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Faculty of Graduate Studies

Feasibility Study of Implementing CSP Technology in Palestine

By

Osama Isam S. Draidi

Supervisor

Dr. Aysar Mahmoud Yasin

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This Thesis was defended successfully on 11/5/ 2016, and approved by

Defense Committee Members	Signature
– Dr. Aysar Mahmoud Yasin / Supervisor	
– Mahmoud Ismail / External Examiner	
– Abdelrahim Abusafa / Internal Examiner	

Dedication

Praise be to Allah, Lord of the worlds

To the Prophet Mohammad
Blessings and Peace be upon him

To my father
To my mother
To my brothers and sisters
To my precious ones
To all friends and colleagues
To my teachers

To everyone working in this field
To all of them

I literally dedicate this work

Acknowledgments

الحمد لله الذي بنعمته تتم الصالحات، والصلاة والسلام على سيدنا محمد وعلى آله وصحبه أجمعين.

Praise is to Allah who gave me the ability and patience to complete this thesis. Peace and blessings be upon His Prophet and his truthful companions.

I would like to thank Dr. Aysar M. Yaseen, my supervisor, for his valuable suggestions, assistance, encouragement, and for his great and continuous effort in helping me at all stages of this study.

A great thankful to my loving father and mother, who keep inspiring me to love the science and success, May Allah give them long and healthy life.

Also special thanks to my deceased cousin "Zaher Draidi" May God have mercy on him and his wife for their support and encouragement that they gave me throughout the thesis.

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

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Feasibility Study of Implementing CSP Technology in Palestine

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Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Date:	التاريخ: 11/5/2016

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Feasibility Study of Implementing CSP Technology in Palestine

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Dr. Aysar Mahmoud Yasin

Abstract

Population growth and economic development are the prominent reasons to a continuous increase in energy demand in Palestine. At the same time conventional energy sources are totally imported from Israeli side, this arise amid growing global concern for the environment. These issues with other factors emphasize the importance of utilizing solar energy in Palestine as one of the renewable energy sources.

The solar energy can be exploited to generate electricity through the technology of concentrated solar thermal power (CSP). This thesis discusses the feasibility of implementing CSP technology in Palestine provided that Palestine has enormous potential in solar energy.

To generalize the study for all Palestinian regions the study includes five regions in Palestine which are Jericho, Hebron, Nablus, Ramallah, and Gaza Strip. Selection site criteria has been applied to assure that the selected site is appropriate for implementing a 1 MW CSP plant as a case study. The parabolic trough technology is found to be the most suitable CSP technology to be used in Palestine.

Different economical and financial indicators were utilized to study the feasibility of utilizing CSP technology in Palestine. The Levelized Cost of Energy (LCOE) from CSP plants without storage system is ranging from

0.2 to 0.5 USD/kWh for the five selected sites in Palestine, whereas it is ranging from 0.19 to 0.47 USD/kWh if three hours of thermal energy storage is used.

The simple payback period (SPBP) of implementing CSP plants in Palestine is ranging from 7 to 25 years, whereas it is ranging from 7 to 18 years if three hours of thermal energy storage is used. Other indicators are estimated like net present value, equity payback period, annual life cycle savings, and benefit cost ratio. The reduction in gas emissions mainly CO_2 is evaluated but financially it has not taken into account. Sensitivity analysis showed that the price of solar field is the governing factor for the differences in financial viability between selected sites. The study showed that 5% and 10% increase in electricity selling price generated by CSP plant (feed in tariff) will remarkably further improving the financial viability.

Chapter One

Introduction

Renewable energy is energy that comes from resources which are naturally replenished on a human timescale, such as solar, wind, geothermal, hydropower, tidal energy, and biofuels. The reasons that make renewable energy is extremely important for the future of our society are: it's clean, secure, reliable, affordable, reducing the dependability on others, generating jobs opportunities, and improving political ties between countries by sharing technological know-how.

Figure 1 shows that the world depends on different types of energy resources, but mainly it depends on conventional energy resources while the renewable energy is ranked in the fourth level [1].
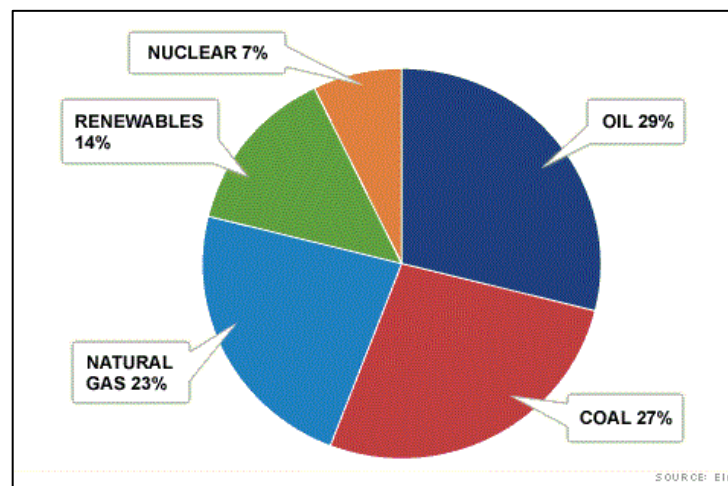
Figure 1: Global Energy Use.

Solar energy is one of most abundant energy sources available in the universe and it is converted into thermal or electrical energy. In 2014, global solar installations grew by 20%, although its contribution is still asterisk in the world energy consumption as shown in Figure 2 [2].
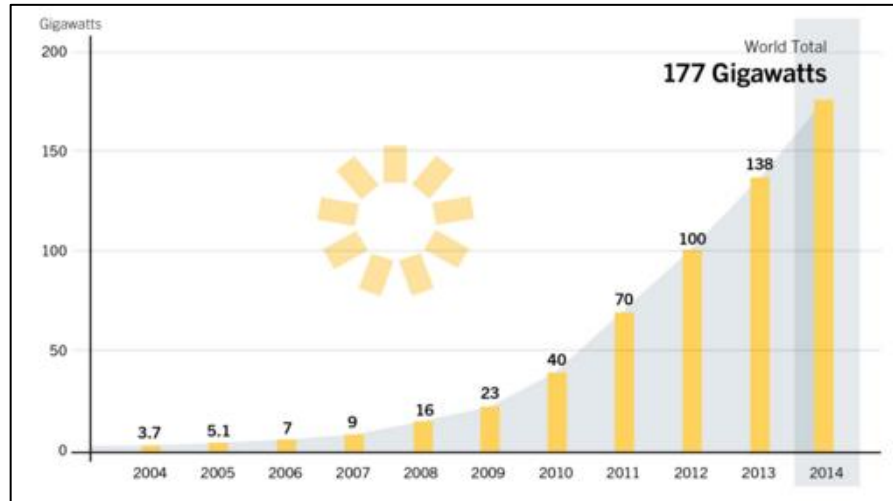
Figure 2: Solar Capacity, 2004-2014.

Solar energy contribution is rapidly increasing, but it still shows low percentage from global consumption as shown in Figure 3 [2].
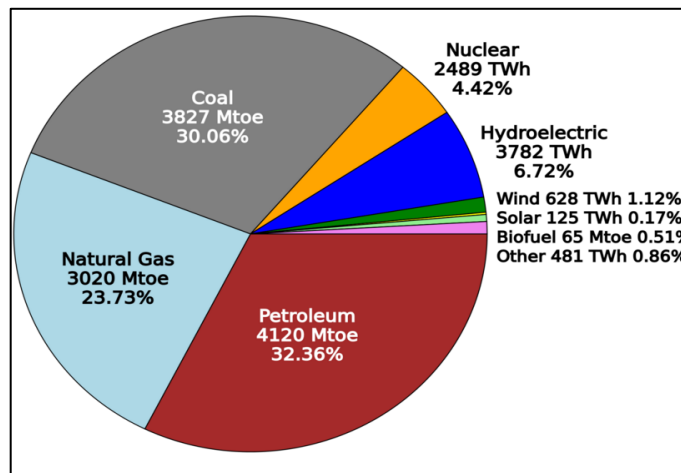
Figure 3: World Energy Consumption.

Solar energy can be utilized using solar photovoltaics and solar thermal power. Solar photovoltaic (PV) is a technology that converts sunlight into direct current electricity by using semiconductors, while the solar thermal power is a technology that converts the sunlight to enough heat energy for electricity production, such as concentrated solar power system (CSP).

A worldwide CSP technologies have attracted researchers and utilities which in turn leads to increase the public and private initiatives towards furthering researches in the field of CSP and CSP pilot projects implementation [3, 4]. Pilot plants and projects have been installed in many countries as shown in Figure 4 where the most CSP technologies are located in Spain and in the USA, although new CSP technologies and large power plants are being experimented [5].
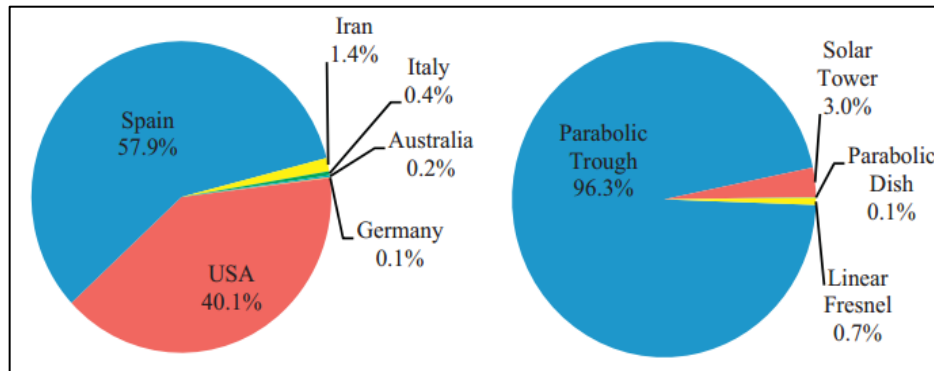
Figure 4: Installed Operational CSP Power (March 2011), by Country and by Technology [6].

In Palestine, utilizing renewable energy for electricity generation is the main motivation behind making Palestinian renewable energy strategy by Palestinian Energy Authority (PEA). The objective of this strategy is to generate 240 GWh electricity from renewable energy sources (RES) which represents about 10% of electrical energy demand by 2020 [7]. Palestine has a high solar radiation potential which is around 5.46 kWh/m^2-day measured on horizontal surface. The main solar thermal applications are water heating, space heating, crop and vegetable drying and green house agriculture. The biomass energy is traditionally utilized for cooking and

heating in rural areas. The geothermal energy could be feasible in Palestine for heating and cooling. The utilization of wind energy could be also feasible in some locations but accurate data are still not available for many locations. Several demonstration projects in the field of biogas are still under investigation in Palestine [8].

The utilization of renewable energy in Palestine for electricity production mitigates the shortage of conventional energy sources and the dependability on energy importations. The electrical energy in Palestine represents about 31% of total energy consumed and the available electrical energy is insufficient to cover all the needs of the local market especially the growth in electricity consumption reaches about 7% [9, 10]. Therefore, Palestine purchases all of its needs of fossil fuels from Israel and imports about 90% of its electricity demand from Israel Electricity Company (IEC).

Palestine has high solar radiation potential which makes it well-qualified to utilize this energy for electricity generation using PV technology and water heating using solar water collectors. The concentrated solar power (CSP) is another approach of utilizing solar energy for electricity generation, but to insure that Palestine is qualified to use this approach, the following research questions are presented:

1- What are the main conditions and requirements needed for implementing CSP systems?

2- Does Palestine fit the requirements and conditions?

3- Can Palestine be presented by one city or zone once discussing the conditions and requirements needed for CSP implementations?

4- Are all CSP technologies suitable for Palestine?

The objective of this thesis is to answer the aforementioned research questions.

This thesis is organized as follows: Chapter one introduces the subject and discusses the main context of the research. Literature review about CSP is discussed in Chapter two while Chapter three addresses the CSP technologies. Chapter four talks about research methodologies where the criteria of selecting CSP sites is illustrated in Chapter five. Chapter six and Chapter seven cover the feasibility study and sensitivity analysis respectively. Finally, the conclusion and recommendations are shown in Chapter eight.

Chapter Two

Literature Review

CSP technology saw a first surge of commercial development between 1984 and 1995, but then no further commercial deployment until 2005, although in that time considerable research, development and demonstration has been taken place. Since then, commercial CSP deployment has recommenced and gained considerable momentum [11].

The real birth of CSP as an industry was in the Mohave Desert in California, USA. It has the largest solar electric generating systems facility (SEGS) which consists of nine solar power plants with 354 MW installed capacity and an annual solar potential of 2700 kWh/m^2 [12].

In 2010, a study has been performed for applying a solar thermal power plant with 50 MWe with total direct normal irradiance (DNI) of 1875 kWh/m^2 in the Dobrogea region-Romania, the output of the study put solutions to energy crises in the country. It showed that CSP plants can compete the conventional thermal plants although the levelized cost of electricity (LCOE) generated is higher than the electricity generated by conventional thermal plants. However, LCOE can be decreased by considering cutting the emissions of carbon dioxide as well as inclusion of thermal storage [13].

In 2010, an initiative has been taken to investigate the feasibility of implementing a 50 MWe parabolic trough solar power plant, the location in Jubail Industrial City-Saudi Arabia with total annual DNI of 2000 kWh/m^2. It showed that the LCOE is 10.7 ¢/kWh, which is three times higher than

electricity offered in Saudi Arabia due to the availability of fossil fuels [14].

In 2012, the possibility of implementing parabolic trough solar thermal power plants has been studied in Algeria with total DNI ranged from 2100 to 2700 kWh/m^2 and the expected output thermal power is ranged from 63 to 107 MW$_{th}$. The study showed that Algeria is accounted among the best insolated areas in the world due to lying in what so-called Sun Belt and it also showed that the power generation costs lie in the range of 12-20 ¢/kWh and of 5-10 cent/kWh for long term considerations [15, 16].

In 2014, a feasibility study of a 30 MWe parabolic trough solar thermal power plant has been investigated in Nawabshah in Nara desert-Pakistan with total annual DNI of 2057.6 kWh/m^2. It showed that the LCOE was 15.47 ¢/kWh [17].

In 2014, a 1 MW parabolic trough solar thermal power plant in Suez Suburbs in Egypt has been performed with total annual DNI of 2190 kWh/m^2. The LCOE was found as 25 ¢/kWh which is higher than electricity generated by conventional power supplies back then [18].

Chapter Three

Concentrated Solar Power Technologies (CSP)

CSP is a technology used for electricity generation that utilizes heat provided by solar irradiation concentrated on a small area called the receiver or absorber. Using mirrors, sunlight is reflected to a receiver where heat is collected by a thermal fluid carrier. The thermal fluid is either used directly in the case of steam generation or via a secondary circuit to power a turbine and generate electricity. CSP systems capture only DNI which makes them best suited and promising for areas having a high percentage of clear sky days.

At present, there are four available CSP technologies as shown in Figure 5: parabolic trough collector (PTC), solar power tower (SPT), linear Fresnel reflector (LFR) and parabolic dish systems (PDS). These CSP technologies are currently in medium to large-scale operation.
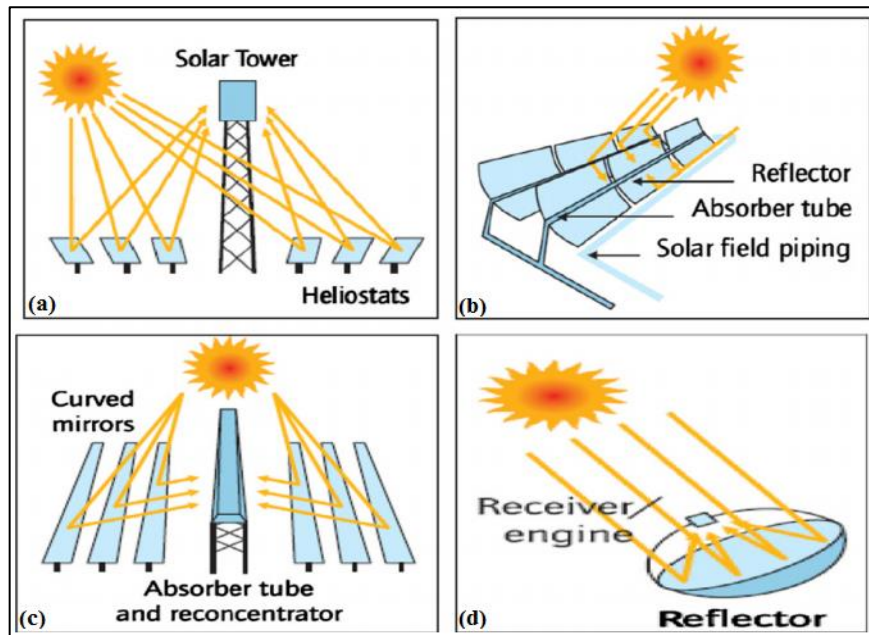
Figure 5 Currently Available CSP Technologies: (a) SPT; (b) PTC; (c) LFR; (d) PDC [19].

3.1   Parabolic Trough Collector (PTC)

A PTC plant as shown in Figure 6 consists of a group of reflectors that are curved in one dimension in a parabolic shape to focus sunrays onto an absorber tube that is mounted in the focal line of the parabola and these reflectors and the absorber tubes move in tandem with the sun as it daily crosses the sky, from sunrise to sunset. The group of parallel connected reflectors is called the solar field.
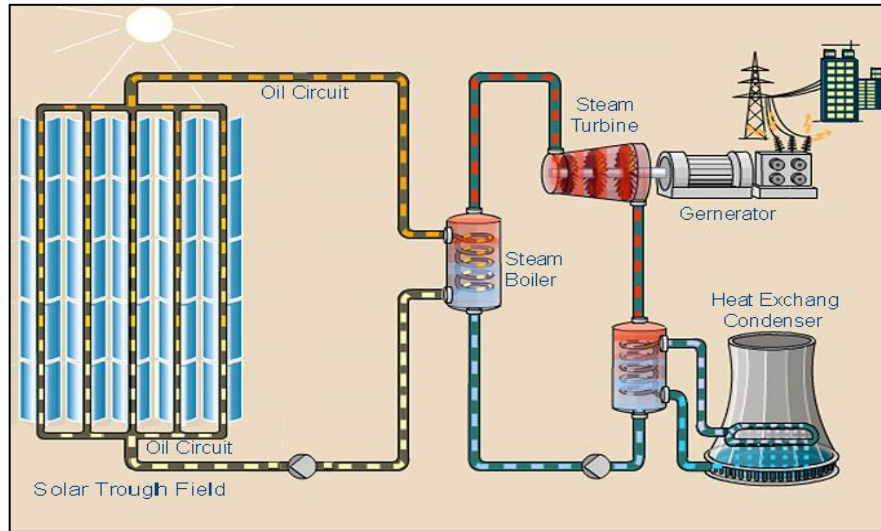
Figure 6: a Parabolic Trough Collector (PTC) Plant.

Typically, thermal fluids are used as primary heat transfer fluid (HTF) such as Therminol VP-1, thereafter powering a steam Rankine power cycle. Other configurations use a direct steam generation (DSG) system without any need to a secondary circuit as shown in Figure 7 [20, 21].
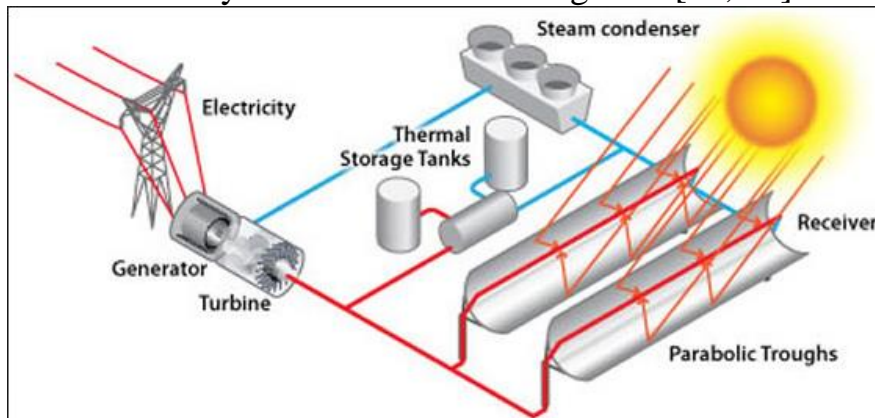
Figure 7: Direct Steam Generation of Parabolic Trough Plant.

The absorber tube as shown in Figure 8, also called heat collector element (HCE), is a metal tube and a glass envelope covering it, with either air or vacuum between these two to reduce convective heat losses and allow for thermal expansion. The metal tube is coated with a selective material that

has high solar irradiation absorbance and low thermal remittance and the glass-metal seal is crucial in reducing heat losses [21, 22].
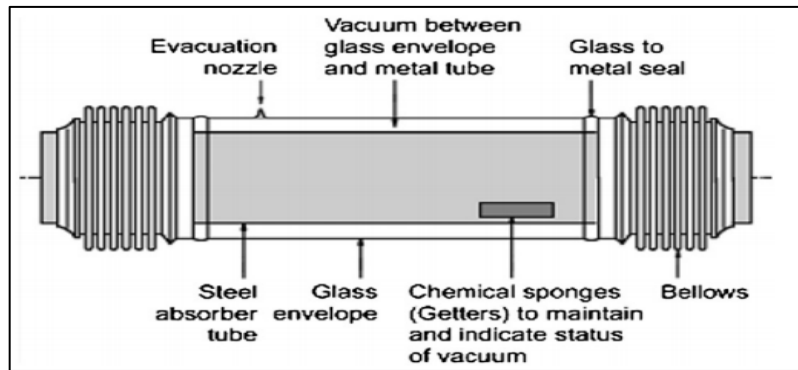
Figure 8: Absorber Element of a Parabolic Trough Collector [21].

3.2   Solar Power Towers (SPT)

SPT, also known as central receiver systems (CRS) as shown in Figure 9. It's a field of sun tracking reflectors, called heliostats that reflect and concentrate the sunrays onto a central receiver placed in the top of a fixed tower.
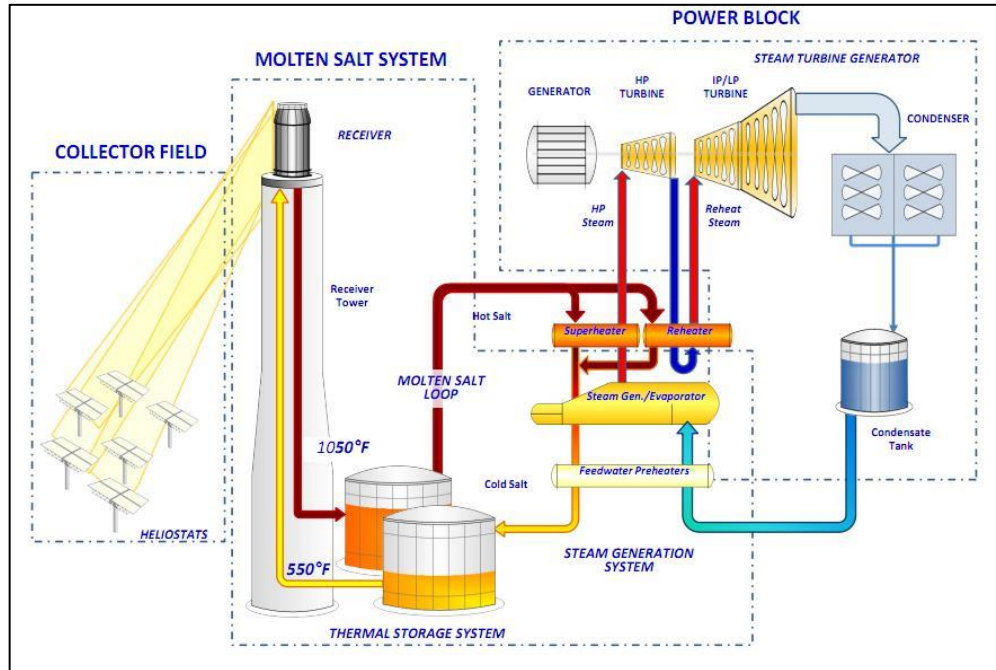
Figure 9: Solar Power Tower Plant Using Molten Salt as HTF and Storage.

Heliostats are flat or slightly concave mirrors that follow the sun in a two axis tracking. In the central receiver, heat is absorbed by HTF, which then transfers heat to heat exchangers that power a steam Rankine power cycle. Some commercial tower plants now in operation use different fluids, including molten salts as HTF and storage medium as shown in Figure 9 while others uses DSG as shown in Figure 10. The concentrating power of the tower concept achieves very high temperatures, thereby increasing the efficiency at which heat is converted into electricity and reducing the cost of thermal storage. In addition, the concept is highly flexible, where designers can choose from a wide variety of heliostats, receivers and transfer fluids. Some plants can have several towers to feed one power block [21-23].
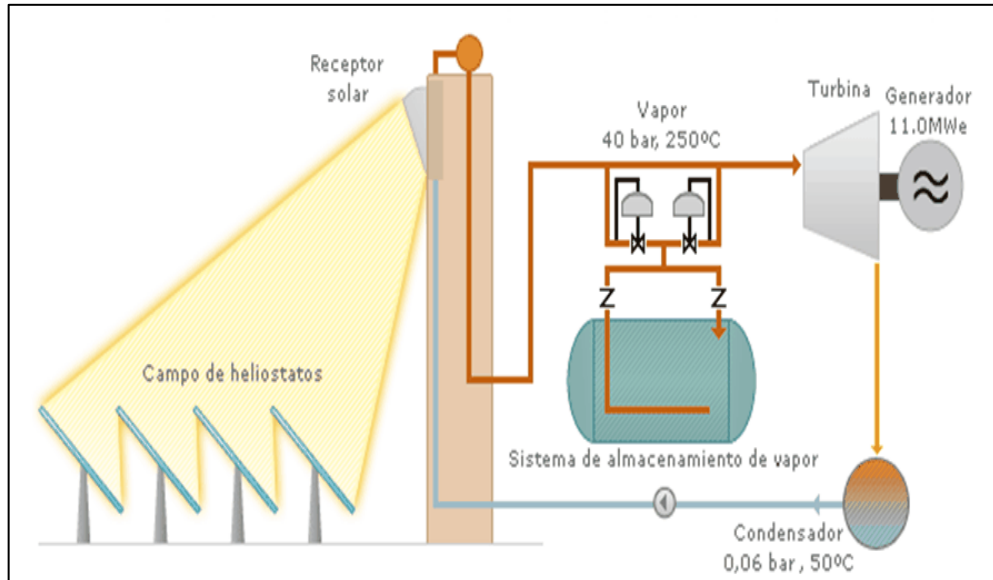
Figure 10: Direct Steam Generation of Tower Power Plant.

3.3   Linear Fresnel Reflector (LFR)

LFR approximate the parabolic shape of the trough systems by using long rows of flat or slightly curved mirrors to reflect the sunrays onto a downward facing linear receiver as shown in Figure 11.
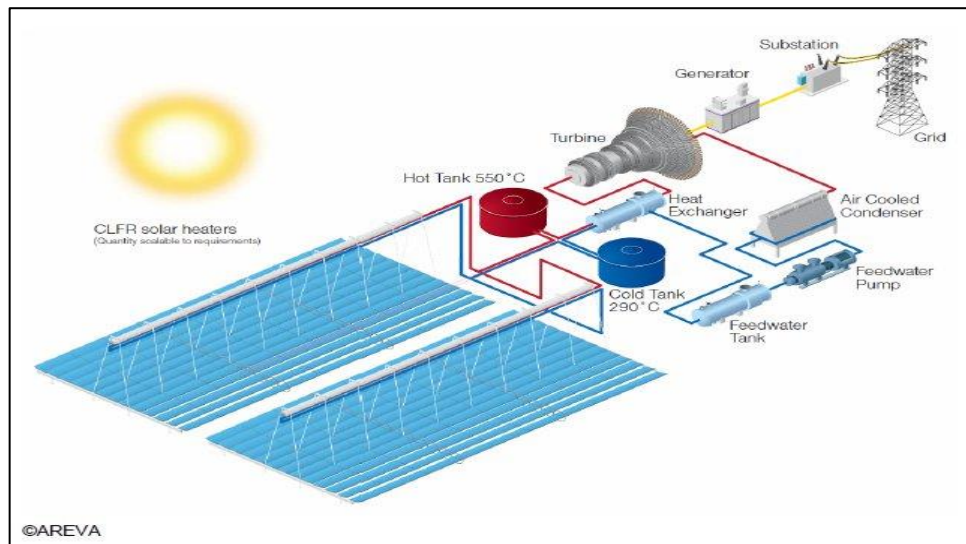
Figure 11: Linear Fresnel Reflectors Power Plant with Molten Salt as HTF and Storage.

The receiver is a fixed structure mounted over a tower above and along the linear reflectors. The reflectors are mirrors that can follow the sun on a single or dual axis regime. The main advantage of LFR systems is that their simple design of flexibly bent mirrors and fixed receivers require lower investment costs, and this facilitates direct steam generation as shown in Figure 12, thereby eliminating the need of heat transfer fluids and heat exchangers.
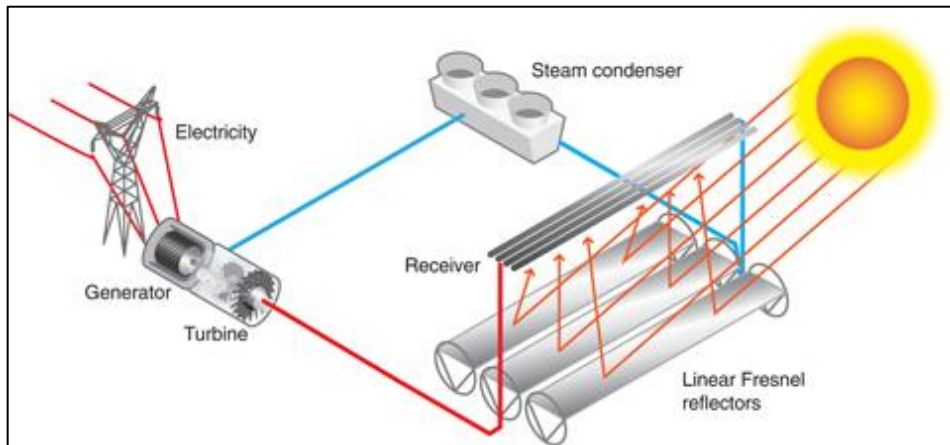
Figure 12: Direct Steam Generation of Fresnel Linear Reflector Power Plant.

LFR plants are however less efficient than PTC and SPT in converting solar energy to electricity. It is moreover more difficult to incorporate storage capacity into their design [22].

A more recent design, known as compact linear Fresnel reflectors (CLFR) as shown in Figure 13, uses two parallel receivers for each row of mirrors and thus needs less land than parabolic troughs to produce a given output [24].
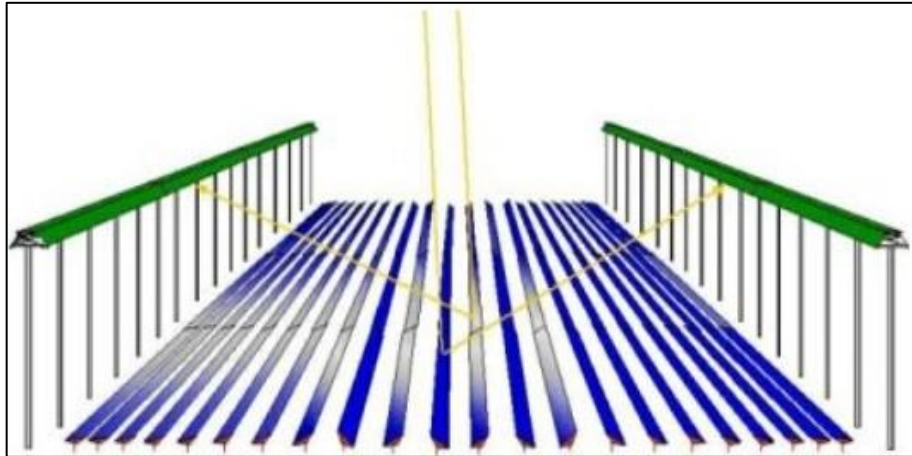
Figure 13: Compact Linear Fresnel Reflector.

3.4 Parabolic Dish Systems (PDC)

PDC, also known as Dish-Stirling Engine (DSE) as shown in Figure 14, concentrate the sunrays at a focal point supported above the center of the dish.
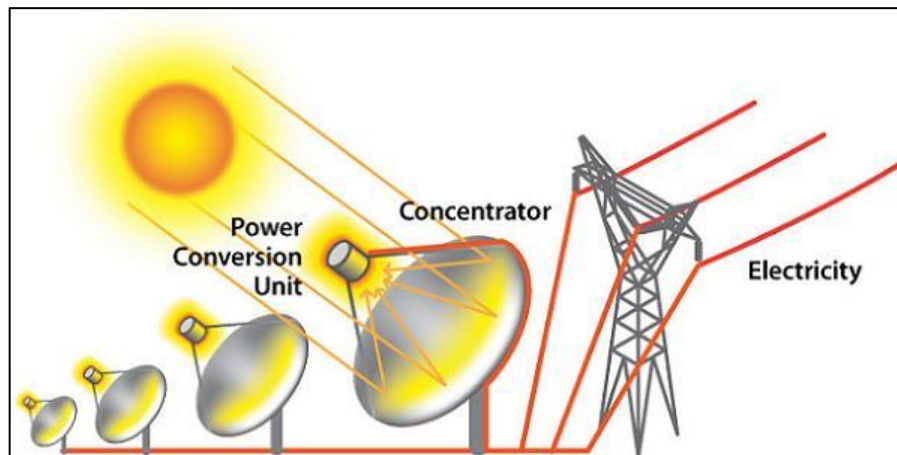
Figure 14: Parabolic Dish Collectors.

The entire system tracks the sun, with the dish and receiver moving in tandem, thereby eliminating the need of each HTF and cooling tower. PDCs offer the highest transformation efficiency of other CSP systems. PDCs are expensive and having low compatibility with respect of thermal storage and hybridization. Promoters claim that mass production will allow

dishes to compete with larger solar thermal systems. Each parabolic dish has low power capacity (typically tens of kW or smaller), and each dish produces electricity independently [22, 24].

3.5 Comparison between CSP Technologies

Within the commercial CSP technologies, PTC plants are the most mature and developed of all commercially operating plants. Table 1 compares between the technologies based on different parameters. One of the most important indicators to compare between different CSP technologies is the capacity factor which is defined as the ratio of its actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.

Table 1: Comparison between Leading CSP Technologies [19,24,25].

Parameter	Parabolic Trough	Solar Tower	Linear Fresnel	Dish-Stirling
Typical Capacity (MW)	1-300	1-200	1-200	0.01-0.025
Maturity of Technology	High (Commercially Proven)	Medium (Pilot Commercial Projects)	Low (Pilot Projects)	Low (Demonstration Projects)
Technology Risk	Low	Medium	Medium	Medium
Max slope of solar field (%)	< 1-2	< 1-4	< 1-2	< 1-4 Array Units. 10% or more, Split Unit.
Operating T (ºC)	20-400	300-565	50-300	120-1500
Solar Concentration Ratio[1]	15-45	150-1500	10-40	100-1000
Thermo-dynamic	Low	High	Low	High

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[1] Solar concentration ratio is used to describe the amount of light energy concentration achieved by a given collector.

efficiency[2]				
Capacity Factor	< 50%, No Storage. > 50%, Yes Storage.	< 50%, No Storage. > 50%, Yes Storage.	< 50%, No Storage. > 50%, Yes Storage.	No Storage
Cooling water (L/MWh)	3000 or Dry	3000 or Dry	3000 or Dry	None
Washing Requirements (L/MWh)	300	300	300	75
Land Occupancy	Large	Medium	Medium	Small
Investment Cost ($/kW)	4000-5000 (No Storage). 6000-9000 (3-8h storage).	4000-5000 (Water Steam, No Storage). 8000-10000 (6-10h storage).	3500-4500 (No Storage). Unspecified Cost (Storage).	4500-8000 (Depending on Volume Production). No Storage systems in Dish-Stirling.
Relative Cost	Low	High	Very Low	Very High

Conclusion:

In general, as shown above, all CSP types can be implemented for any location in Palestine. But, based on the maturity and the risk of CSP technology, PTC and SPT systems are the suitable ones to be implemented in Palestine.

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[2] Thermo-dynamic efficiency is a measure of the performance of a power cycle and it is defined as the ratio of the desired output of the cycle to the required input for the cycle.

Chapter Four

Research Methodology

This chapter provides an outline of the research methodology used to answer the research questions presented in the introduction (chapter one). The following Figure shows the main procedures used in this research.
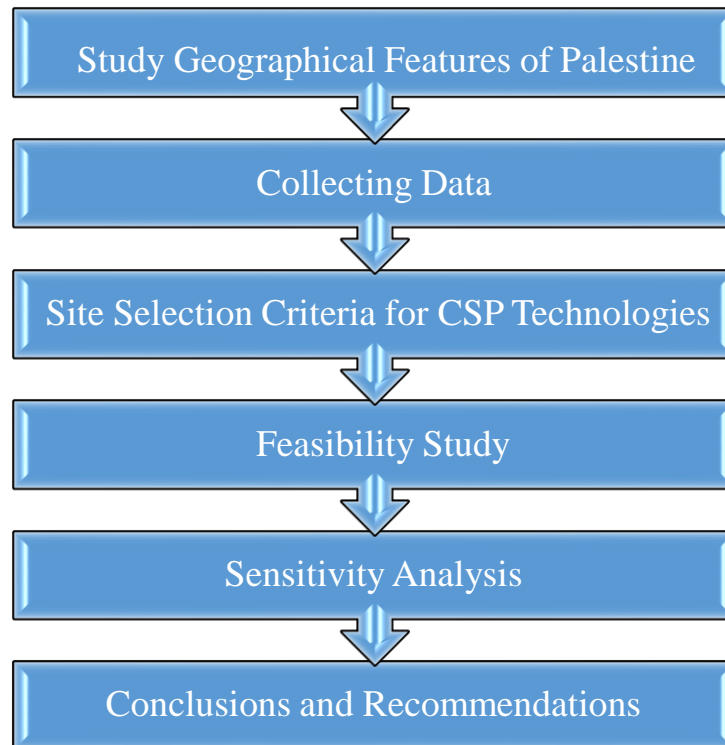
Figure 15: Research Methodology

4.1: Study the geographical features of Palestine.

Palestine is located in the geographical region between Mediterranean Sea and the Jordan River. The study includes the West Bank and the Gaza Strip. Palestine has a highly variable climate conditions modified locally by altitude. In this thesis, Palestine is divided geographically into five regions with different climate conditions: Jericho, Hebron, Nablus, Ramallah, and Gaza Strip.

4.2: Data collection.

A group of Data required to implement CSP systems for Palestinian regions. DNI record (of about 15 years) is one of these required data which represents a significant record for CSP implementations. Other Data such as land and water availability, land slope, transportations, power transmission lines, and meteorological conditions have been collected through interviews, consultations, visitations, and phoning with the relevant sides such municipalities, site-engineers, Ministry of Local Government, National Spatial Plan, and Palestinian Energy Authority. See the details in Chapter Five.

4.3: Site Selection Criteria for CSP Technologies.

To implement CSP technologies for any location, site criteria must be known to determine whether the selected site is suitable for CSP implementation or not through checking the site requirements and conditions needed by CSP systems to be implemented. See the details in Chapter Five.

4.5: Feasibility Study.

To check the viability of the CSP technology for these selected sites, a feasibility study must take place to obtain more information by doing so clarify most of its parameters. See the details in Chapter Six.

5.6: Sensitivity Analysis

To study the impacts of changing some of financial viability parameters on feasibility study, sensitivity analysis stands for that purposes by assuming many scenarios. See the details in Chapter Seven.

Chapter Five

CSP Site Criteria for Selected Palestinian Regions

The selected sites for CSP systems have to comply with certain requirements. These requirements can be divided into five groups: solar radiation requirements, land availability and use, land slope, water availability, infrastructure requirements, and meteorological conditions.

5.1   Solar Radiation potential

In CSP applications, the DNI is very important to be assessed. As shown in Figure 16, the terrestrial solar radiation can mainly be classified into three types: direct, diffuse and global solar radiation.
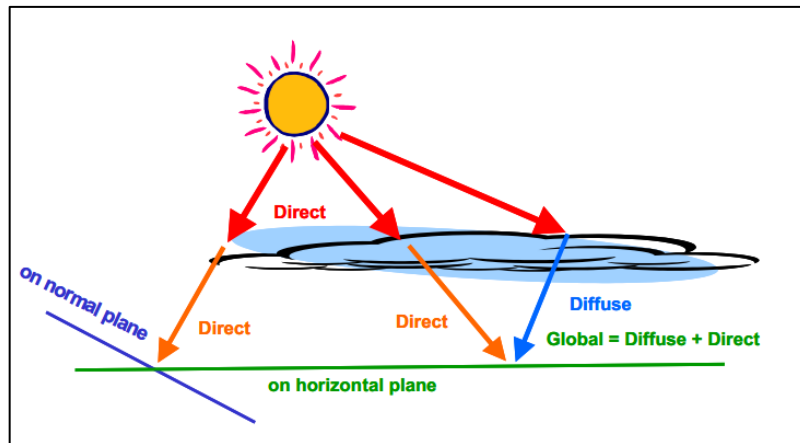
Figure 16: Main Solar Radiation Components.

The direct solar radiation DNI (W/m^2 or kWh/m^2-y) comes from the sun and passes through the planet's atmosphere without deviation and refraction and measured by pyrehiliometer. The diffuse solar radiation scattered by

molecules without having a unique direction and measured by shading pyranometer. The global solar radiation is the sum of the direct and diffuse solar radiation on horizontal surface and measured by pyranometer.

The CSP technology requires sufficient potential of DNI which is ranged between 1900 and 2100 kWh/m²-y to offer more attractive levelized electricity prices. These values are reached in the so-called Sun Belt areas which located at latitudes between 15° and 40° on both hemispheres which includes Palestine [26].

To assess the potential sites for implementing CSP plants, DNI data records (of about 15 years) are required which are collected by ground measurements or satellite measurements or both. The ground measurements have some advantages such as high accuracy and high time resolution whereas the satellite measurements have some advantages such as spatial resolution, long term data, effectively no failures, no soiling, no ground site necessary, and low costs [27].

For Palestine, severe lack of DNI collected data. Therefore, application of models are usually utilized to obtain the required DNI data. These models allow estimating the DNI either from ground measurements or from satellite data. However, in Palestine, the ground measurements are usually not available for many years. Therefore, the satellite data are used to obtain DNI data [28].

To obtain the DNI and meteorological data for Palestine, Solar GIS (Geographic information system) is used. Solar GIS is an estimating model

which has high-resolution global database of DNI and meteorological data computed and updated on a daily bases from satellites [29].

The obtained DNI data shows that Palestine has sufficient DNI potential (in average of 2000 kWh/m^2-y) as shown in Figure 17 which indicates a good condition for implementing CSP plants [28].
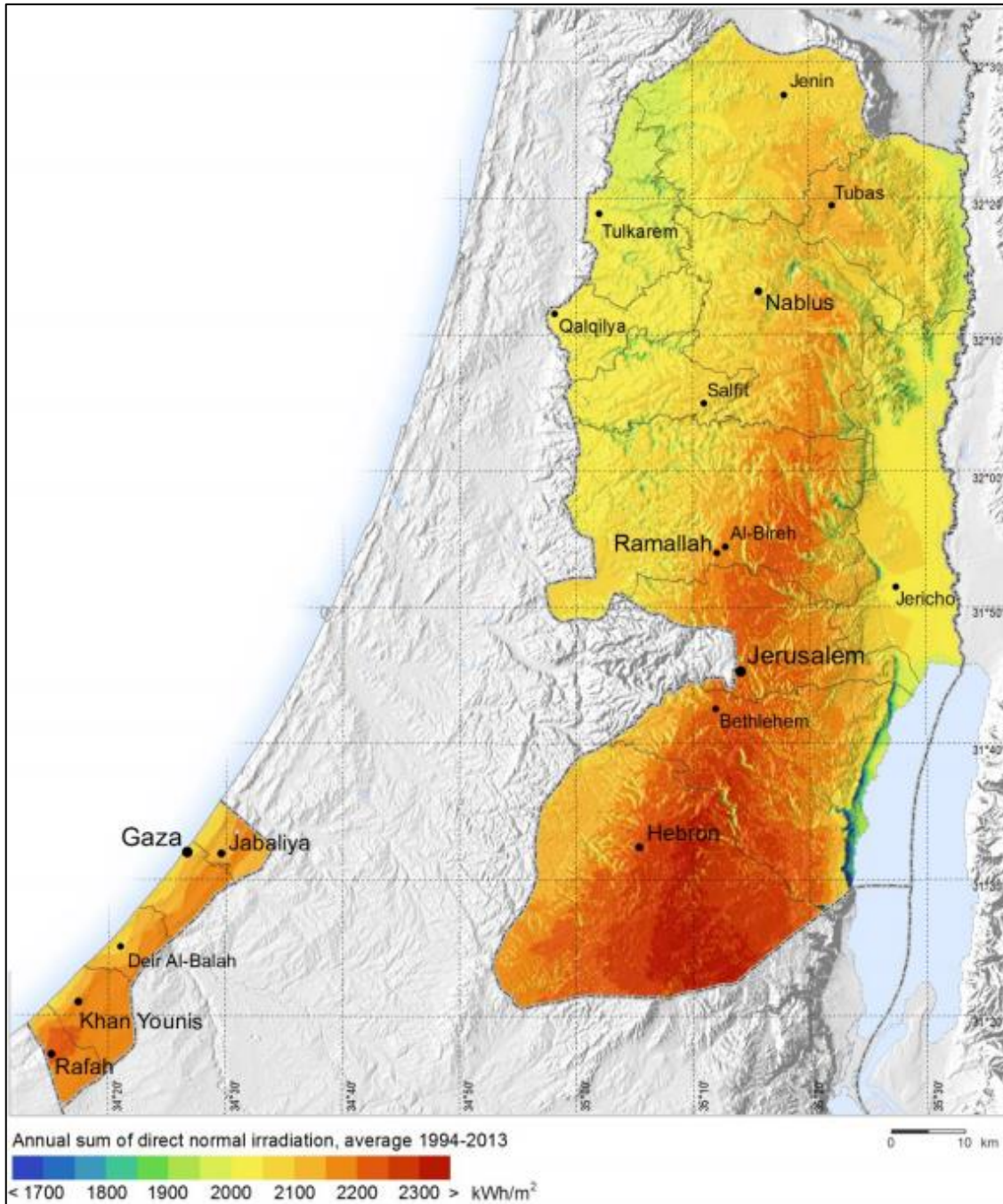
Figure 17: Annual Average Direct Normal Irradiation for West Bank and Gaza Strip.

Based on obtained solar data, the DNI potential for the Palestinian selected sites is shown in Table 2. Each site has DNI potential complies with the minimum amount of DNI required for implementing CSP plants.

Table 2 DNI Potential for Palestinian Governorates. [28]

Governorate	DNI Potential (kWh/m^2-year)

Jericho	2071
Hebron	2286
Nablus	2094
Ramallah	2187
Gaza Strip	2167

5.2 Land Cover, Use, and Slope

CSP plants need a wide land area compared to conventional power plants and the specific surface area for a CSP plant in average is about 25000 m²/MW [34]. The land availability to build large CSP plant is significant and has to comply with certain natural conditions [26].

To select best site for implementing a CSP plant, Exclusion criterion is used [27]. The exclusion criterion stands for excluding all land areas that are unsuitable for the construction of solar fields due to inhabited areas, ground structure, water bodies, land slope, dunes, protected or restricted areas, forests, mountains, agriculture …etc.

Depending on the CSP technology, slope inclination affects the feasibility of a CSP plant and its cost. The line focusing systems (parabolic trough and linear Fresnel power plants) need large flat areas whereas point focusing systems (solar power towers and dish/engine systems) can be constructed on areas with a larger slope inclination due to the punctual foundations of mirrors are independent from each other and no heat transfer fluid circuit are required to connect them [26].

The selected plant site should have an allowable slope depending on the CSP technology type which is ranged about 1-2% for linear focus and up to 3-4% for point focus technologies [26, 27].

As shown in Figure 18, the West Bank and Gaza Strip have various terrain slope which indicates that not all areas are suitable for implementing CSP plants. Therefore, further analysis is required before implementing CSP power plants.
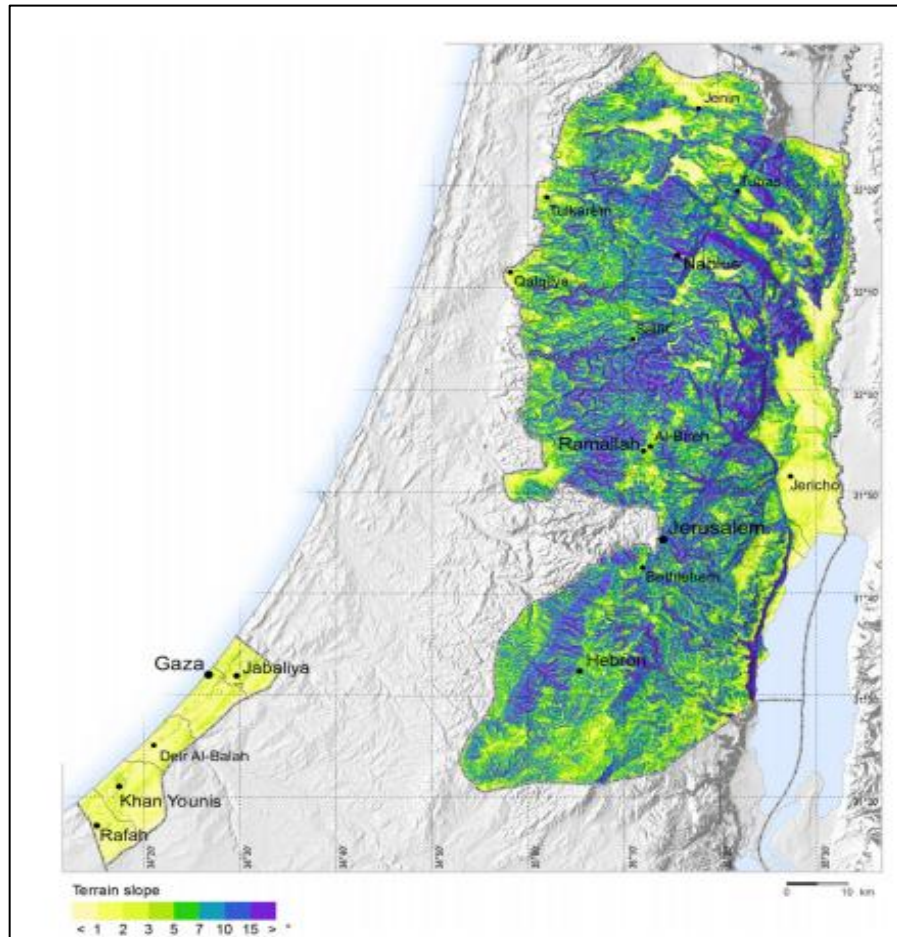
Figure 18: Terrain Slope [28].

From the above discussion, the land availability and land slope for the studied regions are analyzed based on data gathered from Ministry of Local Government and National Spatial Plan [31, 32].

1- Jericho Governorate

Jericho is the lowest area in Palestine and considered one of flat areas which has variety in land use such as built-up areas, heritage, and agriculture as shown in the map in Figure 19.
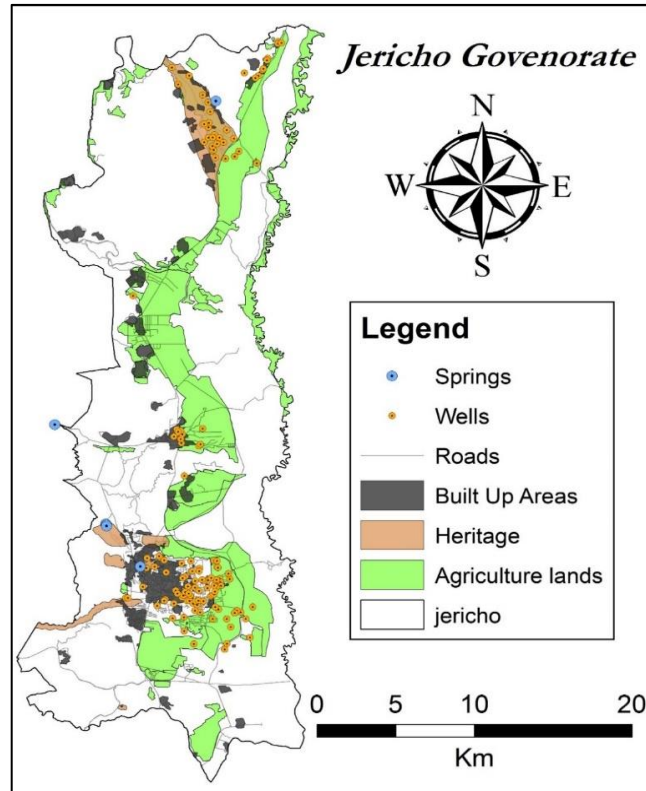
Figure 19: Land Cover and Use for Jericho Governorate.

Figure 20 shows the available unused lands for implementing CSP plants, which is generated by applying the exclusion criterion for Jericho Governorate.
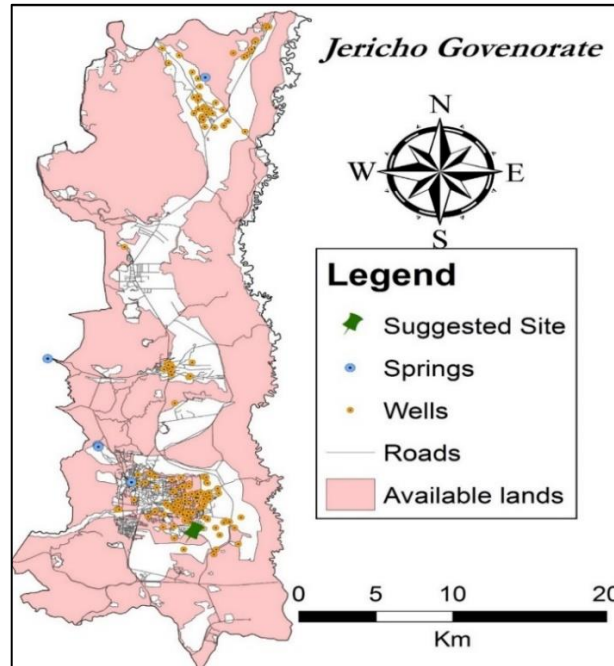
Figure 20: Available Unused Lands for implementing CSP Plants in Jericho Governorate.

The suggested location to implement a CSP plant in Jericho Governorate lies in East South Jericho at latitude 31° 44' 47.72" and longitude 35° 29' 13.43" as shown in Figure 21. The selection is based on detailed study of the available areas with consultation with Jericho municipality [33].
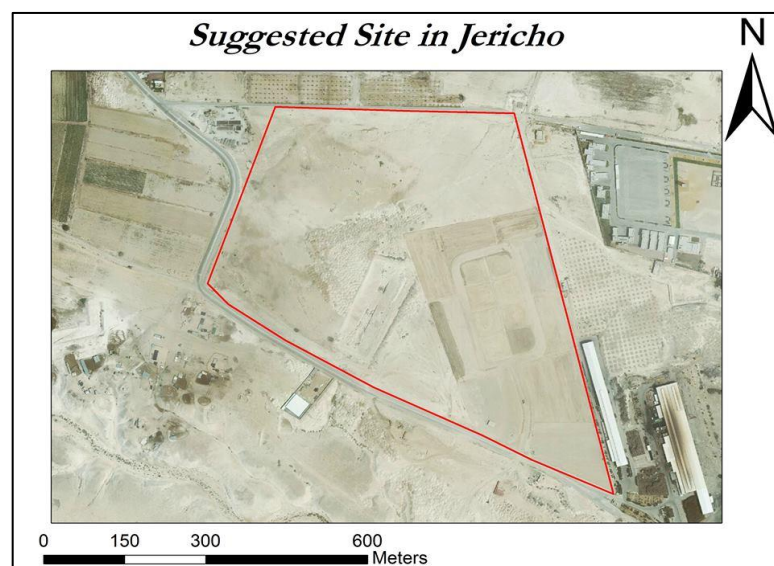
Figure 21: Suggested Site in Jericho.

Figure 22 shows more details about the selected site contour.
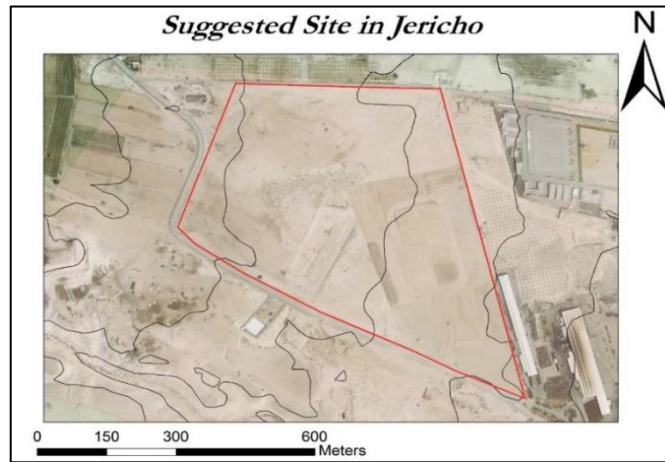
Figure 22: Contour of Suggested Site in Jericho.

According to the Figures shown above, Jericho has sufficient land availability for implementing CSP plants as well as the suggested site has acceptable slope which is 1.3%.

2- Hebron Governorate.

Hebron is considered one of mountainous in Palestine which has variety in land use as shown in the map in Figure 23.
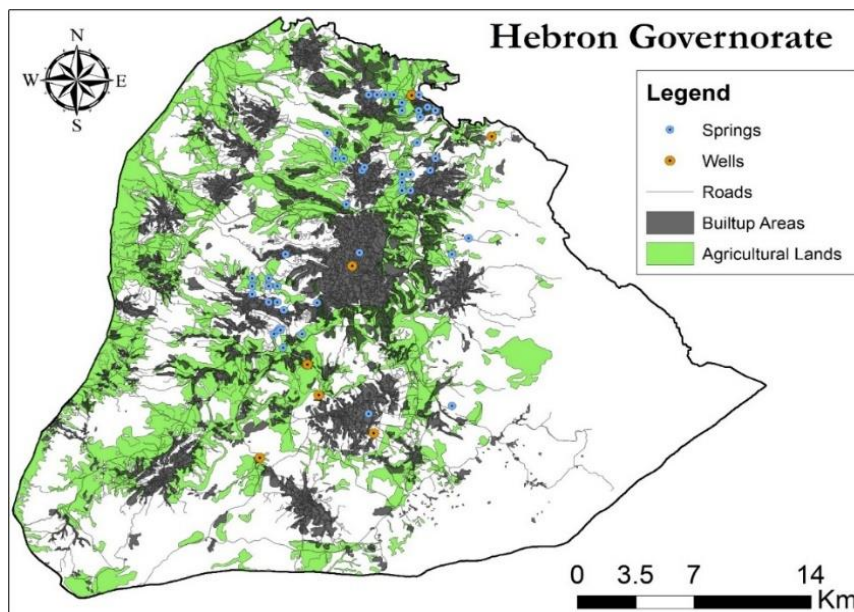
Figure 23: Land Cover and Use for Hebron Governorate.

Figure 24 shows the map for unused available lands which is generated by applying the exclusion criteria for Hebron Governorate, and depending on the slope inclination, these lands could be suitable for CSP implementations.
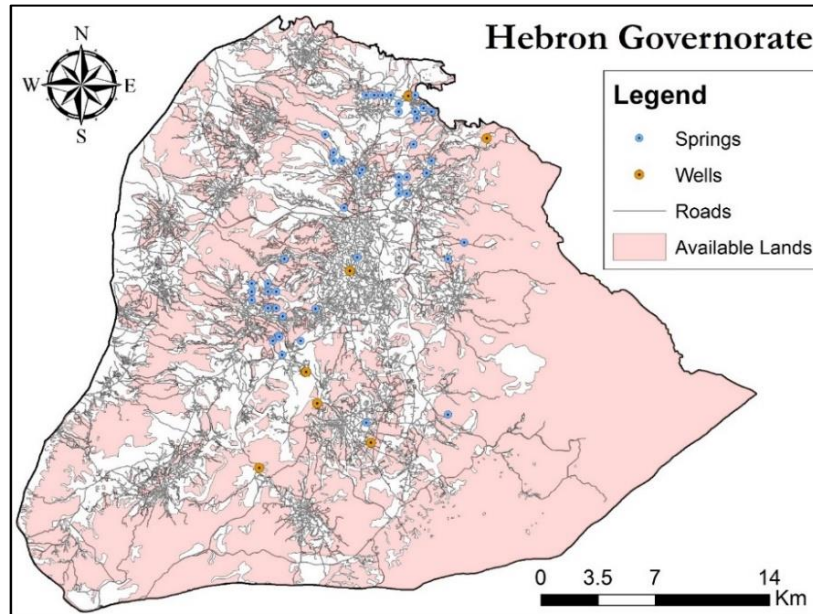
Figure 24: Available Unused Lands for implementing CSP Plants in Hebron Governorate.

The following Figure shows the contour of Hebron Governorate.
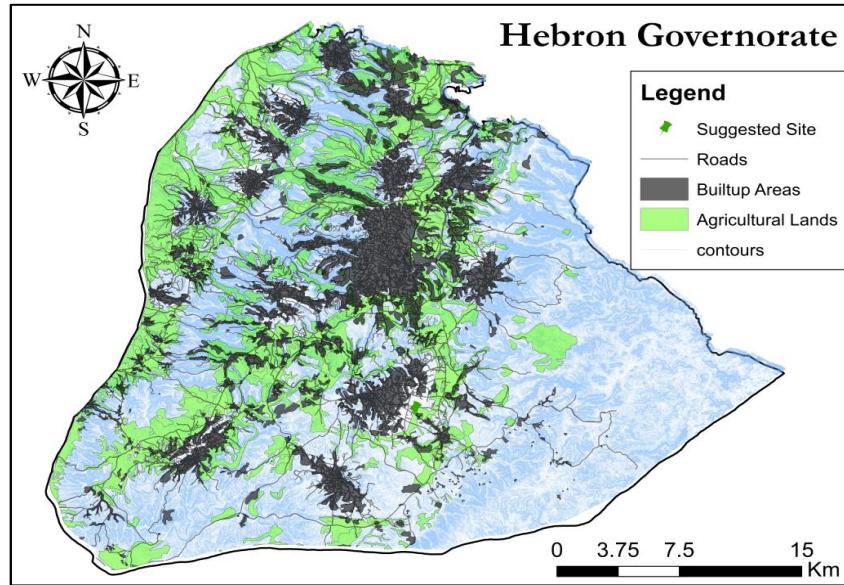
Figure 25: Hebron's Contour.

Hebron Governorate has inclination slope greater than needed inclination slope for CSP systems which in turn leads to difficulties in selecting the suitable sites with suitable inclination to implement CSP plants.
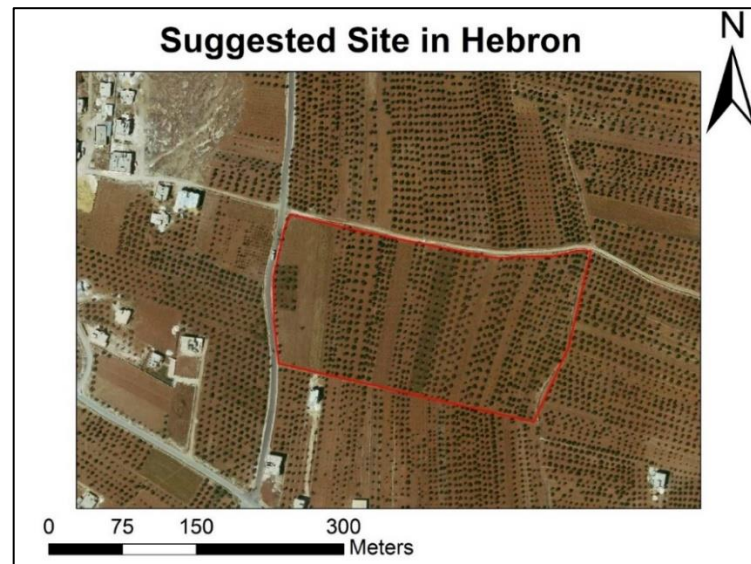
Figure 26: Suggested Site in Hebron.

Figure 26 shows the suggested location to construct a CSP plant which lies in East Yata-Hebron at latitude 31° 26' 22.26" and longitude 35° 06' 48.50".
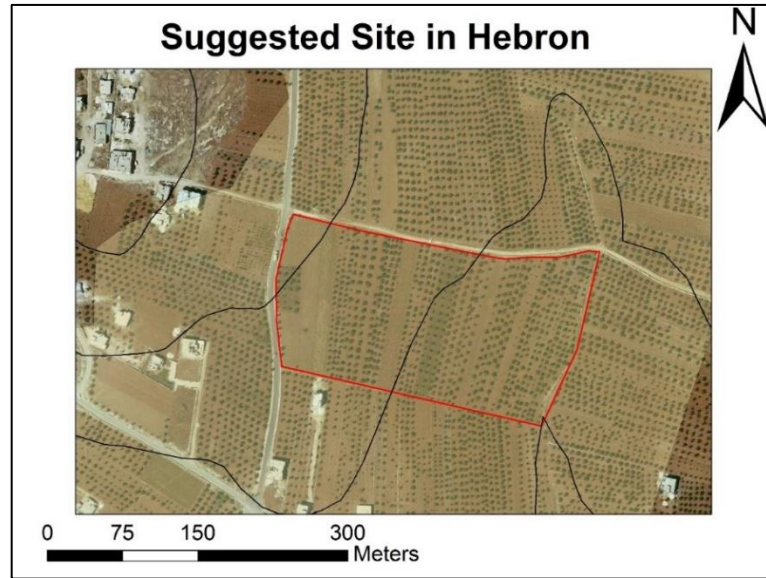
Figure 27: Contour of Suggested Site in Hebron.

Figure 27 shows more details about the selected site contour. The site is selected after consultations with the GIS engineers in Hebron municipality [34].

According to the above discussions and illustrations, Hebron has insufficient land availability for implementing CSP systems due to its slope inclination and the suggested site has acceptable slope for implementing CSP systems which is 1.6%.

3- Nablus Governorate

Nablus is considered one of mountainous areas in Palestine with variety in land use as shown in the map in Figure 28.
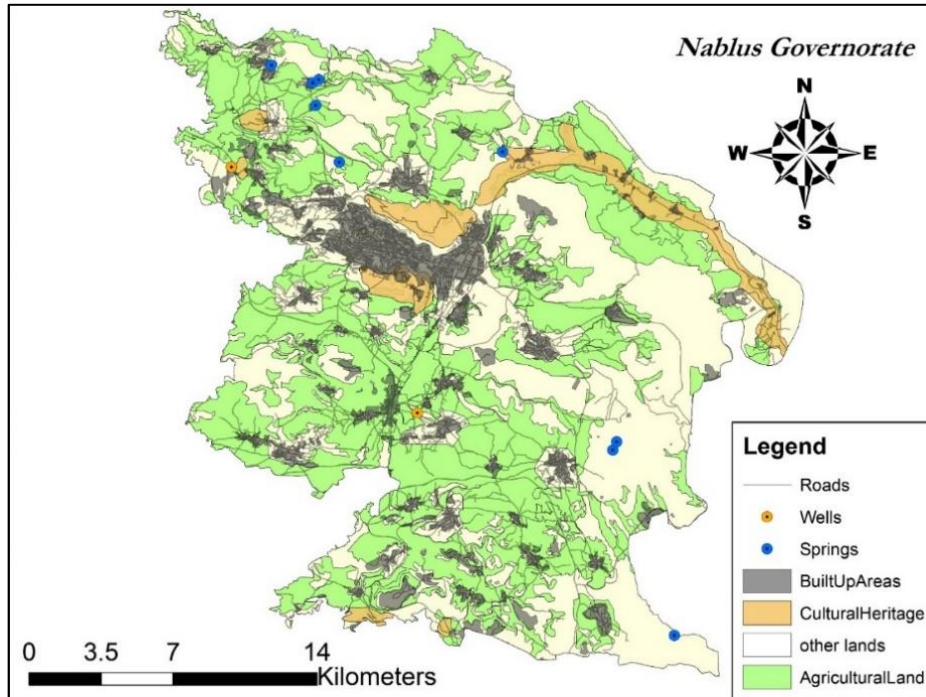
Figure 28: Land Cover and Use for Nablus Governorate.

Figure 29 shows the available unused lands for implementing CSP plants, which is generated by applying the Exclusion criterion for Nablus governorate.
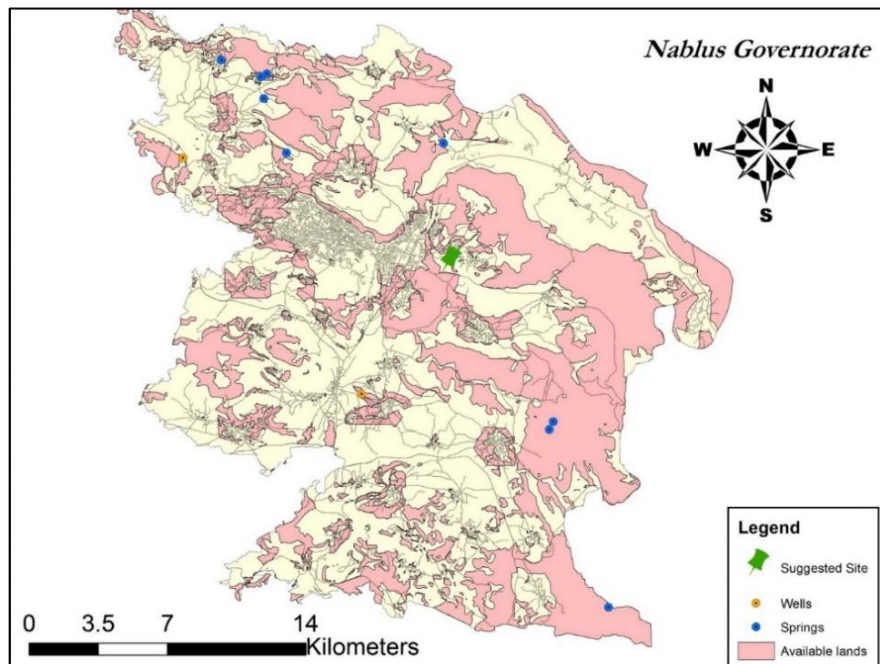
Figure 29: Available Unused Lands for implementing CSP Plants in Nablus Governorate.

The suggested location to construct a CSP plant in Nablus Governorate lies in East Nablus at latitude 32° 12' 09.73" and longitude 35° 18' 54.83" and named "AL-Maqbara Asharqia" as shown in Figure 30. The selection is based on consultations with planning department in Nablus municipality [35].

Figure 30: Suggested Site in Nablus.
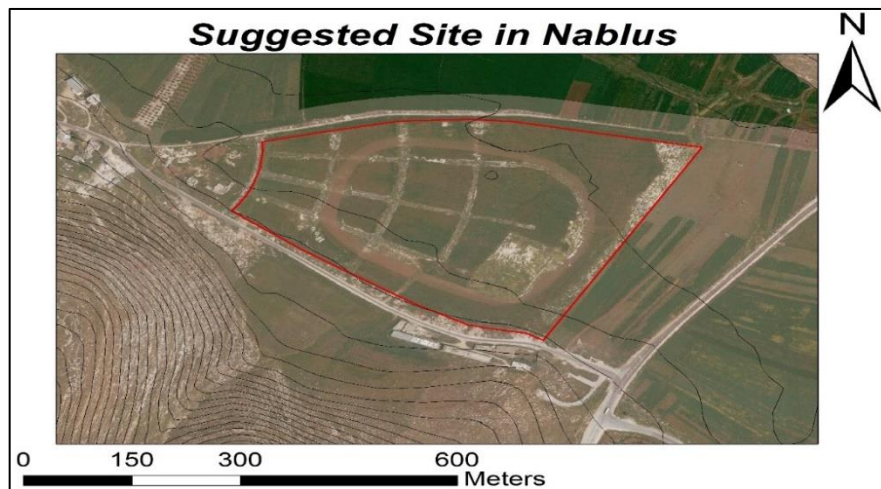
Figure 31: Contour of Suggested Site in Nablus.

Figure 31 shows more details about the selected site contour. According to the above discussions and illustrations, Nablus has sufficient land availability as well as the suggested land has acceptable slope which is 2%.

4- Ramallah

Ramallah is also considered one of mountainous areas in Palestine with different variety of land use as shown in the map in Figure 32.
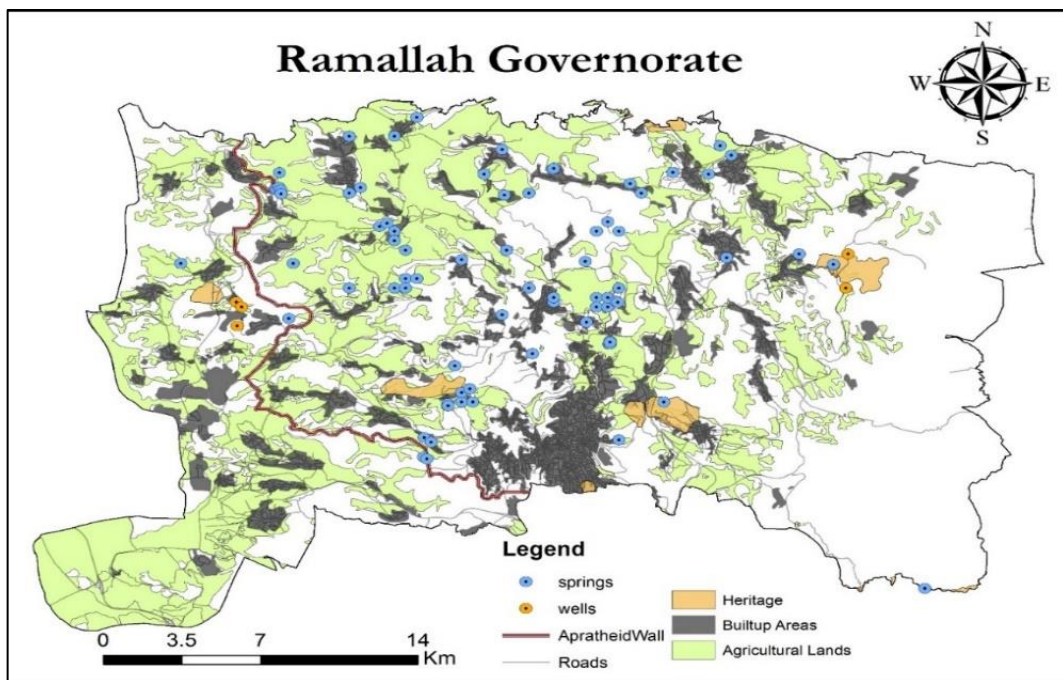
Figure 32: Land Cover and Use for Ramallah Governorate.

Figure 33 shows the available unused lands for implementing CSP plants, which is generated by applying the Exclusion criterion for Ramallah governorate.
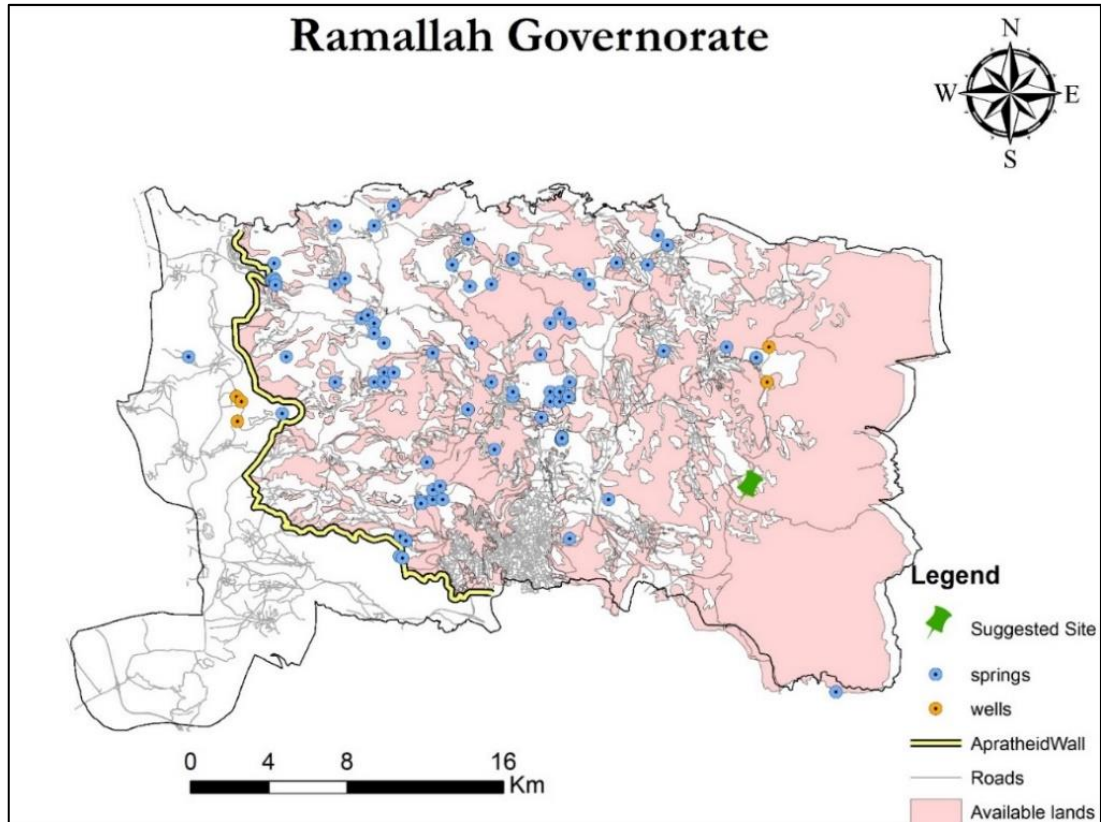
Figure 33: Available Unused Lands for implementing CSP Plants in Ramallah Governorate.

The contour of Ramallah as shown in Figure 34 shows that the governorate has inclination slope greater than needed inclination slope for CSP systems, which in turn leads to difficulties in selecting the suitable sites with suitable inclination to construct CSP systems.
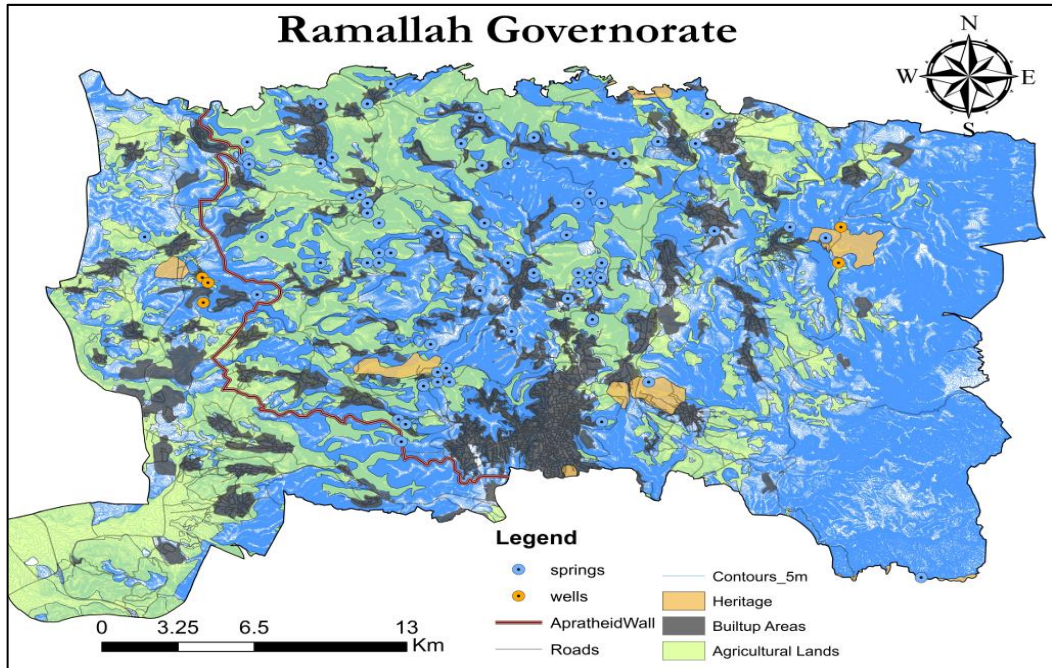
Figure 34: Ramallah's Contour.

However, after sightseeing and consultations with the GIS and planning department in Ramallah municipality [36], the suggested location to construct a CSP plant in Ramallah Governorate lies in South East Ramun-Ramallah at latitude 31° 55' 29.21" and longitude 35° 19' 08.01" as shown in Figure 35.
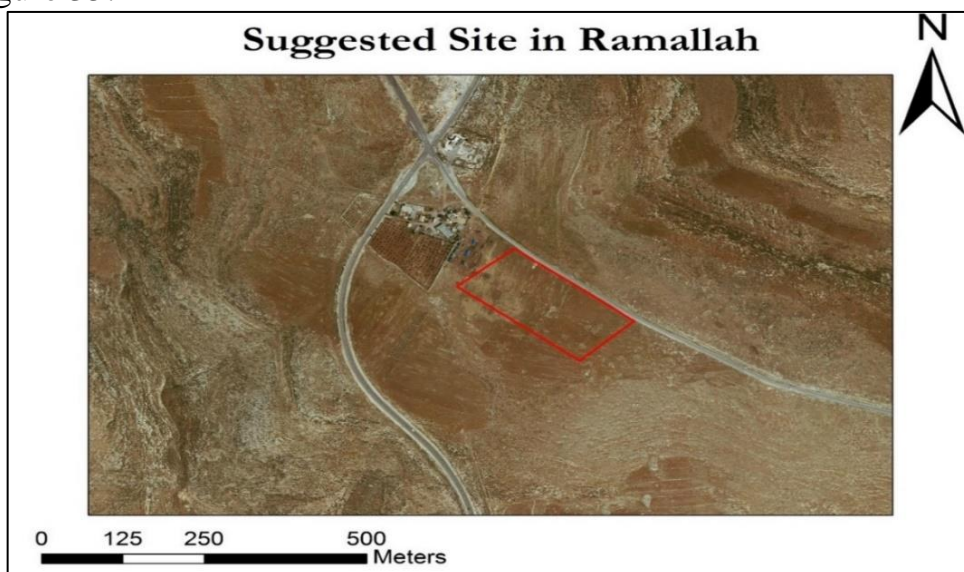
Figure 35: Suggested Site in Ramallah.

Figure 36 shows more details about the selected site contour.
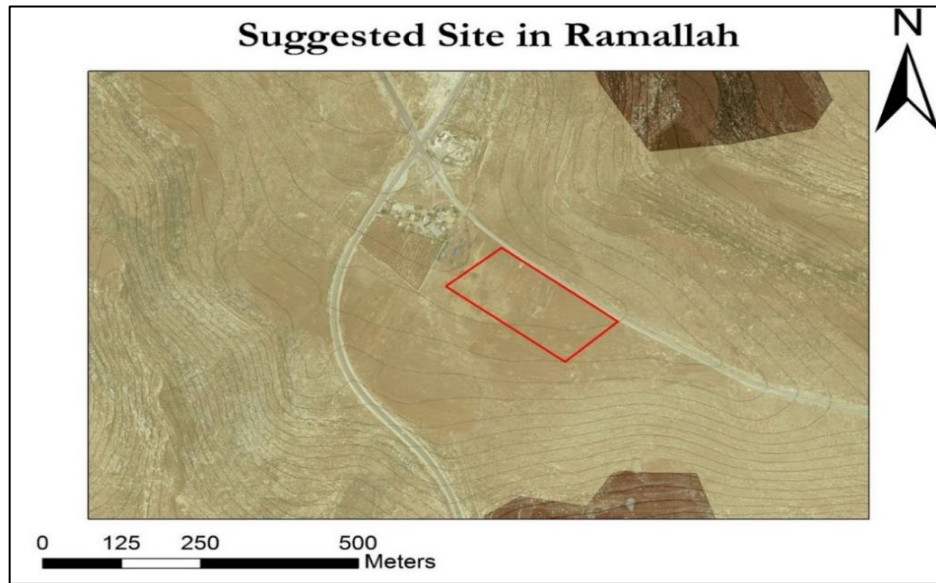
Figure 36: Suggested Site in Ramallah after Checking the Contour.

According to the above discussions and illustrations, Ramallah has insufficient land availability for implementing CSP systems due to its slope inclination and the suggested site has acceptable slope for implementing CSP systems which is 2%.

5- Gaza Strip

Gaza strip is considered one of flat areas in Palestine with different land use as shown in in Figure 37 which illustrates a built map based on data gathered from mappings software.
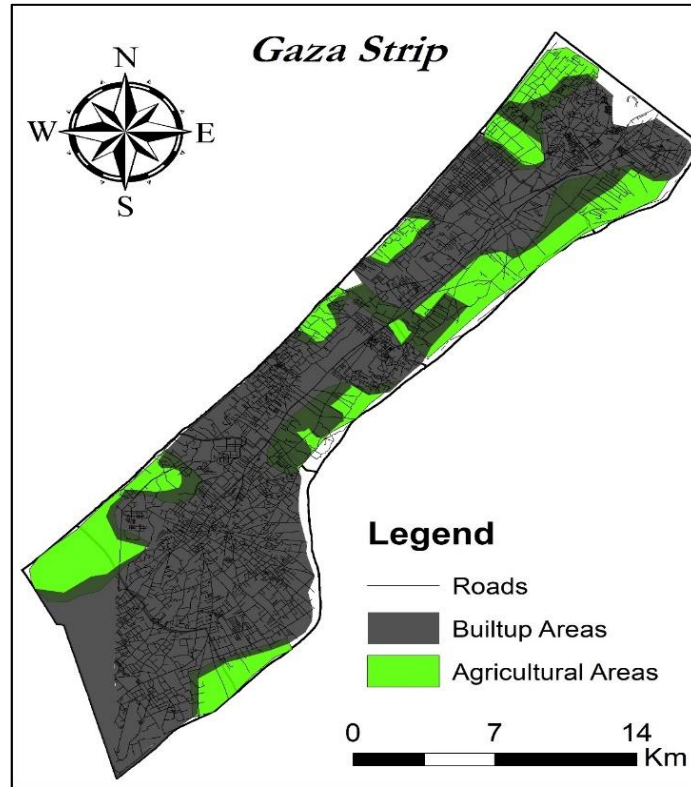
Figure 37: Land Cover and Use for Gaza Strip.

Figure 38 shows the available unused lands for implementing CSP plants, which is generated by applying the Exclusion criterion for Gaza strip.
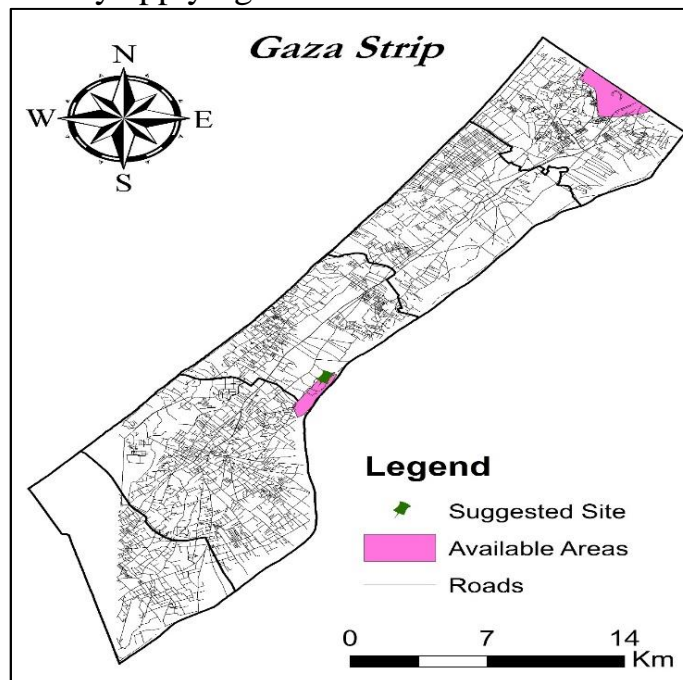

Figure 38: Available Unused Lands for implementing CSP Plants in Gaza Strip.

The suggested location is one of fewer locations available to construct a CSP plant in Gaza Strip which lies in north east Jarara-Gaza Strip 31° 22' 08.26" and longitude 34° 21' 53.21" as shown in the Figure 39. The selection is based on information gathered by consultation with Gaza municipality. This area is restricted by Israel occupation. So, the selection of this site depends on upcoming political resolutions that might allow either the government or public to use this area for industry or other infrastructure projects.

Figure 39: Suggested Site in Gaza Strip.

According to the above discussions and illustrations, Gaza Strip has insufficient land availability for implementing CSP systems and the suggested land has acceptable slope (1.8%).

5.3   Water Availability

Water availability for concentrating power plants is important, especially if they are equipped with wet cooling systems. Wet cooling systems are favorable for the CSP plant operation because of higher possible power

plant efficiencies and lower investment costs in comparison to CSP plants with dry cooling systems. This justifies the importance of water availability for such plants. For wet cooling systems, all CSP technologies except Dish-Stirling need about 3 m^3 of water for each MWh produced. For dry cooling systems, all CSP technologies except Dish-Stirling need about 0.3 m^3 of deionized water for washing requirements for each MWh produced, while the Dish-Stirling needs about 0.075 m^3 of deionized water for washing requirements for each MWh produced [37].

The water availability for the studied regions is analyzed based on data gathered from Ministry of Local Government and National Spatial Plan.

1- Jericho Governorate

Jericho has abundant water resources such as wells and springs as shown in Figure 40.
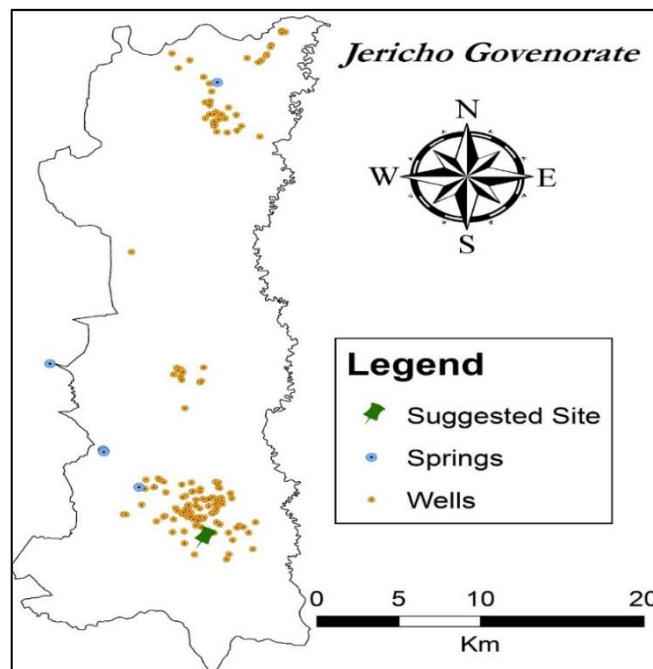
Figure 40: Water Resources in Jericho.

The selected site in Jericho is close to water connection grids as shown in Figure 41.

Figure 41; Water Connection Grids for Jericho Selected Site.

According to Figures shown above, the selected site is close to the water resources as well as it has water connection grids.

2- Hebron Governorate

Hebron has sufficient water resources such as wells and springs as shown in Figure 41.
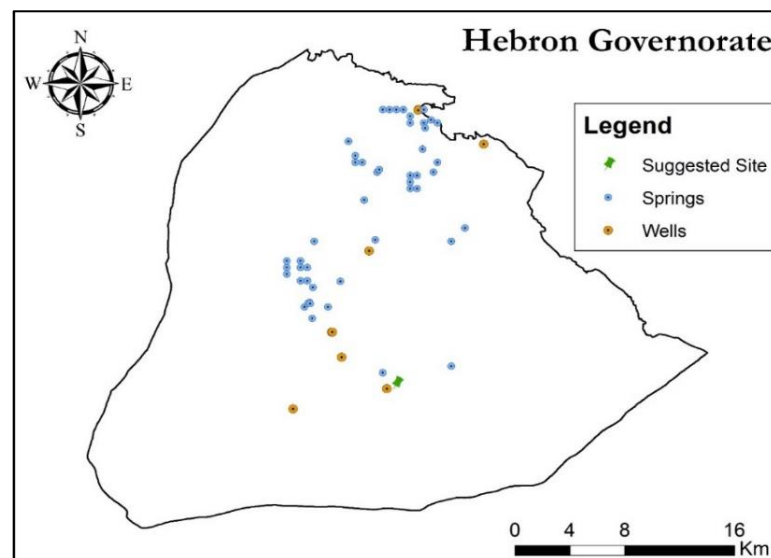
Figure 42: Water Resources in Hebron.

The selected site in Hebron is close to water connection grids as shown in Figure 43.
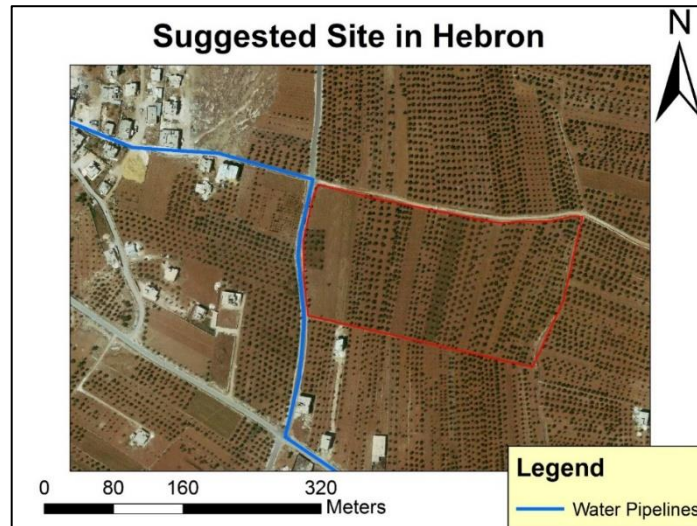
Figure 43: Water Connection Grids for Hebron Selected Site.

According to Figures shown above, the selected site in Hebron governorate is close to water resource as well as it has water connection grids.

3- Nablus Governorate

Nablus suffers from lack of water resources, which in turns leads to intermittent pumping of water throughout the day. The Figure 44 shows the water map for Nablus governorate.
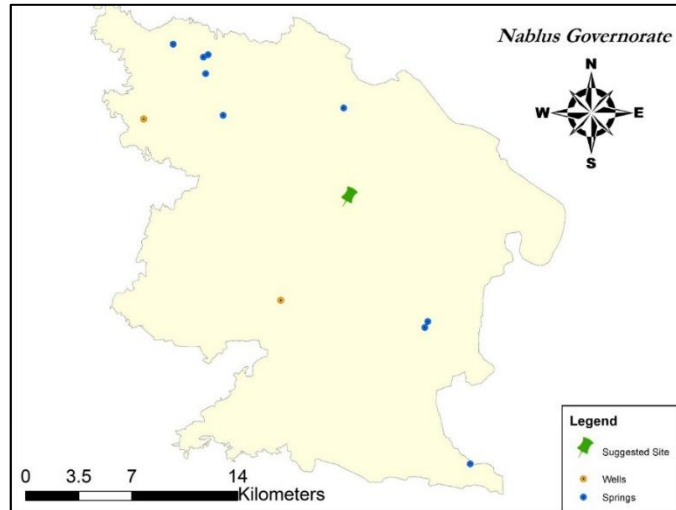
Figure 44: Water Resources in Nablus.

The selected site in Nablus is much close to water connection grids as shown in the Figure 45.

Figure 45: Water Connection Grids for Nablus Selected Site.

According to Figures shown above, the selected site in Nablus governorate has water connection grids for implementing CSP systems.

4- Ramallah

Ramallah has sufficient water resources such as wells and springs as shown in Figure 46.
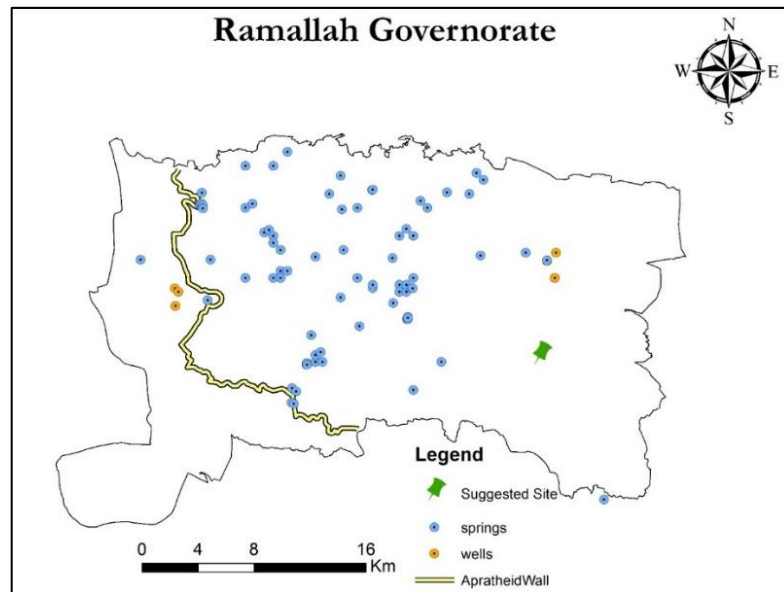
Figure 46: Water Resources in Ramallah.

The selected site in Ramallah does not have water connection grids. Therefore the Figure 47 shows suggested water pipelines for the selected site.
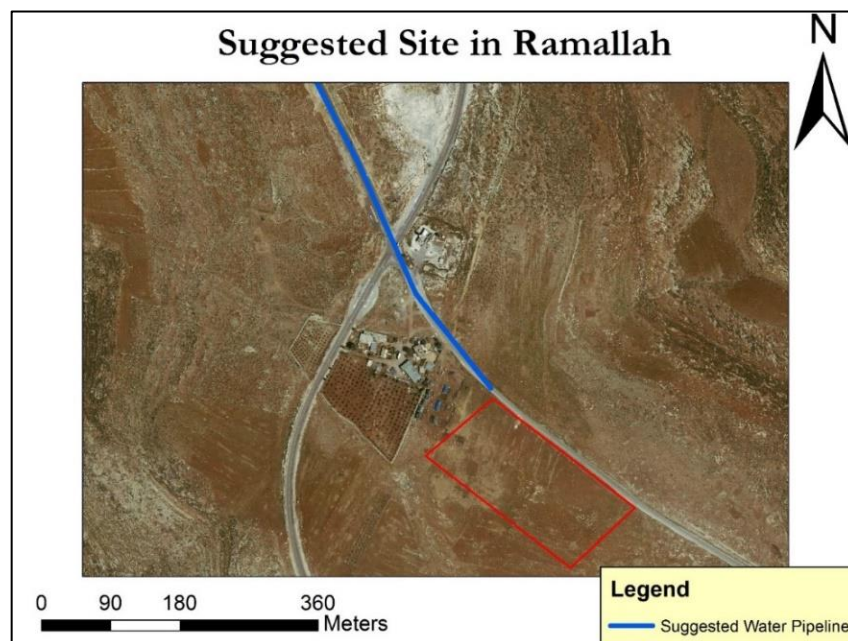
Figure 47: Suggested Water Pipeline for Ramallah Selected Site.

According to Figures shown above, the selected site in Ramallah governorate is near water resources. Therefore, it is recommended to construct big wells filled with needed water for operating.

5- Gaza Strip

Gaza Strip has a lot of municipality wells and infiltration basins as shown in Figure 48 and the selected site in Gaza Strip is near to these water sources. A future pipeline is planned and suggested for the selected site.
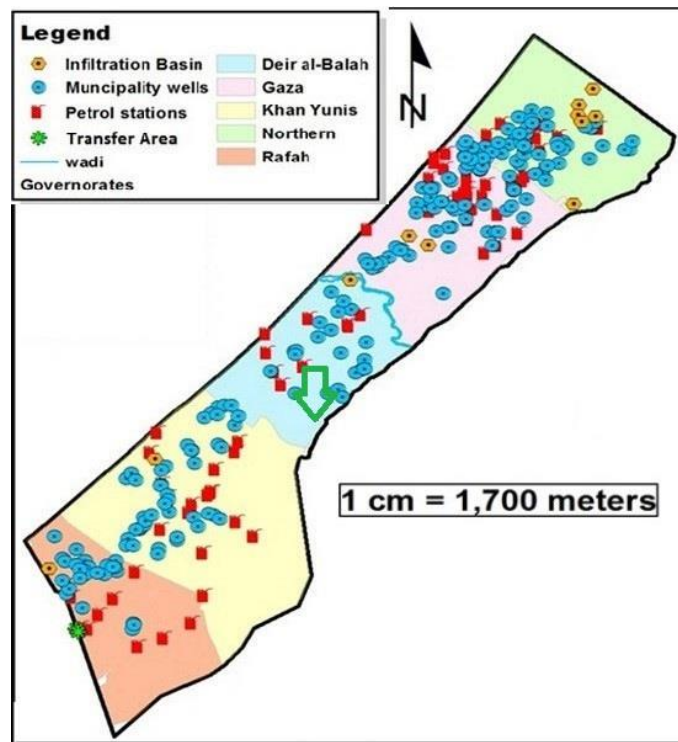
Figure 48: Map of Water in Gaza Strip [38].

The water connection grid as shown in Figure 49 for the selected site is suggested based on the predictive view for any future development of the water connection grid for the area that contains the selected site.
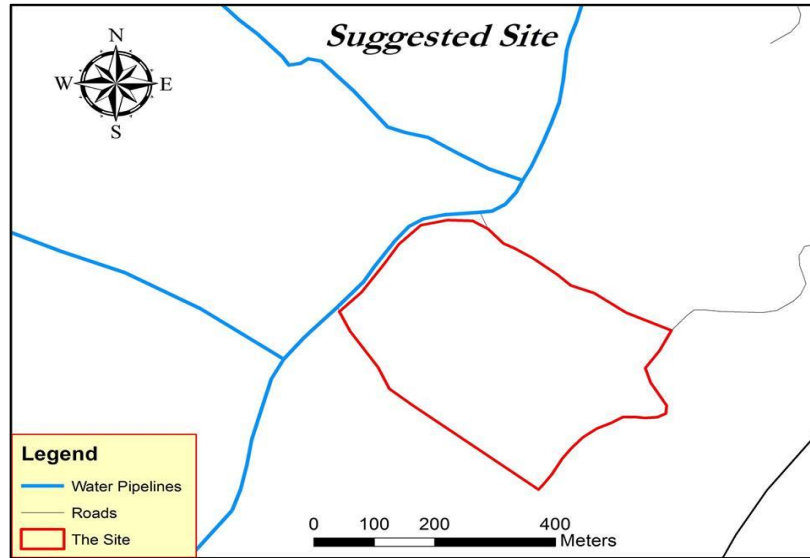
Figure 49: Suggested Water Pipeline for the Gaza Selected Site.

5.4 Transportation

The proximity of the CSP plants to existing highways is desirable. Access roads must be suitable for transporting the different and heavy equipments to the site like turbine, generators, reflectors, pipes etc. If roads are not qualified, the investment cost of a CSP plant construction will increase. The plant site is recommended to be located relatively close to a populated area to provide construction workers and operating personnel for the plant [27].

In West Bank and Gaza Strips, the transportation grids are well-constructed and reaches to about all areas as shown in Figure 50.
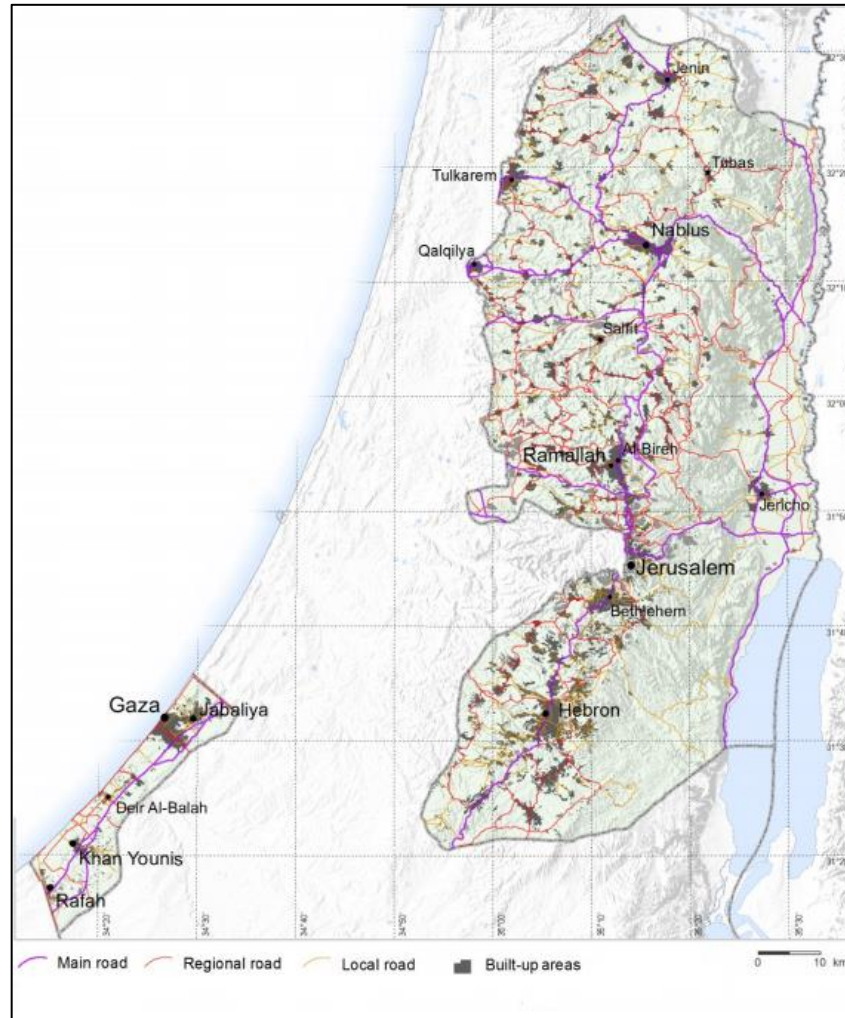
Figure 50: Built-up Areas and Road Infrastructures [28].

From the above discussion, the transportation for the studied regions are analyzed based on data gathered from Ministry of Local Government and National Spatial Plan [31, 32].

1- Jericho Governorate

The selected site is located within the transportation grids of the city as shown in Figure 51.
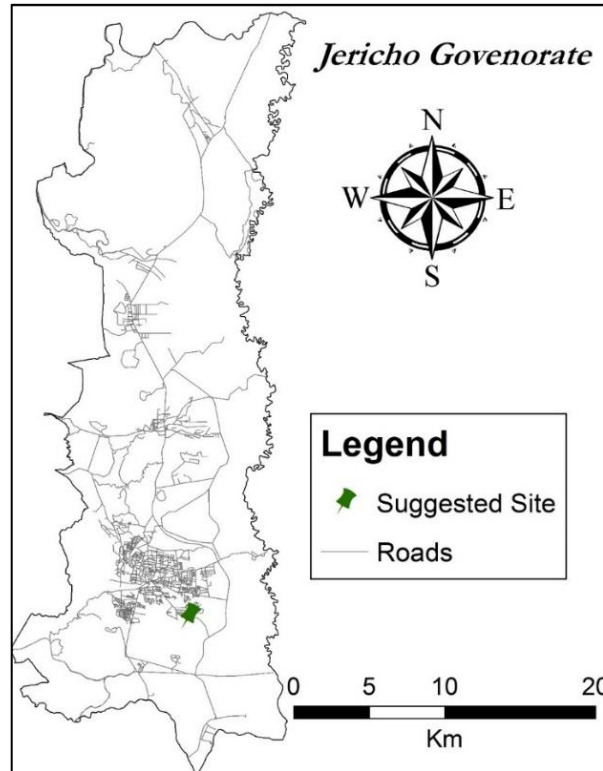
Figure 51: Transportation Grid in Jericho Governorate.

According to Figures shown above, Jericho has well-constructed and suitable transportation grid for transporting the different and heavy equipments of CSP systems to the site.

2- Hebron Governorate

The selected site is located within transportation grids of the city as shown in the Figure 52.
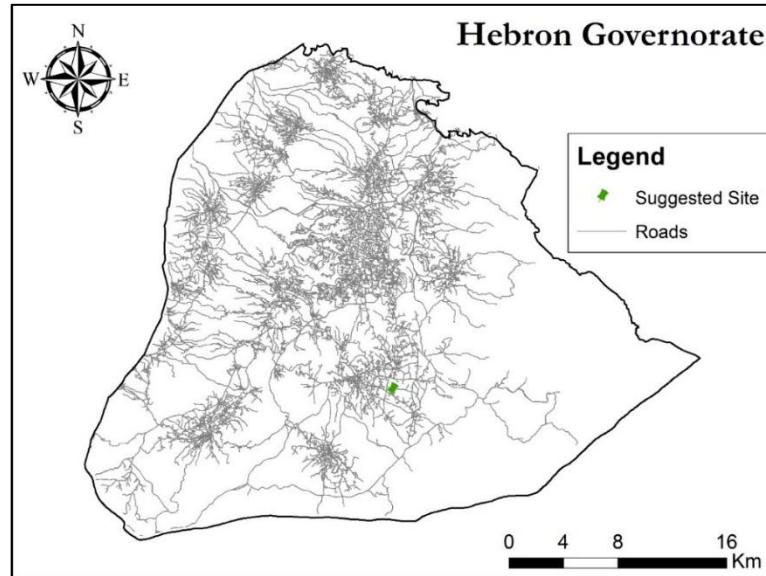
Figure 52: Transportation Grid in Hebron Governorate.

According to Figures shown above, Hebron has well-constructed and suitable transportation grid for transporting the different and heavy equipments of CSP systems to the site.

3- Nablus Governorate

The selected site is located within transportation grids of the city as shown in Figure 53.
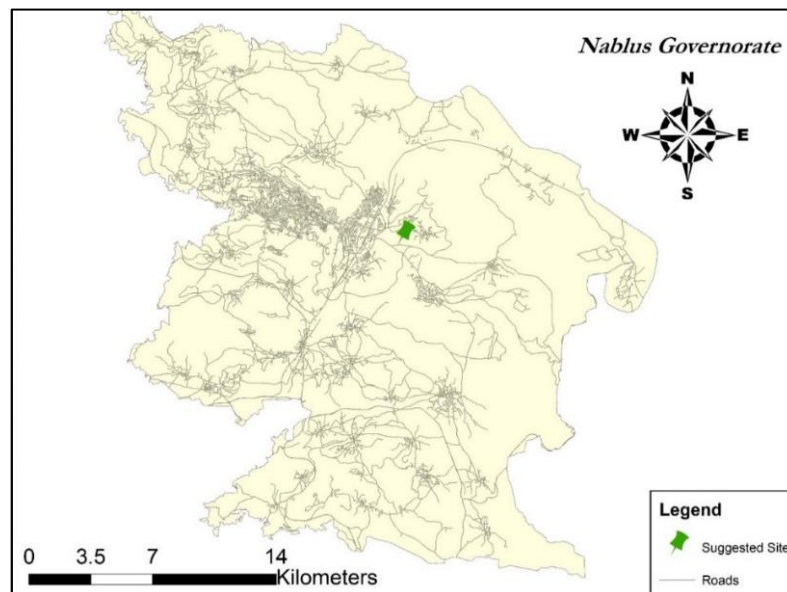
Figure 53: Transportation Grid in Nablus Governorate.

According to Figures shown above, Nablus has well-constructed and suitable transportation grid for transporting the different and heavy equipments of CSP systems to the site.

4- Ramallah Governorate

The selected site is near transportation grids as shown in Figure 54.
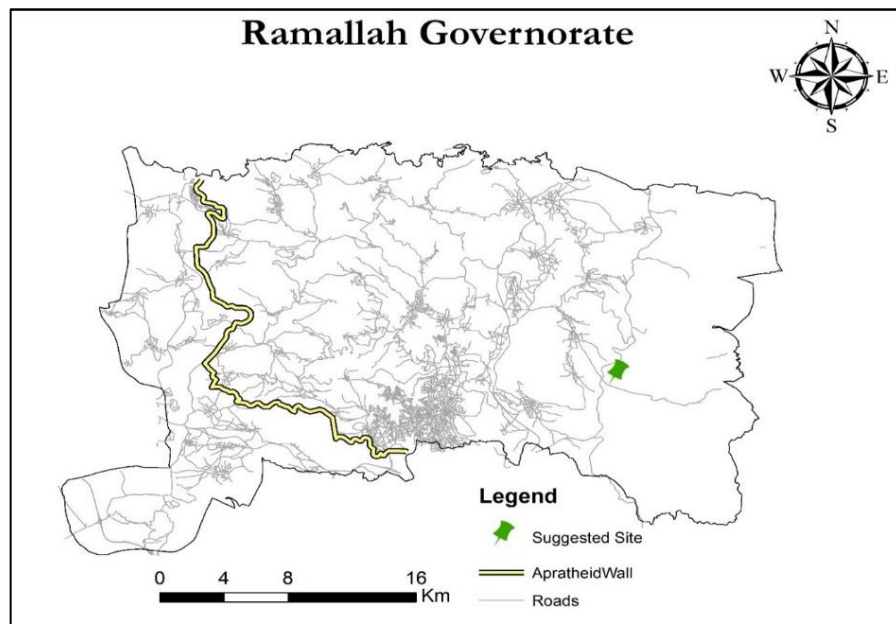
Figure 54: Transportation Grid in Ramallah Governorate**.**

According to Figures shown above, Ramallah has well-constructed and suitable transportation grid for transporting the different and heavy equipments of CSP systems to the site.

5- Gaza Strip

The selected site is located on local transportation grid as shown in the Figure 55. For any future development, these local roads would be main roads. This map is built based on data gathered from mappings software.
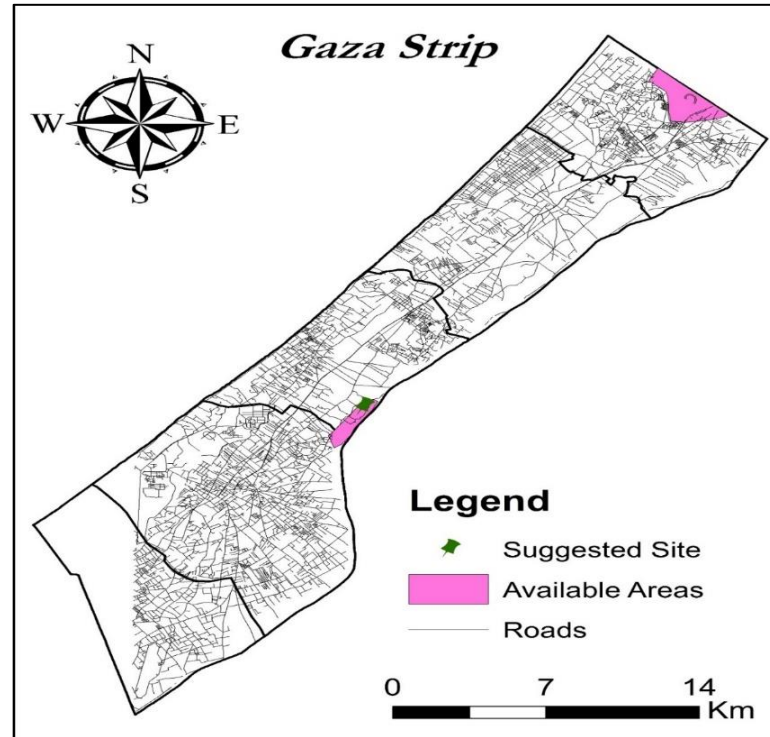
Figure 55: Transportation Grid for Gaza Strip.

According to the Figures shown above, Gaza Strip has well-constructed and suitable transportation grid for transporting the different and heavy equipments of CSP systems to the site.

5.5 Power Transmission Lines

The location of a CSP plant site close to existing power transmission lines is desirable. Large CSP plants need high voltage lines to transmit the generated electrical power to consumers. A short distance from the transmission lines is an advantage because the infrastructure investment costs are lower [27].

In general, power transmission lines cover most regions of Gaza strip and West Bank especially they are small regions. Figure 56 shows the power

transmission lines map for West Bank and Gaza Strip, this enables CSP plants to be integrated easily with the grid.
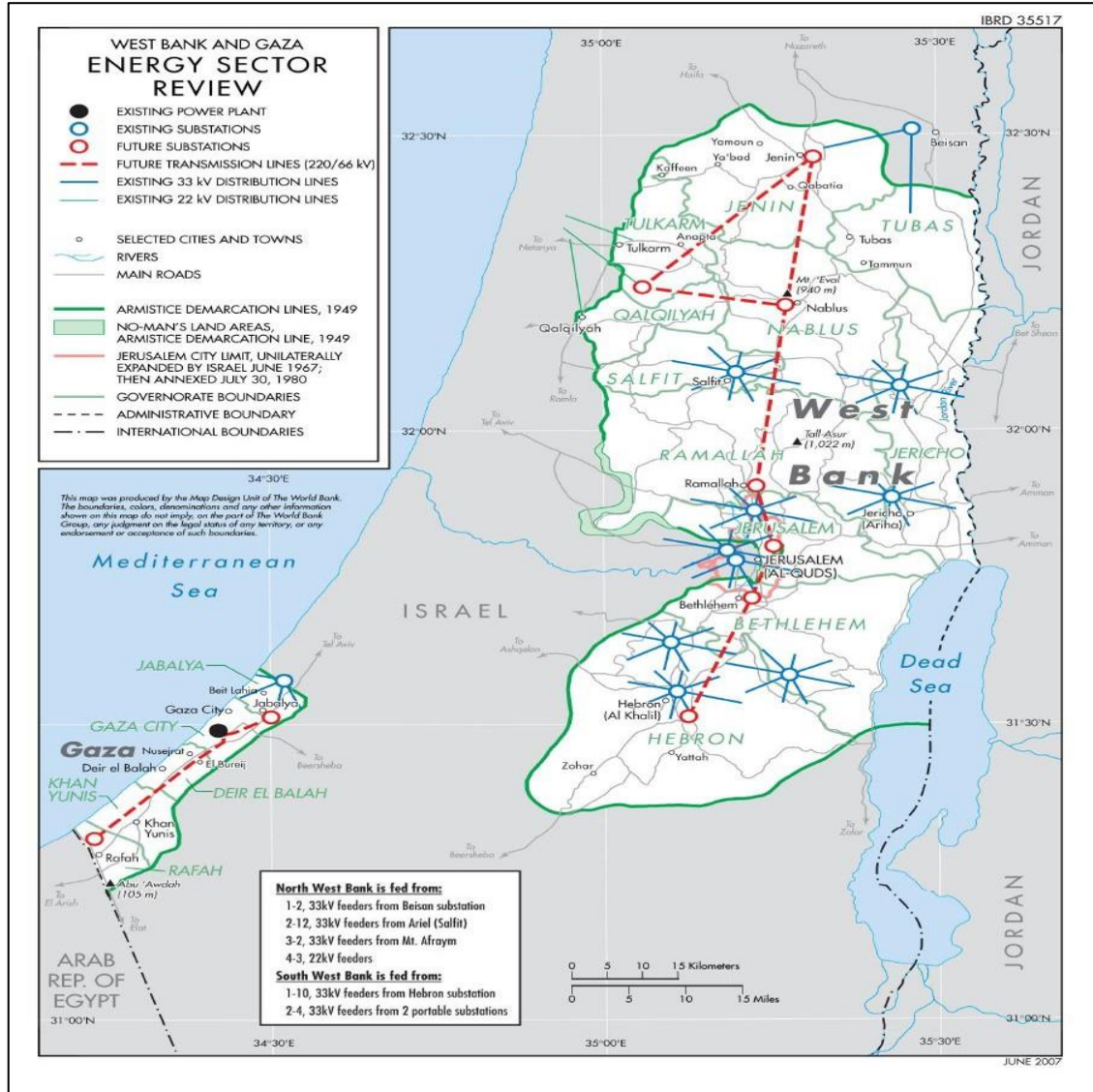
Figure 56: Transmission Lines Map for West Bank and Gaza [39].

From the above discussion, the transmission lines for the studied regions are analyzed based on data gathered from Ministry of Local Government and National Spatial Plan [31, 32].
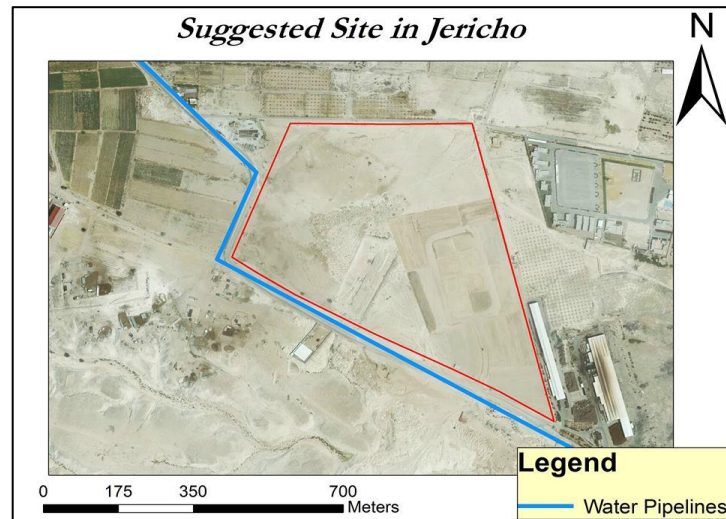
1- Jericho Governorate

The selected site is located close to the 33kv transmission line as shown in Figure 57, therefore the site has well- installed transmission line to transmit the generated electricity from CSP systems to the consumers.
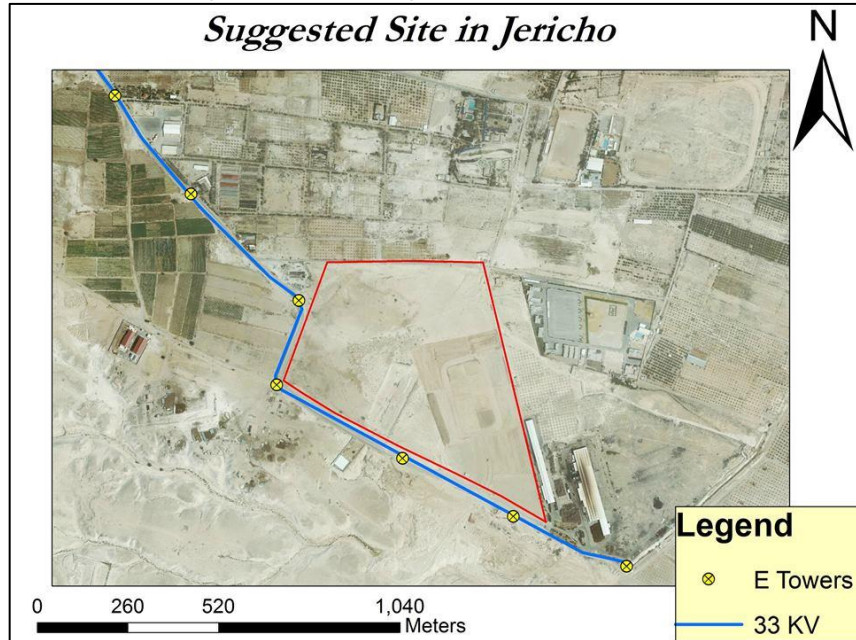
Figure 57: 33kv Transmission Line for the Site in Jericho.

2- Hebron Governorate

The selected site is located close to the 33kv transmission grid as shown in the Figure 58.
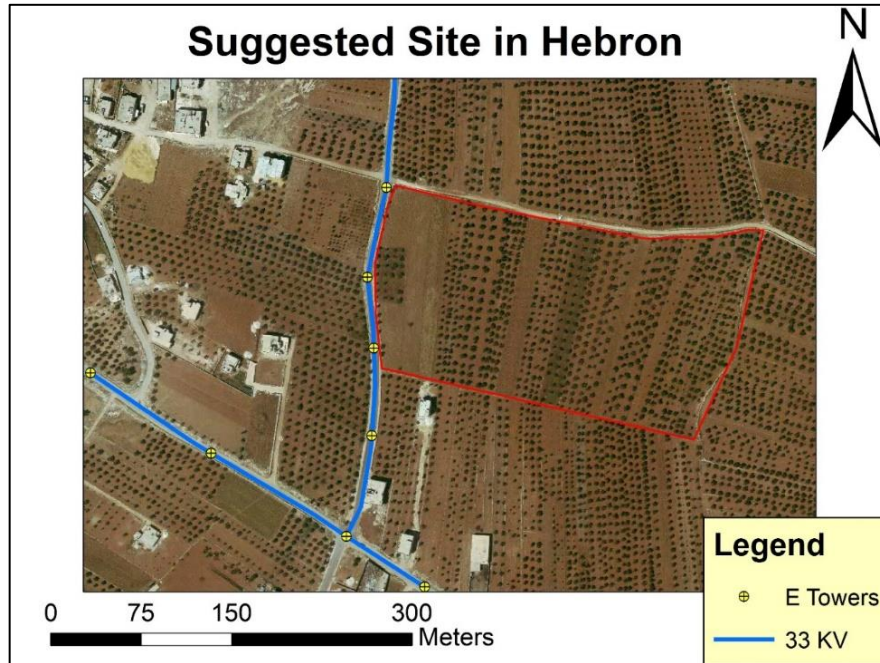
Figure 58: 33kv Transmission Line for the Site in Hebron.

The site has well-installed transmission line to transmit the generated electricity from CSP systems to the consumers.

3- Nablus Governorate

The selected site is located near proposed 33kv transmission grid as shown in Figure 59.

Figure 59: 33kv Transmission Line for the Site in Nablus.

According to the Figures shown above, the site has a proposed well-installed transmission line to transmit the generated electricity from CSP systems to the consumers.

4- Ramallah Governorate

The selected site is located close to the 33kv transmission grid as shown in Figure 60.
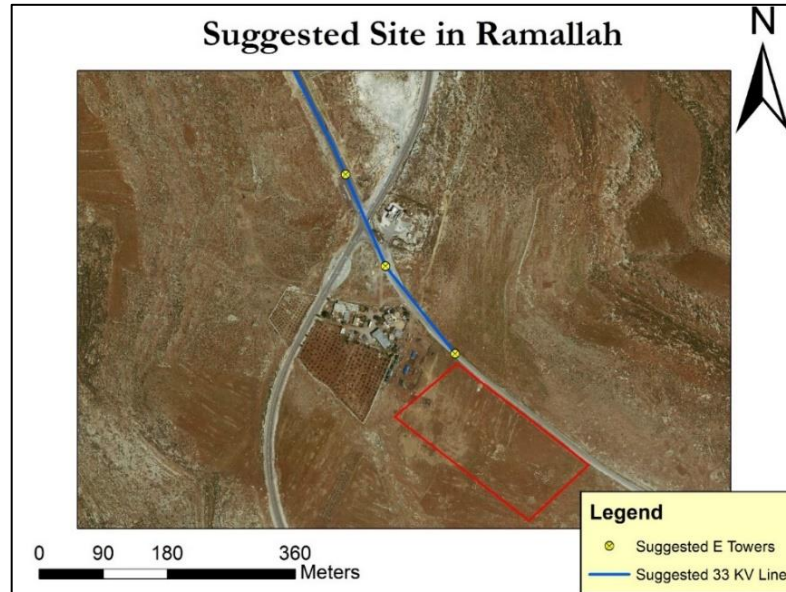
Figure 60: 33kv Transmission Line for the Site in Ramallah.

According to the Figures shown above, the site has well-installed transmission line to transmit the generated electricity from CSP systems to the consumers.

5- Gaza Strip

Currently, no power transmission lines pass near the selected site. The future extension of the lines will pass near selected site as shown in Figure 61
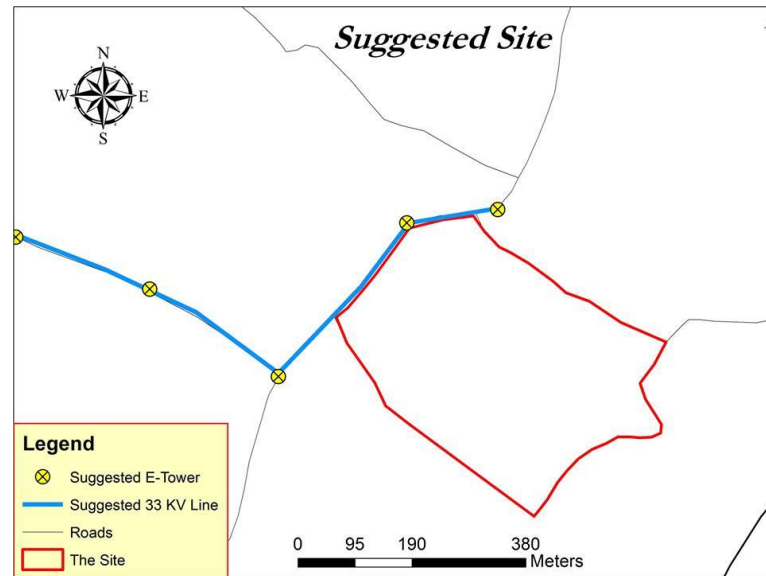
Figure 61: Suggested 33kv Transmission Line for the Site in Gaza Strip.

5.6   Other Meteorological Conditions

Meteorological conditions have both positive and negative impacts on the selection of a solar site. For instance, rain and snow may be effective in washing the mirrors and can help lower plant costs. But, if rainfall and snow occur frequently, the isolation available to the plant may drop [26]. Among other negative meteorological conditions are wind, ambient temperature, humidity, and severe weather. Solar field specifications limit operation of the plant in high wind conditions. The ambient temperature and humidity affect thermal cycle efficiency as with conventional power plants. Severe weather conditions, such as hail, tornadoes, hurricanes and flash flooding, could seriously affect plant operation [27].

5.6.1 Wind

The performance and structural design of the solar field is influenced by high winds because of the solar field is not designed to operate at winds of more than 30 to 70 km/h (8.3 to 19.5 m/s) and it depends on the selected

CSP technology. Wind forces dictate the collector structural design. Since the structure constitutes about 40% of the solar field cost, it is important to know both of the frequency distribution curve of wind velocities and to optimize the structure for these conditions. The solar field is designed to survive wind speeds of 120 to 130 km/h (33.3 to 36.1 m/s) with the collectors stowed in non-operating face down position [27].

As shown in the Figure 62, the West Bank and Gaza Strip has low average annual wind velocities which do not impact on the performance of CSP systems.
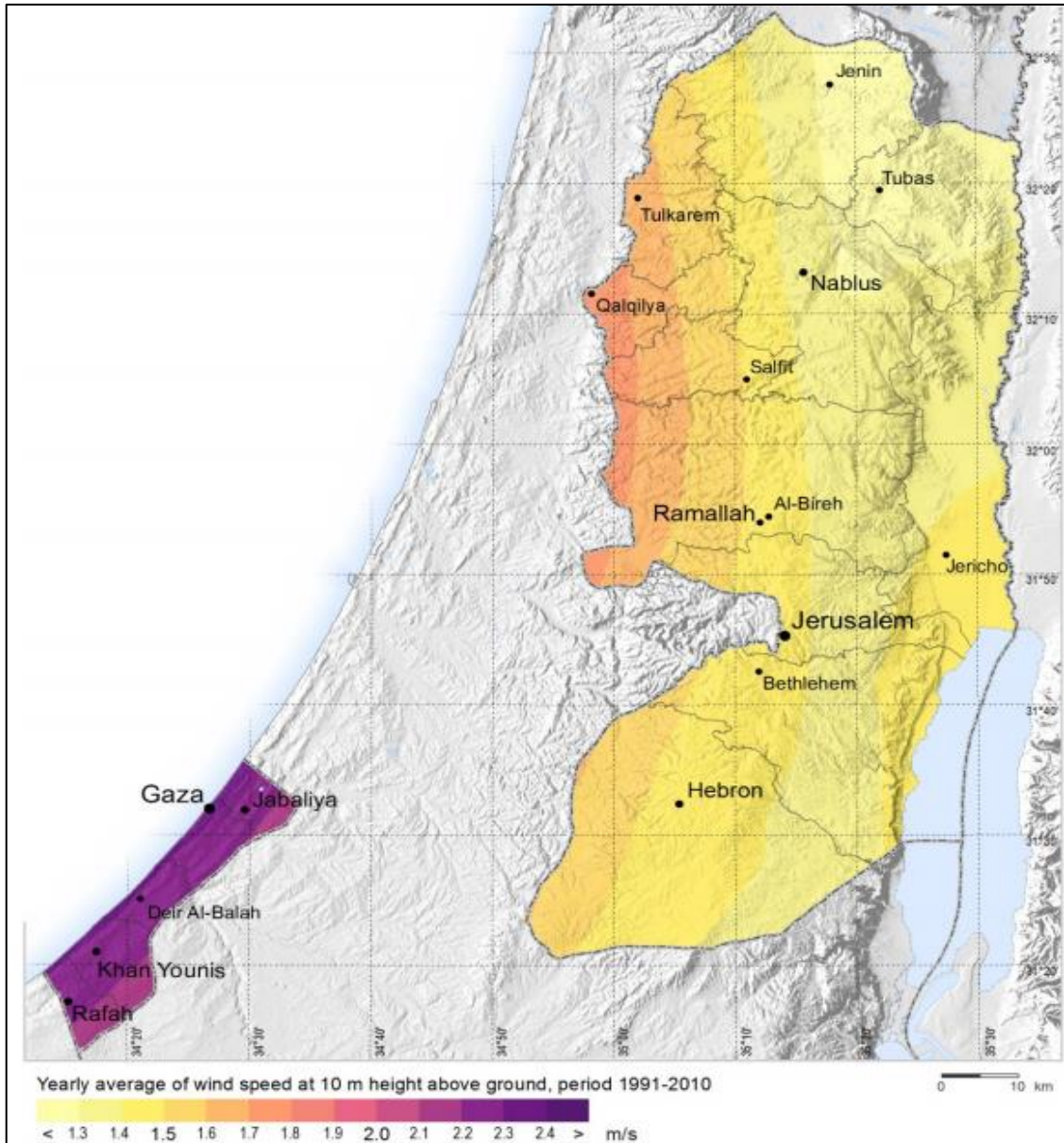
Figure 62: Annual Average Wind velocity [28].

The studied regions as shown in Figure 63 to Figure 67 have low average annual wind velocities, which in turn results in avoiding intermittent operations and less supporting connections [28].

Figure 63 shows the wind rose of Jericho Governorate which illustrates that the average wind speed never exceeds 1.5 m/s.
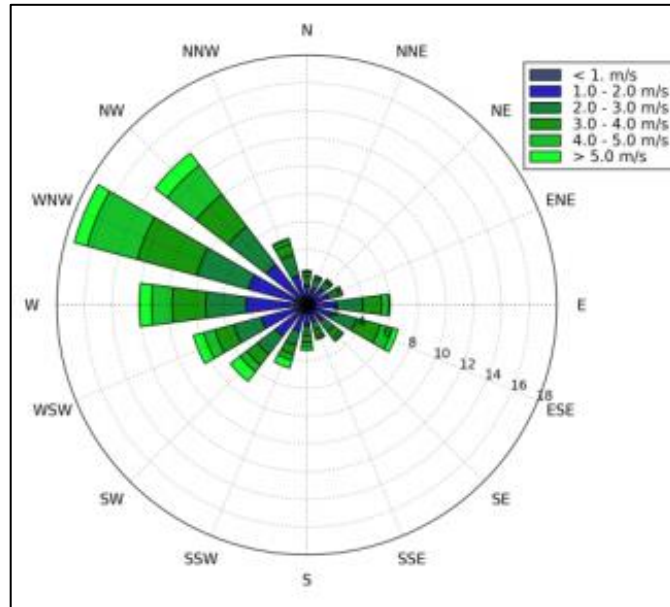
Figure 63: Average Annual Wind Speed and Direction in Jericho.

The wind rose of Hebron Governorate is shown in Figure 64 which illustrates that the average wind speed never exceeds 2.4 m/s.
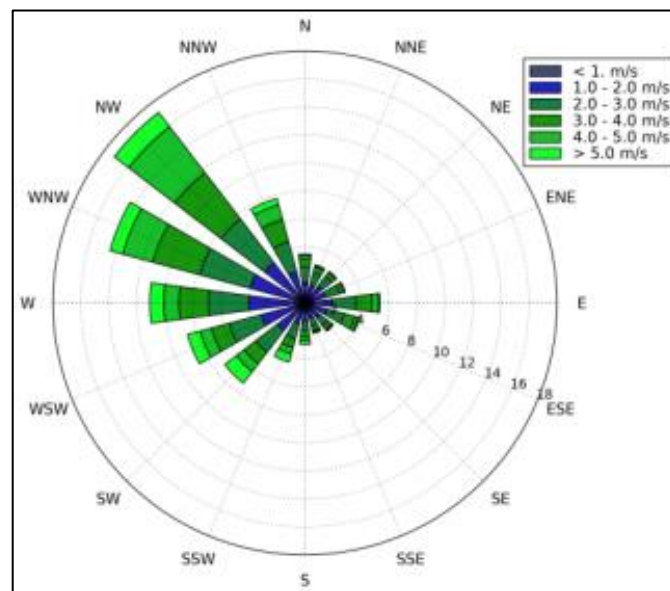
Figure 64: Average Annual Wind Speed and Direction in Hebron**.**

The average wind speed of Nablus Governorate is within the range 1.76 m/s as shown in Figure 65.
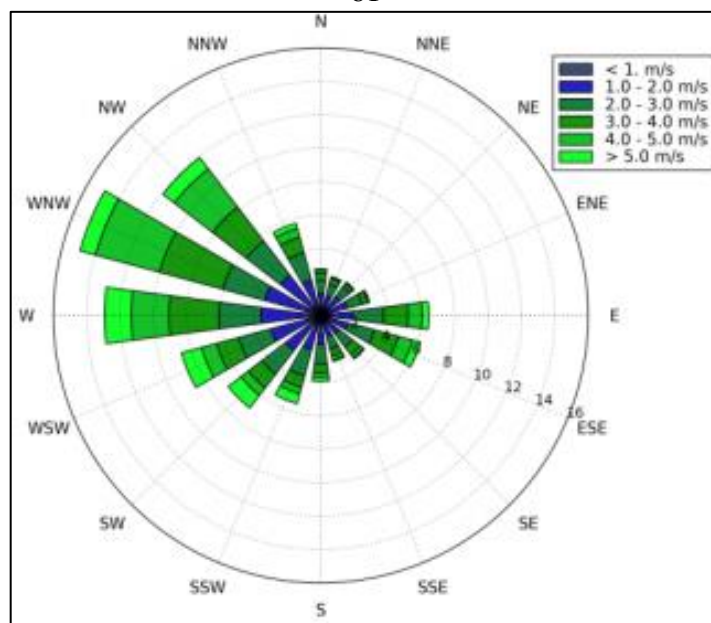
Figure 65: Average Annual Wind Speed and Direction in Nablus.

Figures 66 and 67 show wind roses of Ramallah Governorate and Gaza Strip. The figures show the average wind speed of Ramallah is 2.84 m/s and Gaza Strip is 2.8 m/s.
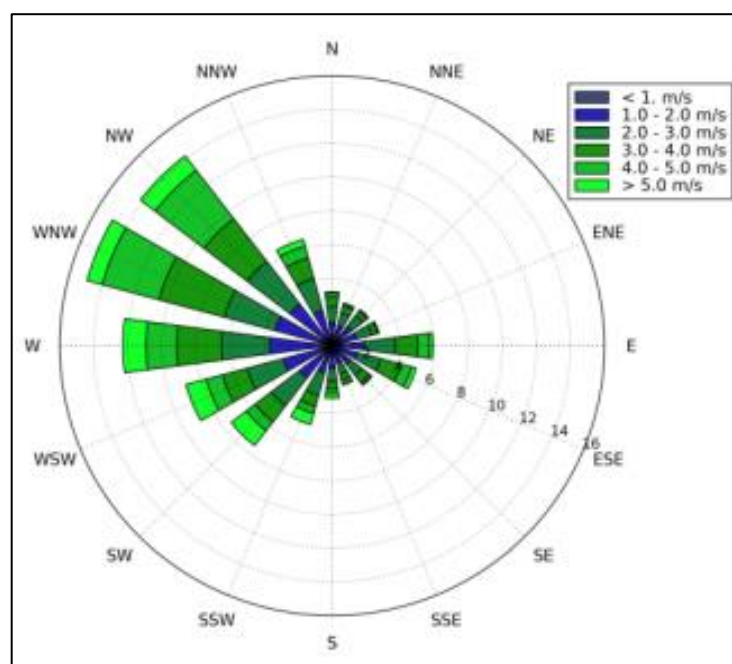
Figure 66: Average Annual Wind Speed and Direction in Ramallah.
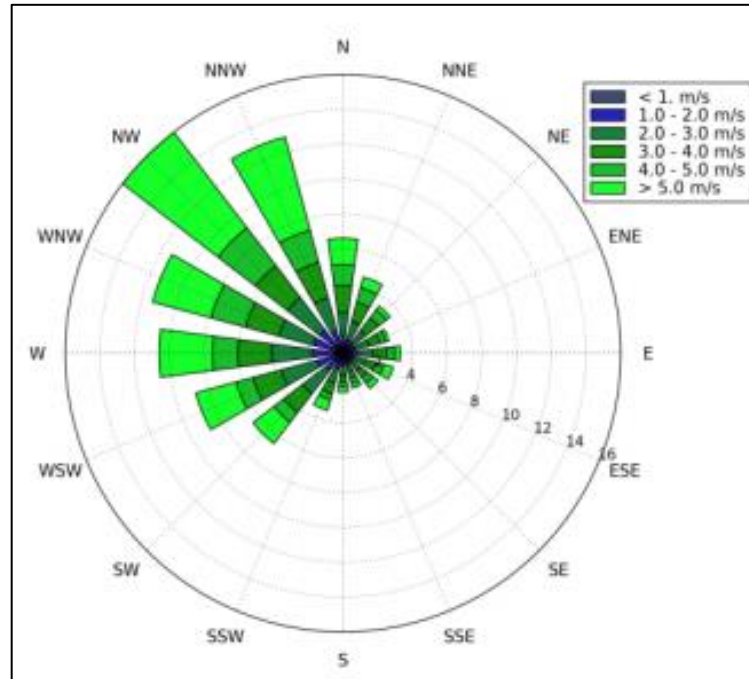
Figure 67: Average Annual Wind Speed and Direction in Gaza Strip.

As shown above, all Figures represent the wind speed for suggested governorates in general, but particularly, the wind speeds for the selected sites have to be found which require further analysis of wind speeds.

5.6.2 Ambient Temperature

The performance and the efficiency of the solar power plant are dependent on the ambient temperature, which has two contrasting effects on the efficiency of the solar field and solar block [40].

The efficiency of the solar field depends on the convective losses of the heat transfer fluid and the collectors to the ambient air. These losses are dependent on ambient temperature. The lower the ambient temperature, the higher the losses and vice versa.

The efficiency of the power block is indirectly a function of the ambient temperature and it is dependent on the condenser efficiency. For wet

cooling, the efficiency of the condensers increases with decreasing wet bulb temperature, which is a function of ambient temperature and relative humidity, and vice versa.

From the above discussion, the ambient temperature of the studied regions is analyzed from 1994 to 2013 and found to be as following:

Table 3: Ambient Temperature for Palestinian Governorates [28].

Governorate	Average of Annual Ambient Temperature (°C)
Jericho	22.8
Hebron	17.0
Nablus	17.9
Ramallah	17.0
Gaza Strip	20.5

As shown in Table 3, the average of annual ambient temperature for the selected sites are acceptable which does not affect the efficiency of the solar field and power block.

5.6.3 Humidity

The performance and the efficiency of the power block are also dependent on the humidity of the air. The efficiency of the wet cooling system decreases with increasing relative humidity, which in turn results in reducing the efficiency of the power block. As a result, the overall energy yield of CSP plants is affected by changing relative humidity conditions [40].

The humidity of the studied regions is analyzed from 1994 to 2013 and found to be as following:

Table 4 Relative Humidity for Palestinian Governorates [28].

Governorate	Average of Annual Relative Humidity (%)
Jericho	45.5
Hebron	68.0
Nablus	68.2
Ramallah	70.5
Gaza Strip	64.6

As shown in Table 4, the average annual relative humidity for all Palestinian different regions are generally mild which negatively affect the efficiency of power block.

After studying the selected sites based on the criteria of selecting CSP sites, Table 5 shows a summarization of the results.

Table 5 Summarization of the Criteria Results for all Palestinian Regions.

Region Criteria	Jericho	Hebron	Nablus	Ramallah	Gaza Strip
DNI Potential	> threshold[3]	> threshold	> threshold	> threshold	> threshold
Lands Availability for CSP systems	Available	Limited Availability	Available	Limited Availability	Limited Availability
Lands Availability Use	Unused	Unused	Unused	Unused	Unused
Slope for Selected Sites (%)	1.3	1.6	2	2	1.8
Water Availability for Selected Sites	Available	Available	Available	Available	Available
Transportation Availability for Selected Sites	Available	Available	Available	Available	Available

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3 The DNI potential threshold value is 1900 kWh/m^2-year.

Transmission Line Availability for Selected Sites	Available	Available	Available	Available	Available
Wind Velocity for Selected Sites	< limit[4]	< limit	< limit	< limit	< limit
Average Ambient Temperature for Selected Sites (°C)	22.8	17.5	17.9	17.0	20.5
Average Relative Humidity for Selected Sites (%)	45.5	68.0	68.2	70.5	64.5

Table 6 shows further results about suitable CSP technology for selected sites.

Table 6 The Suitable CSP Technologies for Selected Sites, Unused Available Lands.

The Technology for the Selected Site					
Governorate	Slope (%)	Parabolic Trough	Solar Tower	Linear Fresnel	Dish-Stirling
Jericho	1.3	✓	✓	✓	✓
Hebron	1.6	✓	✓	✓	✓
Nablus	2	✓	✓	✓	✓
Ramallah	2	✓	✓	✓	✓
Gaza Strip	1.8	✓	✓	✓	✓
The Recommended Technologies for the Unused Available Lands Based on Lands Conditions					
Jericho	Flat Areas	✓	✓	✓	✓
Hebron	Mountainous Areas		✓		✓
Nablus	Mountainous Areas		✓		✓
Ramallah	Mountainous Areas		✓		✓
Gaza Strip	Flat Areas	✓	✓	✓	✓

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4 The wind velocity is 19.5m/s.

Conclusion

1. The DNI potential of the selected sites comply with the minimum amount of DNI required which makes them suitable for solar thermal power generation.

2. Except Gaza Strip, after exclusion criteria, all Governorates have available unused lands which make them suitable for CSP implementations.

3. All selected sites have slope inclination complies with required CSP technologies slope.

4. All selected sites have availability of water resources, transportations, and power transmission lines which facilitates and supports the construction and operating process.

5. Mild weather conditions such as ambient temperature, wind velocity, and humidity available in all selected sites which make them less-effective on solar field and power block.

6. Based on technical conditions and requirements of the site selection criteria, Jericho governorate is the typical region to implement CSP systems.

Chapter Six

Feasibility Study for the CSP Selected Sites in Palestine

The feasibility study is one of the research tool to answer the research questions presented in the introduction (chapter one). This chapter answers the most of the questions asked by decision makers about the feasibility of such projects in Palestine.

Feasibility studies can be used in many ways but primarily focus on proposed business ventures. A feasible business venture is one where the business will generate adequate cash-flow and profits, withstand the risks it will encounter, remain viable in the long-term and meet the goals of the founders [41].

In this chapter, parabolic trough system has been taken as high commercially and technically proven technology (Table 1, chapter three). Table 7 shows the technical specifications for the implemented CSP system.

Table 7 Technical Specifications for the Parabolic Trough System.

Specification	Value
Capacity	1 MW
Capacity Factor	36 % (no storage) [42] 50 % (3hrs storage)
Annual Electricity Generation	3154 MWh (no storage) 4380 MWh (3hrs storage)
Destination of Generated Power	To Grid

To avoid the limitation in land availability for some selected regions like Gaza Strip, 1MW capacity has been selected to include all selected region in this study.

The storage system has been proposed in this study assuming capacity factor of 50%. The storage system is vital in the case of excess thermal energy generated by the CSP plant as the capacity of the steam turbine is not sufficient to deal with all thermal energy generated.

The levelized cost of energy (LCOE) is the most commonly used parameter for the feasibility study of the solar thermal power plant and it can be significantly affected by the inputs and assumptions employed. As well as, there are other parameters contribute in feasibility study and represents helpful tools for assessment CSP projects [43].

To estimate the LCOE of CSP technologies, the annual electricity generation (AEG) by a CSP system can be estimated as shown in the following formula:

$$AEG_{csp} = (365 * 24)CF_{csp}P_{csp} \qquad (1)$$

Where P_{csp} represents the capacity of the CSP system and CFcsp the capacity factor of the CSP system.

$$LCOE_{csp} = \left[\frac{C_{csp}CRF + \xi C_{csp}}{AEG_{csp}}\right] \qquad (2)$$

Where C_{csp} represents the capital cost of CSP system, ξ represents annual repair and maintenance factor, ξC_{csp} represents the annual operational and maintenance cost, and CRF represents the capital recovery factor which converts a present value into a stream of equal annual payments over a specified time, at a specified discount rate (interest) and it can be estimated

using eqn (3). The cost of emissions reduction in LCOE$_{csp}$ is neglected because Palestine isn't listed in Kyoto protocol parties.

$$CRF = \frac{d(1 + d)^{t_{csp}}}{(1 + d)^{t_{csp}} - 1} \qquad (3)$$

Where d is the discount rate which is defined as the rate used to discount a stream of future cash flows to their present value, and t_{csp} is the useful lifetime of the CSP system.

To evaluate numbers of years needed for the investment to be paid back, simple payback period (SPB) is estimated which is defined as the ratio between the capital investment and net income per year. It can be also defined as difference between the net value of energy produced and the net value of operation and maintenance O&M. SBP can be calculated using eqn (4).

$$SPB = \frac{Capital\ Investment}{Net\ Income\ per\ year} \qquad (4)$$

The simple payback method is not a measure of how profitable one project is compared to another. Rather, it is a measure of time in the sense that it indicates how many years are required to recover the investment for one project compared to another. The simple payback should not be used as the primary indicator to assess the feasibility of a project. It is useful, however, as a secondary indicator to indicate the level of risk of an investment. Another drawback of the simple payback method is that it does not consider the time value of money, nor the impact of inflation rate on the costs.

The discount payback period (DPP) discounts each of the estimated cash flows and then determines the payback period from those discounted flows. The DPP can be estimated using eqn (5).

$$DPP_{csp} = \left[\frac{ln(B_i - C_i) - ln\{(B_i - C_i) - dC_{csp}\}}{ln(1 + d)}\right] \qquad (5)$$

Where B_i represents the annual benefit accrued to the investor by selling the electricity generated by CSP system, C_i ($=\xi C_{csp}$) the annual cost of operation and maintenance of the CSP project. *Bi* can be estimated using the following expression.

$$B_i = 8760 CF_{csp} P_{csp} p_e \qquad (6)$$

Where p_e is the purchase price of electricity delivered by the CSP system. In addition to payback period, there is a good indicator called equity payback period which is defined as the length of time that it takes for the owner of a project to recoup its own initial investment (equity) out of the project cash flows generated, which makes it a better time indicator of the project merits than the simple payback.

The net Benefit-Cost (B-C) ratio, which is the ratio of the net benefits to costs of the project and can be estimated using eqn (7). A ratio of greater than one indicates that the project is a viable one.

$$\left(\frac{B}{C}\right)_{csp} = \left(\frac{1}{C_{csp}}\right)\left[\sum_i^{t_{csp}}\left(\frac{(B_i - C_i)}{(1 + d)^i}\right)\right] \qquad (7)$$

The net annual benefit accrued to the investor (Bi-Ci) assumed to be uniform over the useful life of the CSP project.

The net present value (NPV) of the CSP system indicates if the projected earnings generated by a project or investment (in present dollars) exceeds the anticipated costs (also in present dollars) or not. So generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss.

The following expression illustrates the estimation of NPV of a project.

$$NPV_{csp} = \left[\sum_{i}^{t_{csp}} \left(\frac{(B_i - C_i)}{(1+d)^i} \right) \right] - C_{csp} \qquad (8)$$

In this study, the site has been separately selected for implementing CSP systems and underwent to site selection criteria to assure that the site selected is suitable for CSP systems or not. The land price of the site depends on the region as well as depends on if it is located in Area A or B or C[5]. There are many things decides the land price in Palestine, but generally, speaking about the price of land in Palestine is high with respect to the neighboring countries. A sensitivity analysis has been performed to recognize the elements which affect the feasibility study.

Table 8 shows the input parameters used in the economic evaluation of the proposed technology.

Table 8 Input Parameters for Economic Evaluation.

Parameters	Symbol	Value		
Capital Cost of CSP	Ccsp	4500	$/kW	(no

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5 According to Oslo Accord, Area A is directly followed to Palestinian National Authority, Area B and C are directly followed by Palestinian National Authority but still under the Israeli control.

		storage)
		6000 $/kW (3hrs storage)
Annual Repair and Maintenance Cost of CSP as a Fraction	ξ	0.02
Discount Rate	d	0.1
Useful Lifetime of CSP System	Tcsp	30 years
Capital Recovery Factor	CRF	0.106
Electricity Export Rate	-	0.175 $/kWh

The solar field represents a main part in the specified capital cost. For Palestinian regions, the cost of the solar field is not the same as other regions in the world. It is also different within the country. So, the percentage of cost of the solar field represents 9% of capital cost. This percent has been deducted from the total capital cost resulting a new capital cost without and with thermal storage of 4100 $/kW and 5500 $/kW respectively [37].

As illustrated above, the cost of solar field for selected sites is calculated as shown in Table 9.

Table 9 Cost of Solar Field for Palestinian Selected Sites.

Governorate	Area of Selected Land (m^2/MW)	Cost of Selected Land ($/m^2$)	Total Cost of Selected Land ($/kW)
Jericho	25,000	50	1,250
Hebron	25,000	11	275
Nablus	25,000	25	625
Ramallah	25,000	7	175
Gaza Strip	25,000	357	8,925

Based on the added cost of the land price, new capital cost is obtained for selected sites as shown in Table 10.

Table 10 Capital Cost of Palestinian Selected Sites.

Governorate	Cost of Solar Field ($/kW)	New Capital Cost without Storage ($/kW)	New Capital Cost with Storage ($/kW)
Jericho	1,250	5,350	6,750
Hebron	275	4,375	5,776
Nablus	625	4,725	6,125
Ramallah	175	4,275	5,675
Gaza Strip	8,925	13,025	14,425

As shown in Table 10, the capital cost of CSP is mainly affected by the land price. In Gaza Strip, the Capital cost of CSP system without storage increased remarkably from 4100 $/kW to 13025 $/kW due to the land prices in Gaza Strip are higher than any other Palestinian region.

To facilitate the assessment, RETScreen International Clean Energy Project Analysis Software is utilized to perform a more professional and complete financial analysis of the CSP project. RETScreen is a decision-support tool designed to help decision makers and energy professionals to evaluate the financial viability of renewable energy. The RETScreen Solar Thermal Power Project Model can be used to evaluate anywhere in the world the energy production and financial performance of solar thermal power projects, from gird types of central grid, central grid and internal loads, isolated-grid, isolated-grid and internal loads, and off-grids. RETScreen provides an access to a global climate database based on ground measurement and NASA satellite data, allowing analysis of projects around the world [44].

Using RETScreen for CO_2 reduction, Table 11 shows the amount of CO_2 reduced by using CSP technology instead of using conventional power supply.

Table 11 Annual GHG Emission Reduction (tCO$_2$).

Type of Fuel	GHG Emission Factor tCO$_2$/MWh	Annual GHG Emission Reduction tCO$_2$
C.F=36%, AEG$_{csp}$=3153.6 MWh		
Natural Gas	0.481	1,516.88
Coal	0.913	1,384.91
Oil	0.931	2,936.00
C.F=50%, AEG$_{csp}$= 4380 MWh		
Natural Gas	0.481	2,106.78
Coal	0.913	3,998.94
Oil	0.931	4,077.78

Also, RETScreen has been used for Cost Analysis to the Palestinian CSP selected sites. Table 12 shows the inputs of initial costs and annual costs for implementing CSP system without storage.

Table 12 Initial and Annual Costs for CSP Selected Sites without Storage.

Features	Jericho	Hebron	Nablus	Ramallah	Gaza
Initial Costs					
Feasibility Study ($)	70,000	70,000	70,000	70,000	70,000
Development ($)	128,250	128,250	128,250	128,250	128,250
Engineering[6] ($)	2,006,250	1,093,750	1,300,860	769,500	5,210,28

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[6] It comprises the site's land and its design, mechanical design, electrical design, civil design and construction supervision.

					8
Solar Thermal Power ($/MW)	1,357,100	1,357,100	1,357,100	1,357,100	1,357,100
Road Construction ($/km)	50,000	50,000	50,000	50,000	50,000
Transmission Line ($/km)	55,000	55,000	55,000	55,000	55,000
Substation ($)	250,000	250,000	250,000	250,000	250,000
Spare Parts ($)	40,713	40,713	40,713	40,713	40,713
Training & Commissioning ($)	25,000	25,000	25,000	25,000	25,000
Contingencies ($)	125,140	125,140	125,140	125,140	125,140
Interest during Construction ($)	118,258	118,258	118,258	118,258	118,258
Annual Costs					
Parts and Labor ($)	85,500	85,500	85,500	85,500	85,500
Contingencies ($)	855	855	855	855	855

Table 13 shows the results of financial viability for implementing CSP systems in the selected sites based on the RETScreen software.

Table 13 Financial Viability of Implementing CSP without Storage for Selected Sites.

Category	Jericho	Hebron	Nablus	Ramallah	Gaza
Project Costs and Saving/Income Summary					
Total Initial Costs ($)	5,347,637	4,200,477	4,546,586	4,081,929	12,306,552
Total Annual Costs ($)	86,355	86,355	86,355	86,355	86,355
Total Annual Saving and Income ($)	583,819	583,819	583,819	583,819	583,819
Financial Viability Parameters					

Simple Payback Period (yr)	9.9	7.9	8.8	7.5	20
Equity Payback Period (yr)	9.0	7.3	8.0	6.8	18
Net Present Value ($)	500,478	1,419,564	971,204	2,607,048	-8,683,057
Annual Life Cycle Savings ($/yr)	50,024	150,586	103,025	276,554	-921,092
Benefit to Cost (B-C) Ratio	1.43	2.01	1.75	2.09	0.68

As shown in Table 13, the parameters of financial viability varied from region to other due to the change in land prices. In Gaza strip, as shown also in Table 13, due the land price, the NPV is negative and (B-C) is less than one which means, the implementation of CSP system is unviable.

For CSP systems with storage, RETScreen has been used for Cost Analysis to the CSP selected sites with 3 hours storage system. Table 14 shows the inputs of initial costs and annual costs for implementing CSP system with 3 hours storage system.

Table 14 Initial and Annual Costs for CSP Selected Sites with 3 Hours Storage.

Features	Jericho	Hebron	Nablus	Ramallah	Gaza
Initial Costs					
Feasibility Study ($)	70,000	70,000	70,000	70,000	70,000
Development ($)	170,250	170,250	170,250	170,250	170,250
Engineering ($)	2,193,750	1,197,440	1,470,000	964,750	5,770,000
Solar Thermal Power ($/MW)	1,357,100	1,357,100	1,357,100	1,357,100	1,357,100
Road Constructi	50,000	50,000	50,000	50,000	50,000

on ($/km)					
Transmission Line ($/km)	55,000	55,000	55,000	55,000	55,000
Substation ($)	250,000	250,000	250,000	250,000	250,000
Storage System ($)	567,500	567,500	567,500	567,500	567,500
Spare Parts ($)	65,546	65,546	65,546	65,546	65,546
Training & Commissioning ($)	25,000	25,000	25,000	25,000	25,000
Contingencies ($)	185,939	185,939	185,939	185,939	185,939
Interest during Construction ($)	237,580	237,580	237,580	237,580	237,580
Annual Costs					
Parts and Labor ($)	113,500	113,500	113,500	113,500	113,500
Contingencies ($)	1,135	1,135	1,135	1,135	1,135

Table 15 shows the financial viability of implementing CSP with 3 hours storage system.

Table 15 Financial Viability of Implementing CSP with 3 Hours Storage for Selected Sites.

Category	Jericho	Hebron	Nablus	Ramallah	Gaza
Project Costs and Saving/Income Summary					
Total Initial Costs ($)	6,671,177	5,517,130	6,021,847	5,291,211	14,420,283
Total Annual Costs ($)	114,635	114,635	114,635	114,635	114,635
Total Annual	810,860	810,860	810,860	810,860	810,860

Saving and Income ($)					
Financial Viability Parameters					
Simple Payback Period (yr)	11.2	8.5	9.3	7.6	27
Equity Payback Period (yr)	10.1	7.8	8.5	7.0	25
Net Present Value ($)	978,956	2,357,816	1,772,545	2,937,310	-8,541,652
Annual Life Cycle Savings ($/yr)	103,847	250,115	188,030	311,588	-906,092
Benefit to Cost (B-C) Ratio	1.40	1.74	1.62	1.78	0.63

As shown in Table 15, adding storage system increased the capital cost of CSP which in turn led to increase the net present value, annual life savings, simple payback period, and equity payback period where the benefit to cost ratio decreased. In Gaza Strip, adding storage system does not change the unviability of implementation CSP system.

Figures 68 through 71 summarize the results of Tables 13 and 15 in charts form.
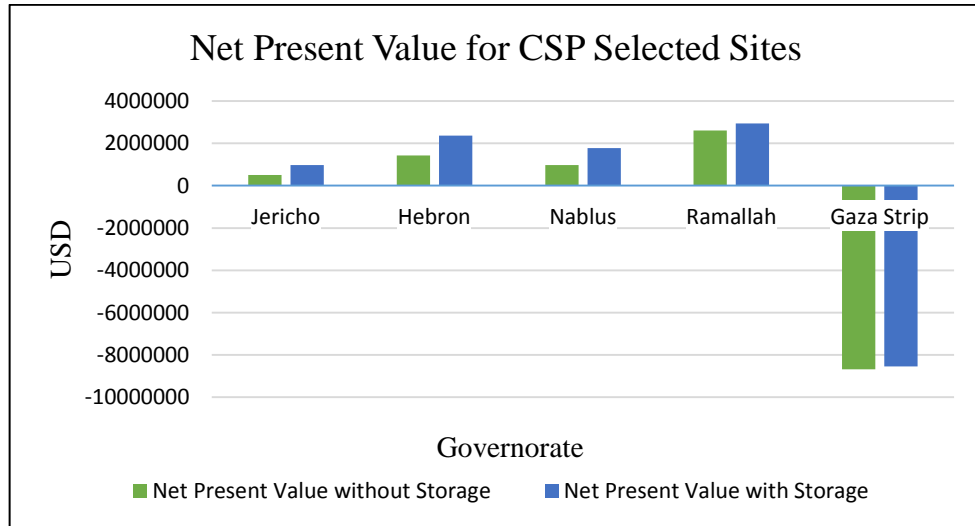
Figure 68: Net Present Value for Palestinian CSP Selected Sites.

Figure 68 showed that using storage system led to increase of energy production due to excess energy generated by this CSP system which in turn led also to increase the net present value as well as the annual life cycle savings have increased as shown in Figure 69.
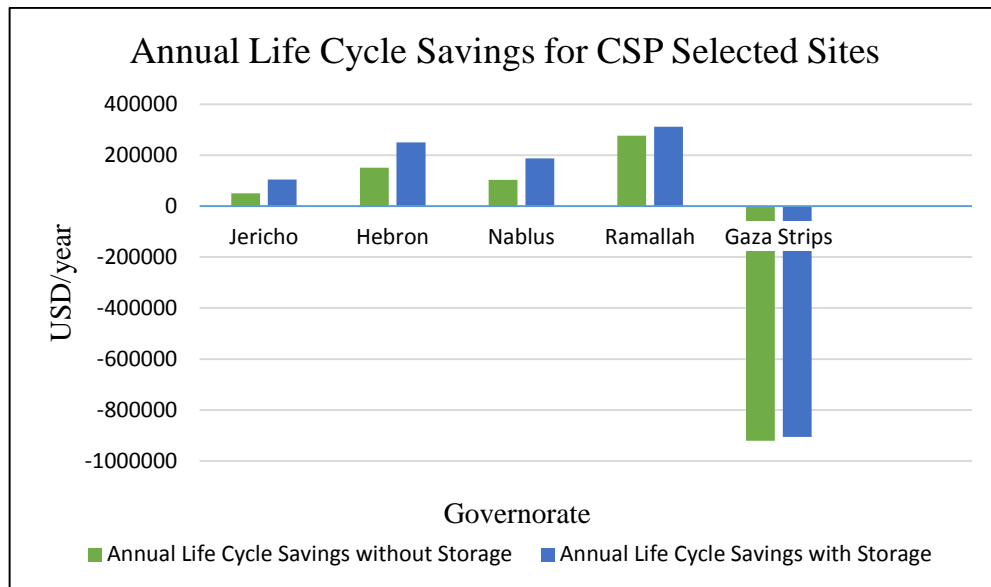
Figure 69: Annual Life Cycle Savings for Palestinian CSP Selected Sites.

Simple and equity payback period have increased as shown in Figure 70 by adding storage system due to adding the storage system increases the capital cost of CSP which made the payback periods greater than ones in CSP systems without storage.
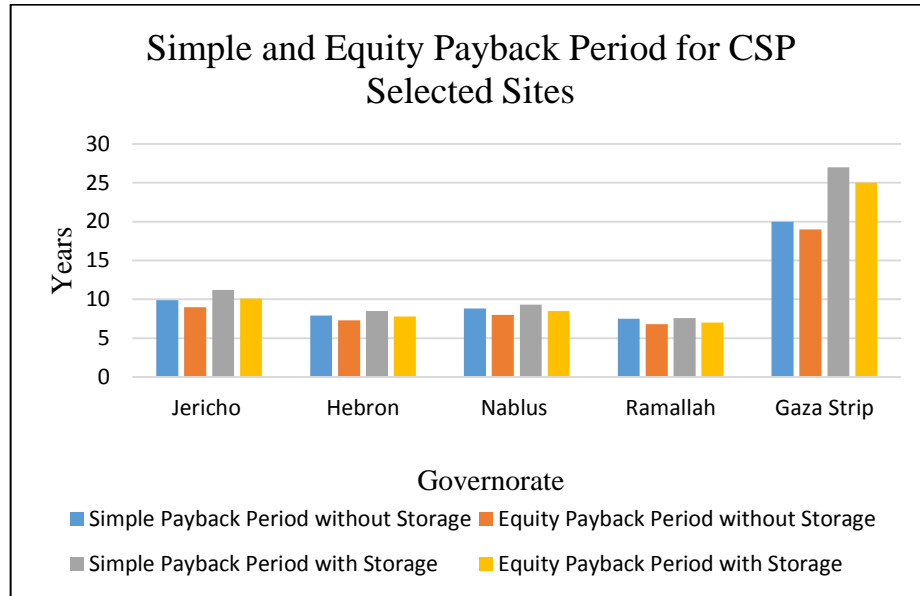
Figure 70: Simple and Equity Payback Period for Palestinian CSP Selected Sites.

The (B-C) ratio is inversely proportional to the investment cost, it decreases as the initial cost increases. So, as shown in Figure 71, the (B-C) ratio decreased caused by adding storage system.
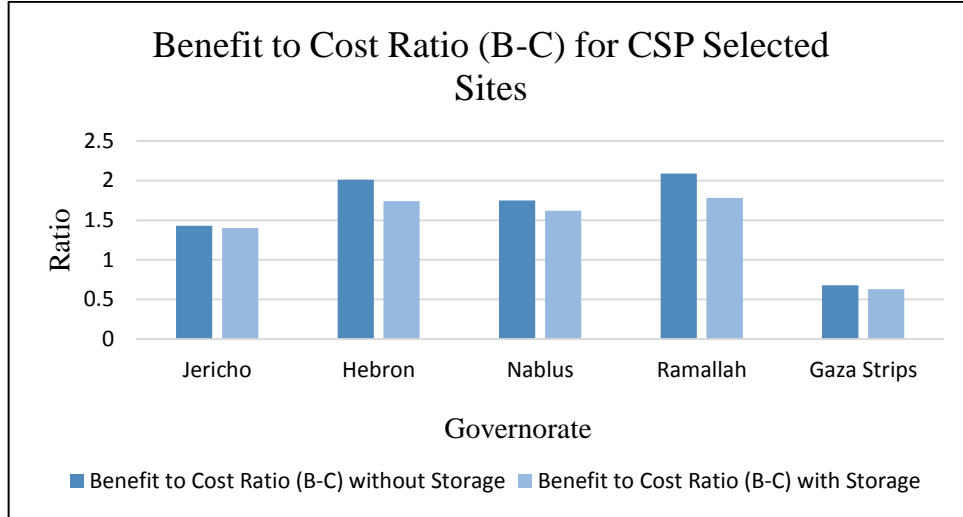
Figure 71: Benefit to Cost Ratio (B-C) for Palestinian CSP Selected Sites.

The levelized cost of energy (LCOE$_{csp}$) is the most commonly used parameter for the feasibility study of the solar thermal power.

From RETScreen, the capital cost of CSP system for selected sites with and without storage is shown in Table 16.

Table 16 The Capital Cost of CSP System without/with storage.

Governorate	C$_{csp}$ without Storage ($)	C$_{csp}$ with Storage ($)
Jericho	5,347,637	6,671,177
Hebron	4,200,477	5,517,130
Nablus	4,546,586	6,021,847
Ramallah	4,081,929	5,291,211
Gaza Strip	12,306,552	14,420,283

Using Eqn 1, 2, and 3, Table 17 shows LCOE of CSP system for selected sites without and with storage system.

Table 17 LCOE of CSP System for Selected Sites without Storage.

Governorate	LCOE$_{csp}$ without Storage ($/kWh)	LCOE$_{csp}$ with Storage ($/kWh)
Jericho	0.215	0.193
Hebron	0.170	0.160

Nablus	0.183	0.173
Ramallah	0.164	0.153
Gaza Strip	0.496	0.468

Figure 72 summarizes the results shown in the Table 17 which represents the LCOE for the CSP selected sites with and without storage system.
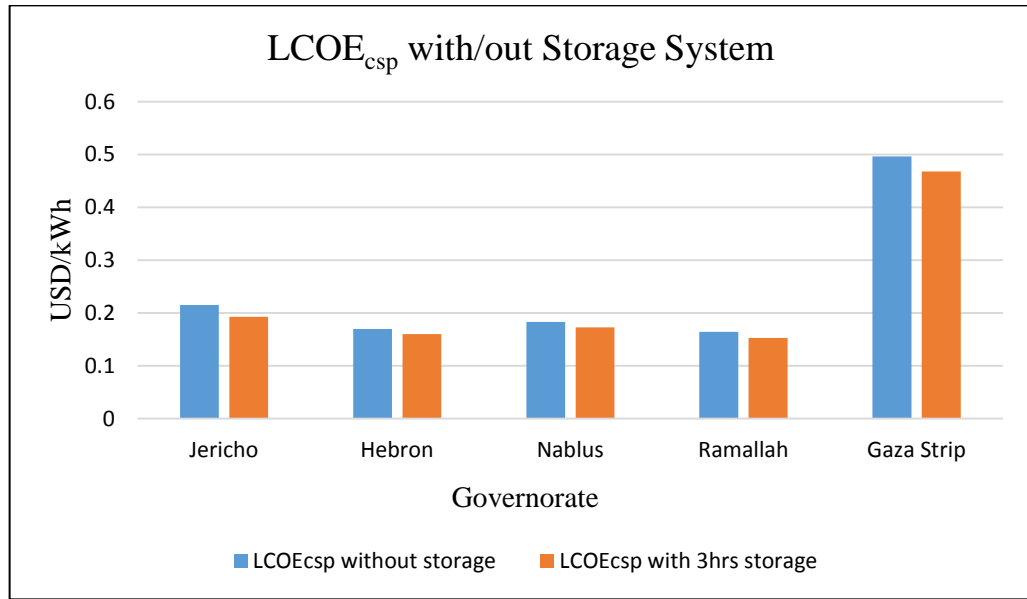
Figure 72: $LCOE_{csp}$ for CSP Selected Sites with and without Storage System.

As shown in Figure 72, the LCOE for CSP systems with storage is lower than ones without storage

Conclusion

1. The solar field for the selected sites represented the main effective part in the specified capital cost of CSP system. Based on land prices, Gaza site occupied the first place, Jericho's occupied the second place, Nablus's, Hebron's, and Ramallah's came third, fourth, and last respectively.

2. Based on levelized cost of energy for CSP system with and without storage, Gaza has the highest LCOE whereas Ramallah has lowest LCOE.

3. Adding storage system to the CSP plant led to change in financial parameters.

4. Based on financial viability, Ramallah CSP site occupied the first place in financial viability, Hebron's occupied the second, while Nablus's, and Jericho's came third and last respectively.

5. The implementation of CSP system in Gaza site is not viable based on results in Table 13 and 15.

Chapter Seven

Sensitivity Analysis for Effective Conditions

A sensitivity analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions by creating a given set of scenarios and it is used within specific boundaries that will depend on one or more input variables. Sensitivity analysis is a way to predict the outcome of a decision if a situation turns out to be different compared to the key predictions [45]. For this study, as the outcomes shown in Table 14, the price of solar field for selected sites and the price of electricity export rate have significantly affected the financial viability analysis. In this chapter, this input variable "price of solar field" and "electricity export rate" undergo for several scenarios to notice the role of changing these input variables on financial viability analysis for CSP selected sits. The scenarios are designed as follows:

First scenario:

The cost of CSP selected site is granted by government or other.

This scenario is important to study the effect of land cost on the feasibility study and the cost of kW generated by a parabolic trough system becomes 4100 $/kW as the land is granted.

Based on this scenario, Table 18 shows the financial viability of implementing CSP system.

Table 18 Financial Viability of the 1ˢᵗ Scenario for implementing CSP System in Selected Sites.

Category	Jericho	Hebron	Nablus	Ramallah	Gaza
Project Costs and Saving/Income Summary					
Total Initial Costs ($)	2,531,041	2,531,041	2,531,041	2,531,041	2,531,041
Total Annual Costs ($)	82,820	82,820	82,820	82,820	82,820
Total Annual Saving and Income ($)	583,819	583,819	583,819	583,819	583,819
Financial Viability					
Simple Payback Period (yr)	5.1	5.1	5.1	5.1	5.1
Equity Payback Period (yr)	4.8	4.8	4.8	4.8	4.8
Net Present Value ($)	3,152,474	3,152,474	3,152,474	3,152,474	3,152,474
Annual Life Cycle Savings ($/yr)	334,412	334,412	334,412	334,412	334,412
Benefit to Cost (B-C) Ratio	2.25	2.25	2.25	2.25	2.25

As shown in Table 17, all the financial viability parameters became fixed as the CSP selected site is granted.

Figures 73 through 76 summarize the results of Tables 14 and 17 in chart forms.
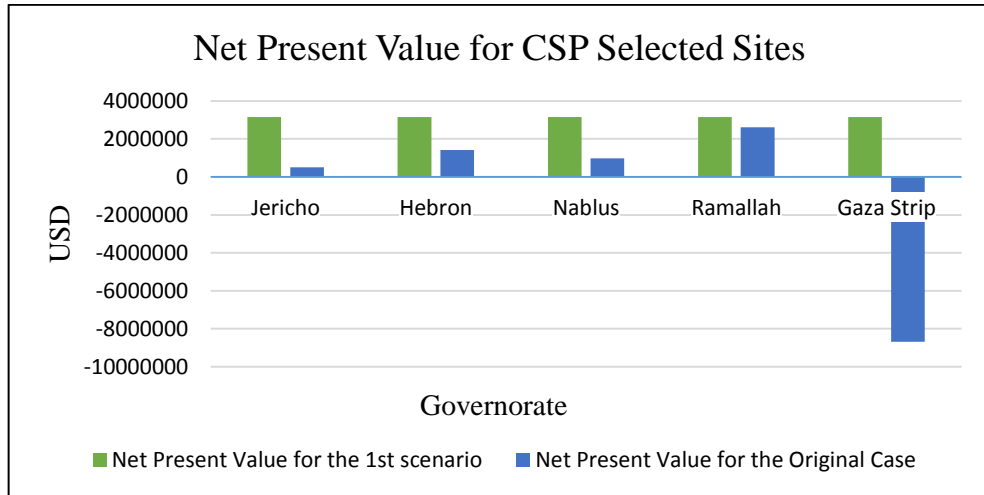
Figure 73: Net Present Value for CSP Selected Sites.

As shown in Figure 73, the net present value for the 1ˢᵗ scenario in compared to net present value for the original case has increased which means that the solar field cost will remarkably affect financial viability parameters as shown also in Figure 74 for the annual life cycle savings.
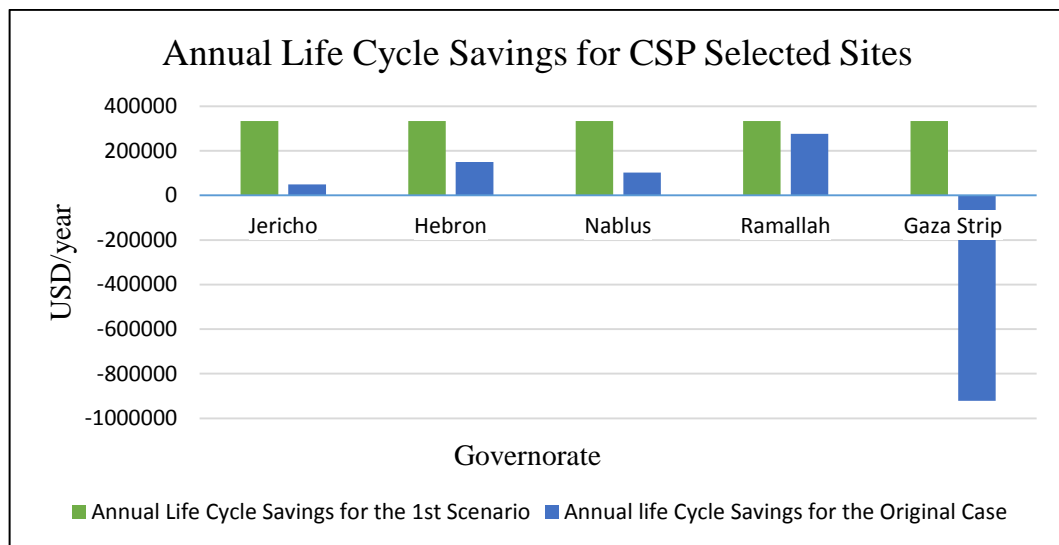
Figure 74: Annual Life Cycle Savings for CSP Selected Sites.
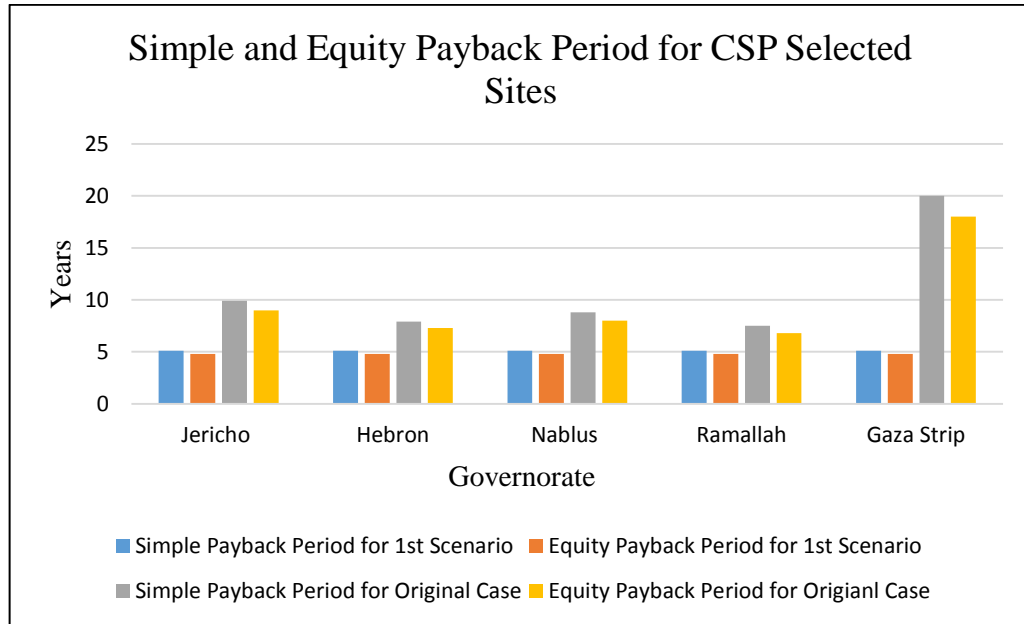
Figure 75: Simple and Equity Payback Period for CSP Selected Sites.

Besides the change the 1ˢᵗ scenario made on net present value and annual life cycle savings, the payback periods as shown in Figure 75 have decreased by this scenario. In Gaza site, as the solar field is granted, the payback periods have decreased noticeably, which means that cost of solar field has a big effect on financial viability parameters.
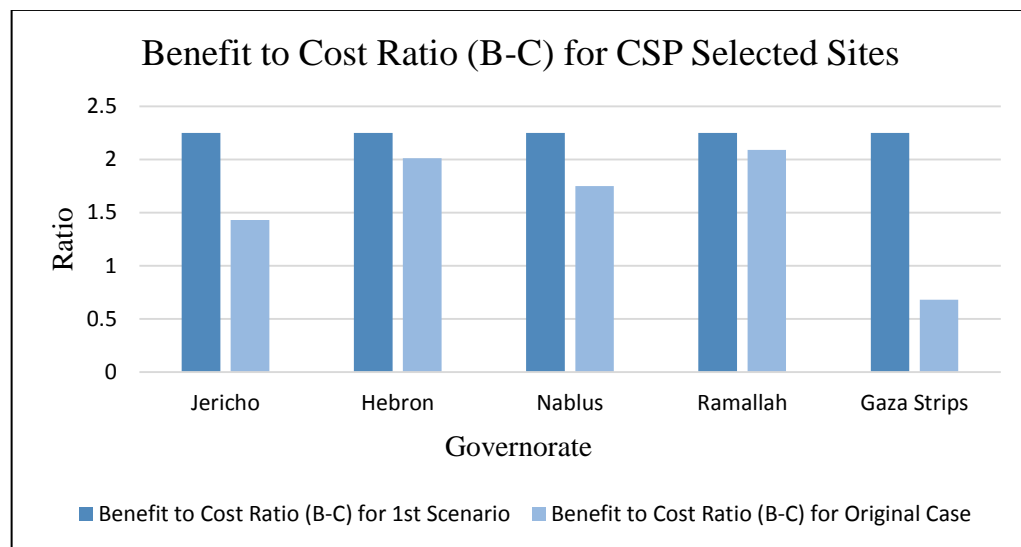
Figure 76: Benefit to Cost Ratio (B-C) for CSP Selected Sites.

The (B-C) ratio is inversely proportional to the cost of CSP system, in Figure 76, the benefit to cost ratio increased as the cost of solar field is granted. In Gaza site, the (B-C) ratio is noticeably increased due to its land price was the highest with respect to other selected sites

Second scenario:

The CSP selected site is contracted as a 750,000$ lease for 30 years.

This scenario is important to study the change that the increase of land price made on financial parameters and the cost of kW generated by a parabolic trough system in this scenario is 4100 $/kW.

Based on this scenario, Table 19 shows the financial viability of implementing CSP system.

Table 19 Financial Viability of the 2nd Scenario for implementing CSP System in Selected Sites.

Category	Jericho	Hebron	Nablus	Ramallah	Gaza
Project Costs and Saving/Income Summary					
Total Initial Costs ($)	3,353,978	3,353,978	3,353,978	3,353,978	3,353,978
Total Annual Costs ($)	82,820	82,820	82,820	82,820	82,820
Total Annual Saving and Income ($)	583,819	583,819	583,819	583,819	583,819
Financial Viability					
Simple Payback Period (yr)	6.7	6.7	6.7	6.7	6.7
Equity Payback Period (yr)	6.2	6.2	6.2	6.2	6.2
Net Present Value ($)	2,329,537	2,329,537	2,329,537	2,329,537	2,329,537
Annual Life Cycle Savings ($/yr)	247,115	247,115	247,115	247,115	247,115
Benefit to Cost (B-C) Ratio	1.69	1.69	1.69	1.69	1.69

As shown in Table 18, the financial parameters started to decrease in compared to results for 1st scenario as the cost of solar field began to increase.

Figures 77 through 80 summarize the results of Table 18 in chart forms.

Net Present Value for CSP Selected Sites
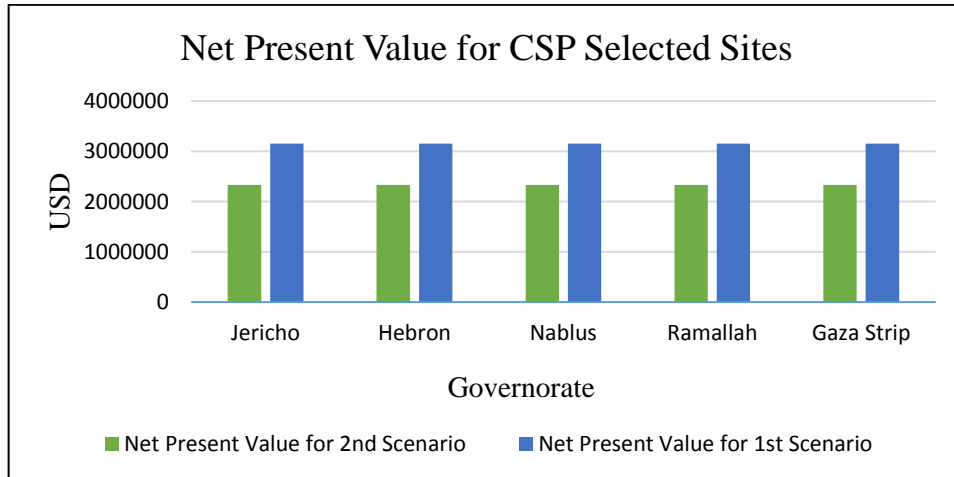
Figure 77: Net Present Value for CSP Selected Sites.

The net present value in 2nd scenario compared to 1st scenario decreased by increasing the cost of solar field as shown in Figure 77. Even the annual life cycle savings as shown in Figure 78 decreased with increasing the cost of solar field.

Annual Life Cycle Savings for CSP Selected Sites
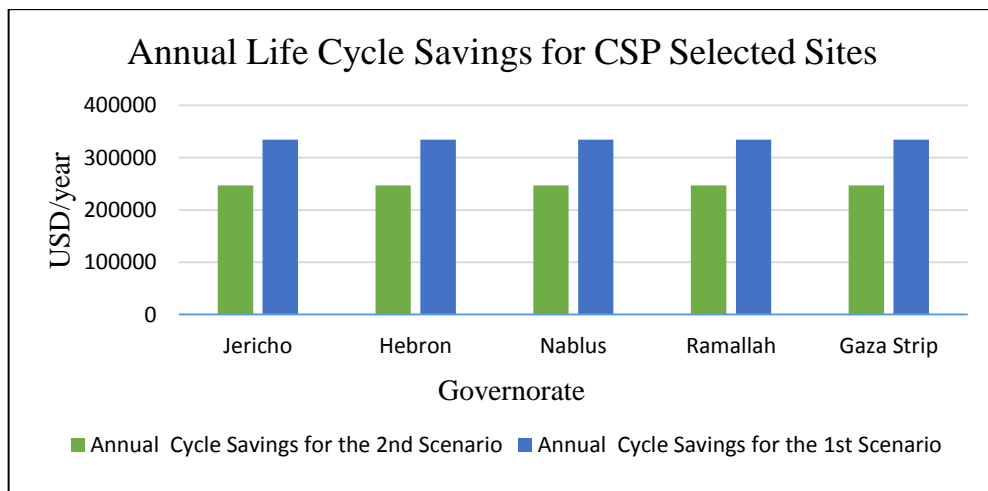
Figure 78: Annual Life Cycle Savings for CSP Selected Sites.
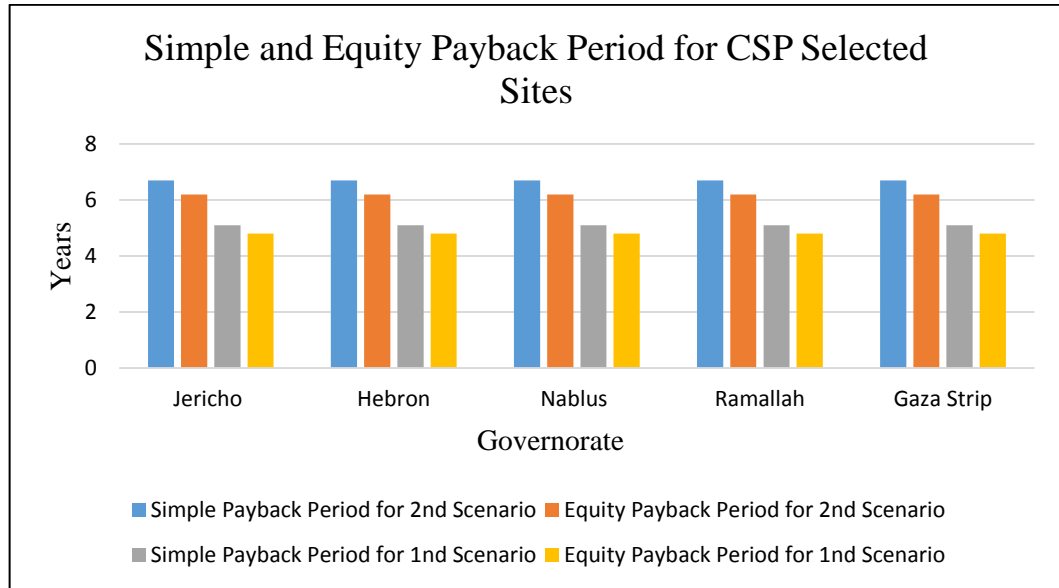
Figure 79: Simple and Equity Payback Period for CSP Selected Sites.

As shown in Figure 79, the payback periods for the 2nd scenario in comparison to the 1st scenario increased by increasing the cost of solar field. The (B-C) ratio as shown in Figure 80 decreased with increased the solar field cost.
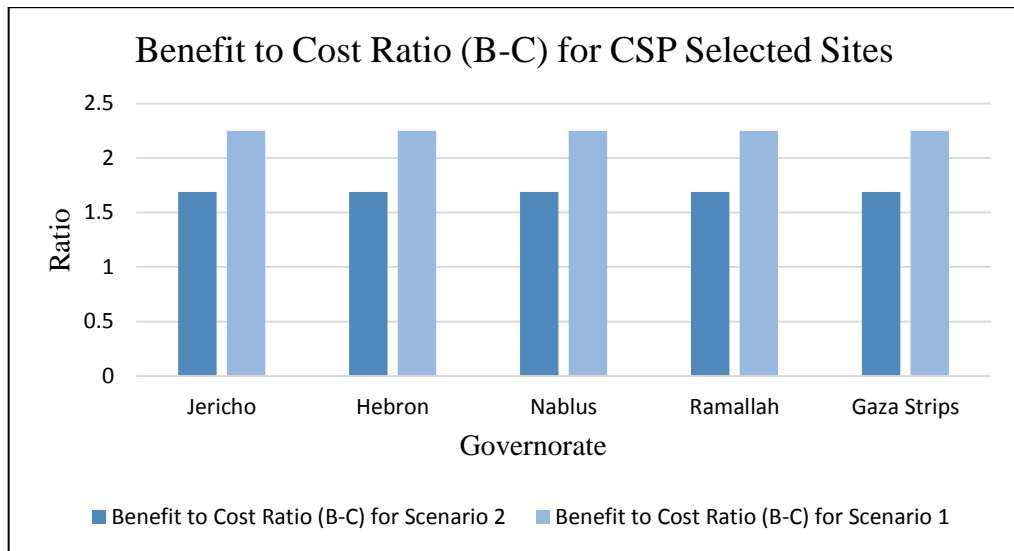
Figure 80: Benefit to Cost Ratio (B-C) for CSP Selected Sites.

Third scenario:

Electricity export rate has increased from 0.175 $/kWh to 0.184 $/kWh by applying 5% incentive.

This scenario is also important to study the effect of electricity export rate on the feasibility study. The outcomes for financial viability analysis are shown in Table 20 and the cost of kW generated by a parabolic trough system is shown in (Table 10, column 3).

Table 20 Financial Viability of the 3rd Scenario for implementing CSP System in Selected Sites.

Category	Jericho	Hebron	Nablus	Ramallah	Gaza
Project Costs and Saving/Income Summary					
Total Initial Costs ($)	5,347,637	4,200,477	4,546,586	4,081,929	12,306,552
Total Annual Costs ($)	86,355	86,355	86,355	86,355	86,355
Total Annual Saving and Income ($)	612,201	612,201	612,201	612,201	612,201
Financial Viability					
Simple Payback Period (yr)	9.4	7.6	8.4	7.2	19
Equity Payback Period (yr)	8.5	7.0	7.4	5.9	17.8
Net Present Value ($)	800,500	1,719,560	1,271,204	2,950,015	-8,320,057
Annual Life Cycle Savings ($/yr)	90,095	190,780	140,842	315,550	-870,265
Benefit to Cost (B-C) Ratio	1.5	2.09	1.95	2.18	0.78

As shown in Table 20, due the change in electricity export rate, the parameters of financial viability changed from region to other. In Gaza strip, as shown also in Table 19, the change in electricity export rate did not do anything to Gaza site situation, the NPV is still negative and (B-C) ratio is also still less than one which means, the implementation of CSP system is unviable.

Figures 81 through 84 summarize the results of Table 20 in chart forms.
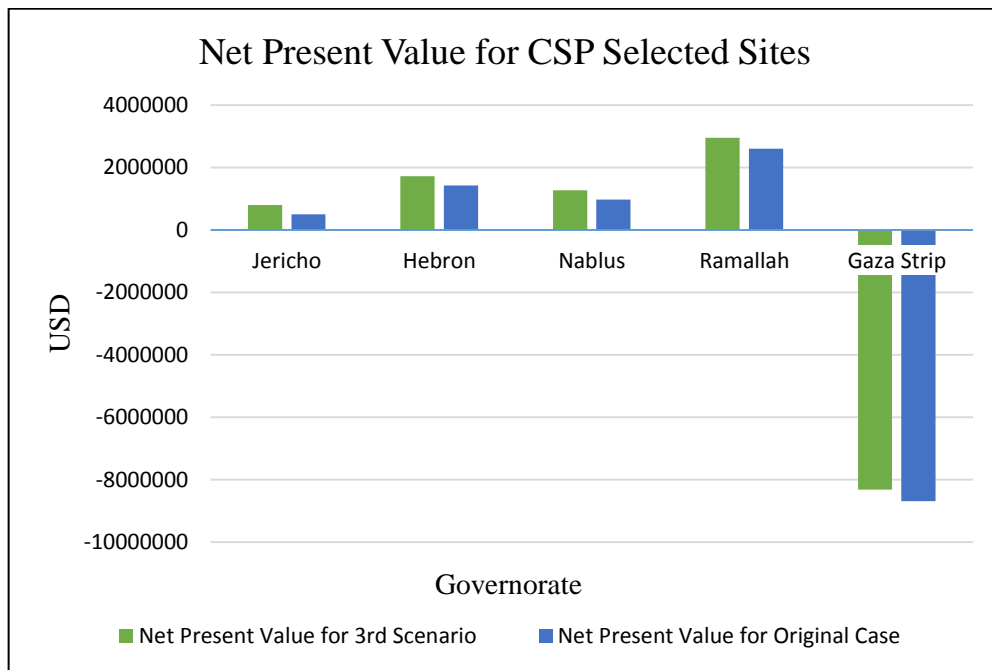
Figure 81: Net Present Value for CSP Selected Sites.

As shown in the Figure 81, the net present value gradually increased by increasing the electricity export rate as well as the annual life cycle savings as shown in Figure 82.
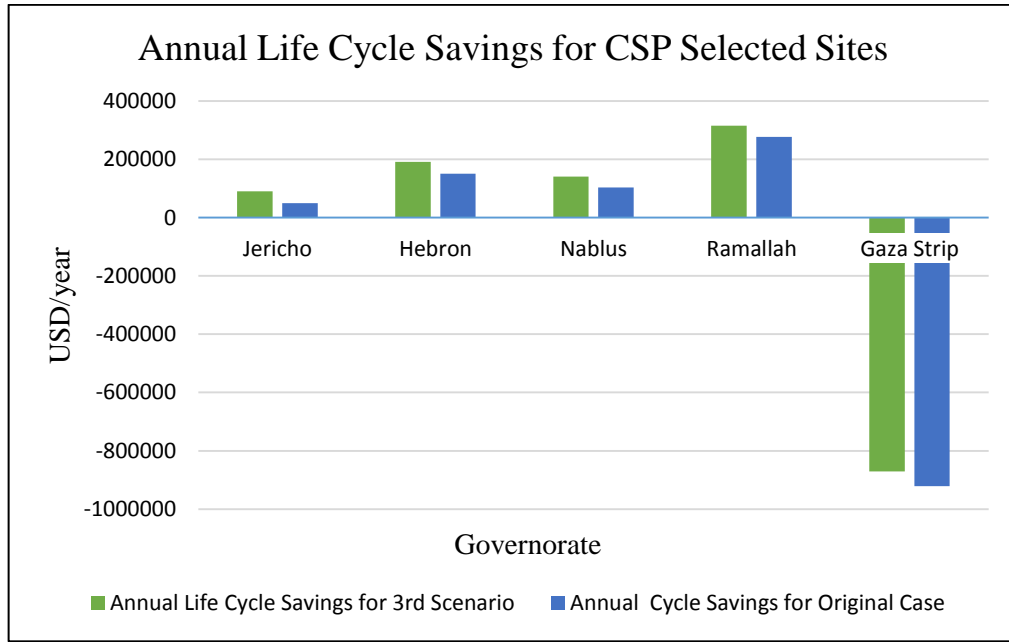
Figure 82: Annual Life Cycle Savings for CSP Selected Sites.

The increase of electricity export rate with respect to original condition led to decrease the payback periods as shown in Figure 83 due to the increase in electricity export rate leads to more savings than lower rates.
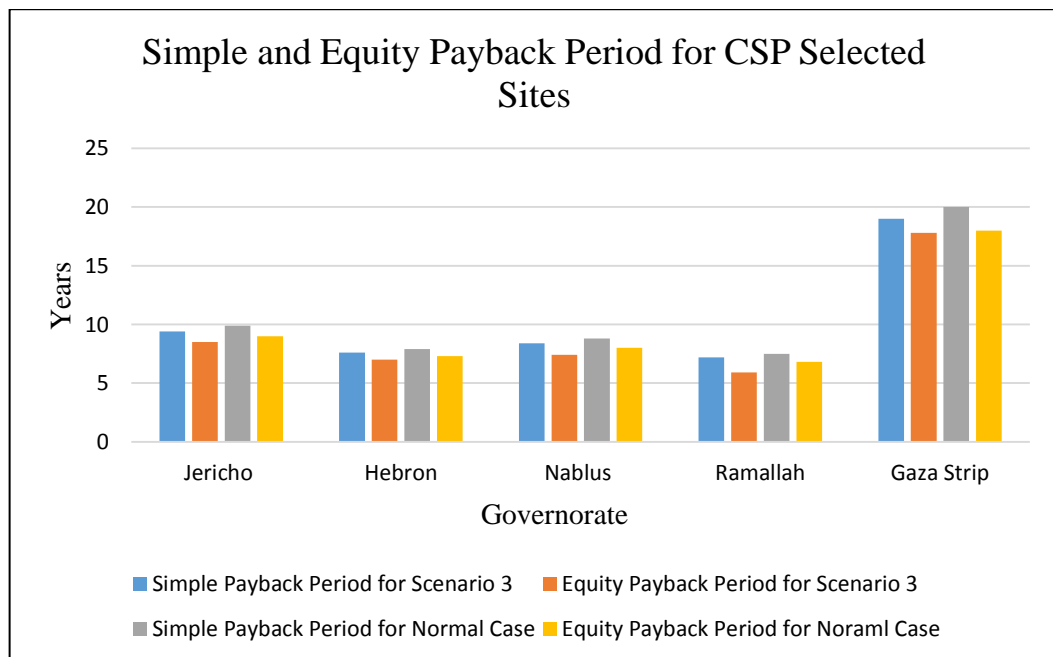
Figure 83: Simple and Equity Payback Period for CSP Selected Sites.

The (B-C) ratio also increased gradually with increase of electricity export rate as shown in Figure 84 due to the benefits have increased by applying this rate.

Benefit to Cost Ratio (B-C) for CSP Selected Sites
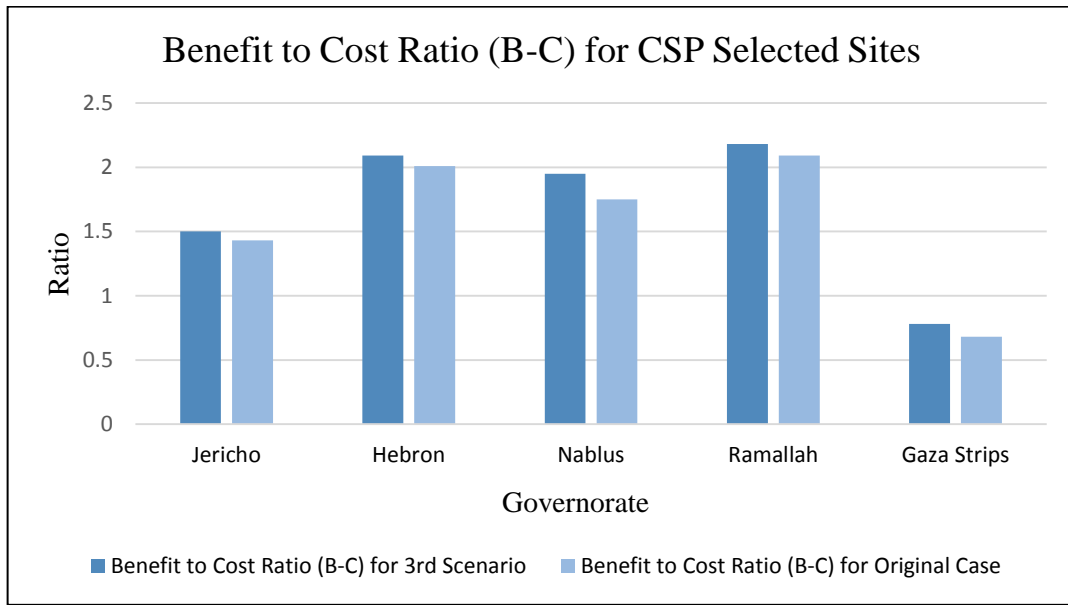
Figure 84: Benefit to Cost Ratio (B-C) for CSP Selected Sites.

Conclusion

1- Based on the scenarios taken in this chapter, the solar field and the electricity export rate cost for selected sites mainly affect the financial viability parameters.

2- The implementation of CSP system in Gaza site is viable based on 1st scenario and 2nd scenario whereas it is not viable to implement a CSP system based on 3rd scenario.

Chapter Eight

Conclusion and Recommendations

8.1 Conclusion

This thesis proved that the CSP technology is one of the best solutions to meet the energy shortage and achieve the green energy goals for Palestine in general. It also shows that some of selected sites have completely fulfilled the site selection criteria needed for implementing CSP systems, whereas the others sites met issues in fulfilling completely the site selection criteria such as the land availability in Gaza strip and high slope inclination in Hebron.

The Economic study in this thesis also proved from one side that all $LCOE_{csp}$, payback periods, net present values, annual life cycle savings and benefit cost ratios have a remarkable change from each other due to the change in the cost of the solar field and storage system. From the other side, based on technical requirements and conditions, Jericho Governorate is typical region to implement CSP technology whereas it proved through feasibility analysis that Ramallah CSP site took the first place, Hebron's, Nablus's, Jericho's and Gaza CSP site occupied the second, third, fourth, and last respectively.

The sensitivity study in this thesis has been taken into account to recognize the change in financial viability that some scenarios made such as the changing in solar field cost and electricity export rates. It showed that the change of CSP land cost and electricity export rate have clear effect on feasibility study.

8.2   Recommendations

1- Performing more studies about CSP in Palestine (within B.sc graduation projects, M.Sc. thesis or Ph.D. thesis), where the measurements of the different conditions have to be in details and separately carried out.

2- Passing laws and legislations that encourage the investment in CSP technology such as incentives for CO_2 reduction.

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جامعة النجاح الوطنية

كلية الدراسات العليا

دراسة الجدوى لتوليد الطاقة الكهربائية بواسطة الانظمة الحرارية في فلسطين

إعداد

أسامة عصام سليم دريدي

إشراف

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ب

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الملخص

النمو السكاني والتنمية الاقتصادية هي من أهم الأسباب البارزة لزيادة المستمرة في الطلب على الطاقة في فلسطين. وفي الوقت نفسه يتم استيراد بشكل كامل جميع مصادر الطاقة التقليدية من الجانب الإسرائيلي وسط تزايد الاهتمام العالمي بالقضايا البيئية. تؤكد هذه القضايا مع وجود عوامل أخرى على أهمية استخدام الطاقة الشمسية في فلسطين باعتبارها واحدة من مصادر الطاقة المتجددة.

الطاقة الشمسية يمكن استغلالها لتوليد الكهرباء من خلال تقنية استخدام الاشعة المركزة لتوليد الكهرباء (CSP). تتناول هذه الأطروحة إمكانية تنفيذ هذه التكنولوجيا في فلسطين بحيث أن فلسطين لديها جهد اشعاعي شمسي هائل.

لتعميم الدراسة على جميع المناطق الفلسطينية, تغطي الدراسة خمس مناطق في فلسطين والتي هي أريحا والخليل ونابلس ورام الله وقطاع غزة. وقد تم تطبيق معايير اختيار الموقع للتأكد من أن الموقع المحدد مناسب لتنفيذ محطة بمقدرة 1 ميغاواط. بحيث اعتبرت تكنولوجيا Parabolic Trough Collectors الأكثر ملائمة لكي تستخدم في فلسطين.

استخدم العديد من المؤشرات الاقتصادية والمالية المختلفة لدراسة جدوى استخدام هذه التتكنولوجيا في فلسطين. بحيث وجد تكلفة انتاج كيلوا واط ساعة (LCOE) من دون نظام التخزين تتراوح 2،0–0،5 دولار أمريكي / كيلو واط ساعة للمواقع الخمس المختارة في فلسطين، في حين أنها تتراوح 0،19–0،47 دولار أمريكي / كيلوواط ساعة إذا استعمل نظام تخزين لمدة ثلاث ساعات.

وجد ان فترة الاسترداد لتنفيذ مثل هذه المحطات في فلسطين (SPBP) تتراوح ما بين 7–20 سنة من دون استخدام نظام تخزين بينما وجدت هذه الفترة من 7–25 في حال استخدم نظام تخزين بمدة 3 ساعات. العديد من المؤشرات ايضا استخدمت في هذه الدراسة كصافي القيمة الحالية, وفترة استرداد الاسهم المستثمرة في المشروع, والمدخرات السنوية لفترة حياة المشروع ومعامل الفائدة على التكلفة. بحيث تم تقيم تقليل الغزات الانبعائية مثل ثاني اكيد الكربون ولكنه لم يتم ادخال هذا العامل في الحسابات الاقتصادية.

تم ايضا في هذه الدراسة دراسة اثر تغير بعض المتغيرات على متغيرات اخرى ولا سيما الاقتصادية منها بحث بينت ان عنصر سعر الارض يعتبر حاسم في التمييز الجدوى الاقتصادية بين هذه المواقع المختارة. أيضاً بينت الدراسة ان زيادة سعر بيع الكهرباء بمعدل 5% و 10% سيحسن من الجدوى الاقتصادية لتطبيق هذه التكنولوجيا في فلسطين.