى جدوى استخدام الخلايا الشمسية في انتاج الطاقة سواءا من الحقول الشمسية أو من نظام الخلايا الشمسية للبيوت السكنية.

الطاقة الشمسية المنتجة من قطاع البيوت السكنية تعطي فرصة اكبر للمواطنين عموما للاستثمار او على الأقل تغطية احتياجهم من الكهرباء. الحقول الشمسية تكلفتها اكثر من تكلفة الطاقة الشمسية المنتجة من القطاع السكني ولكنها تتميز بحرية اختيار المساحة المناسبة على عكس طاقة القطاع السكني المحكومة بالمساحة المتاحة في أسطح البيوت السكنية.

الدراسة اعتمدت على مدينة الظهران في المنطقة الشرقية من المملكة العربية السعودية كموقع للتطبيق الدراسة وأخذ المعلومات اللازمة للمناخ وجغرافية المكان وكذلك المعلومات الخاصة بالمنازل السكنية واستهلاكها للطاقة.

ونتائج الدراسة أظهرت أن الطاقة الشمسية المنتجة من القطاع السكني ساهمت في خفض قمة الأحمال للبيوت السكنية ولم أن 25% من أصحاب البيوت السكنية في المملكة العربية السعودية استخدموا الطاقة الشمسية في بيوتهم لساهم ذلك في خفض الحمل العالي للمملكة والبالغ 72 قيقا وات بنسبة 5% ليصبح سقف الأحمال 68 قيقا وات بدلا من 72 قيقا وات وهذا بالتالي سيساهم في خفض البترول المستهلك في انتاج الكهرباء وخفض انبعاث الغازات المصاحبة لحرق البترول.

CHAPTER 1

INTRODUCTION

1.1 Background

Countries all over the world are facing a major crisis of energy resources, as 81% of energy consumed is mainly supplied by fossil fuels, which are non-renewable resources [1]. It is expected that the global demand on energy will increase by 56% in the period between 2010 and 2040. The major influencer on this increase is the fast-growing Asian economies [15]. Renewable energy resources may solve the energy crisis but it creates only 14% of the world total energy production [1]. Green House Gases (GHGs) emission is a major problem that is released by fossil fuels. Buildings consume about 40% of the total world energy and are responsible of 33% of the total (GHGs) emissions in the world. With high demands for energy in Saudi Arabia which has ranked the country among the fastest countries in load growth globally, some measures must be implemented in order to relieve the demand.

Saudi Arabia (SA) is a developing country and is growing rapidly. Being a developing country with an enormous growth rate of about 7-8% annual growth. The Saudi local energy consumption rate has experienced a huge increase over the last decade. [32]. The electricity demand increased rapidly by 5%-10%, which was driven by economic activities, population growth, and subsidized energy prices. In fact, the energy demand per capita in Saudi Arabia is 2.5 times that of Euro countries, and it is one of the highest demands globally. Moreover, this high demand is even increased because of the consumption of sea water desalination plants. Hence, Saudi Arabia needs to cope with the huge energy demand through commissioning power generation plants that add more pressure on prices and fossil fuel resources. The availability of fossil fuel and the energy subsidiary contribute to inefficient energy consumption and lead to infeasible solar energy reliance. Seemingly, the energy market is still at very early stage of liberalization and lack for necessary policies and regulations to the extent that it almost does not exist. [13]

SA is expected to install 120 GW by 2030 in order to cope up with such high demand. Such step will result in an expected investment that will reach about 134 billion dollars. This high expected consumption will result in a local demand of 3 million barrels of oil each day to meet the demand expected in the year 2030 as all existing power plants rely on oil and natural gas. Such consumption will deeply impact national income from oil [4].

Due to several factors including urbanization, population burgeoning, developing economy and infrastructure modernization, the building sector in SA is booming. This huge increase in the number of building and the demand on energy is creating a large burden for the country. As per King Abdullah City of Atomic and Renewable Energy (KACARE), buildings are consuming more than 78% of the total energy consumption in SA. [5]. 70% to 80% of this energy is consumed in cooling buildings [6]. Creating more energy efficient homes in SA that produce electricity on site will significantly reduce the risks associated with the increasing consumption of fossil fuel and related CO_2 emissions. A proposed resolution that will overcome such challenges and maintain acceptable sustainability levels in both building and energy sectors was to produce about 9500 megawatts of renewable energy by 2023. [19]

The load factor is an average power consumed divided by a peak power consumed over a period of time. The power load factor in SA is about 66% because the peak demand is high in summer season which needs high cooling loads [6]. It is low when compared with Europe countries. The load factor in Spain for example in 2016/2017 was 91.4%, and the load factor in Western Europe was almost the same of Spain. The monthly total electricity consumption of S A shows sharp peaks in summer season and that leads to decrease the power load factor [6].

ECRA has issued what it has described as Small-Scale Solar PV Systems Regulations document in 2017 laying the ground for using Solar PV in small scale application. The Photovoltaic (PV) have a high potential as the country is blessed with abundant solar resource. KACARE measured the global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI) in SA in 2015. The average daily GHI is about 6.2 kWh/m2. Annual average daily Direct The average daily DNI, is about 5.9 kWh/m2. [30] For the Eastern Region, the total average daily of GHI, DNI, and DHI are 5.8, 5.5, and 2.2 (kWh/m2) respectively.

1.2 The Research Problem Statement

This study plans to assesses the PV output potential from the building sector in Eastern region in SA and determine the potential of photovoltaic (PV) energy output from a sample building and its impact in terms of shaving the peak load demand in KSA.

The work will also compare the technical, regulatory, environmental and socio-economic aspects of distributed generation from the building sector against the large-scale PV farm-based generation in Saudi conditions.

1.3 Significance of the Research

According to Saudi vision 2030, SA means to shift towards renewable energy resources. The solar energy seems to be the backbone of this shifting trend in the country. An investment of US$2 Billion has recently been signed between SA and Soft Bank. As a matter of fact, the regulator body in SA Electricity and Cogeneration Regulatory Authority (ECRA) has authorized home owners to utilize Solar PV for net metering application [16].

1.4 Research Objective

This research has many objectives:

1. study the impact of net metering system on the residential buildings
2. study the consumption of the building and the energy unit index (EUI) of the building.
3. study the PV output potential from the Saudi building sector and the impact on the peak demand of SA.
4. study the costs and benefits of the PV system in distributed buildings.
5. study the costs and benefits of the PV system in a solar farm
6. Compare the building sector distributed generation with large scale PV-farm based generation in terms of techno-economics.

7. finally, it compares the technical, regulatory, environmental and socio-economic aspects of distributed generation against the large-scale PV farm-based generation in Saudi conditions.

1.5 Limitations of the study

The thesis has the following limitations:

- The study will apply on the residentials buildings in Dhahran city in the eastern region of SA. We chose 60 residentials buildings as a case study.
- Also, we chose Dhahran city to be the location of the site of the solar farm.

1.6 Research Methodology

The methodology depends on assessing a farm of PV generation and compares that with a PV generation of building sector of a part of Eastern region of Saudi Arabia. The methodology depends on assessing the existing PV plants in order to discover status of the existing plants. This will enable us to determine how much investments need to be allocated in order to upgrade the plants or build a new plant. This is the first part, to assess the large scale of PV power plant in terms of: production, economic, and environmental impact. On the other hand, the methodology depends on assessing the small-scale PV generation from building sector. Sample of sub region in Eastern region of Saudi Arabia will be chosen and evaluated across criteria that reflects the status of such region. Finally, the results from both large and small scale will be compared to each other. Moreover, simulation works using software will be carried out to compare the results. The diagram (Figure 1) explains how the process will be implemented in order to make the comparison between the large-scale PV (farm of PV) and the small scale or building PV) in eastern region in Saudi Arabia.

The research methodology will be divided into five steps:

1) Comprehensive literature review of the building sector, its energy profile and the power sector

2) Develop Models to determine the potential of PV power output from typical sample buildings

3) Extrapolate the modeling results to estimate the overall building sector potential

4) Match the power generation and load profiles at regional and national levels to determine the scope for peak load shaving.

5) Comparing the technical, regulatory, environmental and socio-economic aspects of distributed generation against the large-scale PV farm-based generation in Saudi conditions.

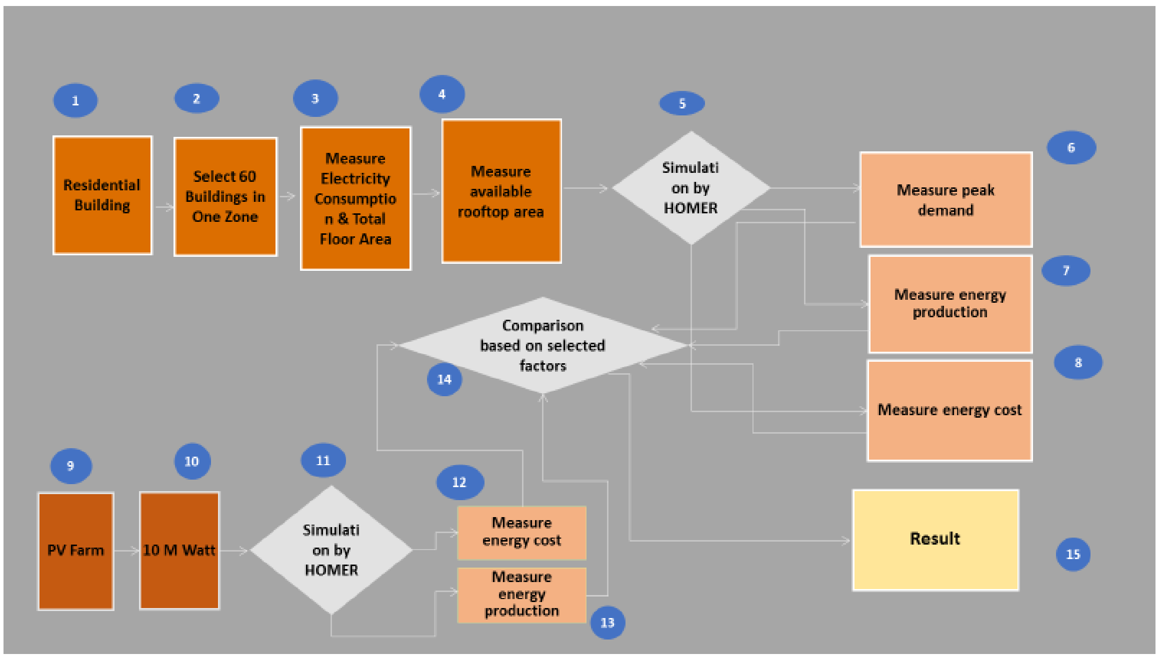

Figure 1. Methodology of the study.

CHAPTER 2

LITERATURE REVIEW

Being a developing country with an enormous growth rate of about 7-8% annual growth, SA is expected to be among the top countries with high energy growth rate. The Saudi local energy consumption rate has experienced a huge increase. [Fig. 2]. [32] The demand of electricity increased rapidly by 5%-10%, which was driven by economic activities, population growth, and subsidized energy prices. In fact, the energy demand per capita in SA is 2.5 times that of European countries, and it is one of the highest demands globally. Moreover, this high demand is even increased because of the consumption of sea water desalination plants. Hence, SA needs to cope with the huge energy demand through commissioning power generation plants that add more pressure on prices and fossil fuel resources. The availability of fossil fuel and the energy subsidiary contribute to inefficient energy consumption and lead to infeasible solar energy reliance. Seemingly, the energy market is still at very early stage of liberalization and lack for necessary policies and regulations to the extent that it almost does not exist. [13]

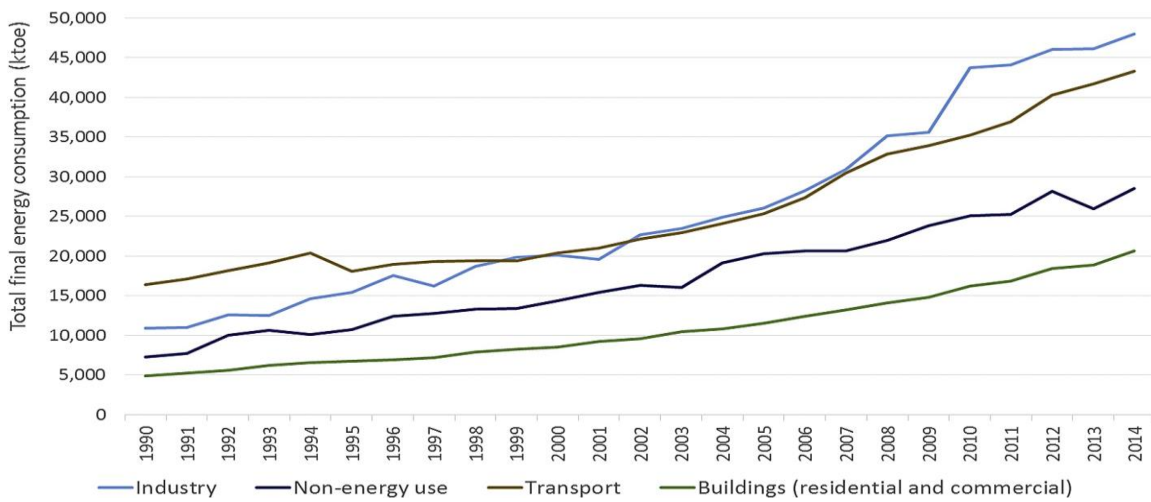

Fig. 2. The consumption of energy (1990-2014) in SA. [32]

2.1. Energy demand in SA

To recover this high demand, SA is going to install more than about 120 GW of electricity by 2030 (Figure 3) and that will require investments of about 134 billion dollars. Existing power plants rely on oil and natural gas, it is anticipated that to meet that demand in 2030, SA will consume 3 million barrels of oil each day, which significantly impact the economy by reducing the income of the country from oil exports [4].

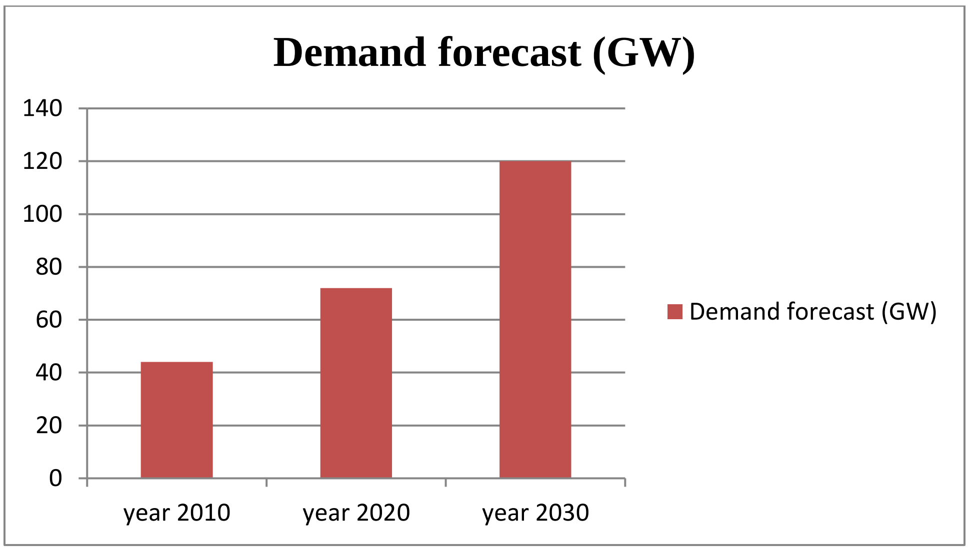

Figure 3. Electricity demand forecast (GW) in 2030 [4]

The building sector in SA is booming due to several factors including urbanization, population burgeoning, developing economy and infrastructure modernization. This huge increase in the number of building and the demand on energy is creating a large burden for SA. As per KACARE, buildings are consuming more than 76% of the total energy consumption in Saudi Arabia. [Figure 4] [5] 70% to 80% of this energy is consumed in cooling buildings [6]. Creating more energy efficient homes in Saudi Arabia that produce electricity on site will significantly reduce the risks associated with the increasing consumption of fossil fuel and related CO_2 emissions. SA decided to develop 9,500 megawatts of renewable energy by the year of. [19]

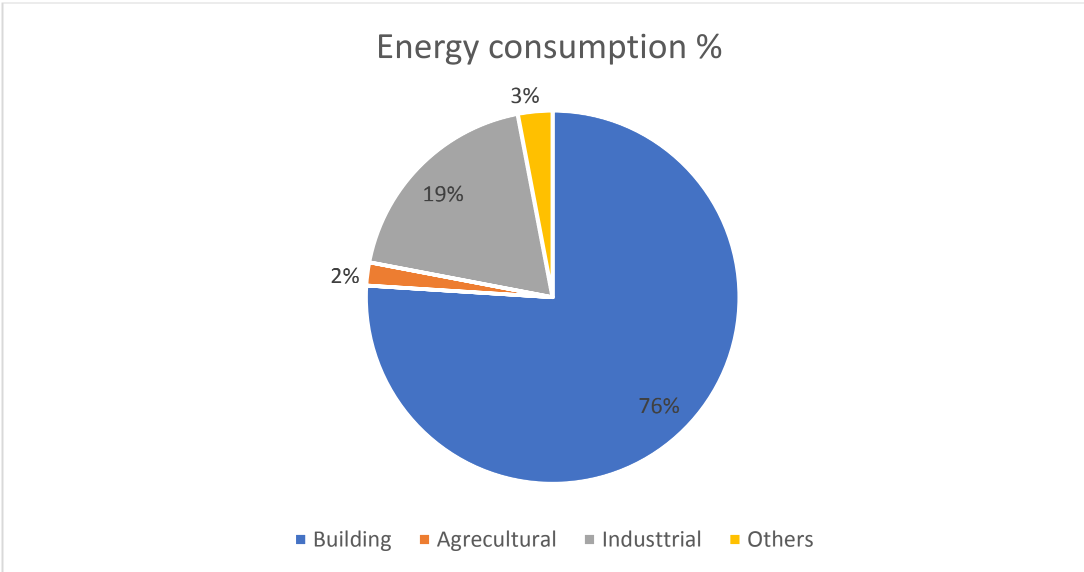

Figure 4. Consumption by Sector in Saudi Arabia. [K.A.CARE] [47]

2.2. The load factor of SA

The load factor is the average of the energy that is consumed over the peak of the consumed energy over a one year. The total power load factor of SA is within an average of 66% because of the high cooling load in summer season where temperature is. [6] The total power load factor of SA is low when compared with Europe countries. The load factor in Spain for example in 2017 was 91.4% (Figure 5), and the load factor in Western Europe was almost the same of Spain (Figure 6). Also, load factor will be decreased in the next 10 years. [6] The monthly total electricity consumption of SA shows a low load factor. (Figure 7) [6].

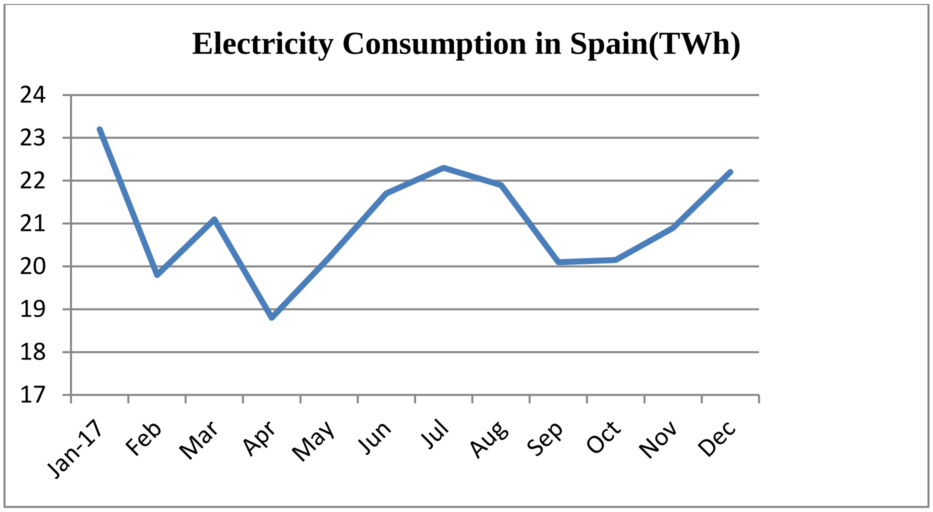

Figure 5. Electricity demand in Spain 2017 [Redrawing from: AleaSoft]

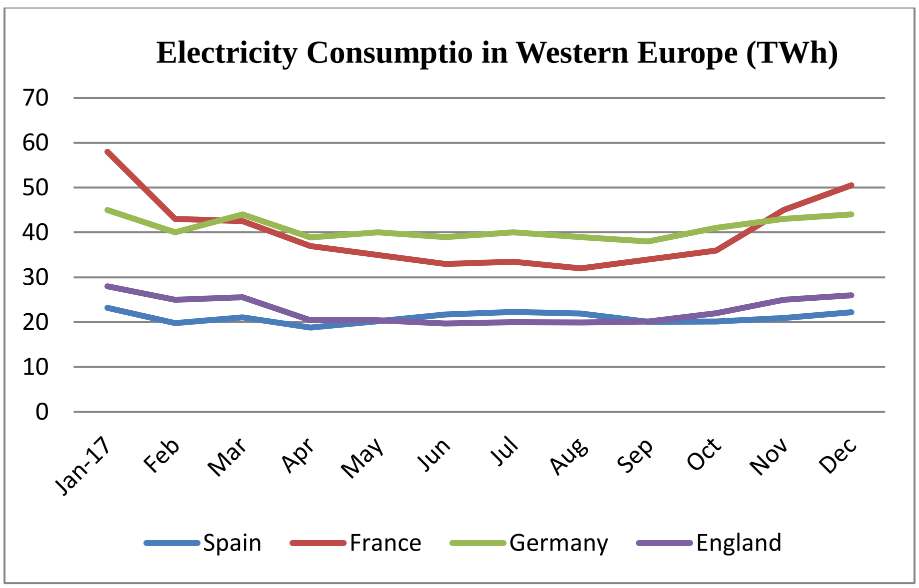

Figure 6. Electricity demand in Western Europe 2017 [Redrawing from: AleaSoft]

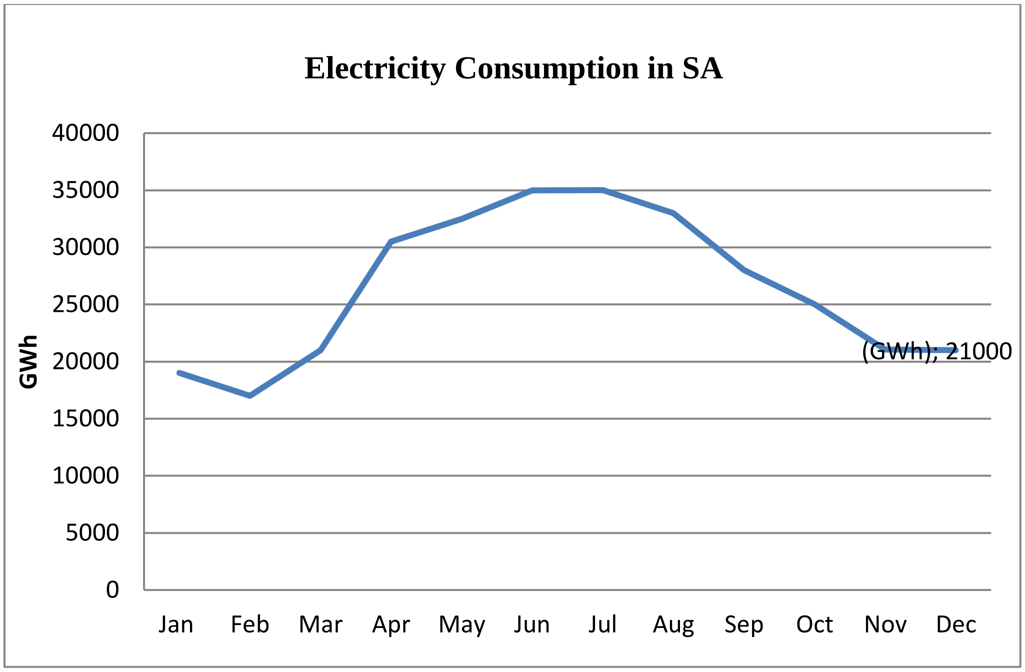

Figure 7. The electricity consumption in SA/ month (2014). [6]

Emissions per capita in SA are so high, (7th largest per capita emitter in the world in 2014). [25]

ECRA (Electricity and Cogeneration Regulatory Authority) regulates the electricity sector. It supervises the restructuring of the electricity sector and the entry of private operators for private production projects.

In 2011 ECRA launched the Electricity Industry Restructuring Plan (EIRP), a 10-year plan to unbundle and eventually privities the currently vertically integrated sector. A major step is expected by the end of 2016 with the split of the state monopoly into several companies. [25]

The Government holds 74.3% of the shares of Saudi Electric Company SEC, 18.8% are held by the private sector, and 6.9% by Saudi Aramco. SEC is the main generating company with around 75% of the total capacity.

Electricity production is entirely thermal. In 2015, electricity production reached 336 TWh with installed capacity of 81.6 GW (56% oil and 44% gas). [25]

As of January 1, 2018, ECRA announced a threefold increase in the electricity tariff. For most residential users, they will now be paying 0.18 SR/kWh (0.48 $/kWh) compared to 0.05 or 0.1 SR/kWh (0.013 or 0.026 $/kWh). The direct impact of this on users is an increased monthly electricity bill. At the same time, the increased tariffs will solidify the business case for renewable energy projects: instead of a payback period of ~10-15 years, small-scale solar PV deployments are now expected to have payback period of ~5-7 years, which is attractive considering the 25-year lifecycle of the system. Moreover, another policy incentive that could be deployed is a Time-of-Use tariff where higher tariffs are applied for peak times, during the day which coincides with peak solar PV output. [41]

2.3. Renewable energy in SA

According to Saudi vision 2030, Saudi Arabia means to shift towards renewable energy resources. The solar energy seems to be the backbone of this shifting trend in the country. An investment of US$2 Billion has recently been signed between Saudi Arabia and Soft Bank to build a huge project of solar with total capacity of 200 GW (giga watt).

As a matter of fact, ECRA has authorized home owners to utilize Solar PV for net metering application [16]. ECRA has issued what it has described as Small-Scale Solar PV Systems Regulations document in 2017 laying the ground for using Solar PV in small scale application. Solar When looking into a solar map (Figure 8) of Saudi Arabia, it becomes very logical that Photovoltaic (PV) have a high potential as the country is blessed with abundant solar resource. SA receives enormous irradiation about (12,422) terra-watt-hour (TWh) of electricity.

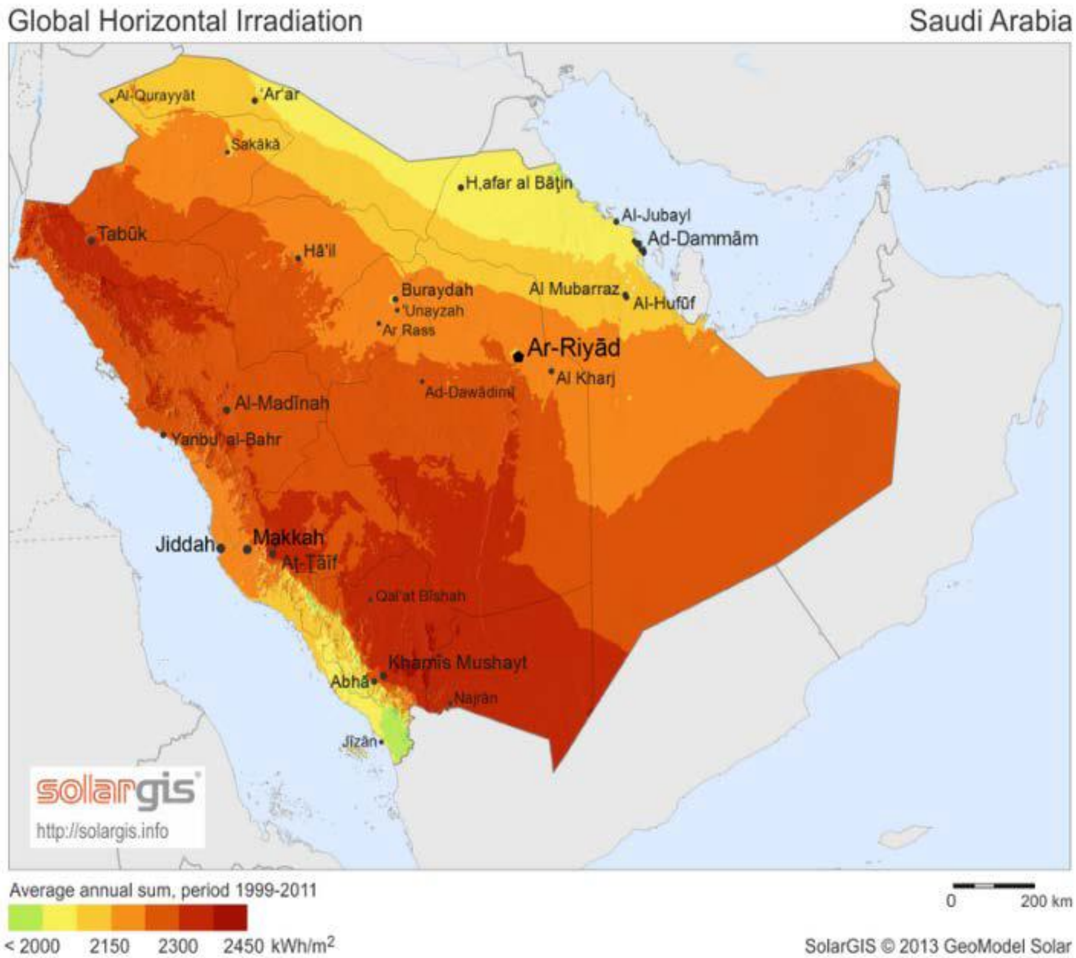

Fig 8. Saudi Arabia solar map

2.4 PV Initiatives in SA

Table.1. illustrated the average daily solar radiation and the sunshine duration in Eastern Region in SA. [30] The average daily total of (GHI), (DNI), and (DHI) are 5.8, 5.5, and 2.2 (kWh/m2) respectively. [Figure. 9]

Table 1. solar radiation and sunshine duration in Eastern Region in SA. [KACARE] [47]

Region	(GHI) (kWh/m2/day)	(DNI) (kWh/m2/day)	(DHI) (kWh/m2/day)	Sunshine Duration (h)
Hafr Al-Baten	5.9	5.7	2.2	
KFUPM	5.8	5.4	2.1	
Al-Ahsaa	6.1	5.5	2.4	
Al-Jubail	5.8	5.5	2.1	
Dammam University	5.8	5.5	2.1	
average	5.8	5.5	2.2	8.4

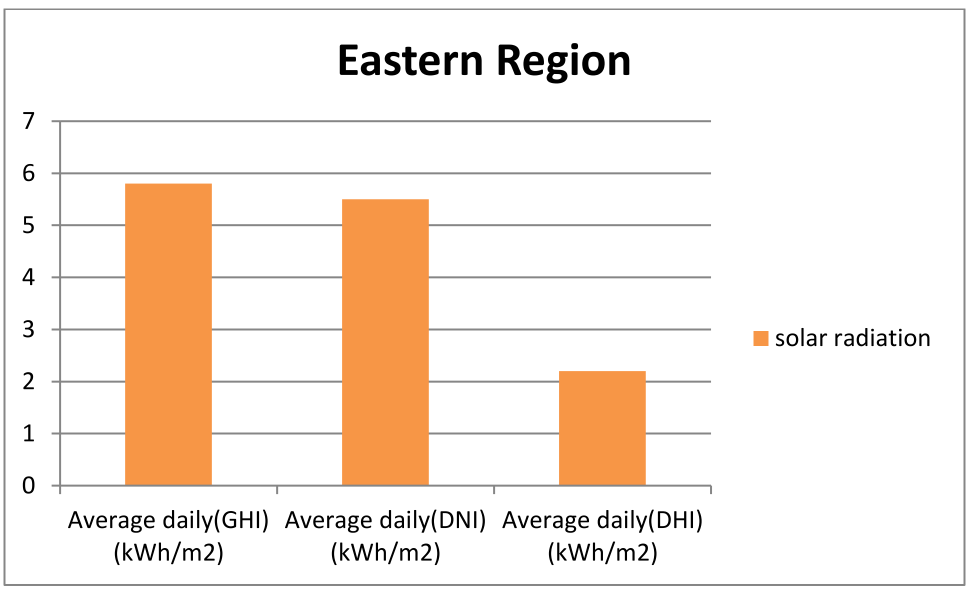

Figure. 9 solar radiation for Eastern region.

The Saudi government has opted for sustainable energy resources as a part of the strategic plan of economic and social transformation. Solar PV is a major part of this plan since SA is one of the richest countries of solar irradiation.

The Arabian Peninsula, especially Saudi Arabia, is a candidate for large expansions of solar energy. SA relies heavily on fossil fuel for electricity generation since it is abundant and low-priced fuel type; thus, deterring any solar-related fuel type projects.

This is because of the high price of such a technology rendering it economically unattractive. On one hand, there are opportunities and great potentials of renewable energy in SA, as it is available abundantly.

The average daily solar radiation in SA is about 5.9 kWh/m2, and SA has about 311 days of clear sky per year. [20] Under SA vision 2030, the solar energy is being planned to give about 9.5 GW from the total renewables production. [19]

S.A has set a target plan to install 54 GW of renewable energy by 2032. The plan is consisting of, 16 GW PV, 25 GW CSP, 9 GW wind, 3 GW waste-to-energy and 1 GW geothermal. The investment in the 16 GW of solar PV is more than $100 billion. [Fig.10]. [34]

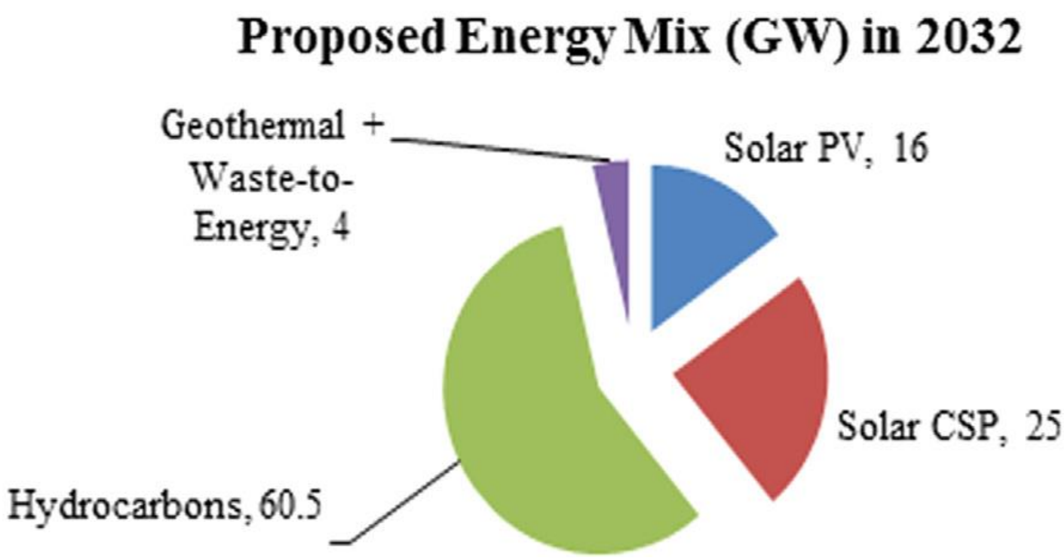

Fig. 10. Planned EnergyMix2032. [34]

The Kingdom's production of renewable energy is expected to hit 71.6 Giga watts/hour in 2032.

The Sustainable energy outlook for Saudi Arabia is shown in figure 11.

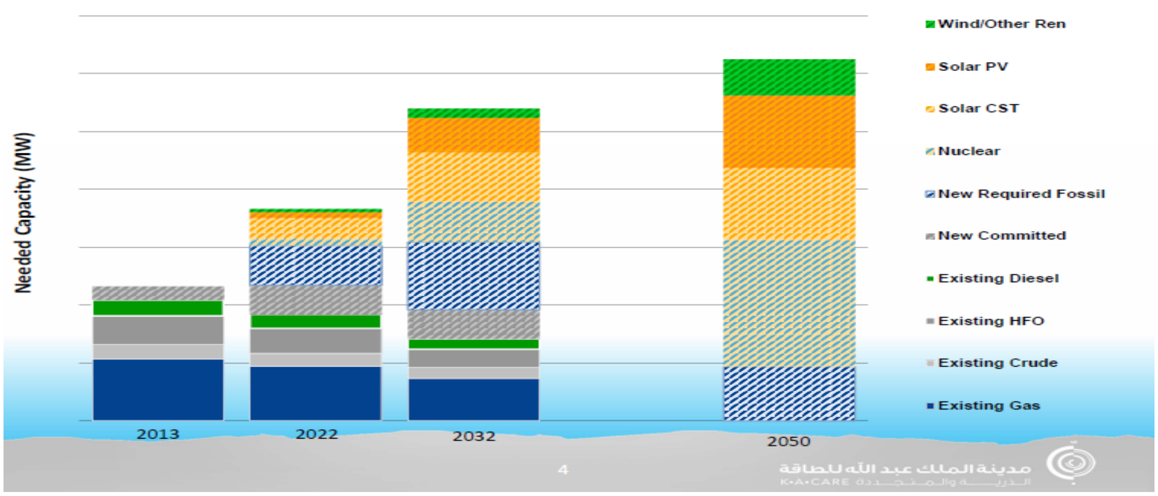

Figure.11 Sustainable energy outlook for Saudi Arabia. Source: K.A. CARE. [47]

Uses of solar energy in SA have been rising since 1961. [38] Since 2007, SA has established many organizations to improve solar energy like KACARE and KACST. Table 2 shows many solar energy projects developed in SA until 2013. [22]

Table 2. Solar energy projects in SA until 2013.

The project	(kW)	Year of establishing
King Abdul-Aziz Airport	5400	2013
King Abdullah Petroleum Studies & Research Center (KAPSARC)	3500	2012
Saudi Aramco Solar car Park	10500	2011
Princess Norah Bent Abdul-Rahman Univ.	25000	2013
King Abdullah Financial District	200	2012
King Abdullah University (KAUST) Solar Park	2000	2010
PV Hydrogen	350	1993
Solar Village	350	1981

Source: (KAPSARC)& (KAUST). [19]

There are many drivers that make it necessary to go for solar-based power generation. These factors range from the nature of Saudi Arabia in terms of solar radiation and wide desert land to the load demand profile that is driven by air-conditioning during summer in which peak loads occur. [13]

Hence, Saudi Arabia needs to cope with the huge energy demand through commissioning power generation plants that add more pressure on subsidized prices and fossil fuel resources. The availability of fossil fuel and the energy subsidiary contribute to inefficient energy consumption and leading to infeasible solar energy generation. Seemingly, the energy market is still at very early stage of liberalization and lack for necessary policies and regulations to the extent that it almost does not exist. [13]

The target percentage of renewable generation is 30% of the total generation capacity in 2032. [13]

It is argued that solar-based power generation opens the door for new job opportunities upon building up renewable industries. Hence, niches arise in Saudi Arabia with special technologies that are adapted to the desert weather conditions, so a new industry branch is formed with a large-scale of highly qualified job creation.

Carbon footprint according to some data is among the highest in the world in the GCC region. That being said, there has been no action taken to protect the climate domestically, which of course slowed down the international climate negotiations. [13]

2.5 Net Metering in Saudi Arabia

In August 2017, ECRA issued a regulatory framework for electricity consumers to operate their own small-scale solar power less than (2 MW) generating systems and export power to the national grid, offsetting this amount against their own consumption. As such, this creates a significant financial incentive and accelerates private sector investment in small-scale renewable energy applications. This will come into force in November 2018 and pre-qualified, registered installers must carry out the work in order for the system to be eligible.

Net metering experience in Saudi Arabia is totally new. As a matter of fact, the regulator body in Saudi Arabia, ECRA has authorized home owners to utilize Solar PV for net metering application [44].

ECRA has issued what it has described as Small Scare Solar PV Systems Regulations document in 2017 laying the ground for using Solar PV in small scale application. The regulation focuses mainly on three stakeholders: the utility (Saudi Electricity Company), the consumer and consultants/contractors.

The regulation hence focus on setting terms, conditions, requirements and process by which small scale solar PV systems can be managed and regulated. In order for a consumer to benefit from, they have to satisfy the following conditions:

a) should comply with the allowed rated capacity as specified under the regulations;

b) must be located within the consumer housing premises;

c) should not exceed a capacity of 1 MW in one Premises;

d) should not exceed a capacity of 5 MW in the area of supply at any distribution zone for a city; and should not be less than 1 kW.

The distribution company should provide the net metering service and such arrangement has to comply with Saudi Distribution Code laid out by ECRA.

The process of having small scale PV connection employing net metering consists of the following steps:

Choosing of solar PV certified consultants/ contractor.

Making enquiry about PV installation to distribution company (SEC).

Obtaining municipality approval for civil and environmental works.

Design approved by distribution company.

Inspection and energization after the approval from the distribution company.

[44]

2.6. PV over the world

Photovoltaic (PV) or solar cells are clean energy technologies which converts the sunlight into electricity without any emissions. Since 2012, PV market has witnessed increase on demands every year. In 2012 the global capacity of solar PV was about 68 GW, and by 2015 it increased by 70% to be 227 GW [9]. PV technology can be applied in any scale of projects, from domestic uses up to industrial applications. PV technology has major impacts on energy consumption of buildings in many places of the world [10-17].

PV technology can be applied on any scale of projects, from domestic uses up to industrial applications and it has major impacts on energy consumption of buildings in many places of the world [10]. PVs come in many types that can be installed and integrated with building envelope which are: rooftops, wall mounted, and integrated with glazing systems. The production of PVs depends on the total solar radiations received by the PV panels. PV panels' production will vary at different climatic regions due to the level of solar radiation.

The accumulative installed PV size around the world has grown-up fast. The total accumulative installations reached 320 GW by 2016. [Figure 12] China installed more than 15 GW in 2015, and the total installation of solar PV in china reached more than 43.4 GW, so China becomes the first country in the world in the solar energy. [Fig. 13] [29] [42]

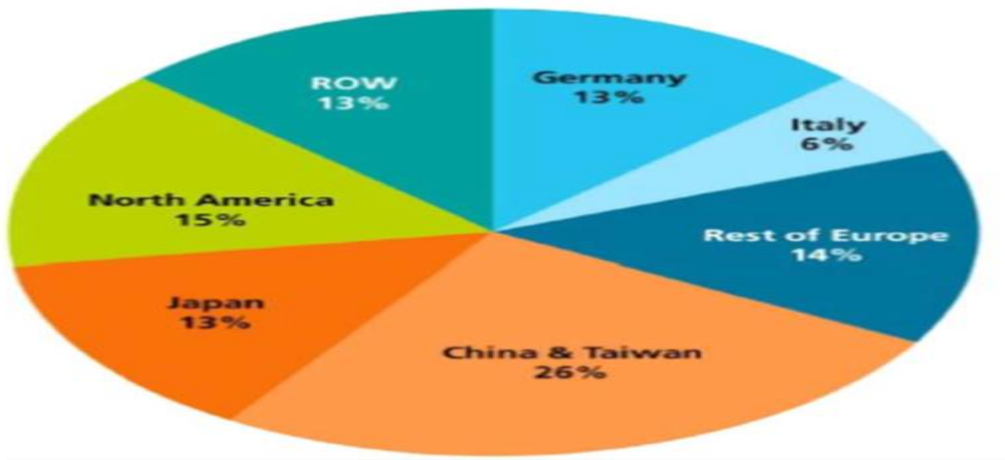

Fig. 12. Accumulative PV size around the world by 2016 (Fraunhofer. Institute.2017)

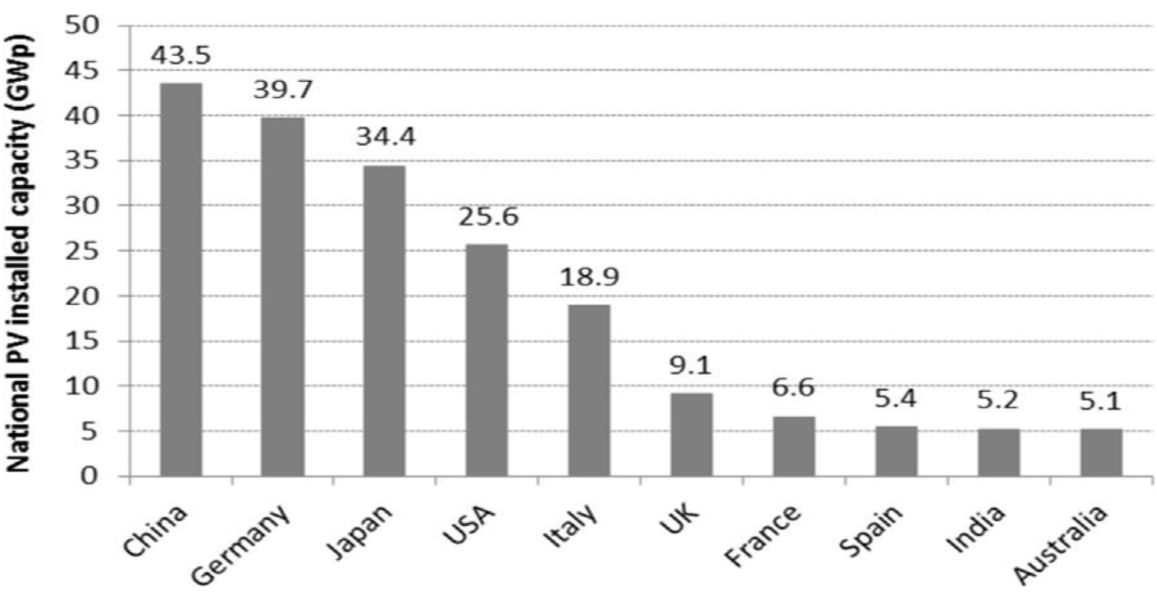

Fig. 13. PV capacity of top ten countries. [35]

In term of cost, the prices of PV system in the word decreased from about $ 4.46 in 2009 to $ 1.42 in 2016. [Figure 14].

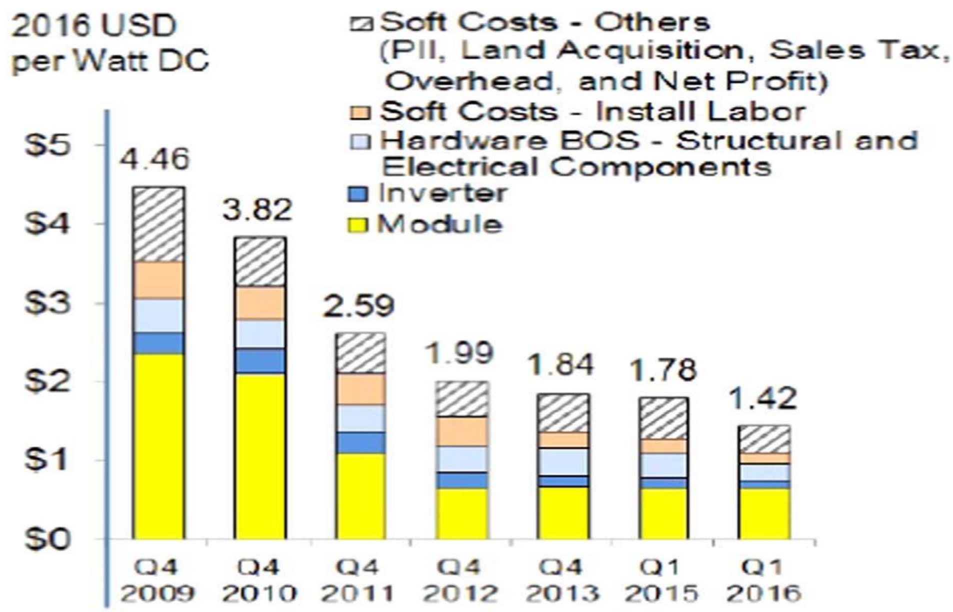

Fig. 14. the price of PV system (2009-2016) [35]

The levelized energy cost of Solar PV is expected to drop by 59% from 2015-2025. [41]

2.7. Solar Farms

The solar farms of PV in the word are shown an increasing in the capacity of PV. The biggest solar farms around the world till 2016 are shown in table 3. [45] When the capacity of the solar PV in the range of 10 MW and more is defined as very large scale photovoltaic.

Table 3 The biggest solar farms around the world till 2016.

Solar farm Site	Capacity (MW)
Rosamond, Solar Star Projects (USA)	579
Desert Sunlight Solar Farm (USA)	550
Topaz Solar Farm (USA)	550
Longyngxia Solar PV Station (China)	480
Charanka Park PV power plant (India)	345
Centrale solaire de Cestas (France)	300
Agua Caliente Solar Project (USA)	290
Copper Mountain III Solar Facility (USA)	250
California Valley Solar Farm (USA)	250
Antelope Valley Solar (USA)	242

A study of [Hassan Z. Al Garni] [31] which is about the suitable location of site for PV power plants or PV farm, it concluded with a map of SA that is shown the suitable regions of PV farm sites and this result depend on five criteria: environmental, location, economic, climatic, and orography. [Figure. 15]

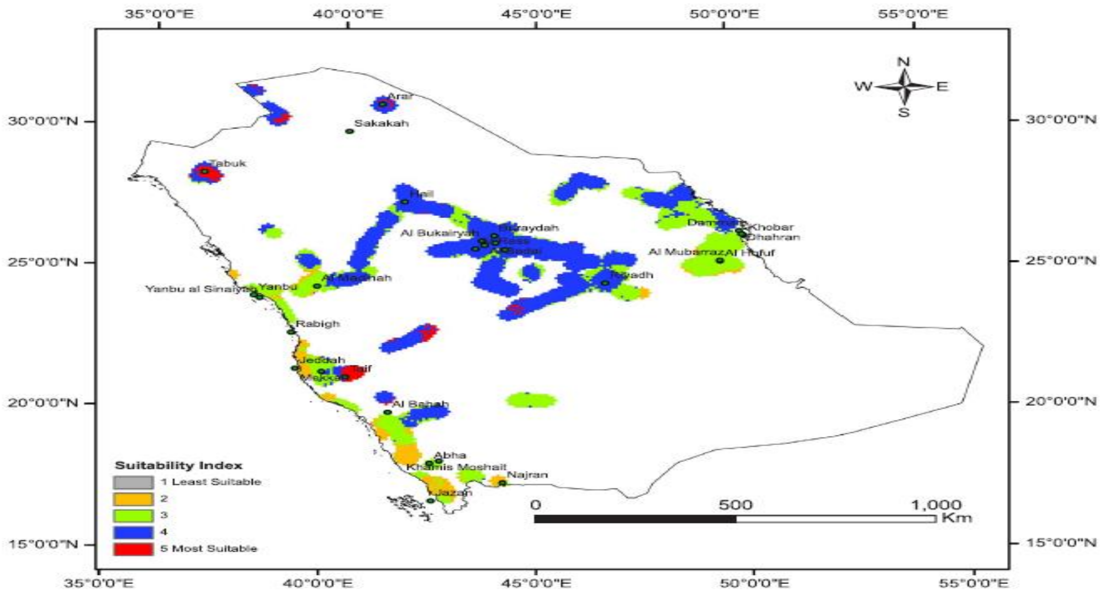

Figure. 15 Most suitable areas for solar power plants. [31]

2.8. PV Generation of building sector

In a study that explored a potential of rooftop solar PV in SA, it calculated the expected energy that can be generated from buildings in 13 cities in SA. It found that the residential buildings in these 13 cities has a total power capacity of 38 GW yearly which can cover 1/3 of the total electricity consumption in year. Foe Eastern region the study found that the maximum power capacity was 4.5 GW. [Table 4] [19]

Table 4. Power capacity in Eastern region.

Apartments (MW)	Villas (MW)	Traditional Houses (MW)	Other Types (MW)	Demand Forecast 2014 (MW)	Total (MW)
277.9	305.1	1,013.80	253.1	2,674.60	4,524.40

These results are reasonable for Eastern region if we compare it to the total number of buildings in the Eastern region. [Table 5] [Figure 16]

Table 5. Number of buildings in Eastern Region, 2010.

Apartment	Villa	Traditional House	Other	Total Housing Unit
287,402	161,911	103,175	22,413	500,465

[Source: Ministry of Economy and Planning (2010)

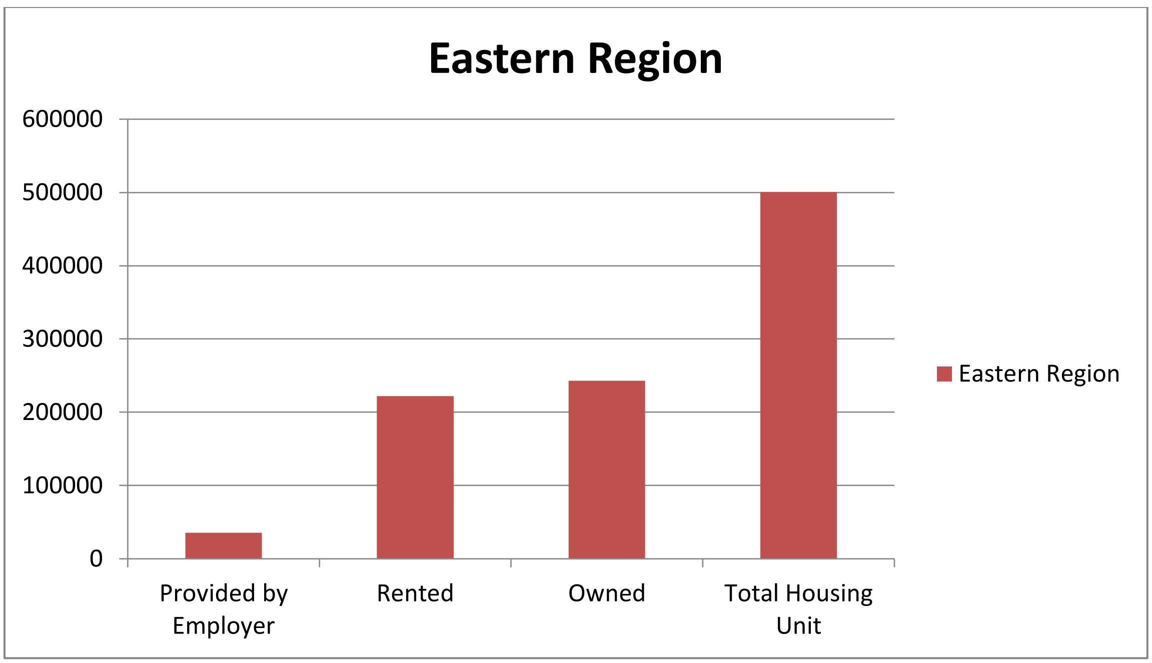

Figure 16. Housing Units in Eastern region.

A study in China, examined the PV application in buildings. The sample project that used has a capacity of 6,983 MW. It founds that the installed capacity of PV in industrial and commercial buildings is higher than that in residential buildings. Figure 17 shows the ratio of power capacity of each type of buildings. [29] The identification of this ratio as the study said, depends on two reasons. The first one is the complexity of the ownerships in many residential buildings. The second is the decreasing of marginal cost of PV installation that is regarding to the increasing in the power capacity. [29]

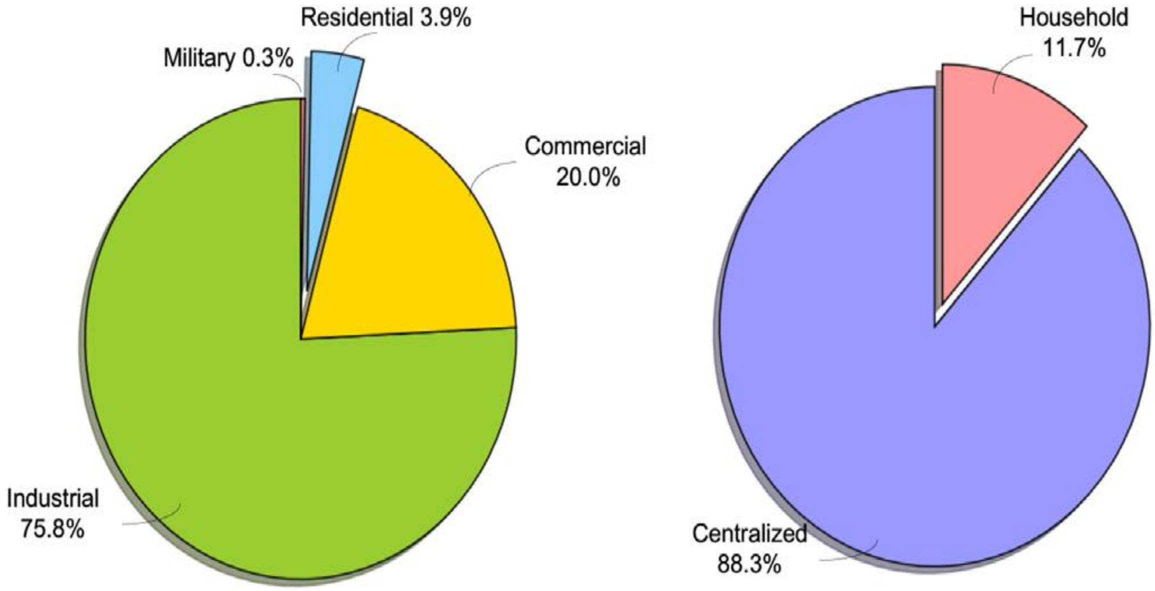

Fig. 17. The power capacity of buildings types.

In a survey in UK to over more than 900 building owners, 88% agreed they would consider using PV in their buildings provided that they are feasible and reliable [14].

CHAPTER 3

Buildings distribution PV

3.1 Buildings sector

Depending on the General Authority of statistics of Saudi Arabia the number of housing units by 2017 is more than 5,466,910 houses [27] and the average of houses that use solar energy in 2017 is around (1.3%). See table 6. Buildings are consuming around 79% of the total electricity production in S.A. [Fig. 17]. [36]

Table 6. Percentage of houses that use solar energy in 2017.

S/N	Administrative Region	Number of houses	Percentage for usage of solar energy at houses
1	Riyadh	1,350,639	1.17
2	Makkah	1,495,392	1.24
3	Madinah	376,129	1.00
4	Al-Qassim	272,078	0.88
5	Eastern Region	758,916	1.88
6	Asir	398,969	1.42
7	Tabuk	166,845	0.79
8	Hail	111,826	2.84
9	Northern Borders	47,848	1.16
10	Jazan	220,238	0.96
11	Najran	106,141	1.87
12	Al-Bahah	83,387	0.77
13	Al-Jouf	78,502	0.85
Total population in Saudi Arabia		5,466,910	
Average number of houses using solar energy		1.294 %	

Source: Household Energy Survey 2017

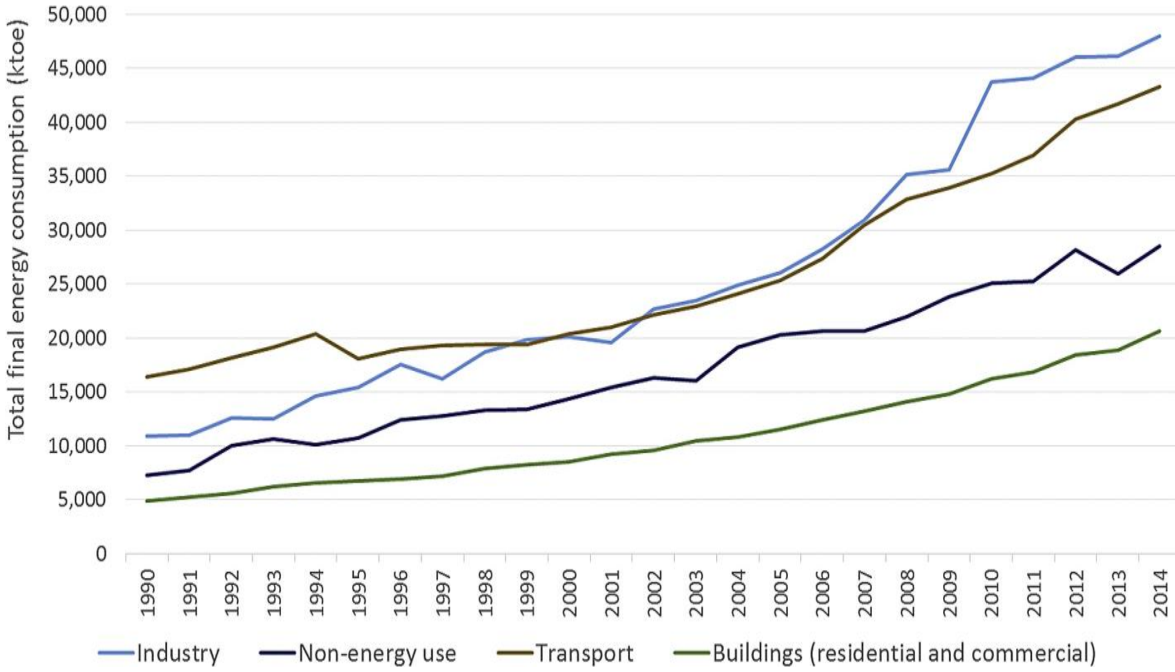

Fig. 18. Energy consumption by sector in SA. [32]

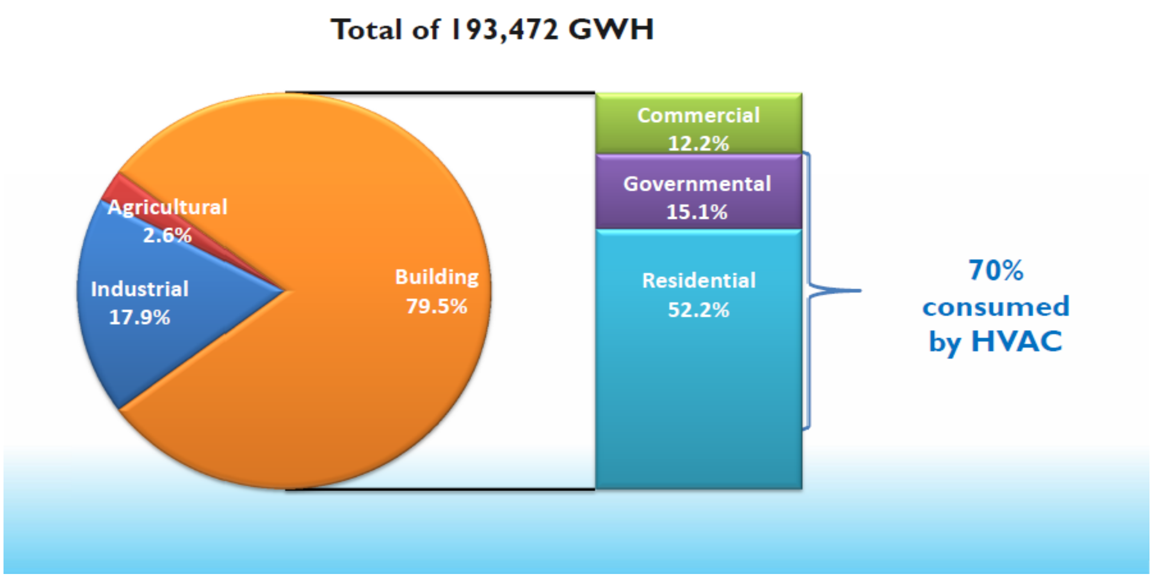

Figure 19. Electricity consumption by sector in SA during 2014. [50]

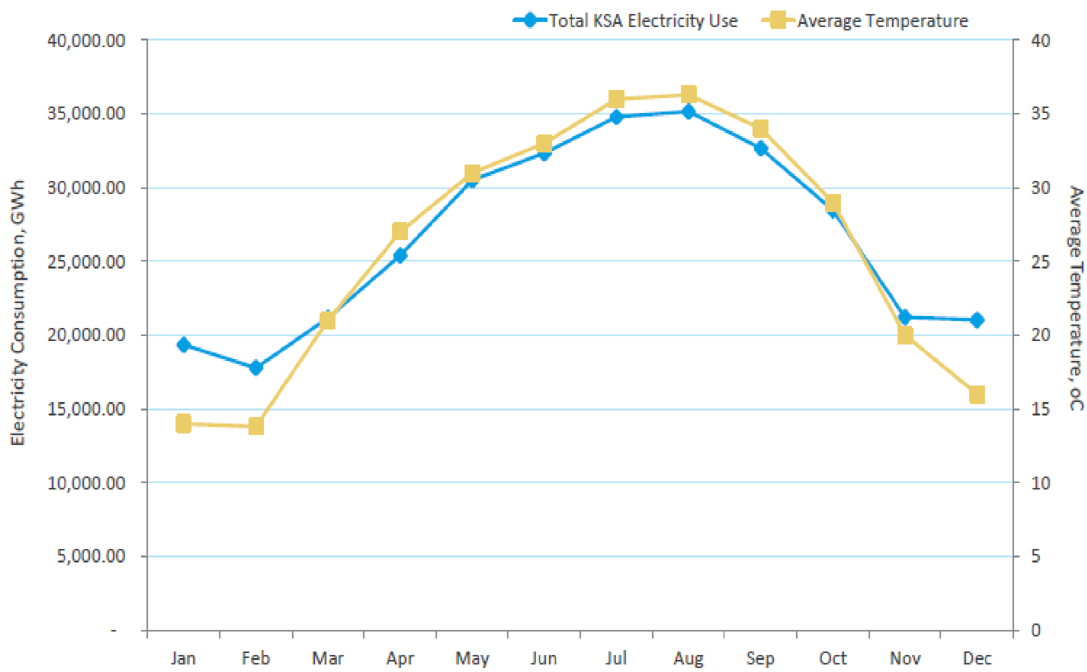

Figure 20. Total consumption of electricity in SA during 2014. [Source: SEC, 2015].

Air conditioning drives seasonal change in electricity consumption and this because of high cooling degree days in most of the cities of S.A. like Riyadh, Dhahran, and Jeddah. See table. 7. The cooling degree days CDD are measures of how cold a location is. The cooling degree day compares the mean outdoor temperatures recorded for a location to a standard temperature, usually 18° C in the SA over the hours of the day. The heating degree day HDD compares the mean outdoor temperatures recorded for a location to a standard temperature (18°) over the day.

Table 7: CDD and HDD for 5 cities in S.A. [32]

City	CDD (°C-days)	HDD (°C-days)
Riyadh	3160	162
Dhahran	3307	79
Tabuk	2422	317

Abha	1740	270
Jeddah	3659	0

Figure 21.a. shows the energy consumption over one year in a residential building in Dhahran city. [36]

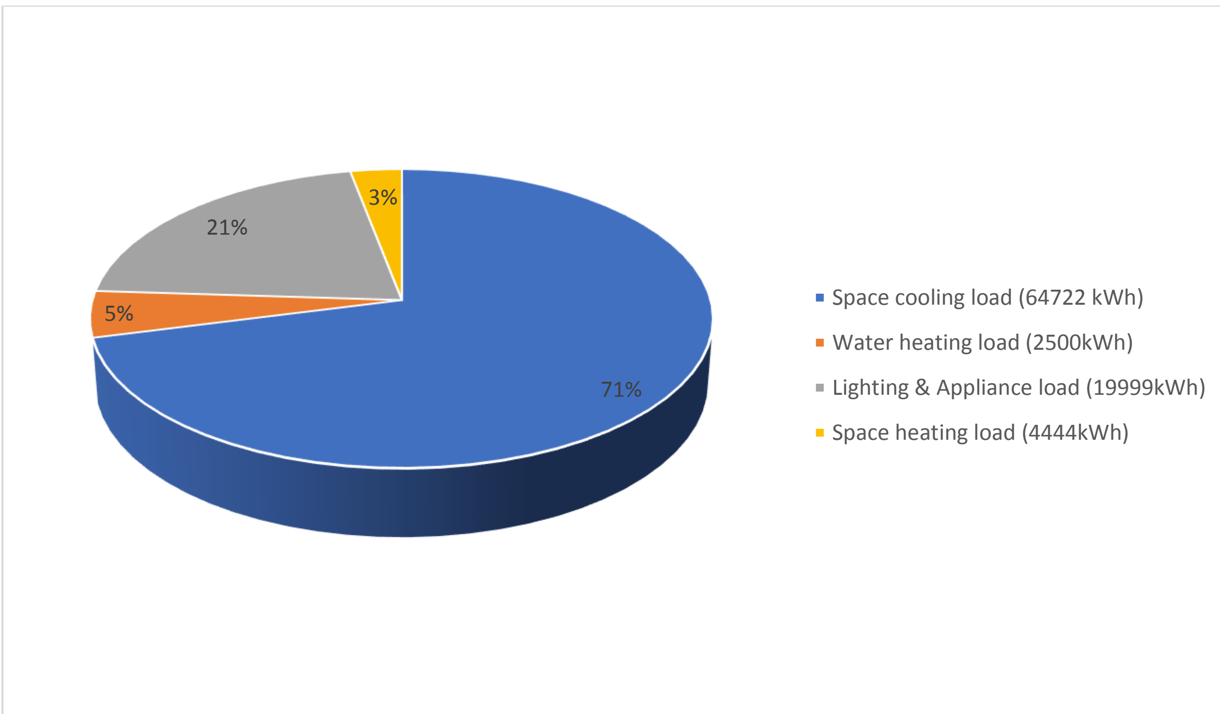

Fig. 21.a. The energy consumption over one year in a residential building in Dhahran city

The actual peak load in SA happens in between 11:00AM to 3:00PM in summer time. [Figure 21.b]

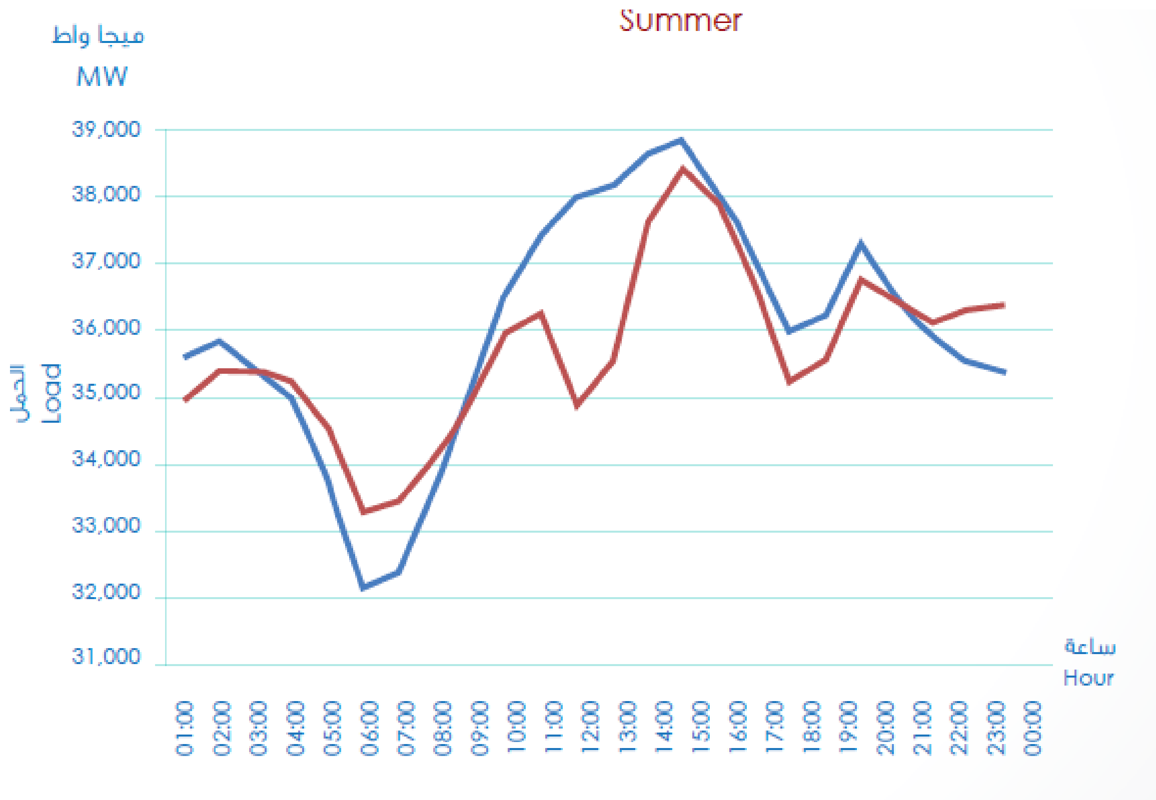

Fig. 21. b. Daily variation in peak load and temperature. [55]

3.2 Case Study of buildings sector

The study was conducted on 60 residential houses in Al-Danah in Dhahran city in the eastern region of SA. (Fig.22). The latitude of the site is 26, 13, 31 and the longitude is 50, 07, 50.

Figure 23.a and 23.b shows the details of the building site.

Figure 22 Location of case study.

Fig23.a: The details of the building site. [2]

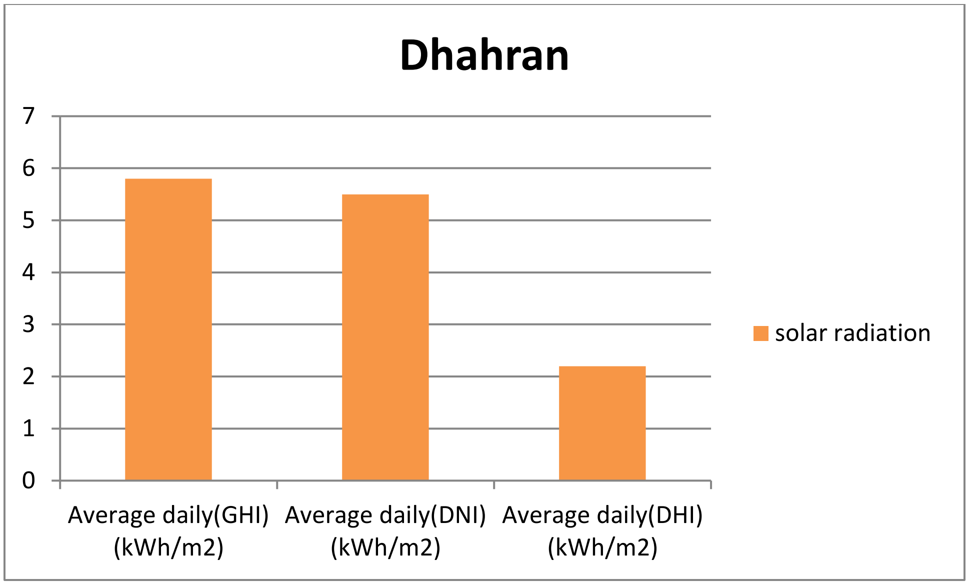

Figure. 23.b solar radiation for Dhahran.

3.2.1 The 60 buildings Load Profiles

We chose 60 residential building from Dhahran city and we study the load profiles of these buildings. We study the fowling:

1- The area of the buildings.
2- The annual energy consumptions of the buildings.
3- The annual cost of the energy consumptions.
4- The available area in the roof for PV system.
5- The energy unit index (EUI) of the buildings.
6- The annual generation of energy from the buildings when using PV system.

There are 5 different types of houses. There are 23 apartments with area that is from 100 m2 to 120 m2 and an installed power capacity of about 22.8 kW. The available area in the roof for PV system in the 23 apartments is 33.6 m2. There are 11 apartments with area that is from 130 m2 to 180 m2 and an installed power capacity of about 30 kW. The available area in the roof for PV system in the 11 apartments is about 50 m2. There are 15 houses with area from 200 m2 to 220 and an installed power capacity of about 38 kW. The available area in the roof for PV system in the 15 houses is about 61.6 m2. There are also 5 houses with area from 300 m2 to 320 and an installed power capacity of about 47 kW. The available area in the roof for PV system in the 5 houses is about 89.6 m2. There are also 4 houses with area of 500 m2 and an installed power capacity of about 65 kW.

The available area in the roof for PV system in the 4 houses is only 77 m2. The details of the buildings are shown in table 8.

Table 8 The load profiles of the buildings.

Dhahran	Area (m*2)	Available Area in the Roof for PV (m2)	Annual Consumption (kWh) 2018	Consumption Cost (SR) 2018	EUI (kWh)/m2
Building 1	120	26.4	37324	5886	311.033
Building 2	120	26.4	32714	5411	272.617
Building 3	120	26.4	28995	4409	241.625
Building 4	120	26.4	46419	7890	386.825
Building 5	120	26.4	15681	2577	130.675
Building 6	120	26.4	14161	2814	118.008
Building 7	120	26.4	27139	4604	226.158
Building 8	120	26.4	13700	2174	114.167
Building 9	120	26.4	17563	2787	146.358
Building 10	210	46.2	40650	3500	194
Building 11	200	44	18555	2887	93
Building 12	120	26.4	14287	2298	119.058
Building 13	220	48.4	33024	5437	150.109
Building 14	220	48.4	36561	6034	166.186
Building 15	220	48.4	34799	5220	158.177
Building 16	220	48.4	36107	5416	164.123
Building 17	220	48.4	32702	4905	148.645
Building 18	220	48.4	38966	5799	177.118
Building 19	320	70.4	42315	7338	132.234
Building 20	320	70.4	50618	8905	158.181
Building 21	200	44	41866	6588	209
Building 22	320	70.4	36344	5451	113.575
Building 23	320	70.4	38654	5798	120.794
Building 24	320	70.4	40100	6015	125.313
Building 25	550	121	45320	6743	82.4
Building 26	550	121	48555	7283	88.2818
Building 27	550	121	52971	7945	96.3109
Building 28	550	121	54766	8215	99.5745
Building 29	711	156.42	74800	15316	105.204
Building 30	820	180.4	99477	21800	121

Building 31	100	22	38890	6411	389
Building 32	200	44	34704	6239	174
Building 33	100	22	26199	4431	262
Building 34	100	22	26258	4465	263
Building 35	180	39.6	34656	6120	193
Building 36	180	39.6	28765	4987	160
Building 37	110	24.2	38942	6574	354
Building 38	110	24.2	56655	9976	515
Building 39	110	24.2	29865	2644	272
Building 40	100	22	26258	4465	263
Building 41	110	24.2	26311	4500	239
Building 42	120	26.4	27717	4470	231
Building 43	120	26.4	27721	4478	231
Building 44	120	26.4	27654	4365	230
Building 45	120	26.4	12989	2655	108
Building 46	120	26.4	27711	4466	231
Building 47	215	47.3	29020	5464	135
Building 48	120	26.4	47698	5632	397
Building 49	210	46.2	34766	6165	166
Building 50	122	26.84	17077	2750	140
Building 51	124	27.28	12077	2150	97
Building 52	125	27.5	15576	868	125
Building 53	200	44	29000	5400	145
Building 54	200	44	18680	2997	93
Building 55	130	28.6	31390	5400	241
Building 56	140	30.8	31436	5476	225
Building 57	150	33	21000	2954	140
Building58	180	39.6	28765	4987	160
Building 59	170	37.4	21580	3618	127
Building 60	176	38.72	21576	3620	123
Average	**212.05**	**46.651**	**33267.8**	**5436.2**	**190**

The load profiles for the buildings were obtained through the electricity bills for one previous year (2018). The load profiles of the 60 buildings show a similar trend of typical energy consumption in building in SA. A study investigated the potential for rooftop application of solar PV in the residential buildings in SA and it is found that 28% of the rooftops can be effectively used for PV application. [60]

The available area in the rooftop is calculated as 28% of total area of building.

The table shows a surge in electricity demand during the summer months as use of HVAC system increases with the cooling demand. The average consumption in buildings over one year is 33267.8 kWh and the average of the cost of the energy is 5436.2 SR.

The energy unit index (EUI) of the building:

EUI = total annual energy consumptions / area of the building.

The average of the EUI of the buildings is 190 kWh/m2.

3.3 The annual generation of energy from the buildings when using PV system

To calculate the annual generation of energy from the building when using PV system, we use HOMER software and we applied the software on the 60 buildings.

3.3.1 HOMER

HOMER (Hybrid Optimization of Multiple Electric Renewables), the micro power optimization model, simplifies the task of evaluating designs of grid connected power systems for a variety of applications

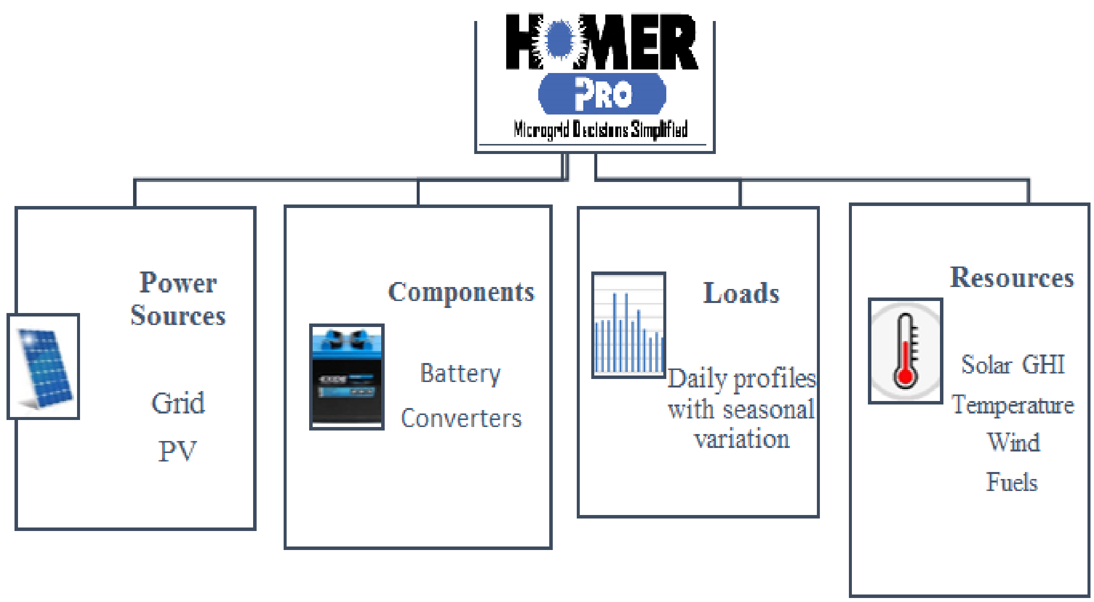

Figure 24 Components of HOMER.

3.3.2 Sample building

The schematic of PV System for a sample building is shown in figure 25. The daily load is 107.32 kWh and the peak power is 22.8 kWp.

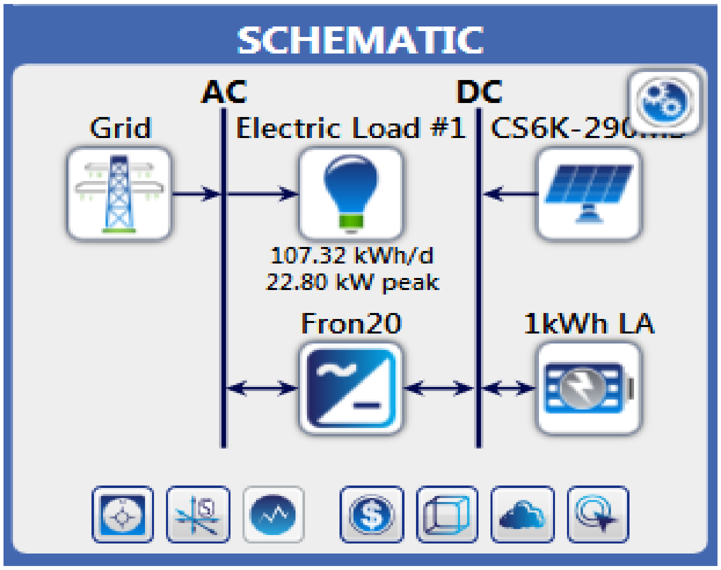

Figure 25 The schematic of PV System for a sample building.

3.3.2.1 System architecture of the sample building

When running the analysis, we use the weather data for Dhahran city and making assumptions for the input data such as the tilt angle, load profile, the net metering scheme, operational cost and life time of the PV system. The general characteristic features of modeled grid-connected PV system are shown in table 10.

Table 10 General features of modeled PV system.

Name	Description
Diesel cost	0.067 $/L
Project Lifetime	20 years
Discount rate	2.75%
Inflation rate	2%

3.3.2.2 Photovoltaic (PV) cell

The photovoltaic modules used for the system design are type 'Mono-crystalline. The specifications of the PV panels are included in table 11.

The cost per kilowatt peak of the PV panels is 1200$. The price includes installation, engineering, and wiring costs. The maintenance fee was entered to HOMER as 10$/kWp.

One PV panel size is1640 mm length by 994 mm width and with a total area of 1.63 m2. So, a 33.6 m2 is enough to fit 85 PV panels with a total system output of 25 kW. Hence, the size of the system for a sample building that entered in HOMER software was 20 kW. Also, solar panel efficiency, temperature, and tilt angle were entered.

Table 11. Characteristic features of PV cells.

PV	Description
PV technology type	Mono-crystalline
Name of PV	Canadian Solar All-Black CS6K-290MS
Manufacturer of PV	Canadian Solar
Efficiency (PV)	17.72%
Nominal operating temperature	45^0C
Temperature Coefficient	-0.39%/ ^{0}C
Lifetime	25 years
Area of PV module	1.63 m2
Slope of panels	Latitude of location
Tracking system	It is fixed
PV panel cost	700 $/kW
Nominal Max Power	25 kW
Dimensions	1640mm x 994mm x 40mm

3.3.2.3 Converter

The size of the inverter is chosen to be 24 kW, same as the sizes selected for the PV array of the sample building. The capital prices for inverters are between 50 to 80 $/kW, with an average of 65 $/kW.

A grid connected central inverter (Frounius Symo 20.0-3-M) was used in the PV system design. The converter has an efficiency of 98% and a rated power of 24 kW. [Table 12]

Table 12. Characteristic features of the converter.

Converter	Description
Name	Frounius Symo 20.0-3-M
Efficiency	98%
Lifetime	10 years
Converter cost	65 $/kW
Replacement	60 $/kW

3.3.2.4 Daily load

A home load profile was calculated by HOMER software. Figure 26.a and figure 26.b show the daily and seasonal load profiles of the sample home.

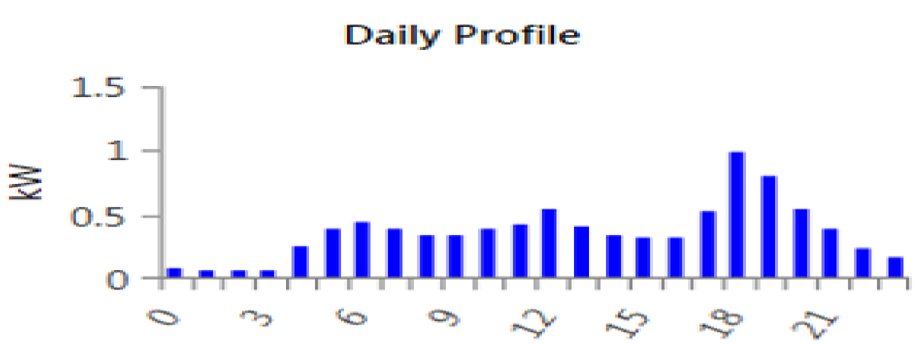

Fig. 26.a The home daily load profile.

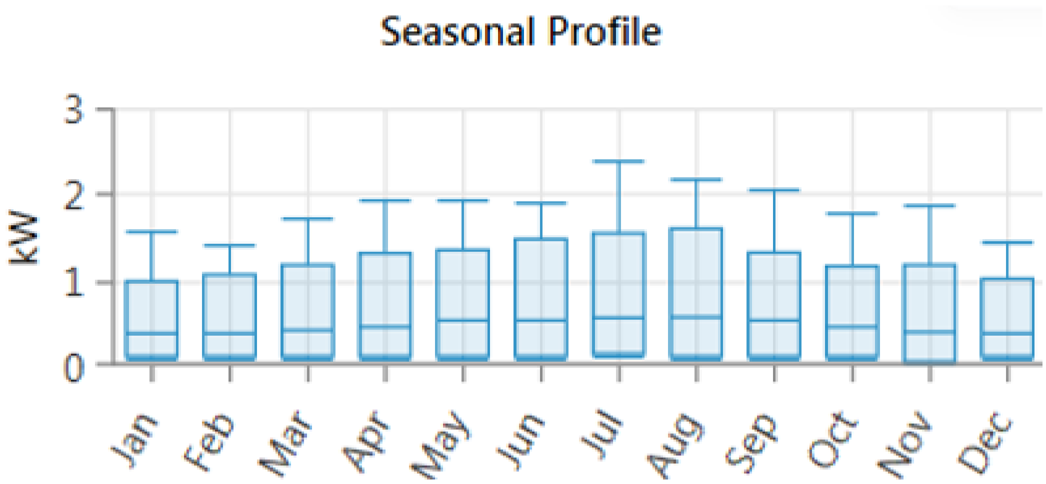

Fig. 26.b The home seasonal load profile.

3.4. The simulation results

3.4.1 The Simulation result of the sample building

Figure 27 shows the simulation result of sample building and we find that:

The total net present cost is $ 48,362.95 and the levelized cost of energy is 0.0406 $ (0.15 SR) and the details of the components of the system are listed in table 13.

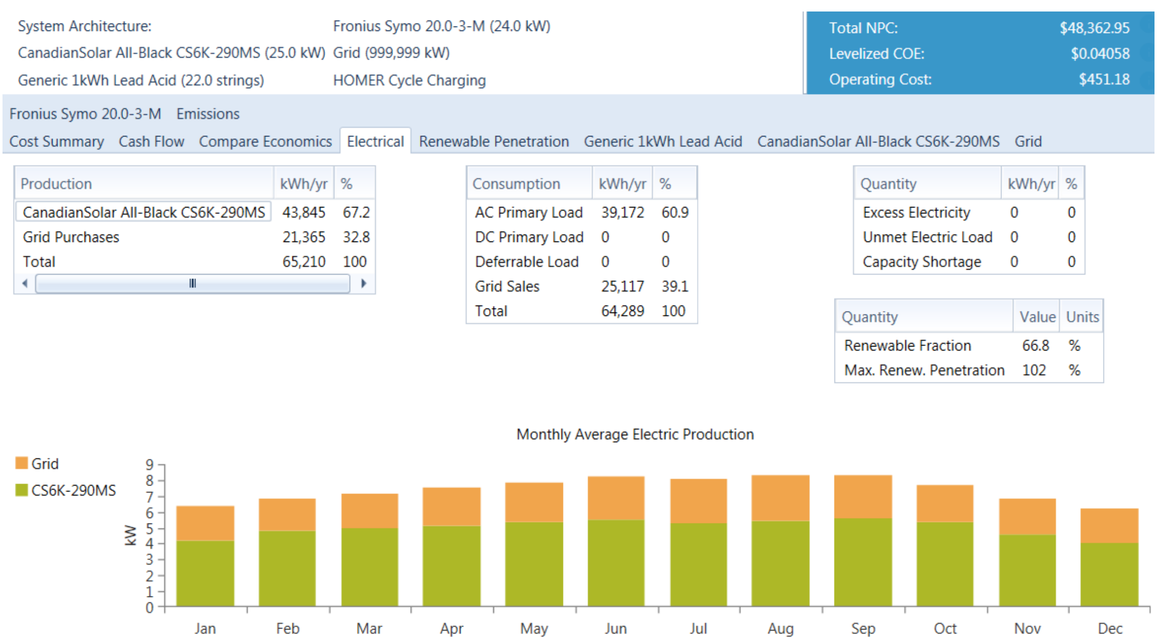

Fig. 27 The simulation result of the sample home. [HOMER]

Table 13 Net Present Costs.

Name	Capital	O&M	Replacement	Total
Canadian Solar All-Black CS6K-290MS	$30,000	$4,634 $0.00	$0.00	$34,634
Fronius Symo 20.0-3-M	$1,200	$ 0.00	$1,115	$2,315
Generic 1kWh Lead Acid	$8,800	$ 0.00	$8,178	$16,978
Grid	$ 0.00	-$5,565	$0.00	-$5,565
System	$40,000	-$930.64	$9,294	$48,363

Figure 28 shows the cost summary of whole system during the 20 years which is the time life of the system. The cost contains:

The capital cost

The operation and maintenance cost

The replacement cost

The salvage.

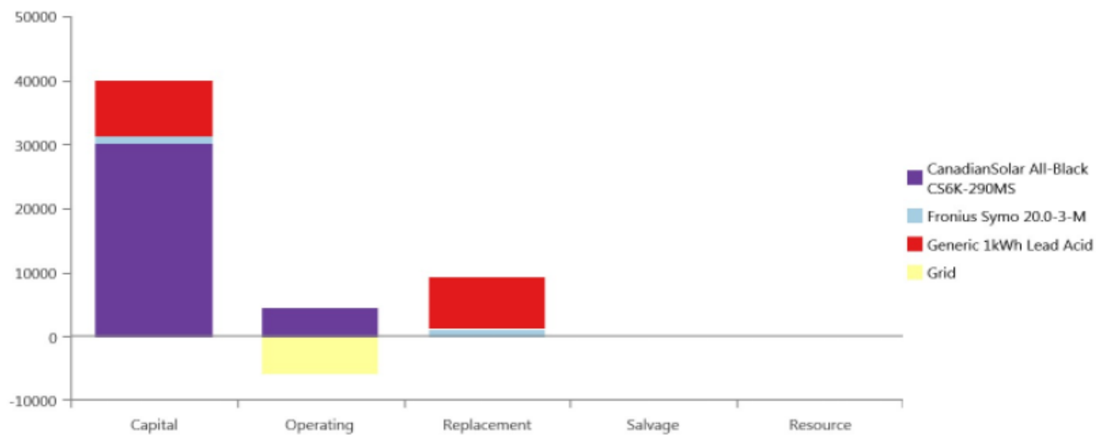

Figure 28 The cost summary

Figure 29 shows the cash flow of the system which contains the capital, the operation and maintenance and the replacement cost.

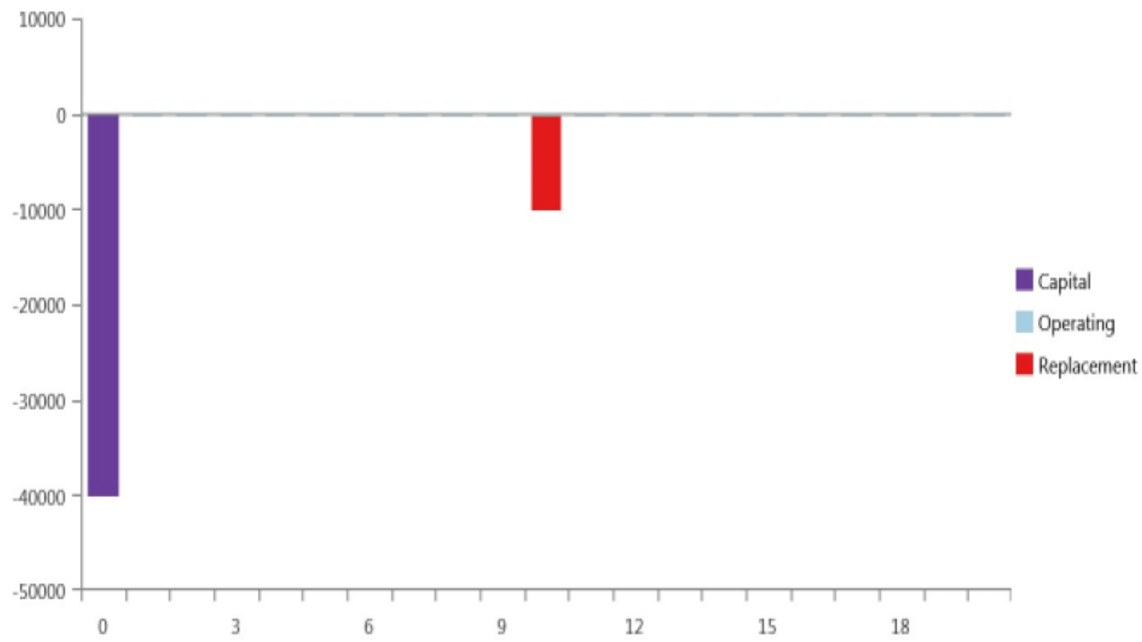

Figure 29 The cash flow.

3.4.1.2 The production summary of the sample building

Table 14 and figure 30 show the production of energy of the net-metering system of the sample house.

Table 14 Production of energy of the net-metering system of the sample house over one year.

Component	Production (kWh/yr)	%
Canadian Solar All-Black CS6K-290MS	43,845	67.2
Grid Purchases	21,365	32.8
Total	62,307	100

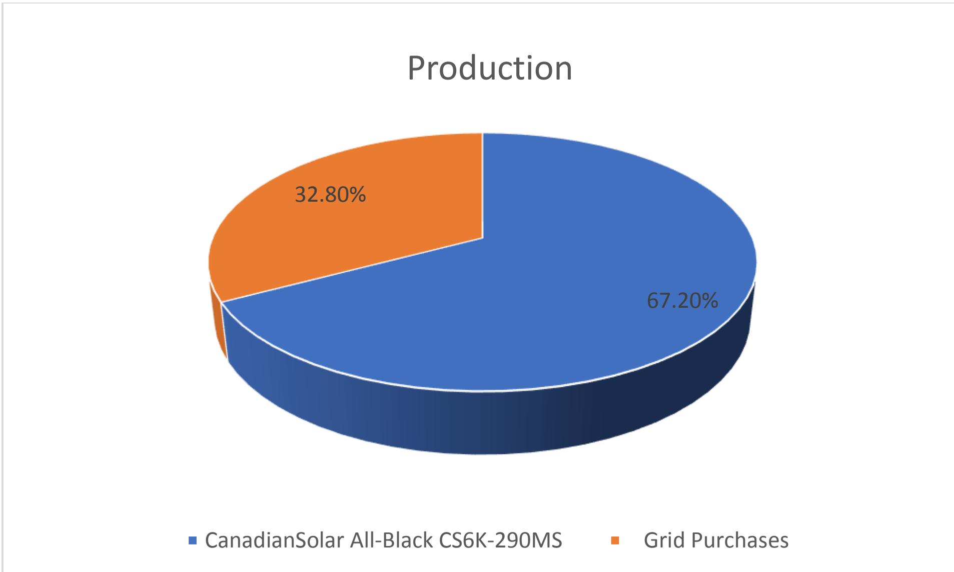

Figure 30. Percentage of production of energy of the net-metering system.

3.4.1.3 Emissions of the sample building

The CO2 reduction was taken into consideration. The reduction of the Carbon Dioxide by the PV system of the sample building is 11,254 kg/y and the reduction of the Sulfur Dioxide is 48.5 kg/y. See table 15.

Table 15 Emissions of the sample building.

Quantity	Without PV system (kg/y)	With PV system (kg/y)	Reduction (kg/y)
Carbon Dioxide	24,757	13,503	11,254
Sulfur Dioxide	107	58.5	48.5
Nitrogen Oxides	28.6	28.6	0

3.4.2 Generation of the PV system of the 60 buildings

After using the HOMER software to simulate the 60 building we find the expected generation of PV system for all building and the cost of generation. The energy generation from PV system for the buildings are listed in table 16.

Table 16 Energy generation from PV system for the buildings.

Dhahran	Area (m*2)	Available Area in the Roof for PV (m2)	Annual PV Generation Per House (kWh)	Annual PV Generation Cost (SR)
Building 1	120	26.4	6468	873.18
Building 2	120	26.4	6468	873.18
Building 3	120	26.4	6468	873.18
Building 4	120	26.4	6468	873.18
Building 5	120	26.4	6468	873.18
Building 6	120	26.4	6468	873.18
Building 7	120	26.4	6468	873.18
Building 8	120	26.4	6468	873.18
Building 9	120	26.4	6468	873.18
Building 10	210	46.2	11319	1528.065
Building 11	200	44	10780	1455.3
Building 12	120	26.4	6468	873.18
Building 13	220	48.4	11858	1600.83
Building 14	220	48.4	11858	1600.83
Building 15	220	48.4	11858	1600.83
Building 16	220	48.4	11858	1600.83
Building 17	220	48.4	11858	1600.83
Building 18	220	48.4	11858	1600.83
Building 19	320	70.4	17248	2328.48
Building 20	320	70.4	17248	2328.48
Building 21	200	44	10780	1455.3
Building 22	320	70.4	17248	2328.48
Building 23	320	70.4	17248	2328.48
Building 24	320	70.4	17248	2328.48
Building 25	550	121	29645	4002.075
Building 26	550	121	29645	4002.075
Building 27	550	121	29645	4002.075

Building 28	550	121	29645	4002.075
Building 29	711	156.42	38322.9	5173.5915
Building 30	820	180.4	44198	5966.73
Building 31	100	22	5390	727.65
Building 32	200	44	10780	1455.3
Building 33	100	22	5390	1194.48
Building 34	100	22	5390	1194.48
Building 35	180	39.6	9702	1309.77
Building 36	180	39.6	9702	1309.77
Building 37	110	24.2	5929	1194.48
Building 38	110	24.2	5929	1194.48
Building 39	110	24.2	5929	1194.48
Building 40	100	22	5390	1194.48
Building 41	110	24.2	5929	1194.48
Building 42	120	26.4	6468	873.18
Building 43	120	26.4	6468	873.18
Building 44	120	26.4	6468	873.18
Building 45	120	26.4	6468	873.18
Building 46	120	26.4	6468	873.18
Building 47	215	47.3	11588.5	1564.4475
Building 48	120	26.4	6468	873.18
Building 49	210	46.2	11319	1528.065
Building 50	122	26.84	6575.8	887.733
Building 51	124	27.28	6683.6	902.286
Building 52	125	27.5	6737.5	909.5625
Building 53	200	44	10780	1455.3
Building 54	200	44	10780	1455.3
Building 55	130	28.6	7007	945.945
Building 56	140	30.8	7546	1018.71
Building 57	150	33	8085	1091.475
Building58	180	39.6	9702	1309.77
Building 59	170	37.4	9163	1237.005
Building 60	176	38.72	9486.4	1280.664
Average	**212.05**	**46.651**	**11429.495**	**1592.5943**

From the table of the energy generation we can see the average energy generation of the buildings is 11,429.495 kWh in the year. The average of the annual cost is 1,592.594 SR (424.69 $).

When compare the average generation of the buildings (table 16) to the average consumption of the buildings (table 8), we found that:

The average energy generation of the buildings / the average consumption of the buildings = 11,429.495 kWh/33267.8 kWh * 100% = 34 %.

We can see that from the table that the cost of the kWh is 0.135 SR. (0.036 $)

CHAPTER 4

Solar Farm

4.1 Most important criteria of solar farm

- Size of the solar farm:

The utility scale PV can be defined as large-scale PV projects which can generate at least 5MW. [56] So, our case study will be 10MW solar power plant.

- Location:

A study [31] estimated the best site selection in S.A. The overlaid result map showed that the most suitable areas to be in the north and northwest of the S.A. It has been found that suitable lands are following the pattern of the approximate range of the proximity to main roads, transmission lines, and urban cities. Also, these areas have, the optimum slop of the land, and the proximity to power lines. [Figure 31]

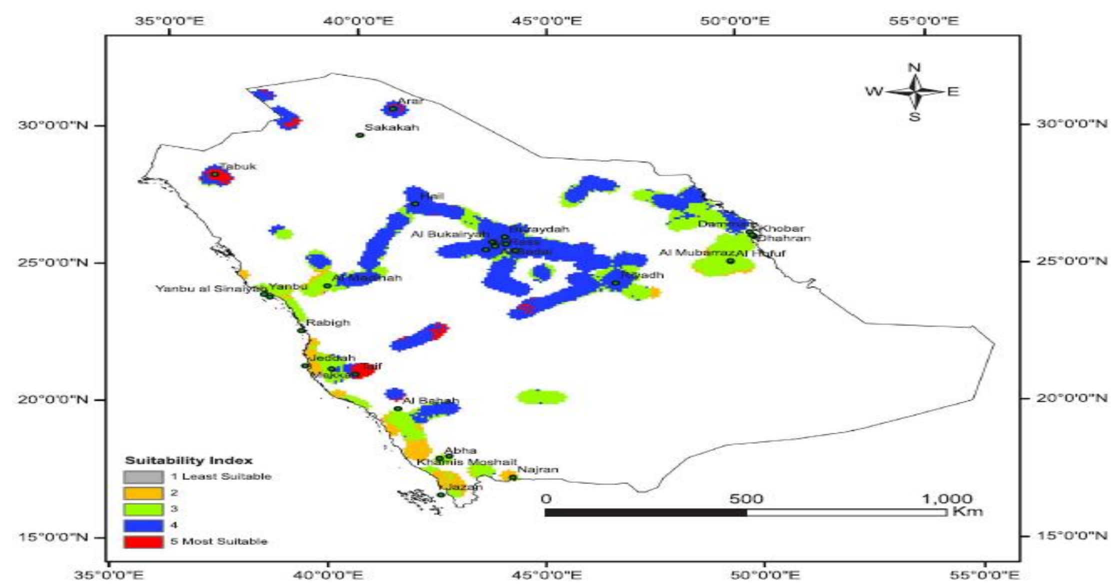

Figure.31 Most suitable areas for solar power plants [31]

- Solar irradiation

Solar irradiation is an essential criterion for largescale PV solar power projects. The minimum solar irradiation in S.A. is higher than the average GHI in Germany and many other European countries and the overall mean of yearly sunshine duration in the Kingdom is 3248 h. [31] [See fig. 32]

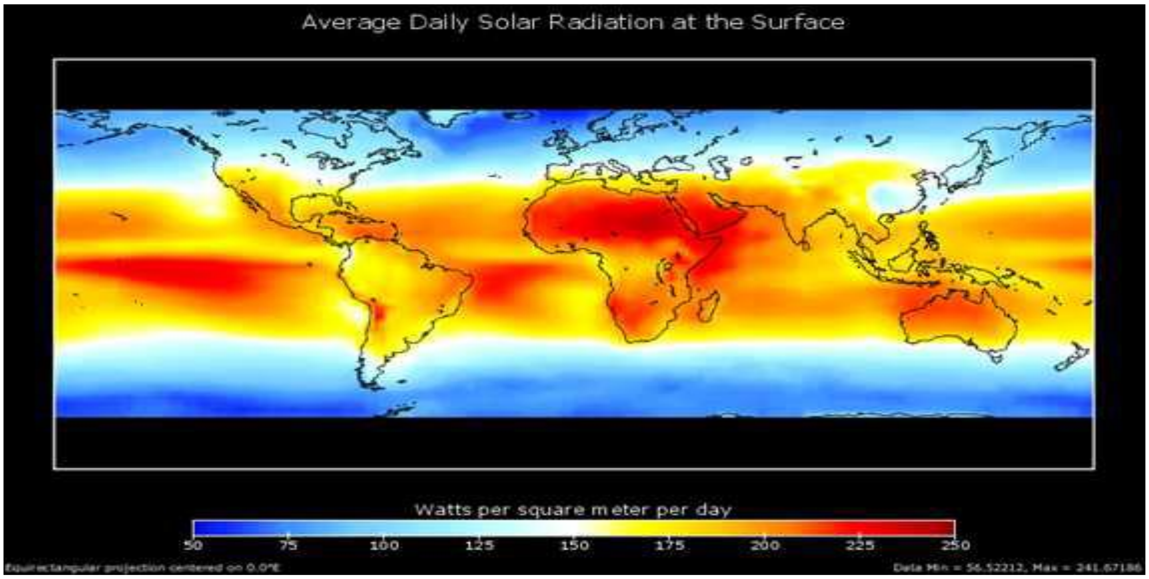

Fig. 32. The amount of solar radiation reaching the ground. [44]

Figure 33 shows the seasonal variation of global solar radiation over S.A.

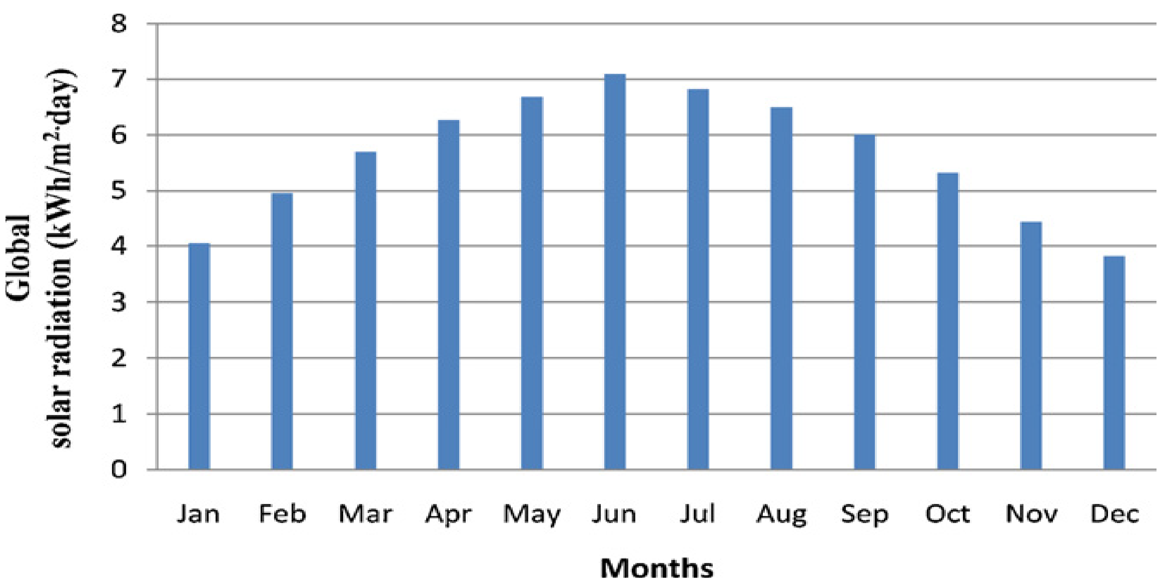

Fig. 33. Solar radiation of SA. [40]

➢ Tilt and azimuth angles:

A south-facing slope is an ideal orientation for solar farm sites and must be between 20° and 26° in SA.

➢ Temperature, humidity, and dust:

Figure 34 shows the average monthly temperature in S.A. Temperature is the second issue that effect the production of solar farm after the solar radiation.

The humidity is shown in figure 35 for some cities in S.A. The dust is also affecting the production of the PV cells, figure 36 shows the most common dust source areas in and around S.A. while figure 37 shows the permanent and temporary sources of dust.

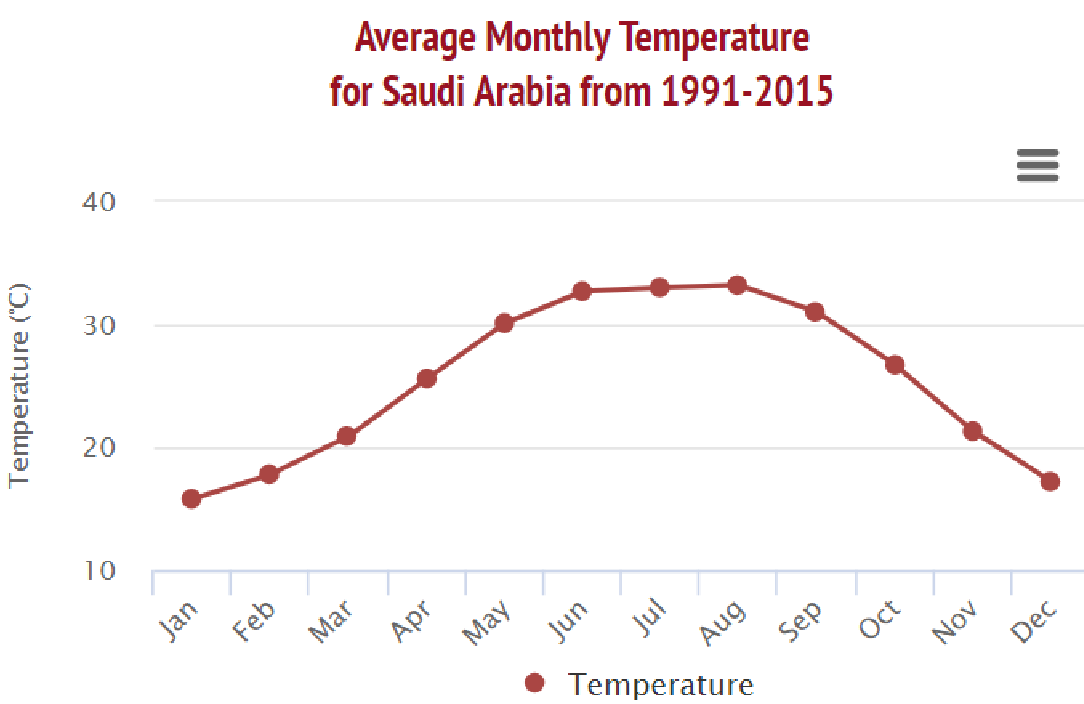

Figure 34 Average monthly temperature in S.A. [55]

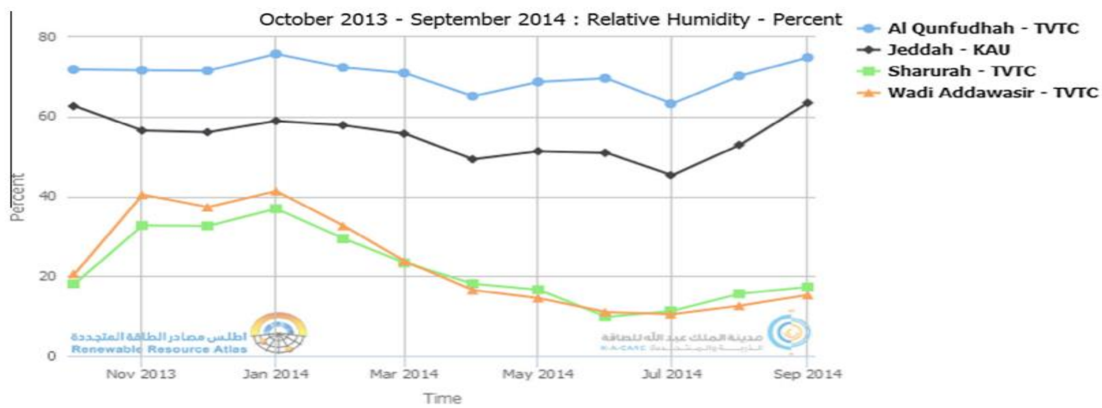

Fig. 35. Humidity levels at 4 different cities in SA.

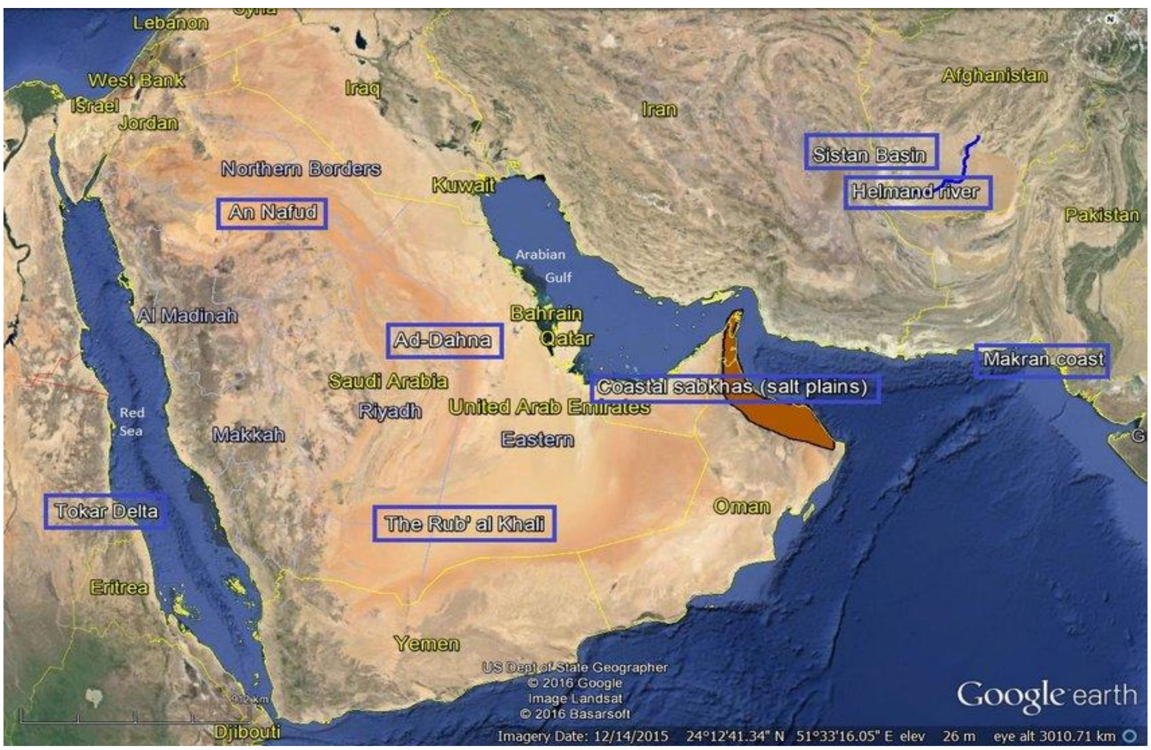

Fig. 36. The most common dust source areas are indicated in blue boxes. [61]

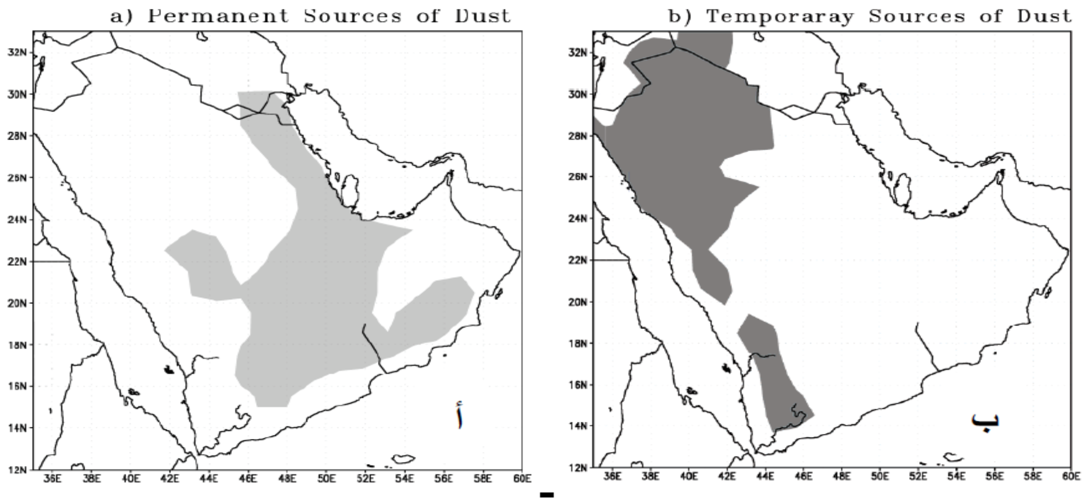

Fig. 37. The permanent and temporary sources of dust in S.A. [61]

There are some criteria that affect the output energy of the solar farm system. These criteria are the solar radiation, the proximity to urban area, the slop of the land, the humidity, the dust, the temperature, the proximity to roads, and the proximity to power lines. Figure 38. Shows the Eigenvalue of the most important criteria of solar farm.

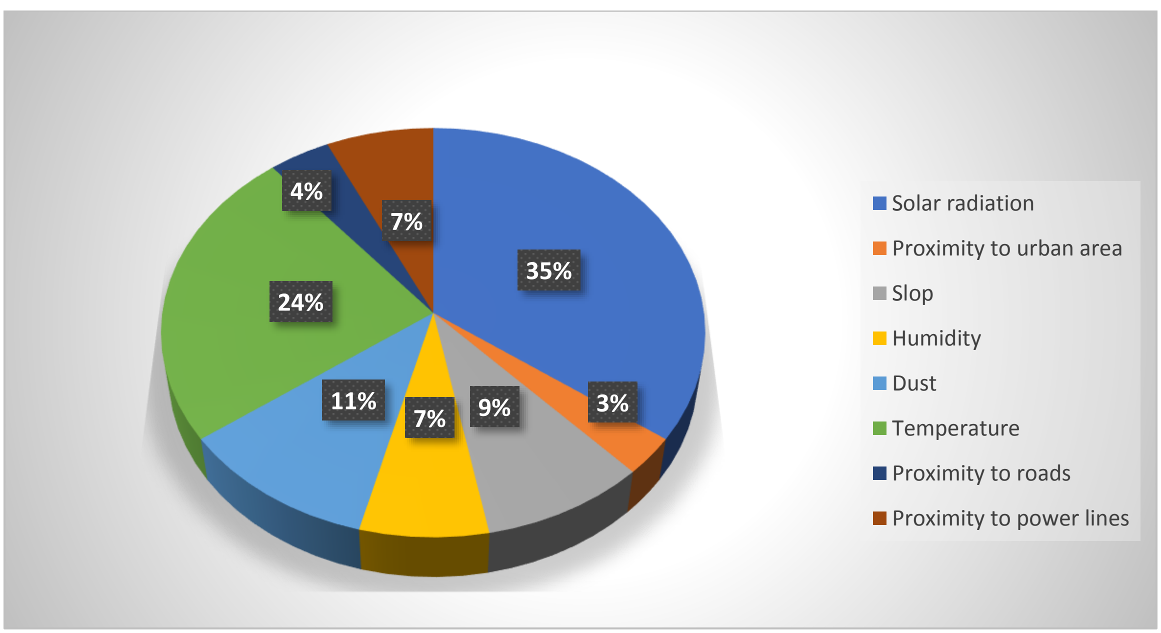

Fig. 38. Eigenvalue of the criteria of solar farm. [31] [2] [61]

4.2 Modeling the PV system

4.2.1 Solar position data for that location

- Location: Dhahran city in Saudi Arabia Latitude: (26.288769) and Longitude: (50.114101) [Fig. 39]

Fig. 39 Dhahran, Saudi Arabia Map

- The tilt angle of the plant is 25.
- Azimuth is 180 (South)
- Solar global irradiance (GHI): the annual average Solar global irradiance of Dhahran is 5.84 kWh/m2/day. [Table 17] Figure 40 shows the GHI over the hours of the day.

Table 17. Annual irradiation incident on Dhahran [33]

Month	Hh (Wh/m²/Day)	Hopt. (Wh/m²/Day)	DNI (Wh/m²/Day)	Iopt. (Deg.)
January	3880	5090	4360	52
February	4800	5830	4810	43
March	6070	6730	5580	30
April	6600	6670	5540	14
May	7790	7340	6750	1
June	8320	7520	7720	0
July	7860	7270	6800	1
August	7440	7310	6620	9
September	6910	7450	6910	25
October	5750	6870	6340	40
November	4170	5320	4430	49
December	3730	5040	4450	54
Year	6120	6540	5870	24

Hh: Irradiation on horizontal plane; Hopt.: Irradiation on optimally inclined plane; DNI: Direct normal irradiation; Iopt.: Optimal inclination.

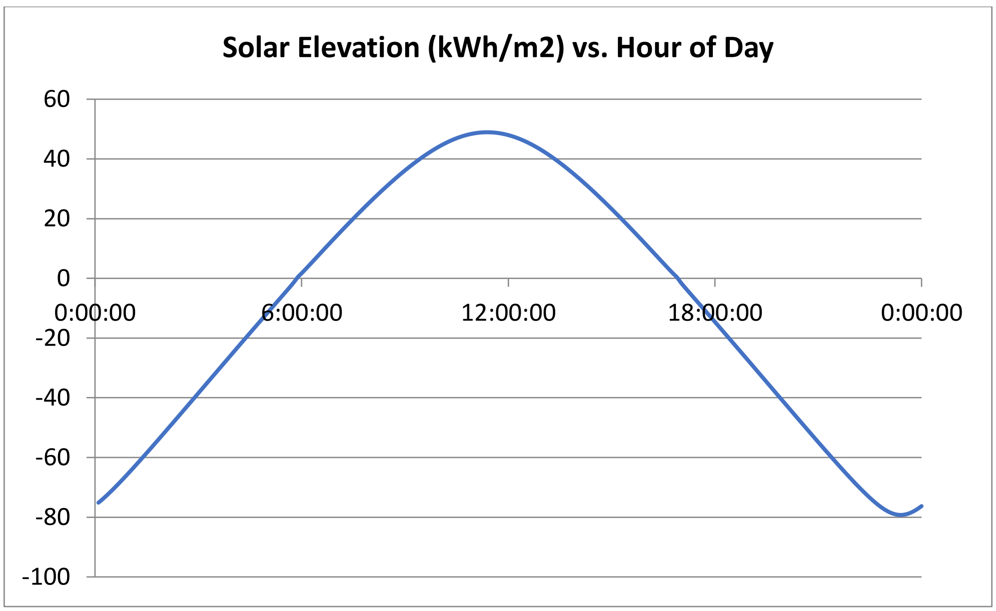

Fig. 40 GHI vs. hour of day [26]

4.2.2 Select the PV array

For installed capacity of 10 MW, a total of 39,218 panels each of 256 W. The total area of the project is 100,000 m2. The area is considered for the PV power plant as 7 m2 for each 1 kW of the panels and about 3m distance between the panels to overcome the shadow. The specifications of the PV-module are listed in table 18.

Table 18 Specifications of the PV-module.

PV array	
Cell Type	Mono-crystalline
STC Max Power	330 W
PV module rated power	256W
Maximum voltage	30.8 V
Maximum current	8.42 A
STC Module Efficiency	17%
Temperature coefficient of $V_{o.c}$	-0.41%/ C
Operating Temperature	-40C - 85C

4.2.3 Solar Power Conditioning unit (PCU)

Solar Power Conditioning unit (PCU) is an integrated system consisting of a controller, and inverter.

Eq. (1) shows calculation of inverter efficiency [11]:

$$\eta(t) = \frac{P_{in}(t) - P_{Loss}(t)}{P_{in}(t)} \quad (1)$$

Where $\mathbf{P_{in}}$ is the instantaneous input power and $\mathbf{P_{loss}}$ is the conversion power loss. When neglecting the efficiency of the wire, the produced power of PV module becomes the input to PV system.

4.2.4 Plant layout

The total rating of the plant is 10 MW occupied over (100,000) square meters of land. The inverter is converting DC to AC power and also it is synchronizing the PV output in the same frequency of the gird. The inverter is also work as a protection system by separating the PV panels from the gird, using fuse switches on both sides, to prevent any high levels of power. [11] Each inverter [Table 19] is connected with one main string combined box. The inverters are connected to transformers. The output of transformer is connected directly to 33 kV grid (See Fig. 41).

Table 19. Specifications of the selected inverter.

Inverter	ABB PSTORE-PSC
Rated power	2880 KVA
Efficiency	96%
Lifetime	20 years

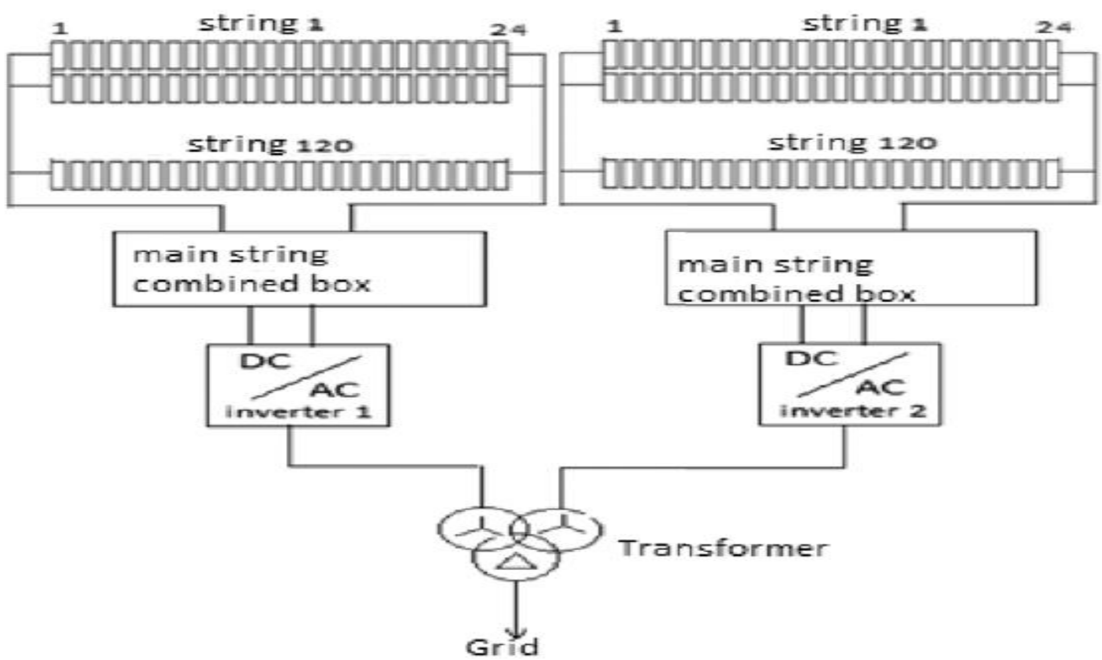

Fig. 41. Plant layout.

4.2.5 Step-up transformers

The rated power of the transformer is 1.5 MVA. The primary voltage of the transformer is 386 V and secondary is directly connected to 33 kV switchyard. The current rating is given as 2.25 A/1124.6 A. The efficiency of transformer is about 97.5 %.

4.2.6 The grid connection interface

To connect the farm to the network we need to build a substation. The substation is containing a transformer, breaker, switchgear and other components of protection.

4.3 The annual generation of energy from 10MW solar farm

To calculate the annual generation of energy from the 10 MW solar farm, we use HOMER software and we applied the software by choosing 47080.21 kWh as the average daily load. We assume that the tariff is 0.048/kWh and 0.0.048 SR/kWh as net-metering price. The software used in the analysis is HOMER.

When running the analysis, the assumption is that the capital cost of the PV panels per kWp = 900 $. The price of the PV panels in SA is now (2018) 900 $/kWp. By using the weather data for Dhahran city and making assumptions for the input data such as the tilt angle, load profile, the net metering scheme, operational cost and life time of the PV system. The nominal interest rate in S.A. is 2.75% and the inflation rate is 2.2%. [23]

4.3.1 Schematic

The schematic of PV System for the farm is shown in figure 42. The daily load is 47080.21 kWh and the peak power is 10MWp.

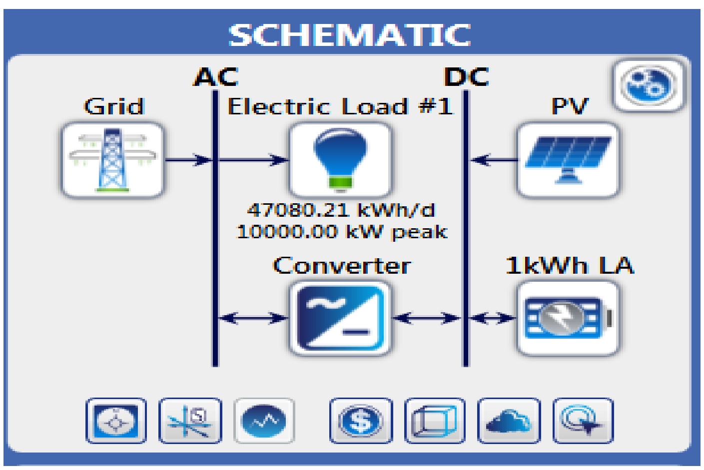

Figure 42 The schematic of PV System. [Source HOMER software]

4.3.2 System architecture

When running the analysis, we use the weather data for Dhahran city and making assumptions for the input data such as the tilt angle, load profile, the net metering scheme, operational cost and life time of the PV system. The General characteristic features of modeled grid-connected PV system are shown in table 20.

Table 20 General characteristic of modeled PV system.

Name	Description
Diesel cost	0.067 $/L
Project Lifetime	20 years
Discount rate	2.75%
Inflation rate	2.2%

4.3.3 Photovoltaic (PV) cell

The photovoltaic modules used for the system design are type ‘Mono-crystalline. The specifications of the PV panels are included in table 21.

The cost per kilowatt peak of the PV panels is 1200$. The price includes installation, engineering, and wiring costs. Also, the maintenance fee was entered to HOMER as 20 $/kWp.

The area of the farm is 10,000 m2. One PV panel size is 994 mm width by 1640 mm length with a total area of 1.63 m2. So, a 10,000 m2 is enough to fit 6,135 PV panels with a total system output of 10MW. Hence, the sizes of the system that entered in HOMER software were 10 MW.

Table 21. Characteristic features of PV cells.

PV	Description
PV technology type	Mono-crystalline
Name of PV	Canadian Solar All-Black CS6K-290MS
Manufacturer of PV	Canadian Solar
Efficiency (PV)	17.72%
Nominal operating temperature	45^0C
Temperature Coefficient	-0.39%/ ^{0}C
Lifetime	25 years
Area of PV module	1.63 m2
The slope	Latitude of location
Tracking system	It is fixed
PV panel cost	700 $/kW
Nominal Max Power	25 kW
Dimensions	1640mm x 994mm x 40mm

4.3.4 Converter

The size of the inverter is chosen to be 9,000 kW. The capital prices for inverters are between 50 to 80 $/kW, with an average of 65 $/kW.

A grid connected central inverter (Frounius Symo 20.0-3-M) was used in the PV system Design. The converter has an efficiency of 98% and a rated power of 9,000 kW.

4.3.5 Simulation result

HOMER software provides full details for each solar system model including the net present worth (NPW), cash flow (CF), capital cost CC, operating cost, and levelized energy cost (LEC, also called life cycle cost LCC). We use 0.048 $/kWh as the tariff of the net-metering system. Table 22 shows the simulation result of the farm.

Table 22 The results of the farm

Year	Generated Energy (kWh)	Tariff ($/kWh)	Production ($)	O&M ($)	Annual Savings in ($)
1	18,789,925	$0.048	$901,916.389	$200,000.000	$701,916.389
2	18,658,395	$0.048	$895,602.975	$210,000.000	$685,602.975
3	18,527,787	$0.048	$889,333.754	$220,500.000	$668,833.754

4	18,398,092	$0.048	$883,108.418	$231,525.000	$651,583.418
5	18,269,305	$0.048	$876,926.659	$243,101.250	$633,825.409
6	18,141,420	$0.048	$870,788.172	$255,256.313	$615,531.860
7	18,014,430	$0.048	$864,692.655	$268,019.128	$596,673.527
8	17,888,329	$0.048	$858,639.806	$281,420.085	$577,219.722
9	17,763,111	$0.048	$852,629.328	$295,491.089	$557,138.239
10	17,638,769	$0.048	$846,660.922	$310,265.643	$536,395.279
11	17,515,298	$0.048	$840,734.296	$325,778.925	$514,955.371
12	17,392,691	$0.048	$834,849.156	$342,067.872	$492,781.284
13	17,270,942	$0.048	$829,005.212	$359,171.265	$469,833.947
14	17,150,045	$0.048	$823,202.175	$377,129.828	$446,072.347
15	17,029,995	$0.048	$817,439.760	$395,986.320	$421,453.440
16	16,910,785	$0.048	$811,717.682	$415,785.636	$395,932.046
17	16,792,410	$0.048	$806,035.658	$436,574.918	$369,460.740
18	16,674,863	$0.048	$800,393.408	$458,403.664	$341,989.745
19	16,558,139	$0.048	$794,790.654	$481,323.847	$313,466.808
20	16,442,232	$0.048	$789,227.120	$505,390.039	$283,837.081
Total	351,826,962		$16,887,694.199	$6,613,190.821	$10,274,503.378

5.3.5.1 Total Net Present Cost

The total net [resent cost is $10,274,503.378 and the levelized cost of energy is 0.29 $/kWh and the details of the components of the system are listed in table 23.

For the farm there is extra cost which is outside the farm which is the substation (transformer) which cost about 250,000 $.

Table 23 Net Present Costs.

Name	Capital	O&M	Replacement	Total
Canadian Solar All-Black CS6K-290MS	$12.0M	$2.29M	$0.00	$14.3M
Fronius Symo 20.0-3-M	$812,723	$0.00	$540,000	$1.16M
Generic 1kWh Lead Acid	$4.00M	$2.29M	$7.22M	$11.8M
Grid	$ 0.00	-$1.24M	$0.00	-$1.24M

System	$16.5M	$3.34M	$8.04M	$26.0M

Figure 44. shows the cost summary of whole system during the 20 years which is the time life of the system. The cost contains:

The capital cost

The operation and maintenance cost

The replacement cost

The salvage.

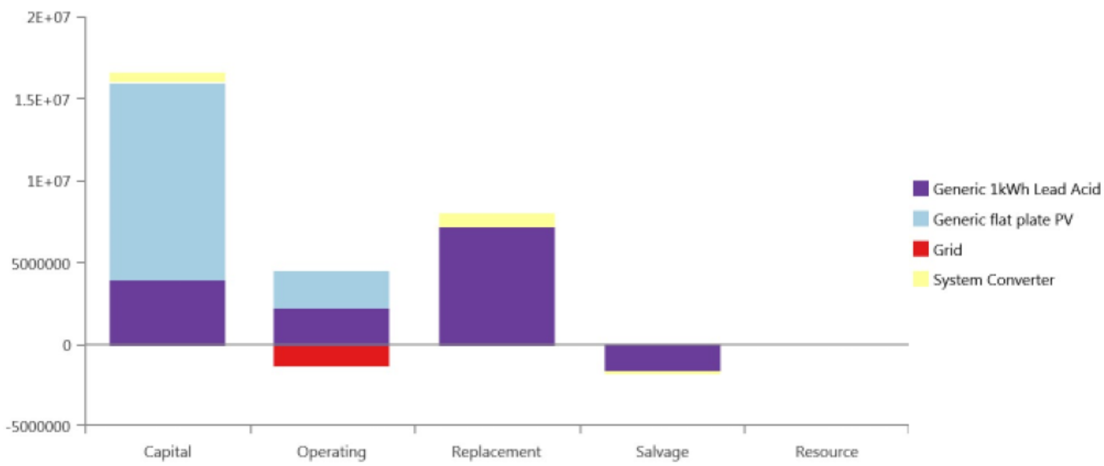

Figure 43 The cost summary.

Figure 45 shows the cash flow of whole system during the 20 years which is the time life of the system. The cash flow contains:

The capital cost

The operation and maintenance cost

The replacement cost

The salvage.

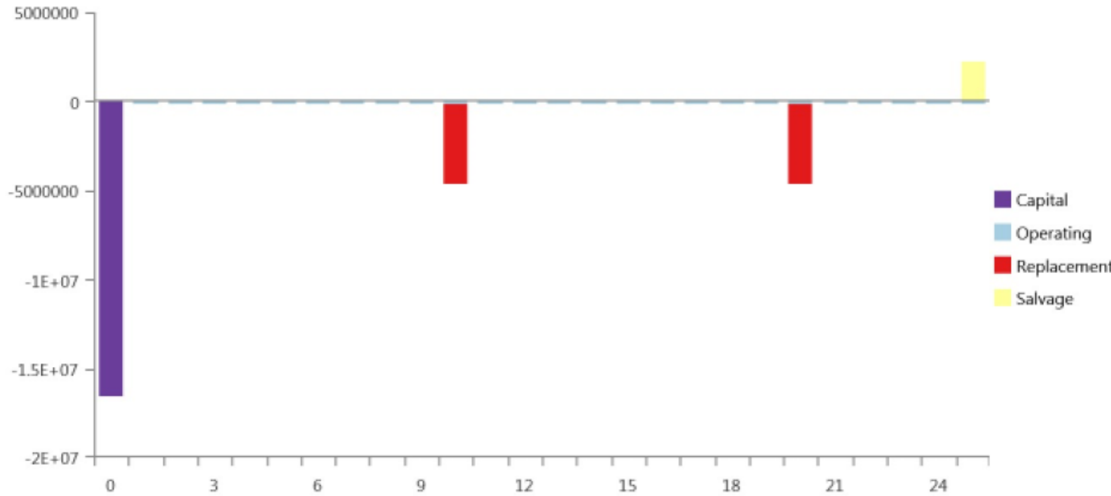

Figure 44 The cash flow.

4.3.5.1 The production summary of the farm

Table 24 and figure 46 show the production of energy of the farm.

Component	Production (kWh/yr)	%
Canadian Solar All-Black CS6K-290MS	18,979,722	67.0
Grid Purchases	9,352,047	33.0
Total	28,331,769	100

Table 24 Production of energy of the farm over one year.

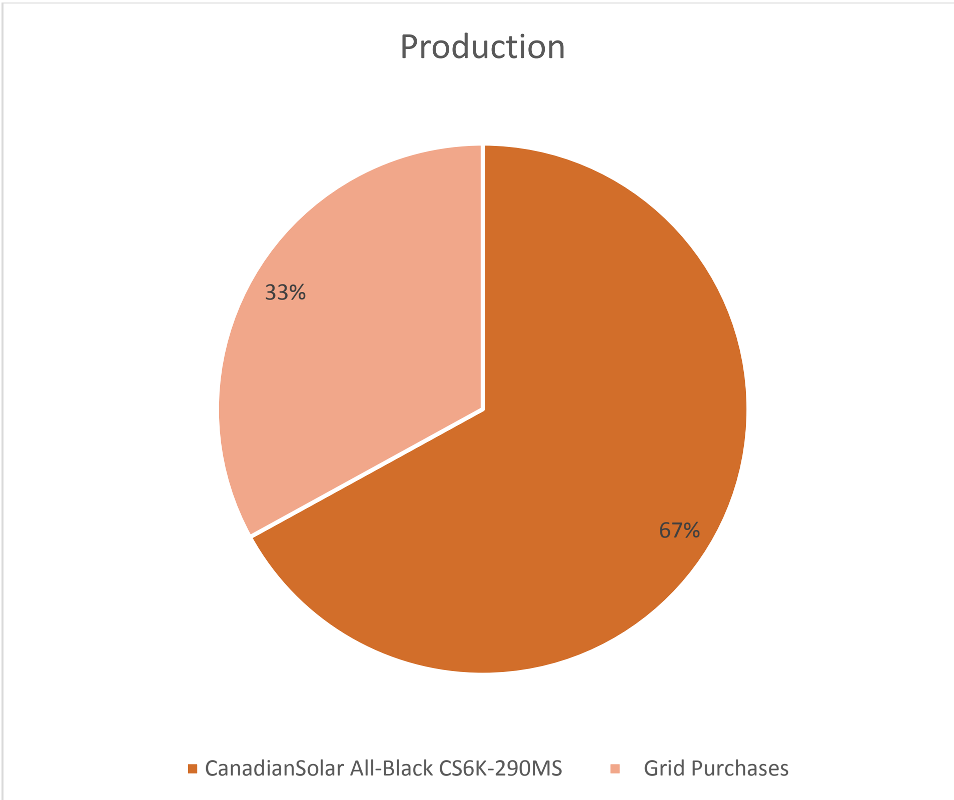

Figure 45 Percentage of production of energy of the farm.

4.3.5.2 Environmental Benefits

According to the US Environmental Protection Agency (EPA):

Electrical Consumption = 0.703 kilograms CO2/kWh.

CO2 emissions (kg per capita) in Saudi Arabia was reported at 19.53 in 2014, according to the World Bank collection of development indicators, compiled from officially recognized sources. [23] The CO2 reduction was taken into consideration. The pollutant emissions in this study are calculated by using these S.A. grid emissions factors, which are the default values of HOMER software. [21] See table 25.

Table 25 Emissions of the farm.

Quantity	Without PV system (kg/y)	With PV system (kg/y)	Reduction (kg/y)
Carbon Dioxide	10,860,463	5,910494	4,949,969
Sulfur Dioxide	47,085	25,625	21,460
Nitrogen Oxides	23,027	12,532	10,495

CHAPTER 5

Discussion

We study the PV system in buildings in term of generation, consumption, cost, and environmental impact. Also, we study the impact of the PV system on the peak demand. We study the solar farm in term of generation, consumption, cost, and environmental impact. We are going to make a comparison between the buildings and the solar farm. The parts that we will discuss in the comparison are:

1.The consumption of energy.

2. The generation of solar energy.

3. The cost of the energy.

4.The losses in the solar system.

5. Operating and maintenance.

6. The reliability of both systems.

7. The availability of area to installed the system.

8. The environmental impact.

9. The social impact.

5.1 Peak demand

The total consumption of SA in 2018 is 330 TWh and the peak is 64 GW. As per KACARE, residential buildings are consuming more than 51 % of the total energy consumption in Saudi Arabia. [5]. So, the percentage of the residential buildings is 51% of the peak which about 32 GW.

When compare the average generation of the buildings (table 16) to the average consumption of the buildings (table 8), we found that:

The average energy generation of the buildings / the average consumption of the buildings = 11,429.495kWh/33267.8kWh * 100% = 34 %, so the average of the generation of the PV system at any home is about 34 % of the consumption of the home in one year.

If only 20% of the residential buildings in SA are using PV system then we can reduce (shave) the peak demand of SA as follow:

(34%) * (20%) * 32 GW = 2.2 GW.

5.2 Generation and consumption

We will apply two scenarios:

5.2.1 Scenarios number 1:

We assume that the generation of the PV system will cover 34 % from the total consumption of the building and the remaining are from the grid network. There are two suppliers that supply the grid network and they are the SEC and the farm. We assume that the PV Farm contribution is 38 % and SEC contribution is 62% from the annual consumption from grid. [Table 26]

Table 26 The contribution of the farm in the generation

Dhahran	Annual PV Generation Per House (kWh)	Annual Consumption (kWh)	Annual Consumption from grid (kWh)	PV Farm Contribution Scenario 1 (38%)	PV Farm Contribution Scenario 2 (Max 100%)
Building 1	6468	37324	30856	11725.28	30856
Building 2	6468	32714	26246	9973.48	26246
Building 3	6468	28995	22527	8560.26	22527
Building 4	6468	46419	39951	15181.38	39951
Building 5	6468	15681	9213	3500.94	9213
Building 6	6468	14161	7693	2923.34	7693
Building 7	6468	27139	20671	7854.98	20671
Building 8	6468	13700	7232	2748.16	7232
Building 9	6468	17563	11095	4216.1	11095
Building 10	11319	40650	29331	11145.78	29331
Building 11	10780	18555	7775	2954.5	7775
Building 12	6468	14287	7819	2971.22	7819
Building 13	11858	33024	21166	8043.08	21166

Building 14	11858	36561	24703	9387.14	24703
Building 15	11858	34799	22941	8717.58	22941
Building 16	11858	36107	24249	9214.62	24249
Building 17	11858	32702	20844	7920.72	20844
Building 18	11858	38966	27108	10301.04	27108
Building 19	17248	42315	25067	9525.46	25067
Building 20	17248	50618	33370	12680.6	33370
Building 21	10780	41866	31086	11812.68	31086
Building 22	17248	36344	19096	7256.48	19096
Building 23	17248	38654	21406	8134.28	21406
Building 24	17248	40100	22852	8683.76	22852
Building 25	29645	45320	15675	5956.5	15675
Building 26	29645	48555	18910	7185.8	18910
Building 27	29645	52971	23326	8863.88	23326
Building 28	29645	54766	25121	9545.98	25121
Building 29	38322.9	74800	36477.1	13861.298	36477.1
Building 30	44198	99477	55279	21006.02	55279
Building 31	5390	38890	33500	12730	33500
Building 32	10780	34704	23924	9091.12	23924
Building 33	5390	26199	20809	7907.42	20809
Building 34	5390	26258	20868	7929.84	20868
Building 35	9702	34656	24954	9482.52	24954
Building 36	9702	28765	19063	7243.94	19063

Building 37	5929	38942	33013	12544.94	33013
Building 38	5929	56655	50726	19275.88	50726
Building 39	5929	29865	23936	9095.68	23936
Building 40	5390	26258	20868	7929.84	20868
Building 41	5929	26311	20382	7745.16	20382
Building 42	6468	27717	21249	8074.62	21249
Building 43	6468	27721	21253	8076.14	21253
Building 44	6468	27654	21186	8050.68	21186
Building 45	6468	12989	6521	2477.98	6521
Building 46	6468	27711	21243	8072.34	21243
Building 47	11588.5	29020	17431.5	6623.97	17431.5
Building 48	6468	47698	41230	15667.4	41230
Building 49	11319	34766	23447	8909.86	23447
Building 50	6575.8	17077	10501.2	3990.456	10501.2
Building 51	6683.6	12077	5393.4	2049.492	5393.4
Building 52	6737.5	15576	8838.5	3358.63	8838.5
Building 53	10780	29000	18220	6923.6	18220
Building 54	10780	18680	7900	3002	7900
Building 55	7007	31390	24383	9265.54	24383
Building 56	7546	31436	23890	9078.2	23890
Building 57	8085	21000	12915	4907.7	12915
Building58	9702	28765	19063	7243.94	19063
Building 59	9163	21580	12417	4718.46	12417

Building 60	9486.4	21576	12089.6	4594.048	12089.6
Average	11429.495	33267.81667	22,208	8298.562233	21838.32167

5.2.1. Scenarios number 1

The generation from scenarios number 1

The generation from the PV system of the home is 34 % of the total consumption which is 33276.82 kWh, so the contribution of the PV system of the home is 11,909.49 kWh.

The PV Farm contribution is 8,298.56 kWh and SEC contribution is 13,645.44 kWh.

The cost for scenarios number 1:

The cost of the PV system generation is:

11,909.49 kWh * (0.036) $/kWh = 428.74 $ where (0.036 $/kWh) is calculated by HOMER software.

The cost of the SEC generation is:

13,645.44 kWh * (0.048) $/kWh = 654.98 $

The cost of the farm generation is:

8,298.56 kWh * (0.048) $/kWh = 398.33 $ where (0.1048$/kWh) is the tariff of the grid.

The saving that is made by PV system is:

(0.048 $ – 0.036 $) * (11,909.49 kWh)/ (0.048 $ * 33276.82 kWh) * 100% = 8.9 % so the saving is 8.9 %.

5.2.2 Scenarios number 2:

We assume that the generation of the PV system will cover 34 % from the total consumption of the building and the remaining are from the farm.

We assume that the PV Farm contribution from the annual consumption from grid is 66%. [Table 26]

The generation from scenarios number 2

The generation from the PV system of the home is 34% of the total consumption which is 33276.82 kWh, so the contribution of the PV system of the home is 11,909.49 kWh.

The PV Farm contribution is 21838.32kWh. [Table 26]

The cost of scenarios number 2:

The cost of the PV system generation is:

11,909.49 kWh * (0.036) $/kWh = 428.74 $ where (0.036 $/kWh) is calculated by HOMER software.

The cost of the farm generation is:

21,838.32kWh * 0.048 $/kWh = 1,048.24 SR

The saving that is made by PV system is:

(0.048 $ – 0.036 $) * (11,909.49 kWh)/ (0.048 $ * 33276.82 kWh) * 100% = 8.9 % so the saving is 8.9 %.

In scenario number 2 the fuel that is used is equal to zero so the emission is also equal to zero.

5.3 The EUI of the buildings.

The load profiles of the 60 buildings shows a similar trend of typical energy consumption in building in SA. The trend shows a surge in electricity demand during the summer months as use of HVAC system increases with the cooling demand. Table 27 shows the average of the energy consumptions of the building over one year, and the EUI of the buildings.

Table 27 The average of the energy consumptions

Building	Annual Consumption (kWh)	EUI (kWh)/m2
Average	**33267.82**	190

The energy unit index (EUI) of the building:

EUI = total annual energy consumptions / area of the building.

The average of energy consumptions of the buildings over one year is **33267.82** kWh while the average of the energy unit index (EUI) is 190 kWh/m2. This increasing of consumptions is due to the low price of the energy. The energy consumptions without PV system will decrease because the price of energy from the grid which contain the generation of the farm is a little bit high.

5.4. The cost of the energy from the building sector and the farm.

The total cost of energy of PV system of building is 0.135 SR/kWh while the total cost of energy of the farm is 0.14 SR/kWh. For the farm there is extra cost for the transformer.

Total cost of the energy inside the farm is 0.14 SR/kWh. Also, the cost of the transformer is 0.02 SR/kWh. So, the total cost of energy of the farm is 0.16 SR/kWh.

5.5 The losses in the solar system.

The loses of the PV system in building and in the solar farm are the same which is 5% and these due to the converter and wires loses, but there are more loses in the solar farm due to the transmission, and distribution which are 5% and 5% respectively. The total loses of the solar farm is 15%.

5.6 Operating and maintenance.

In the building every house need only one person for the operating and maintenance and the cost of maintenance is very low. The farm needs a staff of about 10 persons for operating and maintenance and the cost will be high but it is an opportunity to recruit Saudi youth.

5.7 The reliability

The reliability of the network in Saudi Arabia is 3% of 8760 h of the year [SEC data] and the farm is connected to the network, so it has the same reliability but in the building is almost zero.

5.8 The availability of area to installed the system.

PV cannot cover all of the roof areas mainly due to spacing required for shadow adjustment and any structural features, i.e., HVAC systems, skylights and staircases. The utilizable area therefore needs to be calculated taking into account these obstacles. A study investigated the potential for rooftop application of solar PV in the residential buildings of SA and it is found that 28% of the rooftops can be effectively used for PV application. [60]

However, in the farm the area is available and we can use area of 10,000 m2 for the 10MW farm. We have a huge empty area in Saudi Arabia but still we have a problem of that which is the overpriced of the value of land.

5.9 The environmental impact

CO2 emissions (kg per capita) in Saudi Arabia was reported at 19.53 in 2014, according to the World Bank collection of development indicators, compiled from officially recognized sources. [23] The CO2 reduction was taken into consideration. The building PV system and the farm will help to reduce the CO2 emission and other gases.

5.10 The social impact.

In the building PV system, people can have power and more freedom because they own the project of the PV system but the farm will be owned by companies which means "few people". See table 28.

Table 28 comparison between buildings and farm

	Building	Farm
Generation	34 %	25%
Cost	0.036 $/kWh	0.043 $/kWh
Loses	5%	15%
IRR		
Reliability	controlled	3% of (8760h)
Operating & maintenance	owner	Staff (10 employees)
Environmental	Reduce CO2 Emissions	Reduce CO2 Emissions
Social	Power and freedom for people (owned by people)	Centralization (owned by few people)

CHAPTER 6

Conclusion and Recommendations

The goal of this work was to study a residential building PV system in Saudi Arabia and in term of generation and cost then study a 10M solar farm and finally compare between the two studies. The two studies have been conducted here using HOMER software.

The results show that the distribution building PV system is better than the solar farm and that due to a number of issues. The cost of the solar farm is higher than the cost of the PV system in building and that because of the additional cost of adding substation and addition cost of the transmission and distribution.

The results show that the generation of energy from the PV system of the residentials buildings is about 34% of the total energy consumption of the buildings and if only 20% of the residentials buildings in SA use the PV system then that will shave the peak load of Saudi Arabia by 3.4 %. The solar farm can reduce the emission of CO2 much more than the buildings PV system but the PV system of buildings can help people to have their own sources of energy.

Utilizing a solar PV system as an energy source has many advantages. It can reduce CO_2 emissions and the number of oil barrels that are used to produce energy. Hence, solar system systems are an environmentally friendly source of energy. Using HOMER software has shown that using a PV system aid to maintain fossil fuel for the next generation, reduce emission, reduce load demand, and reduce electricity bills.

I Recommend that:

At the current situation, Saudi Arabia should start the net metering system.

Using PV system in building is better than using solar farm because of many different reasons. The cost in building is less than the cost of solar farm. Also, in term of generation, the generation of the PV of building is totally consumed by the building and the network but the generation is depending on the market and the prices.

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