



Master Thesis

submitted within the UNIGIS MSc. programme

at the Department of Geoinformatics - Z_GIS

University of Salzburg, Austria

Under the provisions of UNIGIS India framework

GIS Approach to Find Suitable Locations for Installing Renewable Energy Production Units in Sinai Peninsula, EGYPT

By

Mohamed Atia abozed Abdelrazek

104378

A thesis submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

Advisor (s):

Dr. Shahnawaz

Egypt, February 2017

Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I had cited all sources of information as well as the data I had used in my project report and indicated their origin.

1 -02-2018

Mohamed Abozed

Acknowledgements

I want to acknowledge my supervisor Dr. Shahnawaz who had supported me many times during this journey and helped me obtain better-focused results, and who gave me the road to my achievements.

I would also like to thank all other UNIGIS instructors for their support and contributions throughout the course of this master. They all have been supported me at all modules since the start day

They were very helpful, and gave all attention and have offered useful perspective and suggestions to help improve my grades.

In addition to the Egyptian public authority, I would also like to express my gratitude to New & Renewable Energy Authority (NREA) for helping in getting the needed information, which helped me in my study.

Finally, thanks to my family for supporting me during my study.

Abstract

In the last decades, Renewable energy widely became more than important for most countries across the world. Therefore, the most of the countries decided to follow the advanced countries such as the United States of America and the European Union countries in producing their needs of energy from the renewable resources. On the other hand, they need to reduce the negative impacts when generating its electrical energy by burning a dozen tons of fossil fuels daily.

Recently, Egypt just took a few steps towards generating its energy from green resources and aimed to generate about 20% percent of its needs from the renewable resources by 2020. Thus, Egypt will benefit from utilization of the decision support tool for proposing the most suitable locations for the renewable systems especially solar wind energy.

The aim of this study was to find the most suitable locations for solar and wind energy across the Sinai Peninsula in order for generating the needed future power from the renewable energy resources.

A suitability model used in this study based on the geographic information systems (GIS) was developed in ArcGIS10.4.1 when a group of raster datasets were reclassified and overlaid by the weighted overlay tool, under the spatial analysis tools. The study conducted at a regional scale for the Sinai Peninsula, Egypt as a case study. The executed suitability model created according to appropriate socio-economic and geographical constraints, in addition, the recent technology's efficiencies and advancements have been considered in order to reach the desired result, which was mapped as results. Thereafter, the methodology of approaching the potential sites is analyzed.

Finally, for both main types of renewable energy, the analysis indicated that the optimal locations of both types of renewable energy fell mainly as highly suitable and located almost near to the western coastlines of Sinai. In addition, there was a potential area in the middle area closed to the transmission lines.

Table of Contents

Science Pledge.....	1
Acknowledgements	2
Abstract	3
Table of Contents	4
List of Figures	7
List of tables	8
List of maps	9
Abbreviations	10
Chapter-1	11
1 Introduction.....	11
1.1 Background	11
1.2 The Renewable energy of Egypt	13
1.3 The History of the Renewable Energy of Egypt	14
1.3.1 The solar energy potential in Egypt.....	16
1.3.2 The well-known types of Solar energy.....	18
1.3.3 The solar irradiation definition	18
1.3.4 The wind energy definition.....	19
1.3.5 The installed wind power plants of Egypt	19
1.4 Objectives.....	22
1.5 Literature review	23
Chapter- 2.....	28
2 Methodology	28
2.1 Software used	32
2.2 Data sources	32
2.2.1 The solar and wind datasets properties.....	34

2.3	Study area.....	35
2.3.1	The Importance of Sinai Peninsula.....	35
2.4	The GIS and renewable energy	37
2.5	Evaluation Criteria for Locating solar PV in Sinai	38
2.6	the solar PV site suitability analysis.....	41
2.6.1	The Solar radiation reclassification of Sinai peninsula	41
2.6.2	Slope of Sinai peninsula	43
2.6.3	Land cover & land use.....	45
2.6.4	Distance to Transmission lines	48
2.6.5	Distance to roads	49
2.6.6	Distance to protected areas	51
2.6.7	Distance to shorelines	53
2.6.8	Distance to cities.....	54
2.6.9	Weighted overlay analysis.....	56
2.7	Defining the wind power suitable areas	59
2.7.1	The Wind energy potential of Sinai.....	59
2.7.2	Defining the wind farm and the selected criteria.....	60
2.7.3	The average Wind speed of Sinai	62
2.7.4	Slope suitability for wind power plants	64
2.7.5	Distance from transmission lines.....	64
2.7.6	Distance from roads.....	65
2.7.7	Distance from cities	65
2.7.8	Distance from shorelines	65
2.7.9	The distance to protected area	66
2.7.10	The land cover & land use verification	66
2.7.11	Distances to Airports	66
	Chapter-3.....	70

3. Processes and Results	70
3.1 Result.....	71
3.1.1 Solar PV suitable map	71
3.1.2 Wind suitable map	74
3.1.3 future work	76
Chapter-4.....	77
4. Conclusion	77
References	79

List of Figures

Figure 1 Total final energy by sources, 2060.....	12
Figure 2 total amount of generated electricity by the installed capacity in Egypt (2011-2016).....	15
Figure 3 the installed capacity of the largest wind farms in Egypt by 2015	21
Figure 4 flow chart of the used methodology	29
Figure 5 the concept of raster reclassification to a common measurement scale	31
Figure 6 an example of solar photovoltaic project in Egypt	38
Figure 7 overview of the solar PV site suitability.....	40
Figure 8 the model builder used in selecting solar PV suitable areas	58
Figure 9 Zafaranah Wind farm production in comparizon to wind speed	59
Figure 10 the overview of wind farms site suitability.....	60
Figure 11 Norway wind farm in the North Sea.....	61
Figure 12 the model builder used in selecting the wind farms suitable areas.....	68
Figure 13 the percentages of suitable lands of the Solar PV.....	72
Figure 14 the percentages of suitable lands for wind farms.....	74

List of tables

Table 1 Data Sources used in the study.....	33
Table 2 Reclassification of Global Horizontal Irradiance.....	41
Table 3 Reclassification of slope	45
Table 4 Reclassifications distances of transmission lines	48
Table 5 Reclassifications distances of roads	51
Table 6 Reclassification distances of Protected Areas.....	51
Table 7 Reclassification distances of shorelines	54
Table 8 Reclassification distances of Cities	54
Table 9 solar PV and wind suitability index	56
Table 10 the Criteria used in Solar PV suitability analysis.....	57
Table 11 reclassification of Sinai average wind speed	63
Table 12 Reclassification distances of the Air Port	68
Table 13 the Criteria used in wind farms suitability analysis	69

List of maps

Map 1 the long-term global horizontal irradiance of Egypt.....	17
Map 2 the wind speed atlas of Egypt & the Middle East at 50 m above the ground	20
Map 3 the map of Egypt and the study area.....	36
Map 4 suitability map of global solar radiation	42
Map 5 The Elevation of Sinai	43
Map 6 suitability of Slope	44
Map 7 Sinai land cover classification	46
Map 8 Land Cover Suitability of Sinai	47
Map 9 Suitability Distances of the transmission lines	49
Map 10 Suitability Distances of the roads	50
Map 11 Suitability Distances of the protected areas	52
Map 12 Suitability Distances of Shoreline.....	53
Map 13 Suitability Distances of cities.....	55
Map 14 The Average wind speed at 50 m above the ground.....	63
Map 15 Suitability of Airport Distances	67
Map 16 Suitability map of the solar PV	73
Map 17 Suitability map of the wind farms.....	75

Abbreviations

Abbreviation	Explanation
AHP	Analytic Hierarchy Process
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Models
ESRI	Environmental System Research Institute
FAO	Food and Agricultural Organization
GIS	Geographic Information Systems
GWh	Gigawatt hour
km	kilometer
km ²	square kilometer
KWh	Kilowatt hour
LCCS	Land Cover Code Systems
m	meter
MCA	Multi-Criteria Analysis
MWh	Megawatt hour
NASA	National Aeronautic and Space Administration
NREA	Renewable Energy Authority (NREA)
NREL	Egyptian National Renewable Energy Laboratory
PV	Photovoltaic
SRTM	Shuttle Radar Topographic Mission
TWh	Terawatt hour
Wh/m ²	watt hours per square meter

Chapter-1

1 Introduction

1.1 Background

In Today's life, our world is faced with an ever-growing energy demand that needs to be met by our energy supply. Our past and present reliance on fossil fuel had led us to question our ability to continue to grow sustainably. It is about 80% of our energy coming from fossil fuels in the 20th century, if our continued reliance on fossil fuels continues in a "business as usual" manner, it will lead to soaring greenhouse gas emissions, a decrease in energy security, air pollution at local and regional levels resulting in health issues, and a lack of universal access to energy (Johansson, Patwardhan, Nakićenović, & Gomez-Echeverri, 2012).

Energy is the essential key element for sustainable development and prosperity of a society in this era (Amer & Daim, 2011) .

In fact, Energy sources are divided into two main groups. Nonrenewable resources, that we are using up and cannot recreate and Renewable resources that can be easily replenished. furthermore, Renewable energy sources include: Solar energy, which can be turned into electricity and heat, Wind energy, geothermal energy from the Earth heat, Biomass from plants, and Hydropower from hydro-turbines at a dam (U.S Energy Information Administration, 2018)

These resources were become free, sustainable, environment, friendly and more economical in long term.

The International Energy Agency (IEA) in its World Energy Outlook 2013 indicates that global energy demand increases by one-third from 2011 to 2035. Demand grows for all forms of energy while the contribution of fossil fuels in the world's energy mix drops from 82% to 76% in 2035. Renewable and nuclear energy resources provide around 40% of the growth in primary energy demand. Renewable energy resources almost supply half of the net increase in electricity generation (International Energy Agency, 2013) Solar energy could provide up to one-third of the world's final energy demand after 2060 according to IEA analysis as shown in figure No1.

Generally, the solar energy consists of two main types. The first one, solar photovoltaic (PV) that convert solar energy into electrical power by a Photovoltaic cell made of a semiconductor material. However, the second is the Concentrating solar power (CSP) that has devices to collect the sun’s rays to heat a receiver to high temperatures and then transformed first into mechanical energy (by turbines or other engines) and then into electricity. Due to its availability, environmental advantages, government incentives and advanced technology, the Solar PV was the fastest growing renewable power technology worldwide over the period (2000-2011) (International Energy Agency, 2013).

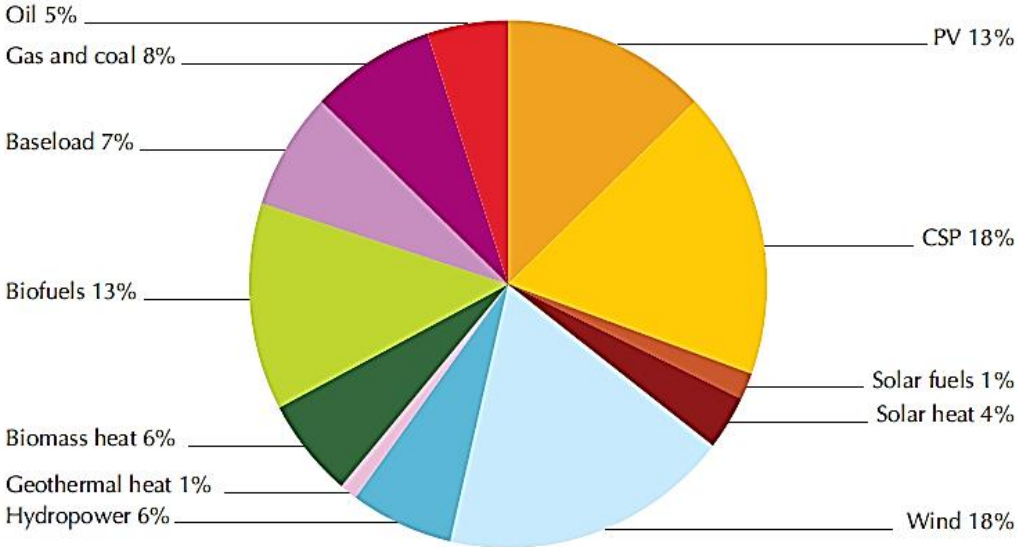


Figure 1 Total final energy by sources, 2060

It is important to say that, one of the barriers to the solar energy development is its limitations and variability, which can be different geographically from one place to another. However, in recent years, the increasing use of the Multiple Criteria decision-making (MCDM) helped to facilitate the decision-making related to site selection for photovoltaic solar energy systems. Since the Solar energy is a natural resource with inconsistent or limited availability, the strategic location selection can play a role to maximize the energy collected and the output power generated (Wee, Yang, Chou, & Padilan, 2012) MCDM offers useful assistant to decision maker in mapping out the problem by providing a flexible tools to handle and bring together a wide range of variables evaluated in different ways (Uyan, 2013)

The Geographical Information system (GIS) is a powerful tool for consulting, analyzing and editing data, map and spatial information. In recent years, GIS-based MCDM had become increasingly popular as a tool for different site selection studies especially for the energy planning. The integration of GIS and MCDM results in a useful tool to solve the site selection problems for solar energy systems (Figueira, Mousseau, & Roy, 2005)

1.2 The Renewable energy of Egypt

It is often said that renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources (Wikipedia, 2017)

As the global energy demand goes up, we must continuously find ways to expand our supply in order to meet this growing demand. As fossil fuels are a limited resource, and will inevitably run out, we must seek out other sources of energy to satiate our growing energy demand. As of 2011, energy from renewable sources (including biomass, hydropower, geothermal, solar, wind, and ocean thermal) supplied 14% of the world's total energy demand (Panwar, Kaushik, & Kothari, 2011)

In the year of 1986, New & Renewable Energy Authority (NREA) was established by the Egyptian government to act as the national focal point for expanding efforts to develop and introduce renewable energy technologies to Egypt on a commercial scale together with the implementation of related energy conservation programs.

(NREA) has a strategic plan in the renewable energy production share to reaches 20% of the total generated energy by 2020 as 12% wind, 6% Hydro and 2% solar. Besides Egyptian Solar plan to install about 3500 MW of solar energy by 2027 (New & Renewable Energy Authority, 2013).

For the last decades, Egypt suffered from the overpopulation problem as well as the increased demands of the energy especially after the Egyptian revolution 2011. Egypt suffered a critical financial crisis. Therefore, the Egyptian government has the ambitious plans in generating its energy depends on a wide range of renewable

resources types for generating electricity such as (water, the wind, solar, geothermal and biomass) produced as on 31.03.14 is estimated at 147615 MW. This includes wind power potential of 102772 MW (69.6%), SHP (Small-Hydro Power) potential of 19749 MW (13.38%), Biomass power potential of 17,538 MW (11.88%) and 5000 MW (3.39%) from bagasse-based cogeneration in sugar mills (Energy statistics 2015). Among the renewable energy sources, solar energy is unique in that it can provide a local source of electricity for people living in rural areas, which are not having direct access to the electric grid.

1.3 The History of the Renewable Energy of Egypt

In 1980, The Egyptian ministry of electricity & energy had established the renewable New & Renewable Energy Authority (NREA) to act as the national focal point for expanding efforts to develop and introduce renewable energy technologies to Egypt on a commercial scale together with the implementation of related energy conservation programs.

As we previously mentioned, Egypt faces a real crisis in generating the needed power due to the economic crisis after the revolution of 25th January 2011 at the same time, there is a huge growth in population rate. Therefore, Egypt had initiated an ambitious plan and take a few steps towards generating its power from the green sources and aimed to increase the renewable energy share from 2% (now) to 20% of the total demand by the year 2020. (New & Renewable Energy Authority, 2016)

Our study focuses on studying the most suitable areas for building a solar and wind energy projects across the selected study area as well as defining the other type of renewable resources then selecting the optimum locations based on standard criteria.

Recently, The Egyptian ministry of electricity & energy formulated its national strategy towards the green energy recourses by implementing its strategic plan by (NREA). Furthermore, the target of this strategy is to satisfy 20% of the electric energy demand from renewable energy resources, by the year 2020.

NREA's strategy including about 12% contribution from wind energy, translating about 7200 MW grid-connected wind farms. Such plan gives a room enough to the private investments to play the major role in realizing this goal. On the other hand,

the contribution from others RE sources about 8% (hydropower, solar energy, concentrated solar power), (New and Renewable Energy Authority, 2013) .

From one hand, electricity demand is rapidly increased which is the high important reason for the Egyptian government to search for an alternative source to generate the needed energy. From the other hand, the demand for energy increased gradually from 1,500 to 2,000 MW/ year, because of the rapid urbanization and economic growth. Moreover, Egypt has been suffering severe power shortages and rolling blackouts over the past 60 years, necessitating the requirement to look to alternative energy options to help meet the gradual increasing demand as a comparison to the increasing number of population.

For decades, Sinai suffers lack of energy and the urban development tools. This is the most important reason which motivated us to carry our study and focus on selecting the optimum locations for establishing the sufficient power plants for solar and wind energy in a large-scale area.

Egyptian government intended to develop Sinai by using the most suitable types of renewable resources that will fit Sinai according to the future national financial plans.

Sinai area consider an important Sinai Peninsula areas estimated by 61000 km². Therefore, these wide areas give a potential chance to use many kinds of renewable resources.

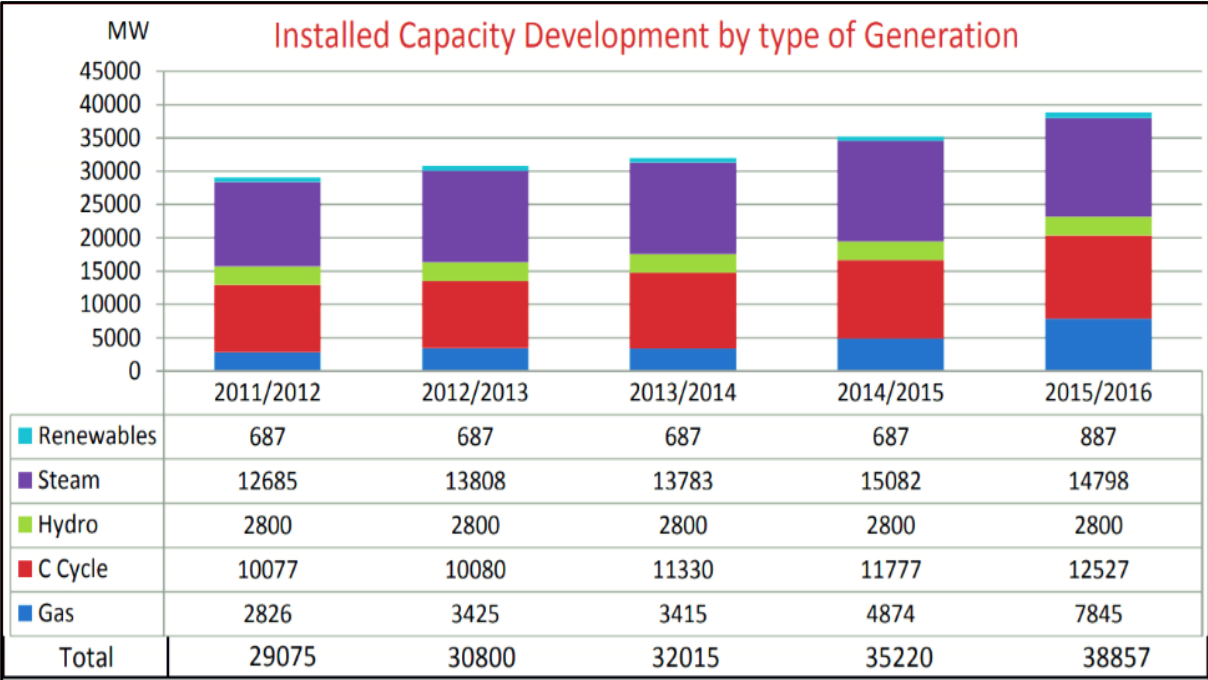


Figure 2 total amount of generated electricity by the installed capacity in Egypt (2011-2016)

Aforementioned, The Renewable energy resources are available in so many kinds like solar, wind, biomass and wave energies but are also abundant in nature. Solar and wind power is one of the most promising renewable energy since Egypt towards achieving its aim by 2020(The Egyptian ministry of electricity and renewable energy) .

1.3.1 The solar energy potential in Egypt

Egypt located within the Mediterranean and Northern Africa Sunbelt is endowed with fabulous solar resources, the annual global solar insolation is estimated to range from 1750 to 2680 kWh/m² and the annual direct normal solar irradiance is estimated to range from 1970 to 3200 kWh/m². Furthermore, the daily sunshine duration ranging from 9 to 11 hours with only a little number of cloudy days over the year (Tsikalakis et al., 2011).

Egypt has a vast potential for solar energy application as per NREA, but the solar power plants cost of investment is currently very high in comparison to the oil and gas-fired power plants and it is envisaged that Egypt's strategy for developing its renewable energy capacity will be mainly directed at the solar and wind sector.

The Sinai Peninsula considers the promising area for establishing the solar and wind power plants due to its unique locations. It has a vast vacant of desserts and free lands with a total area of 61,000 km².

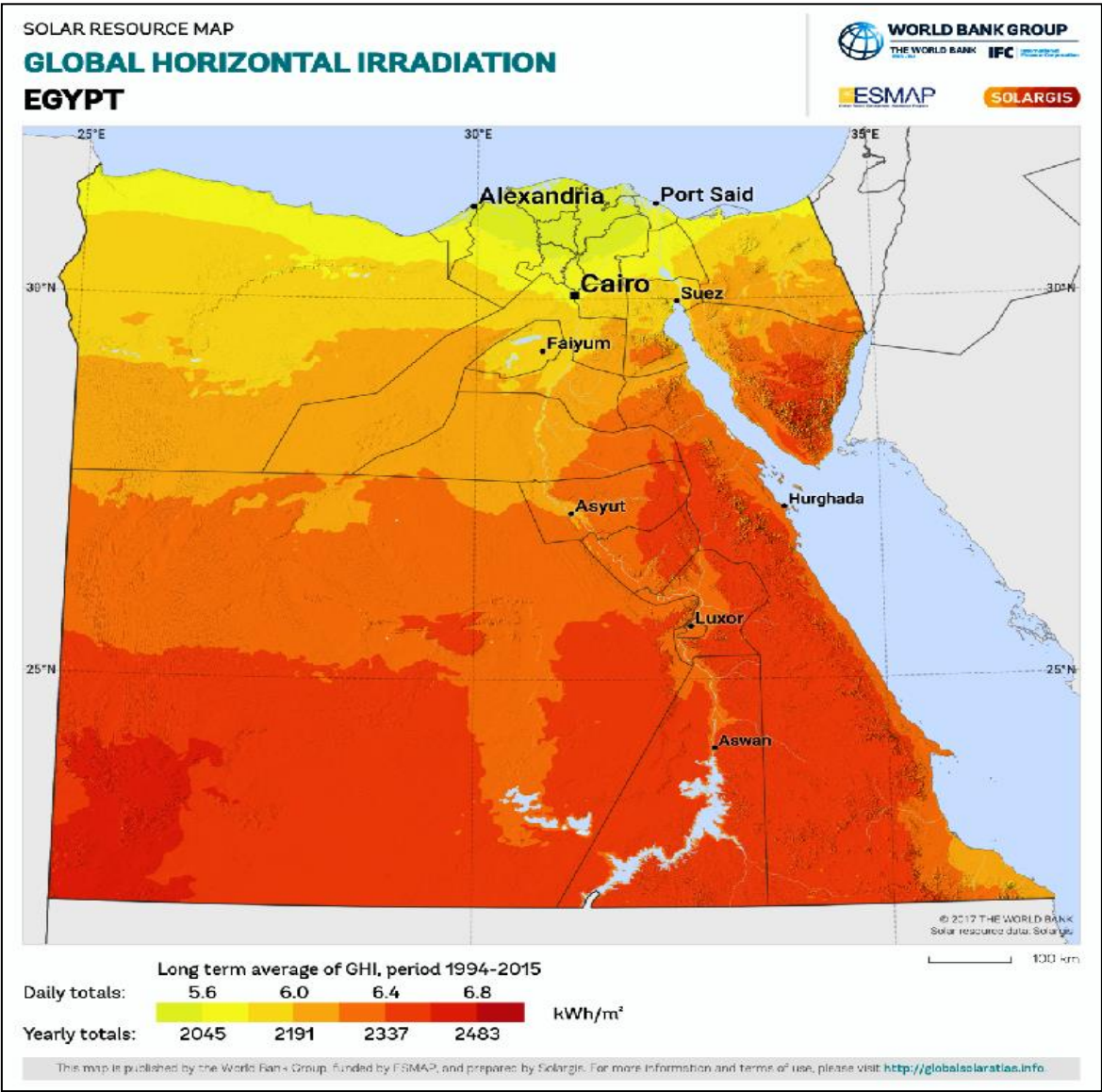
In 1991, (NREA) had issued the Egyptian solar Atlas and indicated that the direct normal solar radiation ranges averages between (2000–3200) wh/m²/y from North to South with very few cloudy days (New & Renewable Energy Authority, 2013).

To come up with the solar energy as a source of green power, it is considered the most well known green power, which have been used through the history. One of the earliest developments in solar technology. it was made by Lavoisier who achieved to construct a (1700°C) solar furnace in the eighteenth century (Brower, 1992). Therefore, wide ranges of solar technologies are available such as solar thermal heating systems, solar PV systems, and solar buildings (Brower, 1992).

In the current study, we shall discuss the Solar PV systems since it considered the most well-known type of the solar energy. However, we have to get a closer look at

the Egyptian solar atlas issued in 1991. It illustrates the Egyptian solar atlas indicating that Egypt as one of the Sunbelt countries is endowed with high intensity of direct solar radiation ranging between (2000–2600) kwh/m² from North to South. The sunshine duration ranges between (9 – 11) hours with few cloudy days all over the year.

In addition to the above information and for more clarification, the World Bank and the International Finance Corporation, collectively The World Bank Group have provided this Global Solar Atlas. The primary aim of this Global Solar Atlas is to provide quick and easy access to solar resource data particularly for Egypt country and generally for the rest countries of the world.



Map 1 the long-term global horizontal irradiance of Egypt

The above map illustrates the long-term average of yearly summaries GHI–Global horizontal irradiation in [kWh/m²y] (Global Solar Atlas, 2017)

1.3.2 The well-known types of Solar energy

To start with the solar power, there are two main types of solar energy, there are the photovoltaic (PV) and thermal solar panels. PV panels directly convert the arriving solar radiation into electricity using the photoelectric effect/photovoltaic conversion Solar PV technology converts energy from solar radiation directly into electricity (Parida, Iniyan, & Goic, 2011). the Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell, an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load, e.g., light bulb (New & Renewable Energy Authority, 2013)

In the Recent years, several projects had undertaken by (NREL);those projects have been implemented or under preparation of for Photovoltaic systems in order to generate the needed power to lighting, water pumping, telecommunications, cooling and advertisements purposes on the commercial scale.

The purpose of this Master thesis is to find optimal locations for solar energy production for utility-scale solar power stations by using GIS and the spatial analysis tools and the multi criteria decision-making technique. The GIS tools give the full functions and capabilities to illustrate, analyze and depict the valuable results for the decision makers.

1.3.3 The solar irradiation definition

It is important to know the solar irradiance and how does it transmitting to the Earth in the form of electromagnetic radiation, which is comprised of photons (Foster, Ghassemi, & Cota, 2009)

The amount of solar irradiance reaching a location on the Earth's surface over a specific time period varies depending on global, local, spatial, temporal and meteorological factors (Redweik, Catita, Brito, & Grande, 2011). however, The

amount of solar radiation left is named global radiation (Klärle, Ludwig, & Lanig, 2013) It consists of direct- and diffuse radiation, whereby (Pandey & Katiyar, 2011) divide the diffuse radiation into sky diffuse and reflected diffuse radiation. Direct radiation passes the earth atmosphere unrestricted to the surface. The scattered radiation that reaches the surface is the sky diffuse radiation and the radiation reflected by the ground, mountains, water and buildings is the reflected diffuse radiation.

1.3.4 The wind energy definition

In these days and ages, wind Energy had considered one of the fastest growing renewable energy in the last two decades. Besides having the most rapid growth, wind energy has become a big part of the energy consumed globally. Wind energy created a new trend for renewable energy three decades ago. The harnessing of wind energy dated back as far as a few centuries ago, with the creation of windmill. However, the true development of the wind technology did not happen until the 1970's. This is partially contributed to the awareness of earth's diminishing natural resources and political pressure to find other inexhaustible alternatives. Situation peaked when the world was hit with the oil crisis in 1973 and the price of oil rocketed overnight globally. The Severity of the condition was pushed further when the issues of pollution and over-exploitation of the earth resources arise (Seng, 2011)

Globally, the wind power industry had been rapidly growing at the staggering rate of nearly 30% per year for the last 10-years. A large ratio of this development is occurring in Europe, North America, and Asia markets. This worldwide success has put exceptional pressure on the manufacturers of wind turbine components such as towers, rotor blades, gearboxes, bearings, and generators.

To put everything into consideration, the wind turbine components are large and heavy.

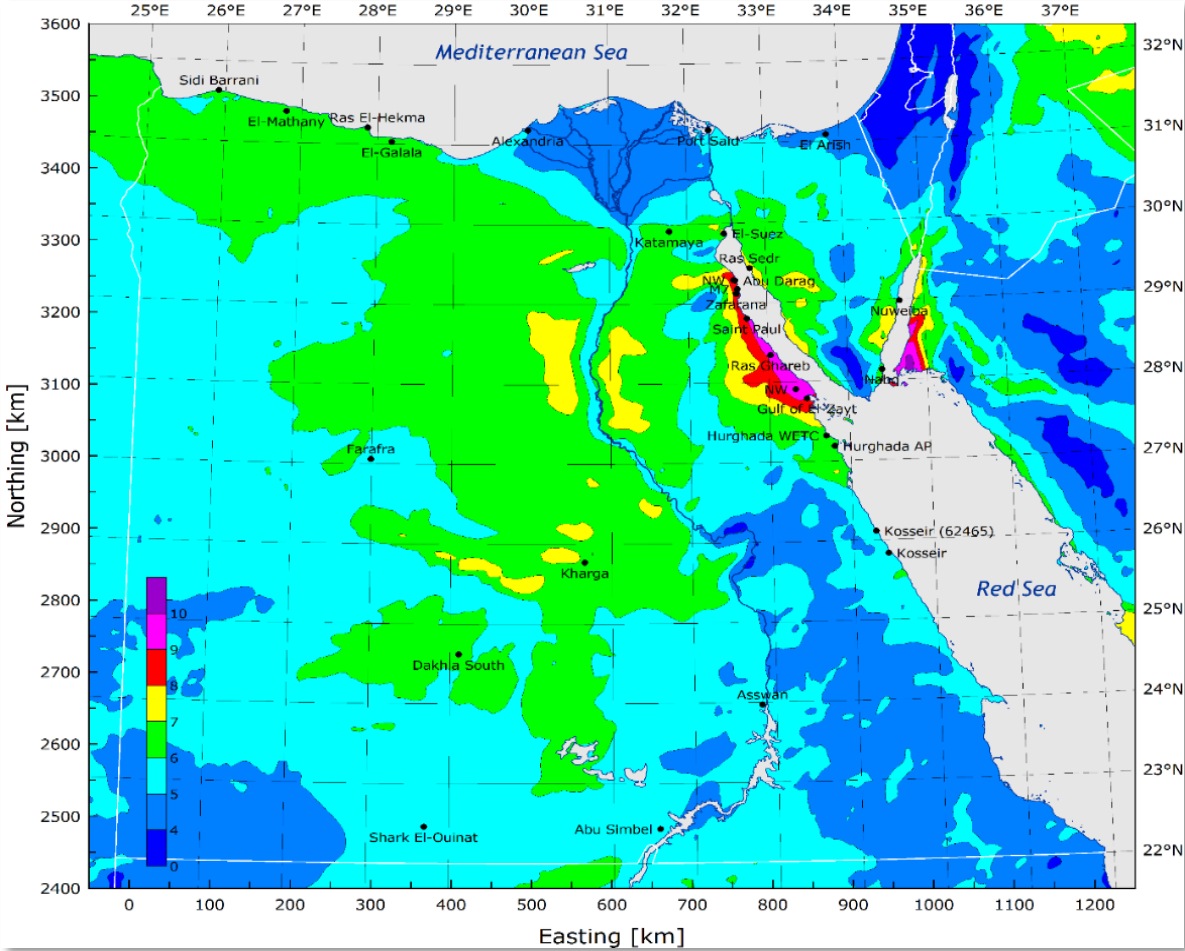
1.3.5 The installed wind power plants of Egypt

In the 2006 year, Egypt issued its wind atlas with the aid of Denmark; it contains a detailed information about the Gulf of Suez. This atlas represents several regions with high wind speed like the red sea coastline, which were considered the most

prominent of eastern Egypt. Furthermore, the wind speed of Egypt, generally in summer is higher than in winter. In addition, the annual average wind speed in Zafarana is about (9 m/s) at 25 m above sea level (Mortensen et al., 2006)

On top of that, In the Gulf of Suez, the five average wind speed reaches 10.5m/s at the same altitude. It was found that nearly (20 GW) of wind, farms can be housed in the Gulf of Suez area, which is comparable to the most favourable regions in northwestern Europe (ED WARNER, 2015)

To sum up, as per the Atlas of wind Egypt energy confirms that the existence of a widespread and particularly high wind energy resource along the Gulf of Suez The existing wind-power resources are only partially used. Installed wind-power capacity accounted for (610 MW) in 2014, which makes Egypt (No 32) in the list of nations with wind-power installations (New &Renewable Energy Authority, 2016)



Map 2 the wind speed atlas of Egypt & the Middle East at 50 m above the ground

It is noticed that the wind atlas of Egypt illustrates, that Egypt considers one of the most promising countries. Therefore, from the Egyptian wind atlas which issued by Parts of the Sinai Peninsula also feature relatively high wind energy resources, in particular along the coast of the Gulf of Aqaba and along the mountain ridge to the West of the Ajmah Mountain (El-Shimy, 2010)

As per NREA, Egypt’s best-developed wind region so far is the Zafarana district, with average wind speeds of around nine meters a second. The project is owned and operated by NREA; consists of a series of linked wind farms, the first of which started construction in 2001. Egypt’s best wind resources are located in the Suez Gulf area with average wind speeds of 10.5 m/s at 50 meters height as well as in the large regions of the Nile banks in the Eastern and Western Deserts with average wind speeds of 7.5 m/s at 80 meters height.

In the year of 2015, Egypt added 200 MW of new wind power, bringing the country’s total wind capacity to 810 MW. Egypt’s wind farms are located in three regions along the Red Sea coast: the biggest one is the (545) megawatt Zafarana wind farm consisting of 700 turbines; the 200 MW Gabal El Zayat wind farm was inaugurated in November 2015, and consists of 134 turbines; and the 5 MW Hurghada wind farm.(ED WARNER, 2015)

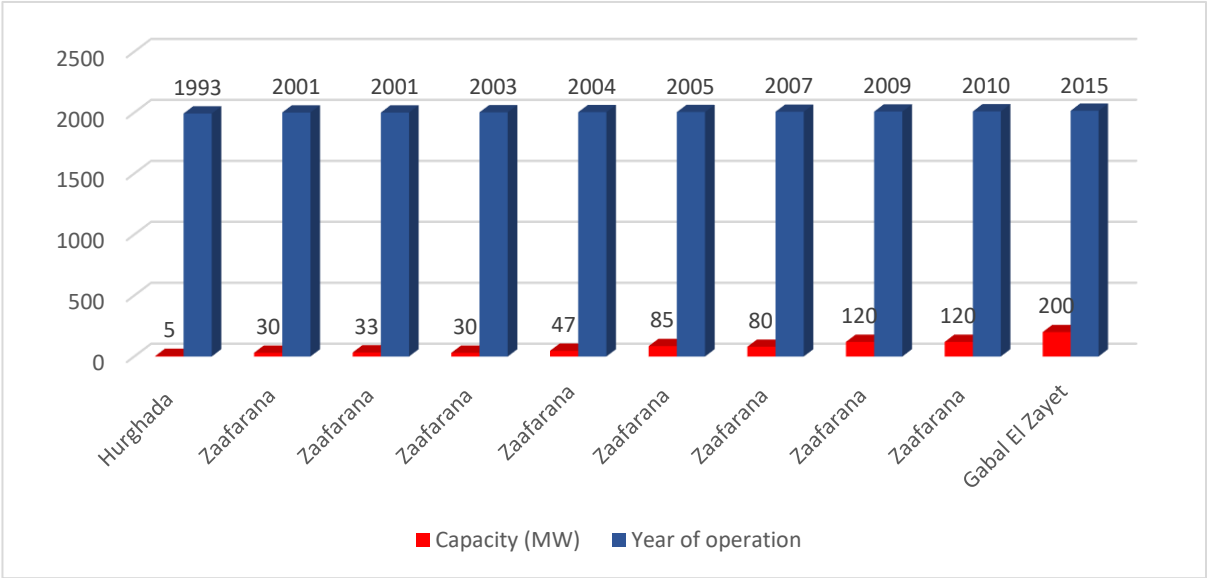


Figure 3 the installed capacity of the largest wind farms in Egypt by 2015

1.4 Objectives

The objective of this study is to use the GIS tools to identify the most Suitable Locations for installing two major types of renewable energy power plants for the wind and solar PV.

In regards to the study area, we have selected the east north area of Egypt to be examined to explore the most suitable areas to establish the new renewable energy power plants.

Egypt will benefit from the outcomes of this study, particularly; when the Egyptian government needs to overcome the stop production of power due to any reasons as well as investing the needed money properly when determining a large scale areas for future and government strategic plan.

We choose to work in the Sinai Peninsula since its unique location. It is located at the crossroads of Africa, Europe, and Asia when connecting all three continents of the world, Sinai considers a unique area.

We have used the multi-criteria analysis and GIS model and the site suitability approach to select the most suitable location for locating the solar PV and wind farms across the Sinai Peninsula.

Furthermore, (NREA) will be benefited from the findings of this study to further promote awareness and understanding of the opportunity for renewable energy developers. However, GIS tools and techniques will check the optimum sites across the study area as well as data processing, analysis, and integration after gathering datasets from various sources, then we defined and develop the criteria model using multi-decision making.

The results of our analysis of the spatial GIS model suitability model were displayed in two main maps for the Sinai Peninsula showed respectively the optimal sites for both types of renewable energy power plants; solar PV and wind power.

Last but not least, It is hoped that this study will promote investments in renewable energy and encourage researchers for further studies not only one Sinai peninsula but also in Egypt.

1.5 Literature review

Recent years, related studies were conducted in the area of suitability analysis performed to find the most suitable locations. It noticed that numerous studies been specialized mainly on the renewable energy resources. It showed the importance of using the GIS tools to locating the renewable energy power plants.

GIS can have a significant contribution as a decision support tool in identifying environmentally feasible locations for wind turbines, which require management and analysis of wide range of spatial data types. GIS analysis might aid to determine appropriate zones according to specific criteria for future development. the MCE define as the evaluation of a set of alternatives, based on multiple factors and constraints, where the factors are quantifiable indicators of the extent to which decision objectives are realized (Malczewski, 2006)

It goes without saying that most of the literature review shows how GIS tools used in different fields such as energy management, renewable energies planning, energy resource allocation, etc. have applied various multi attribute decision-making (MADM) techniques (Prasad, Bansal, & Raturi, 2014)

In our research, we have reviewed a lot of old literature, which has been published on what factors, should be considered in photovoltaic (PV) and wind turbines site selection as well. Furthermore, numerous studies been conducted in the suitability analysis in order for finding the most suitable sites for locating some activity.

It is also helpful to see how they have conducted their research and why they chose their methods, to help to develop and justify my own methodologies. In following part of my thesis, we will explain the result of the important papers on the area of suitability analysis.

(Saleous, Issa, & Al Mazrouei, 2016) This study aimed to assess the viability of establishing wind farms offshore the Emirate of Abu Dhabi, UAE and to identify favorable sites for such farms using Geographic Information Systems (GIS) procedures and algorithms. Conducting a set of suitability criteria was developed including ocean currents, reserved areas, seabed topography, and wind speed. The study presented in section 3 is applied to create the suitability map for potential locations of wind farm offshore the Emirate of Abu Dhabi. Results showed that most

of Abu Dhabi offshore areas were unsuitable, largely due to the presence of restricted zones when the author proved that the GIS-based model was very successful.

(Elsheikh) it shows how GIS-based is used in site selection and decision making process when applying and integrating with the spatial datasets in order to produce suitability map for a hotels best site selection. On a top of that, the suitability areas were first produced by numerically overlaying the road, river, slope and build up layers. The main finding of this study is the map produced the hotel site suitability. They were using the GIS and AHP method. Four layers (road, build up, river, and slope) were overlaid and ranking based on significant of site selection. They considered this map would give planners the tool needs for assessing and minimizing uncertainty for the decision-making and the proposed choice and its risk.

(Effat, 2016) this study revealed how an integration of GIS with MCDM offers a reliable decision support system for the decision makers. In terms of finding the most optimal sites for solar power plants activates. She used the GIS and remote sensing tools and applying the AHP to calculate the weight of criteria of Spatial Multi criteria Evaluation (SMCE) model. A weighted overlay was used to produce a suitability index map for solar energy power. The methodology proves to be useful for DM to develop solar energy farms.

(Uyan, 2013) The study combined the AHP with GIS to find the logical location of solar farms site in Karapinar region, Konya, Turkey in order for getting A land suitability index map by using 5 evaluation criteria were chosen according to attributes of the study area. The presented model of combining AHP with GIS tools showed how the AHP methodology integrates with GIS and how it is remarkably important for the effective and quick evaluation of the solar farm's site selection and Environmental and economic factors were altogether considered in the computation process in order for getting the Final suitability map.

(Kihoro, Bosco, & Murage, 2013) the aim of this study was to develop a suitability map for rice crop based on physical and climatic factors of production using a Multi-Criteria Evaluation (MCE) & GIS approach. they focused on land suitability analysis to identify permissible areas suitable for rice crop production. The outcoming concluded in overlaying the land cover map with the suitability map to

identify variances between the present and potential land use. However, the objectives and goals of this study were achieved with the aid of computer modeling, GIS, and Multi-Criteria Analysis to find the most suitable locations for rice crop.

(Melius, Margolis, & Ong, 2013) in this study, the authors used the GIS' capabilities to identify locations that meet the ideal criteria sets. There were two parts to the research. The first is a solar suitability analysis by utilizing LiDAR data to represent the solar radiation. However, the second part created a 3D model/visualization of the campus using ESRI's City Engine software. The main outputs of this study are the optimal locations for solar panels and estimating the photovoltaic energy potential of identified rooftops.

(Hoogwijk, de Vries, & Turkenburg, 2004) it was an analytical study specialized in the term of the wind energy substantial. Furthermore, the study been made in order to distinguish the different categories of wind power potential and how they can be assessed on a global onshore approach. The study best described in detail the procedure that started from the evaluation of the theoretical wind power potential and results to the estimation of the economic potential providing with cost supply curves.

(Ahmed, Miyatake, & Al-Othman, 2008) in this study, the researchers combined solar PV and a variable-speed WT. A simple and cost-effective MPPT technique is proposed for the PV and WT without measuring the environmental conditions. The detailed hybrid system simulated results that ascertain its feasibility been described. Moreover, he mentioned that the power fluctuation of the hybrid system is less dependent on the environmental conditions compared to the power generated by individual PV and WG systems. In this work, this power fluctuation has been suppressed using a battery, and it will be the subject of future work.

(Salim, 2012) The study used the Geographic Information System (GIS) as a spatial decision support tool to select the appropriate sites in Egypt for groundwater solar desalination. The Model developed by defining and proposing suitable areas of groundwater solar desalination depending on a number of governing factors. Ten different classes of the used data sets were defined. The results of this study showed that the higher the value of the solar radiation, the higher suitability of an area for groundwater solar desalination.

(Kucuksari et al., 2014) in this study the authors discussed how to locate and determine the best size for PV plants. GIS-based use the integrated framework to is presented utilizing mathematical optimization and simulation besides considering the criteria such as solar radiation, slope, elevation, and aspect. In addition, they determined the candidate places and thereafter, via mathematical modeling, presented long-term expansion plan of this technology.

The obtained result indicated that the combination of FAHP, SAW with GIS have a high accuracy in Land suitability analysis modeling and, in this way, climatic criteria have the relative importance. The finding of this showed the suitability of Iran area in five classes.

(Janke, 2010) in this paper, the author revealed that the process for assessing large-scale wind and solar suitability more generally in Colorado without addressing the landfills. In addition, address the criteria used for site assessment: renewable potential (using NREL annual insolation data), land cover, population density, distance to roads and transmission lines, and cities. The analysis assigned weights based on an importance of the criteria, placing the highest value on solar potential (based on the annual insolation) and proximity to transmission lines.

(Effat, 2016) the author used the Analytic Hierarchy Process AHP method, which signifies a specific problem by means of the hierarchical organization of criteria and subsequently uses evaluations to generate weights for criteria and preference scores for classes of different principles based on user/decision maker judgment. The study highlighted the capability of combining digital elevation data and spatial models in providing initial, quantitative, and low-cost analysis.

As a result, the findings were quite useful for land-use decision makers and energy planners on such a regional scale.

(Raji, 2017) In the present study, finding the solar energy optimal sites were found by using the geoinformation technology. Multi-criteria evaluation (MCE) method alongside fuzzy AHP and GIS were combined to produce suitability maps of the northwest region of Nigeria. Data used were based on climate, environmental and proximity factors with respective variables.

The results showed that how the combination of the Multi-criteria evaluation (MCE) method alongside fuzzy AHP and GIS give good results to the decision makers in the suitability analysis processes.

(Charabi & Gastli, 2011) in this study, an assessment of the land suitability for large PV farms implementation in Oman was used. The AHP-OWA using Fuzzy quantifiers in GIS. Fuzzy Logic Ordered Weight Averaging (FLOWA) module is an integrated tool within ESRI ArcMap used in this study.

They claimed that such models would incorporate uncertainty of expert opinions on the criteria used, and their weights by the way. At last, delivered a mechanism for aiding the decision-making through the multi-criteria combination technique.

(Aydin, Kentel, & Duzgun, 2013) in this study, the mathematical tools of a Fuzzy Theory Sets and an MCDM approach used to evaluate the environmental factors together with economic feasibility objectives of wind and solar energies.

Furthermore, they determined feasible locations in terms of environmental and economic feasibility through a fuzzy decision-making procedure that uses ordered weighted averaging algorithm for aggregating multiple objectives.

The related data sets were overlaid to obtain the most feasible locations for hybrid wind solar-PV systems. Finally, the preferable sites were separately recognized and represented wind and solar energy systems by using GIS software.

Based on all of these old studies, it is concluded that GIS based analysis, can calculate ,estimate and locate the solar PV and wind power plants, based on considerations of physiographic and socioeconomic factors would be the most suitable to map solar PV and wind power plants potential in a relatively large area such as Sinai area.

Chapter- 2

2 Methodology

In the following parts, we are going to discuss our methods and how had we conducted the site suitability analysis for locating both types of renewable energy power plants (solar PV and wind).

As we have previously mentioned, the aim of this study is to use the spatial multi criteria decision making and the site suitability analysis in to find the most suitable areas for the installation of a large-scale solar PV and wind farms in sinai peninsula as our study area. However, we have located the two main types of renewable energies (the solar PV and wind) based on the designed principles developed by NREL.¹

In locating the solar PV power plants and wind power task, we have conducted all of our analysis using the ArcGIS10.4.1 in order to perform a site-suitability analysis. However, we have excluded the non-suitable areas such as urban development, water bodies, or environmentally sensitive/protected regions and the mountain areas as well by restricted all of these areas after that, we were conducted the weight overly analysis to depict our result. All in all, the previous steps have been conducted based on numerous of vector and raster layers like the solar irradiance map as a global horizontal irradiance, slope, distance to the main roads and transmission line, distance to city, distance to shorelines, land cover, and distance from the protected areas.

The last step, however, is combining all reclassified vector and raster by using the weight overly tool.

To start with finding the suitable areas for the wind power plants, We have used the average mean wind speed at 50m height, slope, distance from the transmission lines,

¹ The National Renewable Energy Laboratory (NREL), located in Golden, Colorado, specializes in renewable energy and energy efficiency research and development. <https://www.nrel.gov>

distance from main roads, distance from the airports, land cover, and distance from the protected areas and airports respectively.

The list of the data sets used in conducting this study was derived in vector format from many sources. after initially checking that data sets, then converting all to raster format when we used the Euclidean distance tool to convert the formats of those layers to a raster format. Subsequently, The outputs of the previous step will be reclassified into four main categories and finally overweight by the weight overly tool to depicts the final result for the most suitable areas.

it is noticeable that the classification and reclassification processes were conducted based on the old literature and numerous studies based on NREL. Furthermore, the unsuitable areas were excluded based on their nature like the agricultural areas, terrain areas and the protected areas. However, the rest of areas gradually classified from the highly suitable to moderate and unsuitable areas. The below figure (No4) illustrates, in brief, our methodology in finding the most suitable locations for the locating the renewable energy power plants.

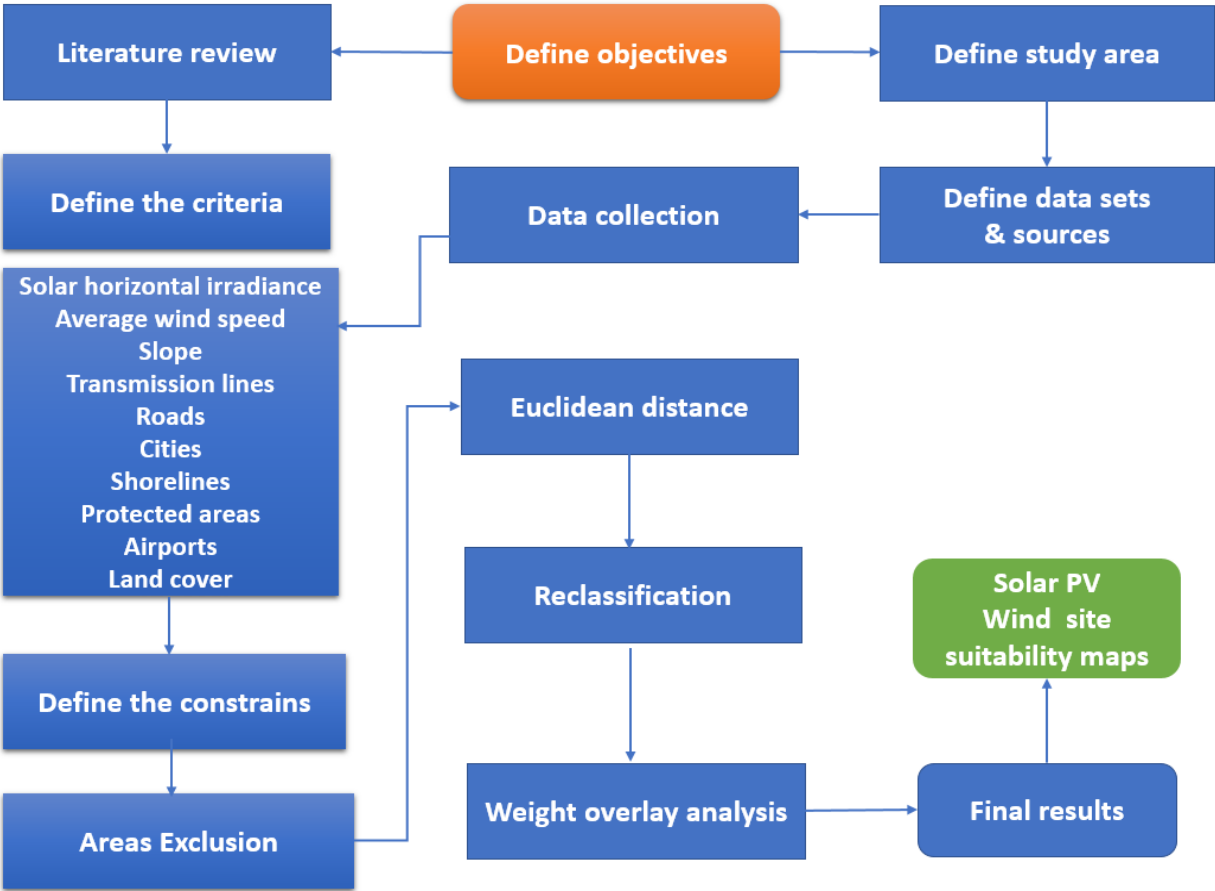


Figure 4 flow chart of the used methodology

It is commonly said that the dataset's accuracy and its updates consider more than important in conducting any research especially if the research related to the spatial studies. Essentially, in case of any missed or inaccurate data, will bring inaccurate results. From a quality assurance perspective, I have uploaded the collected data sets onto ArcGIS10.4.1 to ensure all data and layers are compatible. In addition, we used the ArcGIS10.4.1 software to Perform Spatial Analyst and data Conversion to the collected and generated layers needed to assess the land suitability then reclassifying each of the layers and apply appropriate weights. Last data processing tasks, the Raster Calculator tool Used to combine all layers for a land suitability layer.

The methodological framework of the PV solar & wind farms site selection and the pre-assessment applied in this our study is sequenced in different steps that are summarized and illustrated above in figure (No4).

The results of the Suitability models identified the best or most preferred locations for a specific phenomenon. However, there are main types of problems addressed by suitability analysis included the following parts:

Commonly, in finding the most suitable areas for locating solar plants or wind, there were three main tasks, which were included the following:

1. Data preparation and standardizing had been conducted before assigning the criteria matching with the nature of study then inserting the data into ArcGIS10.4.1
2. Datasets reclassification; reclassifying each dataset to a common scale gradually from one to ten giving lower values to higher suitable values respectively. Then sequentially, excluding the not suitable areas by giving the values of zero.
3. Finally, the reclassified data sets will be combining by using a weighted overlay tool under the spatial analyst tool in the ArcGIS10.4.1. We ran the analysis to weight the datasets using ArcGIS10.4.1 to see which datasets have more influence in the suitability model if necessary, then we combined them (attributes) to create the suitability map suitable sites.

The Weighted Overlay tool applies one of the most used approaches to solve multi-criteria problems such as site selection and best path analysis. However, however,

the weighted overlay analysis consists of a series of tools can complement the Weighted Overlay processes, which has been mentioned earlier.

The Weighted Overlay tool scales the input data on a defined scale (the default being 1 to 9), weights the input rasters, and adds them together. The more favourable locations for each input criterion will be reclassified to the higher values such as nine. In the Weighted Overlay tool, the weights assigned to the input rasters must equal 100 percent. The layers are multiplied by the appropriate multiplier, and for each cell, the resulting values are added together (ESRI Tutorial, 2017)

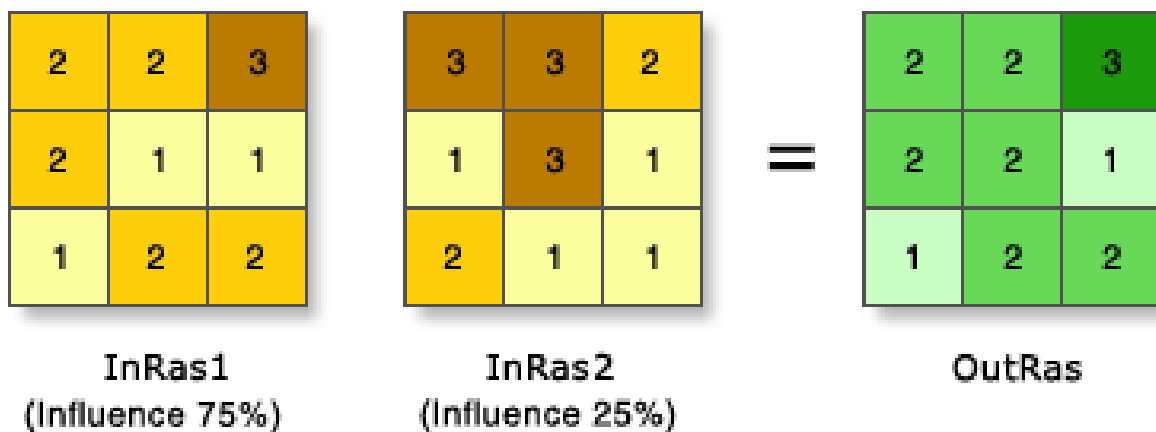


Figure 5 the concept of raster reclassification to a common measurement scale

In the illustration above, the two input rasters have been reclassified to a common measurement scale of 1 to 3. Each raster is assigned a percentage influence. The cell values are multiplied by their percentage influence, and the results are added together to create the output raster. For example, consider the upper left cell. The values for the two inputs become $(2 * 0.75) = 1.5$ and $(3 * 0.25) = 0.75$. The sum of 1.5 and 0.75 is 2.25. Because the output raster from Weighted Overlay is an integer, the final value is rounded to two. Therefore, The Weighted Overlay assumes that more factors that are favourable result in the higher values in the output raster, therefore identifying these locations as being the best. To sum up, the weighted overlay combined the multiple criteria together with certain ranking or rating factors. In the following section, we will discuss how is the overlay tool works in order for conducting the site suitability analyses (ESRI, 2017)

Basically, In order to apply the suitability analysis approach, we should consider the following steps (ESRI Tutorial, 2017)

1. Define the problem.
2. Break the problem into submodels.
3. Determine significant layers.
4. Reclassify the data and generate new raster layers.
5. Weight the input layers.
6. Add or combine the layers.
7. Final analysis and results.

2.1 Software used

The software used to prepare, analyze and manipulate the results of spatial data was the Arcgis10.4.1.in addition, we use the Microsoft excel in analyzing the attributes data.

2.2 Data sources

In fact, the data collection processes were a challenge since it was so difficult to collect various data sets from various location especially in different formats in high and accurate datasets in addition to the data updates. The current study depends on many types of datasets in order to locate the photovoltaic and the wind power plants.

As we can see from the table, (No1) it includes the collected datasets from numerous sources and then sequentially analyzed before it used.

Recently, the term of renewable energy and global warming becoming increasingly prevalent around the globe, Lots of profit and nonprofit agencies are gradually investing in the area of climates changes and effects and weather. The National Renewable Energy Laboratory One of many organizations providing free information. For the purpose of this study, the solar irradiance and wind speed data have been downloaded and used from the global solar atlas and IRENA websites respectively.

First of all, in locating the solar photovoltaic plant's, and selecting the most optimal sites; several datasets were used like the global solar irradiance, slope, land cover, city, shorelines, transmission lines, roads, land cover and protected areas.

Second of all, in regards to finding the most suitable sites for locating the wind power plants suitable areas, multiple datasets had been used like such as the average wind speed at 50m height, slope, cities, shorelines, transmission lines, road, land cover, airports and protected areas in addition to the airport's datasets.

it is important to indicate that, average Wind speed data are used in order to define the wind power potential, while the rest to narrow down from theoretical potential to the technical one since the latter includes certain limitations and obstacles as discussed in the methodology section. For more clarification, the below table includes all information about the datasets used in addition to its format and resolutions. Moreover, besides this, it represents the various types of the used geospatial data and their sources used in the data processing stages in order for defining both of PV solar farm and wind farms site suitability analysis:

Table 1 Data Sources used in the study

SN	Dataset	Format	Links	Resolution
1	Egypt boundry	MDB	http://gadm.org/download	NA
2	Average wind speed	Raster	https://irena.masdar.ac.ae/gallery/#map/346 3	1 km
3	Global solar Irrediance	Raster	http://globalsolaratlas.info/downloads/egypt	1 km
4	DEM	Raster	http://srtm.csi.cgiar.org/	90 m
5	Sinai Land cover	SHP	http://www.fao.org/geonetwork/srv/en/meta_data.show?id=38099&currTab=distribution	NA
6	Sinai roads	SHP	Egyptian survey authority	NA
7	Sinai transmission lines	SHP	http://www.wdpa.org/country/EG	NA
8	Sinai Airports	SHP	Egyptian survey authority	NA
9	Sinai cities	SHP	Egyptian survey authority	NA
10	Sinai shorelines	SHP	Egyptian survey authority	NA
11	Sinai protected areas	SHP	http://www.wdpa.org/country/EG	NA

2.2.1 The solar and wind datasets properties

As we have previously mentioned, the global horizontal solar irradiance and the average wind speed were our most important used factors in defining the most suitable area for solar PV and wind power plants respectively.

In the following sections of this document, we shall discuss these datasets and its attributes as follows:

To start with the Solar irradiance datasets (global horizontal irradiation); these data sets were published in June, 2017. Moreover, it represents the Long-term average of daily totals of global horizontal irradiation (GHI) in Kwh/m². It is covering a period from 1994 to 2015 (from 1999 to 2015 of Egypt)². However, the wind speed data set was downloaded from International Renewable Energy Agency (IRENA) as a raster layer of the average wind speeds (WS) every 1-km on the globe.

On the other hand, The Global Wind Atlas provides a high-resolution wind climatology at (50, 100, 200) m hub heights above the surface for the whole world (onshore and 30 km offshore). These layers have been produced using microscale modelling in the Wind Atlas Analysis and Application Program (WAsP) and capture small scale spatial variability of winds speeds due to high resolution orography (terrain elevation), surface roughness and surface roughness change effects.

The layers shared through the IRENA Global Atlas are served at 1km spatial resolution. Furthermore. The full Atlas contains data at a higher spatial resolution of 250 m, some of the IRENA Global Atlas tools access this data for aggregated statistics.³

² <http://globalsolaratlas.info/downloads/egypt>

³ <http://globalwindatlas.com/>

2.3 Study area

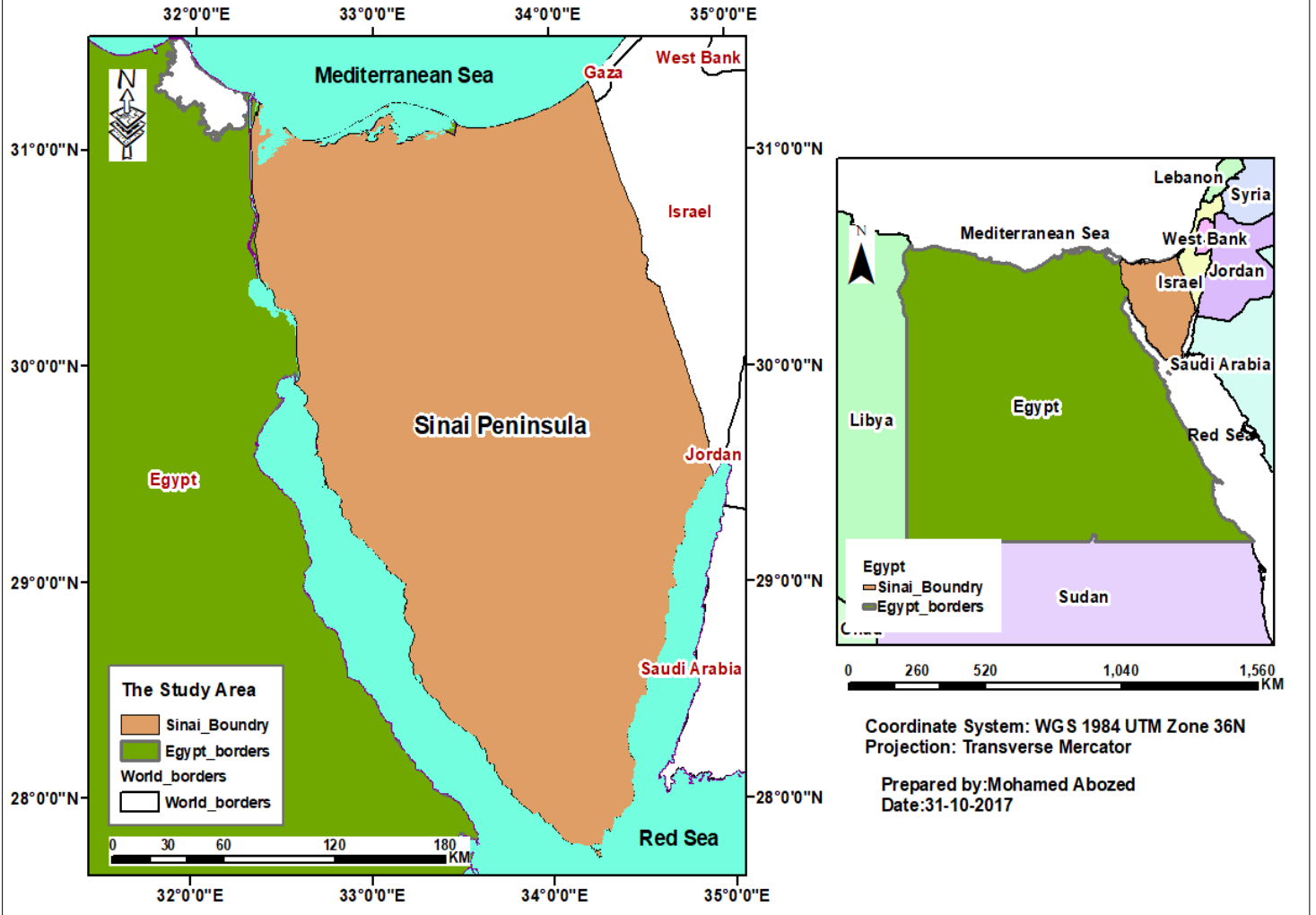
The study area in this thesis is focused in the Sinai Peninsula, which is located in the northeast of Egypt as a study area. Sinai is a triangular peninsula covering an area of 61,000 Sq. km in the northeastern area of Egypt, and joining the great continental land masses of Africa and Asia within the geographic location falling between latitudes 27°43' and 31°19' North and longitude 32°19' and 34°54' East. The Peninsula is located between the Gulf of Aqaba and Gulf of Suez and is bounded from the north by the Mediterranean Sea. It comprises two administrative governorates, North Sinai covering an area of about 27,564.0 square kilometers and South Sinai covering an area of about 31,272.0 square kilometers. North and South Sinai Governorates population reach 395,271 and physical geography includes desert plains, sand dunes and seacoasts, plateaus and mountainous zones. The Mediterranean Sea borders the Peninsula from the north with a shoreline reaching 205 km. The region is rich in mines, where kaolin, manganese, zircon, coal and feldspar exist. Quarrying activities such as gypsum, glass sand, marble, granite, dolomite and limestone are being extracted 159,029 respectively as of 2012 estimates (Central Agency for Public Mobilization and Statistics, 2013)

2.3.1 The Importance of Sinai Peninsula

The Sinai Peninsula has unique geographical features including several advantages for extensive use of solar and wind power. In this context, renewable energy resources appear to be one of Sinai Peninsula present abundant solar potential, which to some extent has been exploited for electricity production. However, the largest part of this potential remains unexploited. Efficient and effective suitable and sustainable energy area in Egypt.

The Peninsula is popular for its unique protectorates, historical and religious sites such as St. Catherine Monastery and Mount Moses. Despite its rich resources, the peninsula is among the least governorates in population density in Egypt. The Egyptian Government had put Sinai's development plan on its top priorities in the previous years. Therefore, recently after the Egyptian revolution 2011, Egyptian government starts to develop the Sinai Peninsula in order for creating a new sustainable and attracting communities that should ensure a stable, economic and sustainable environment in vast desert zones (Effat & Hegazy, 2013)

The study Area Map



Map 3 the map of Egypt and the study area

2.4 The GIS and renewable energy

Geographic Information Systems (GIS) functions and its related software (ArcGIS) was utilized to identify the appropriate locations for PV solar and wind energy power plants development; as well as prioritizing the sites to determine which sites would be most suitable for redevelopment.

Further to our discussion, the GIS designed to store, retrieve, manipulate, analyze and display geographical map spatial data. A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world problems from tracking delivery vehicles to recording details of planning applications, to modelling global atmospheric circulation last but not least, the site suitability analysis.

The combination of a GIS and multi-criteria methods produces an excellent analysis tool that creates an extensive database of spatial and non-spatial data, which will be used to simplify problems as well as solve and promote the use of multiple criteria (Georgiou & Skarlatos, 2016)

For our research, a number of ArcGIS 10.4.1 tools were used to prepare process and manipulate the results and the data used. Furthermore, GIS tools and functions enabled to store, manage, and represent the excluded areas and the results respectively.

Recently, a modern research proposed a Fuzzy AHP-GIS approach to obtain the weights of the used criteria in order to select the best location to implant an onshore wind farm(Sánchez-Lozano, García-Cascales, & Lamata, 2016)

Although determining site suitability for solar PV and wind power plants requires complicated methods in order for conducting data processing and analysis tools and decisions techniques, GIS tools offer significant functions to examine the availability of the ideal location for solar PV and wind power plants using the GIS combined with an analytic hierarchy process (AHP) based on standard criteria.

In regards to the data analysis, i had started the analytical processes when I used the ArcGIS 10.4.1 in order for excluding the areas, which considered unsuitable areas

for locating the solar PV power plants or even the wind farms. This comprises areas such as residential areas, agriculture area, and water bodies.

2.5 Evaluation Criteria for Locating solar PV in Sinai

The current study applied and enhanced the previously used methods and models to create a model to find suitable sites for a PV solar farm as per the nature of our study area. That model was utilized based on various criteria and may provide a illustrated data or even serve as a model for future researchers and studies. Furthermore, may be useful for researchers and developers to be able to visualize optimal sites for future solar power plants in large-scale areas.



Figure 6 an example of solar photovoltaic project in Egypt

PV solar site suitability implementations were affected by different factors. Which have been classified into three main categories: Technical, Economical and Environmental. Those factors included the daily average solar radiation, slope, protected area, land cover, cities, grid proximity, and roads to identify the most

suitable areas for locating the solar PV farm in the Sinai Peninsula. These data were acquired from many sources as per table No1.

According to our study area and its nature, and as per the survey of the old studies and classical research in the area of the green power. We developed the Evaluation criteria based on standard factors and constraints. Furthermore, the procedure designed for the study was based on MCE using the arcgis10.4.1 and the suitability analysis. The MCE decision-making approach was adopted based on the designed principles developed by NREL. Since The NREL guidelines were based on global acceptability (Zell, Engel-Cox, Eckman, & Stackhouse Jr, 2008)

In regards to evaluating the optimal location to implant PV systems, the solar radiation consider is one of the most important factors that determine whether the candidate locations will receive sufficient sunlight throughout the year.

Generally, PV systems efficiency is higher in the sunnier regions, as a rule of thumb, PV systems require a minimum global solar radiation (GHI) of (1300 kwh/m²y) its equal to (3.5 kwh/m² day) for economical operation (Kiatreungwattana et al., 2013).

The Annual global horizontal solar irradiance (GHI) in [kwh/m²] GIS data obtained from the global solar atlas.(Global Solar Atlas, 2017) Solar radiation and other parameters are provided as raster (gridded) data in two formats: GeoTiff and AAIGRID (Esri ASCII Grid). For our study, we choose to download the GeoTiff raster in for processing in the Arcgis10.4.1.

The used GHI layer has a geographic spatial reference (EPSG: 4326) resolution (pixel size) 30 arcsec (nominally 1 km).

The GHI data layer measured as a Long-term yearly average of global horizontal irradiation in kwh/m², covering a period from 1994 to 2015. In addition, it covers the period from 1999 to 2015 on (Sinai Peninsula). On the other hand, the solar atlas of Egypt shows that the high intensity of direct solar radiation ranging from (2000-3200) kwh/m² y gradually from north to south.

In regards to land suitability analysis for locating the renewable energy activity, land specific conditions designed based on NREL's model, the scientific principles

stipulated in NREL’s guidelines were pivoted on social, economic and environmental traits that influence the location of solar PV plants within an area. One key consideration as regards land is that the average land use requirements for solar PV are 7.9 acres/MW which is suitable to incorporate all associated infrastructures concerning its apt location (Ong, Campbell, Denholm, Margolis, & Heath, 2013)

On the other hand, an insignificant decrease in PV system efficiency arises when solar irradiation exceeds 2000 kwh/m²y, due to the negative effect of higher ambient temperatures on PV module efficiency Quaschnig (2004).

Considering everything, the below figure illustrates the solar PV site suitability analysis:

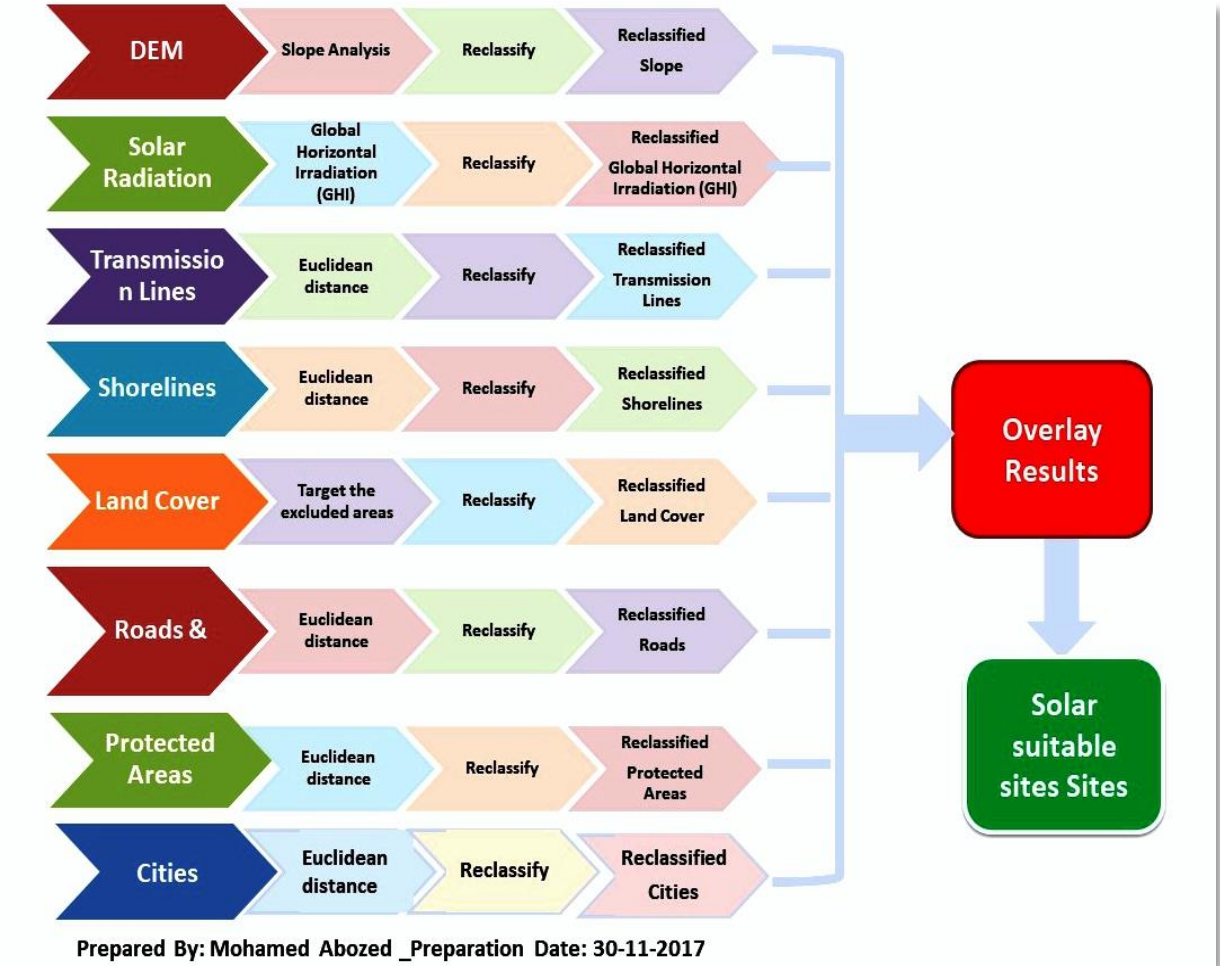


Figure 7 overview of the solar PV site suitability

The reclassification processes manually operated based on four main classes. The class number four (most suitable) and gradual suitability to the rest of classes until unsuitable when the class to one.

Taking everything into consideration, I had restricted the protected areas, built-up areas, agriculture areas, airports were also eliminated from the rest of areas.

2.6 the solar PV site suitability analysis

to come up with determining the the most suitable areas for locating the solar PV power plants. we have passed numerous proceeses starting with defing the study areas then collecting data and sequentially depecting the results.In the following sections, further discussion will explain in more details how did we defined and sequentially ranking the study area for defining the most suitable lands, identifying and prioritizing the potential sites for solar PV power plants. Further discussion in the following sections to explain figure (No8) that illustrated the processes we had conducted our processes as per the following steps:

2.6.1 The Solar radiation reclassification of Sinai peninsula

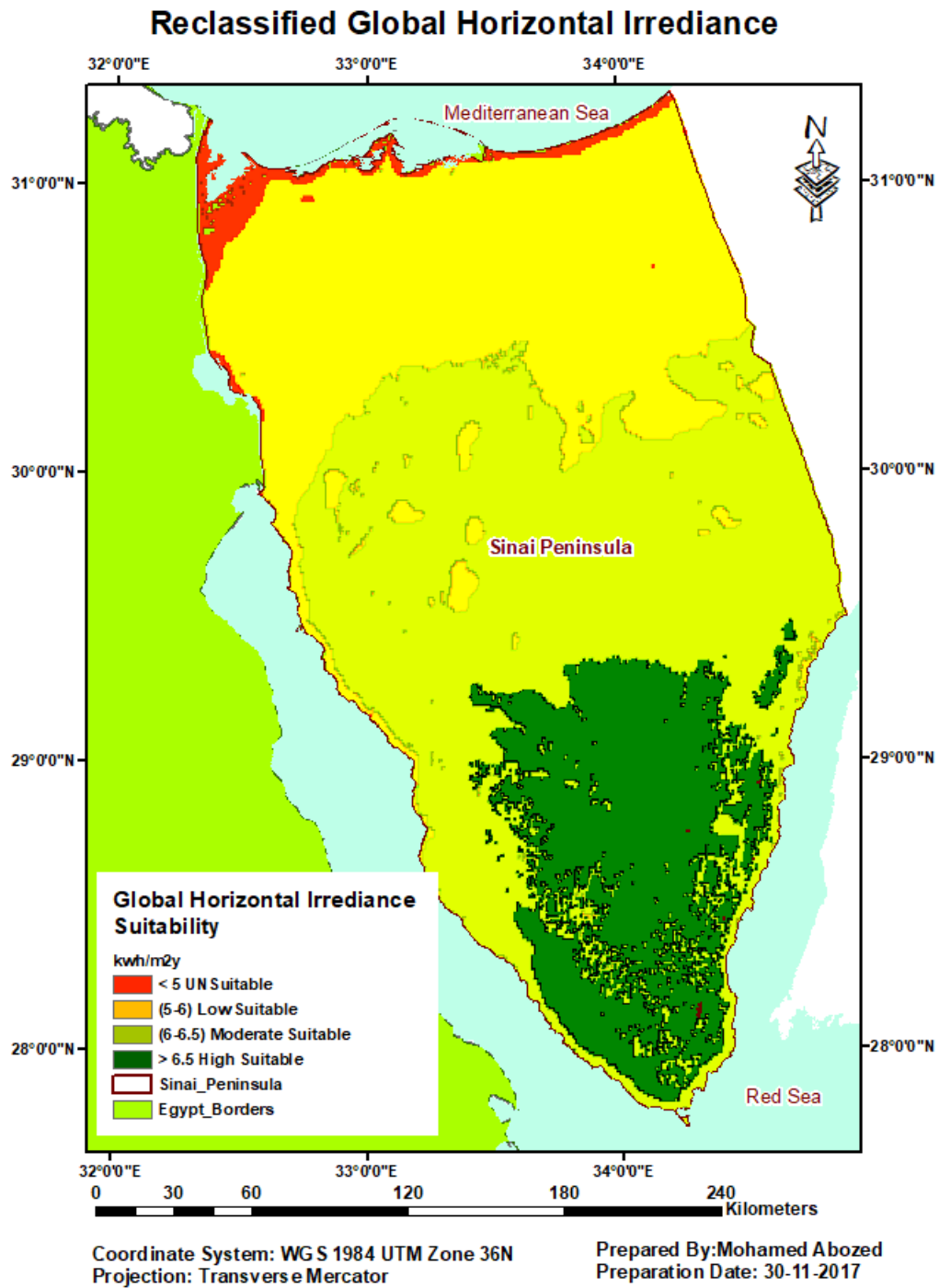
In order for doing the solar PV suitability analysis, I have prepared, analyzed and processed the downloaded the Global Horizontal Irradiation (GHI) layer,which represents the yearly long time average of the global solar irradiance for the years (2004-2011) in kwh/m² with the integration of shadow effects due to surrounding relief in 30 arc/sec (1km) Resolution.

Table 2 Reclassification of Global Horizontal Irradiance

Old values in kwh/m2	New values
0 - 5	1
5 - 6	2
6 – 6.5	3
>6.5	4

As we have mentioned before, and as per the rule of the NREL, the efficient solar PV systems considered the areas with intense sunshine with solar radiation exceeding 1300 kwh/m²y to be economically feasible which is equal 3.56 a day (International Energy Agency, 2010). Thus, the areas with lower than 1300 kwh/m²y considered not suitable. Logically, the average of daily global solar

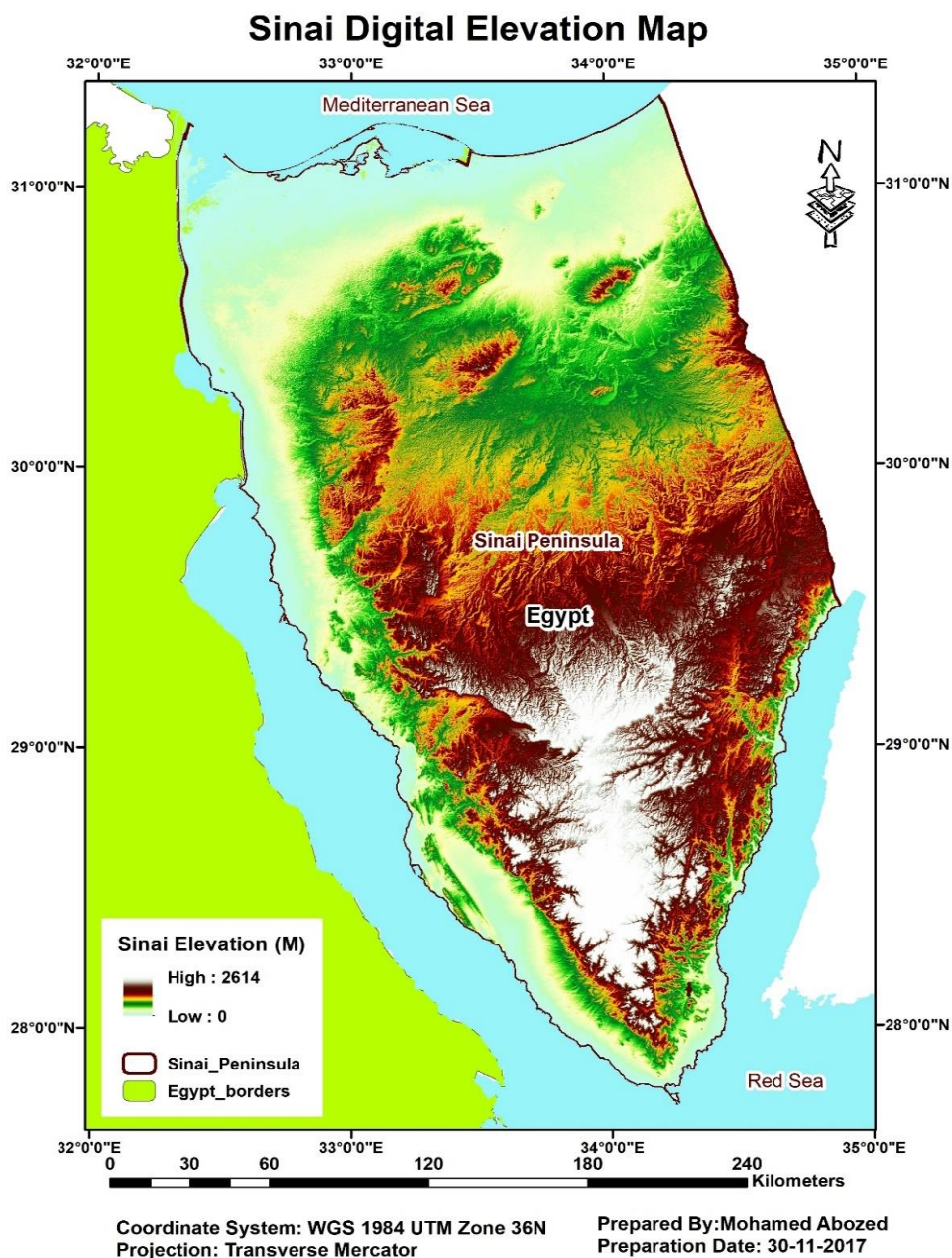
radiation raster data In addition was reclassified to main four categories with high suitable when the solar irradiance exceeded (6.5) kwh/m²day day and unsuitable solar radiation value less than (5) kwh/m²day and marginally moderate and suitable for values between (5 - 6.5) kwh/m²day respectively.



Map 4 suitability map of global solar radiation

2.6.2 Slope of Sinai peninsula

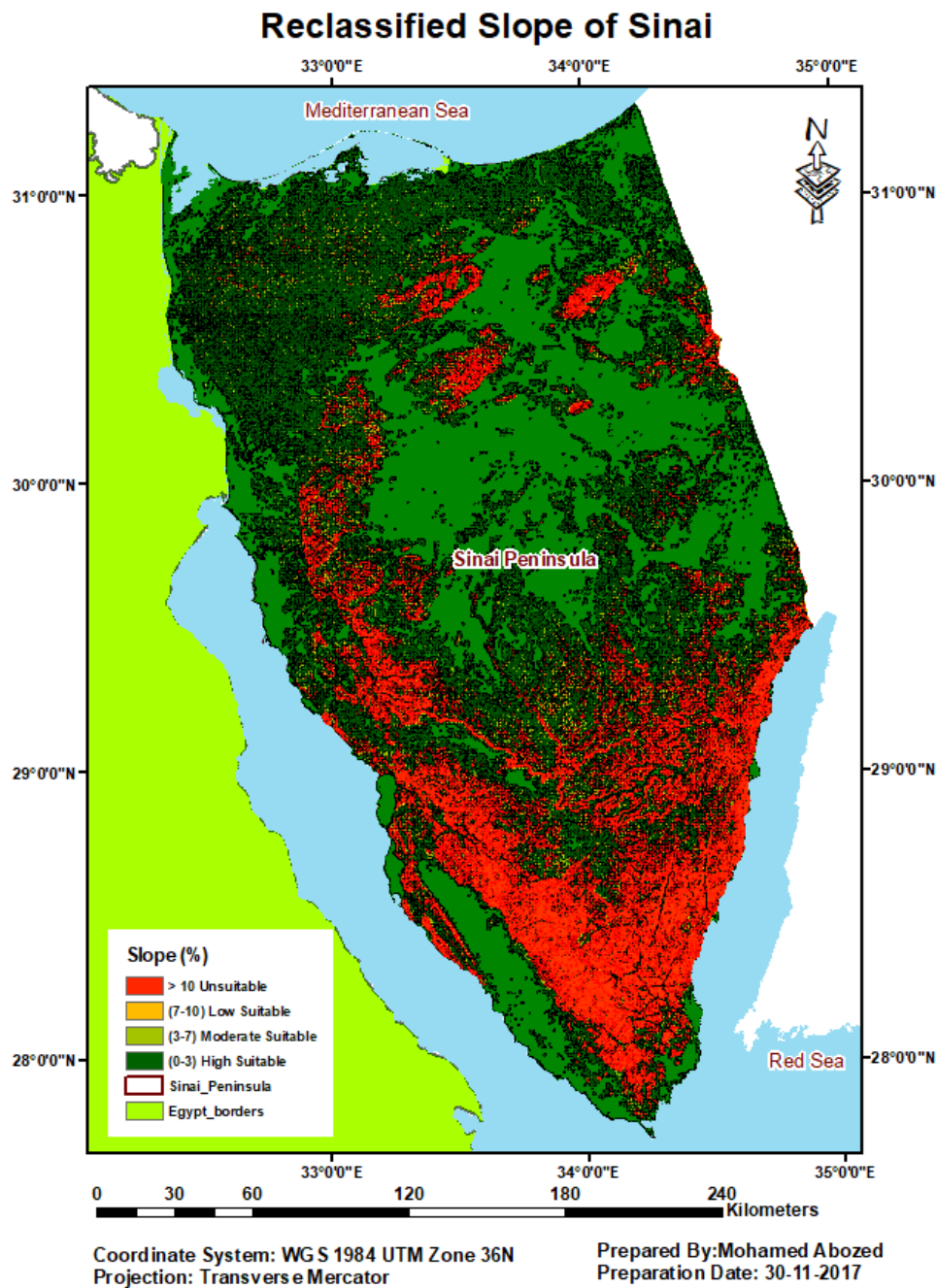
it is commonly known that the Slope means the steepness of a surface. This is consider the main reason why it is a very important factor for any research. Logically, Gradient of land will affect the receiving radiation. Thus, the more flat area, the more amount of radiation received. In order to generate the slope layer, it was generated from the DEM dataset which was downloaded and extracted with the resolution of 90m from the SRTM (Shuttle Radar Topography Mission) global DEM indicates that Sinai Peninsula terrain heights maximum is equal to (2614)M .



Map 5 The Elevation of Sinai

If we get a closer look at the below figure to discover the terrain of Sinai, we can see a tremendous mountain in the middle. On the contrary, we can see the flat land near to the shorelines especially the northern area of Sinai nearest the Mediterranean Sea.

The data classification & reclassification of the slope datasets were digitally processed in ArcGIS 10.4.1 using the Spatial Analyst tools.



Map 6 suitability of Slope

Table 3 Reclassification of slope

Old values(Degree)	New values
0 - 3	4
3-5	3
5-10	2
10-68	1

Furthermore, the two key respects determine the nature of slope in solar PV modelling. At First, slope determines the first-order surface configuration of the land. While the Second, the efficiency of solar power received by solar panels, which it is dependent on a surficial slope. For our study, the slope more than 10 percent was selected to the unsuitable areas. Subsequentially, the value of slope was reclassified to four categories with high suitable for flat (0-3) degrees and unsuitable for slopes greater than 10 degrees and marginally moderate and suitable for values in between (Dawod & Mandoer)

2.6.3 Land cover & land use

Land cover is an important key factor considered in establishing any industrial activities especially the renewable energy power plants.To start with, the solar PV farms, the bare areas and soil lands were considered the most suitable areas in case zero slopes. However, the protected areas, the agricultural areas, built-up areas and the tree areas were generally excluded from our consideration.

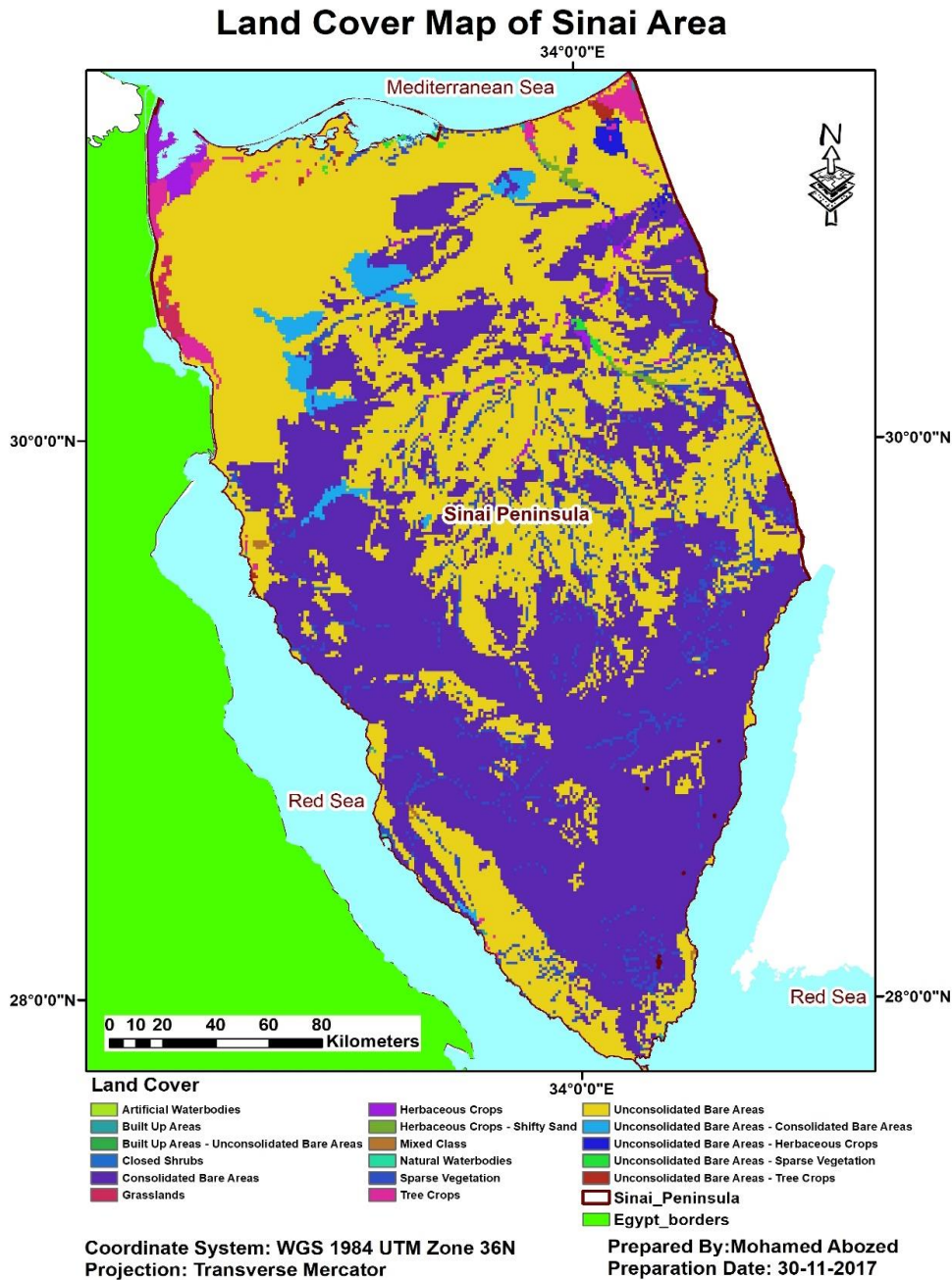
The land cover dataset of the study area was acquired from the “Food and Agricultural Organization of the United Nations (FAO). This land cover database was downloaded in a vector format as ESRI shapefile and then converted to a raster datasets using the ArcGIS 10.4.1.

The land cover daset has been post-processed to generate a vector version at national extent with the Land Cover Code System (LCCS). This Glob cover datasets is currently considered the most recent and finest resolution. It was published in 2002 and intended free public access (Food and Agricultural Organization (FAO), 2002). Furthermore, there were areas of the land cover map that was unsuitable to establish the industrial activities. Firstly, I have excluded (Artificial Waterbodies, Built up Areas, Closed Shrubs, Grasslands, Mixed Class, Natural Waterbodies, Sparse Vegetation, and Herbaceous Crops) from our study due to the nature of these areas.

Secondly, we choose the optimal locations for the solar PV power plant to be located in open areas (bare areas) in order for reducing the impact to the urbanization.

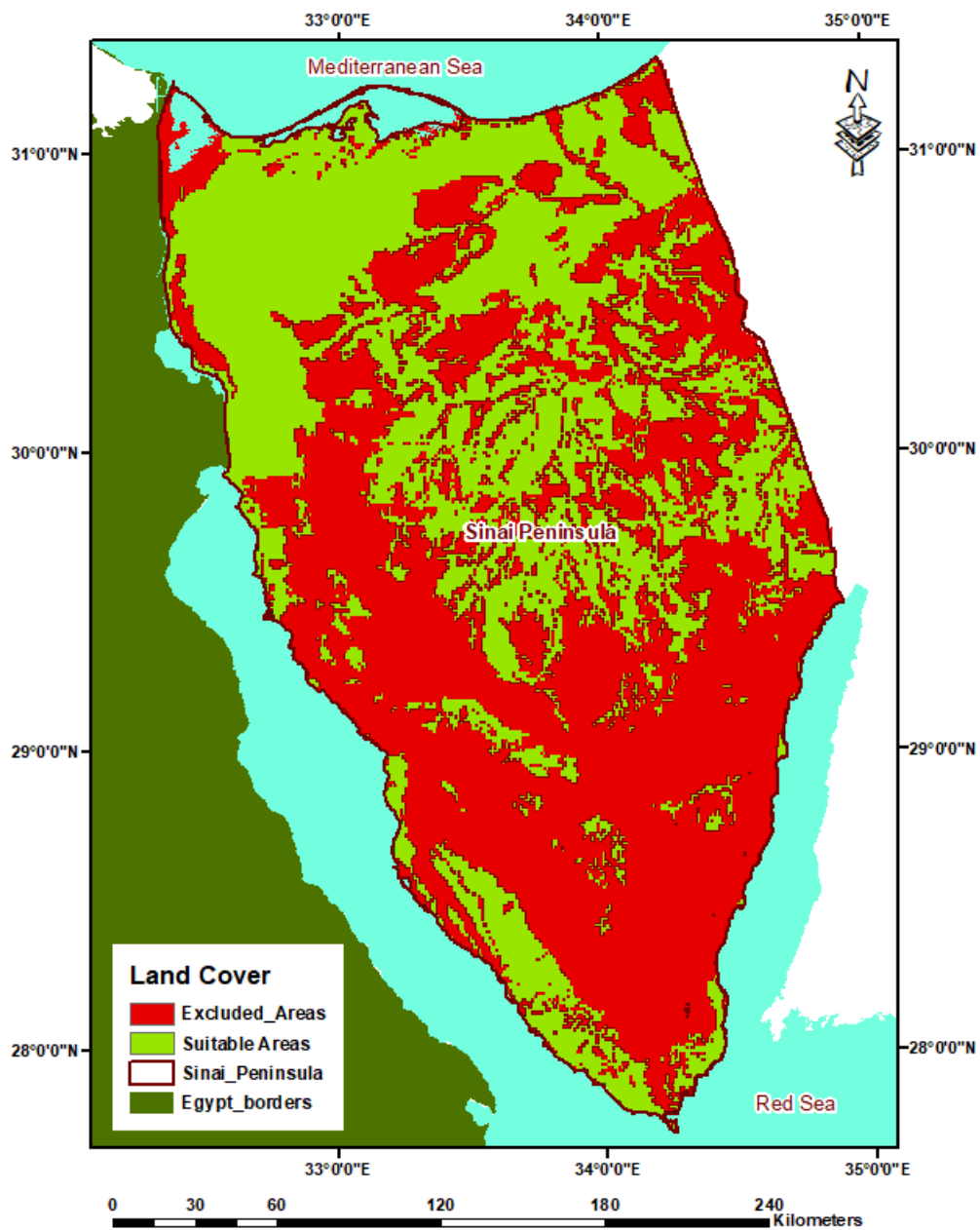
It important to mention that, the FAO datasets, the classes that have been chosen as suitable areas depends on its nature and as per google earth.

All of the aforementioned land cover classes were constrained from the study by assigning them a value of zero.



Map 7 Sinai land cover classification

Reclassified Land Cover Map



Coordinate System: WGS 1984 UTM Zone 36N
Projection: Transverse Mercator

Prepared By: Mohamed Abozed
Preparation Date: 30-11-2017

Map 8 Land Cover Suitability of Sinai

2.6.4 Distance to Transmission lines

The distance between the transmission lines of electricity economically considered as an important factor that seriously should be taken into account in selecting the most suitable locations for building the renewable energy projects.

Table 4 Reclassifications distances of transmission lines

Old values in meters	New values
0 - 500	2
500-5000	4
5000-20000	3
20000 - 105185	1

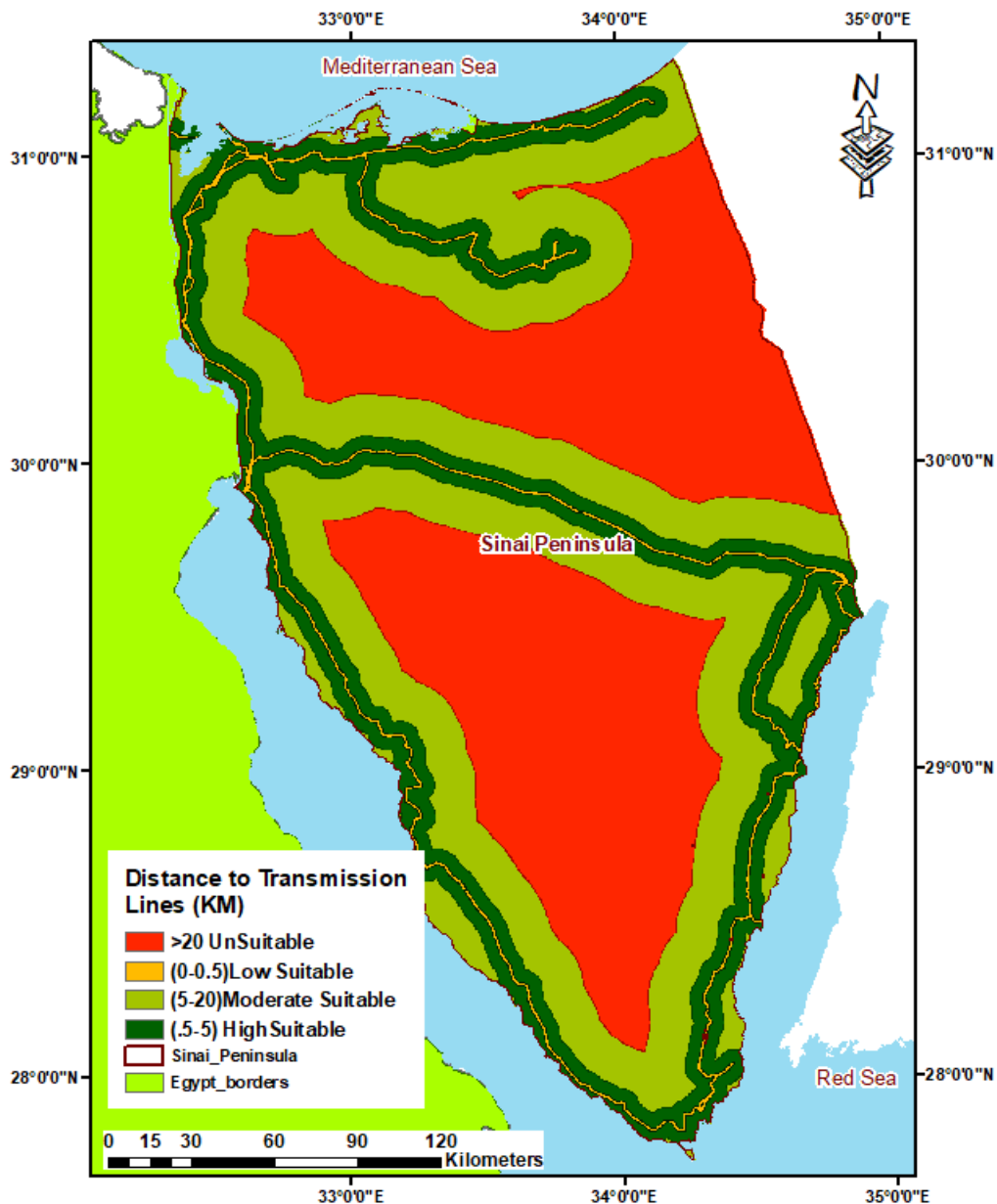
The distance to transmission lines is a necessity in order to transport the energy generated by the solar PV and to reduce the costs of establishment and maintenance. Therefore, we considered these areas as the more suitable sites if it is mainly located close to the transmission lines and far from the solar PV. Moreover, the distance between the proposed sites and the transmission grids depends on the topography of the study area and the distribution network; the local distribution company may also allow direct power injections from the solar PV into the medium voltage networks as per its policy of distribution.

As we have previously mentioned, Sinai Peninsula is a huge free area and the chance establish industrial activities is highly suitable over there. Therefore, the availability of the soil and the desert regions for utilization of solar energy increasing the possibility of eliminating potential areas, we defined the criterion and the distance of 20 km to 500 m respectively as the arrange of suitability (Noorollahi, Fadai, Akbarpour Shirazi, & Ghodsipour, 2016). Finally, the area less than 500 m from the transmission lines will consider low suitable.

In conclusion, we have used Euclidean Distance in ArcGIS 10.4.1 and then reclassified the distance between the transmission lines and the proposed areas as per the table No4.

The below map (No9) illustrates the distances between the proposed areas and the transmission lines.

Reclassified Distances to Transmission lines



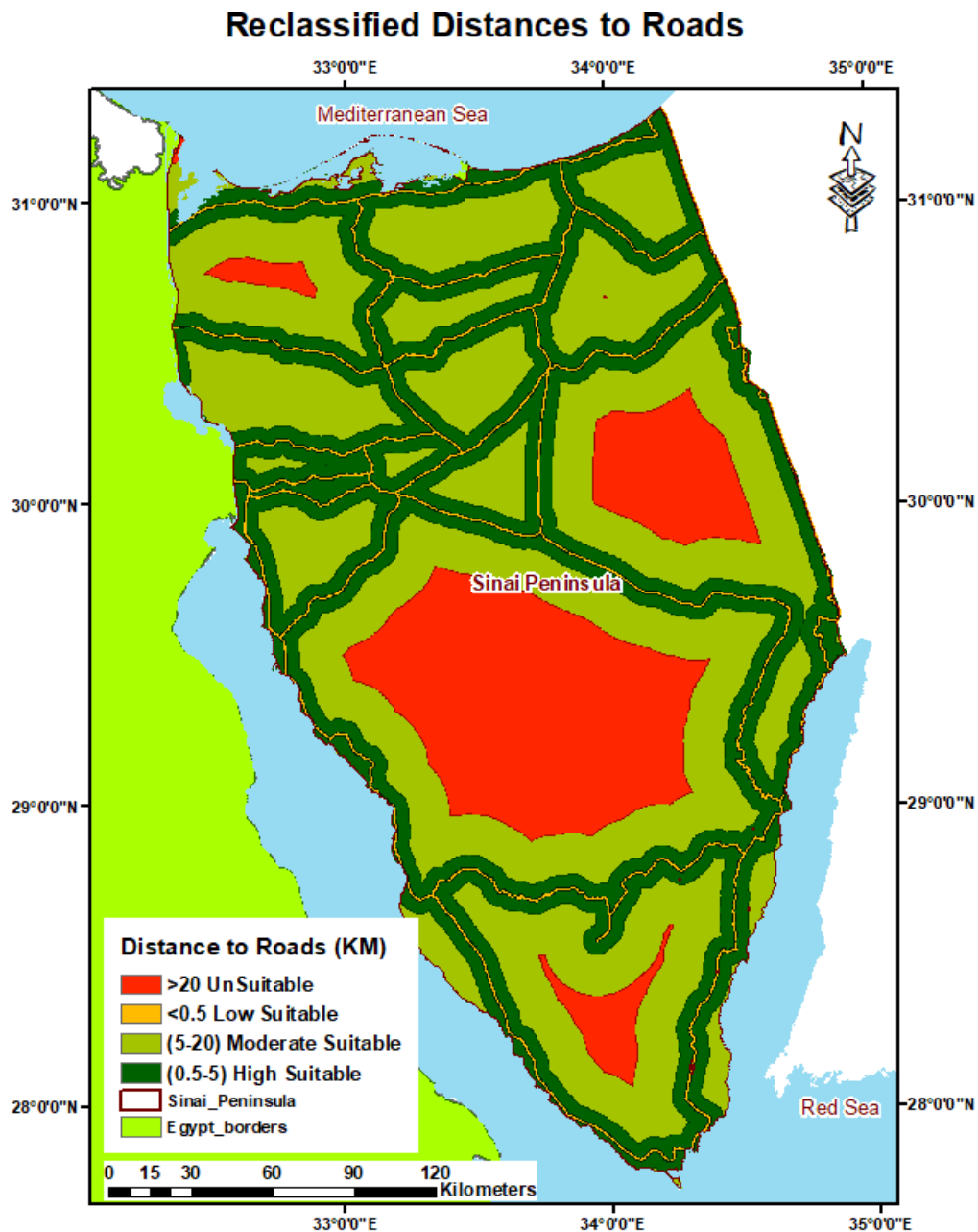
Map 9 Suitability Distances of the transmission lines

2.6.5 Distance to roads

Accessibility to the Renewable energy facilities is a key factor in installation of solar PV plants. This is economically efficient as it curtails the cost of transportation and enhances access.

This proximity measure enhances the focus on potential areas of location thereby easing the phasing out of spatially unsuitable areas. Basically, the Construction of new access roads for transportation of goods and equipment is very expensive and is one of the unavoidable factors in the construction of solar plants.

Although the focus here is on the major road, 20 km and 500m, has been selected as most suitable locations for PV of the study area (Noorollahi et al., 2016)



Coordinate System: WGS 1984 UTM Zone 36N
 Projection: Transverse Mercator

Prepared By: Mohamed Abozed
 Preparation Date: 30-11-2017

Map 10 Suitability Distances of the roads

As we previously did, the procedures we have followed in the transmission lines reclassification, we have used Euclidean Distance in ArcGIS 10.4.1 and then reclassified the distance between the Saini roads and the proposed areas as per the table No5.

Table 5 Reclassifications distances of roads

Old values in meters	New values
0 - 500	2
500-5000	4
5000-20000	3
20000-711196	1

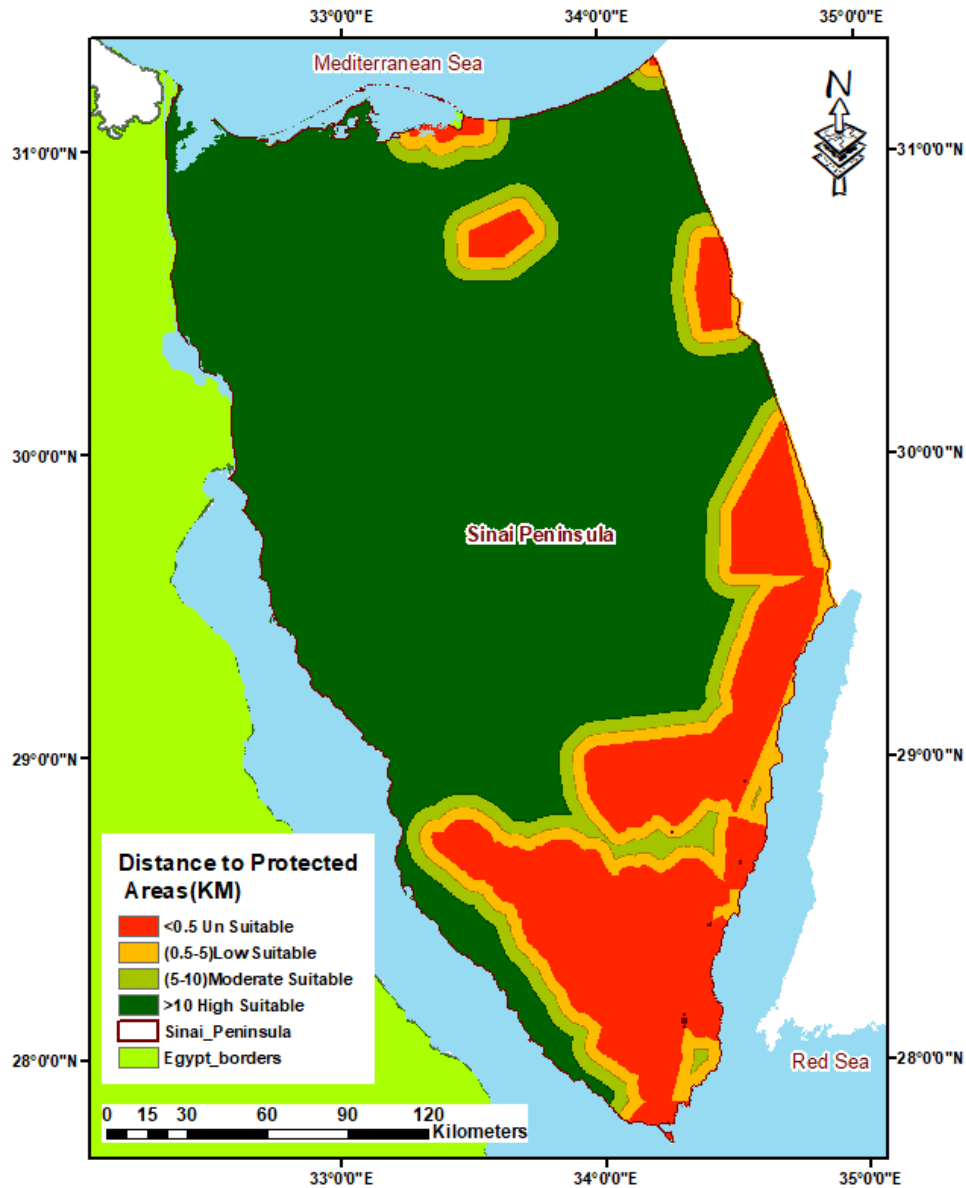
2.6.6 Distance to protected areas

Solar PV power plants should be set apart from a protected area like the inhabited areas or birds sites as well as the historical places. According to the nature of our study and Depending on the technical status and the nature of the study area. Based on the protected area; the distance from the protected areas was reclassified to four categories with high suitable to > 10 km and unsuitable when the distance less than 500 m and marginally suitable, moderate for values in between.

Table 6 Reclassification distances of Protected Areas

Old values in meters	New values
0 - 500	1
500-5000	2
5000-10000	3
10000-152422	4

Reclassified Distances to Protected Areas



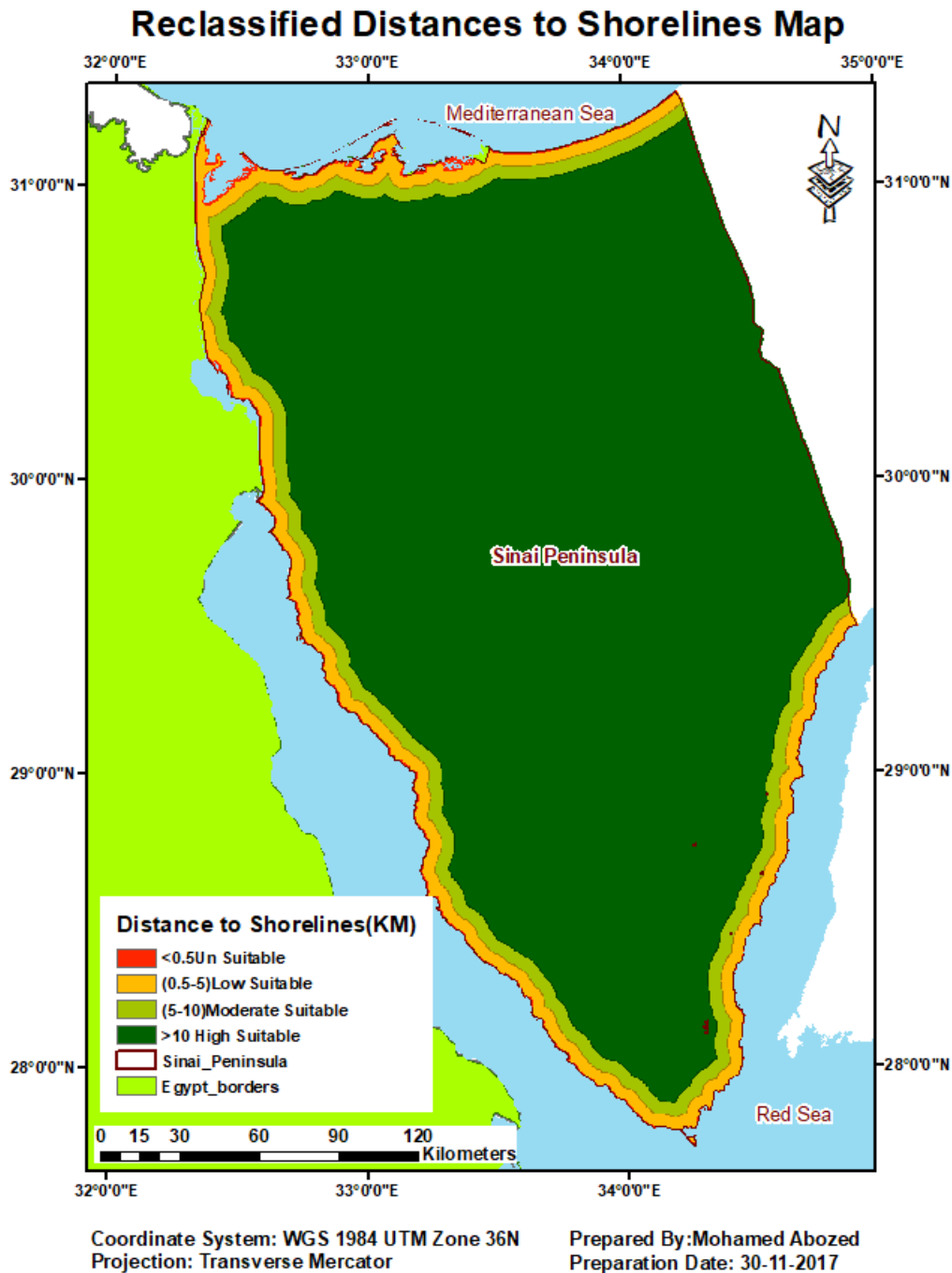
Coordinate System: WGS 1984 UTM Zone 36N
 Projection: Transverse Mercator

Prepared By: Mohamed Abozed
 Preparation Date: 30-11-2017

Map 11 Suitability Distances of the protected areas

2.6.7 Distance to shorelines

The Rivers, lakes, wetlands and shorelines areas were excluded. These areas considered unsuitable for locating the solar power plants. Due to factual reasons and legal regulations. It not deniable that, the water surrounds Sinai. Generally, the more distance from the shorelines the more suitable areas for renewable energy especially.



Map 12 Suitability Distances of Shoreline

Therefore, we only will consider the distance to the shorelines and set the buffer area less than 500 km for the unsuitable area. In addition, the area > 5 km for the most suitable areas (Effat, 2014).

Table 7 Reclassification distances n of shorelines

Old values in meters	New values
0 - 500	1
500-5000	2
5000-10000	3
10000-117650	4

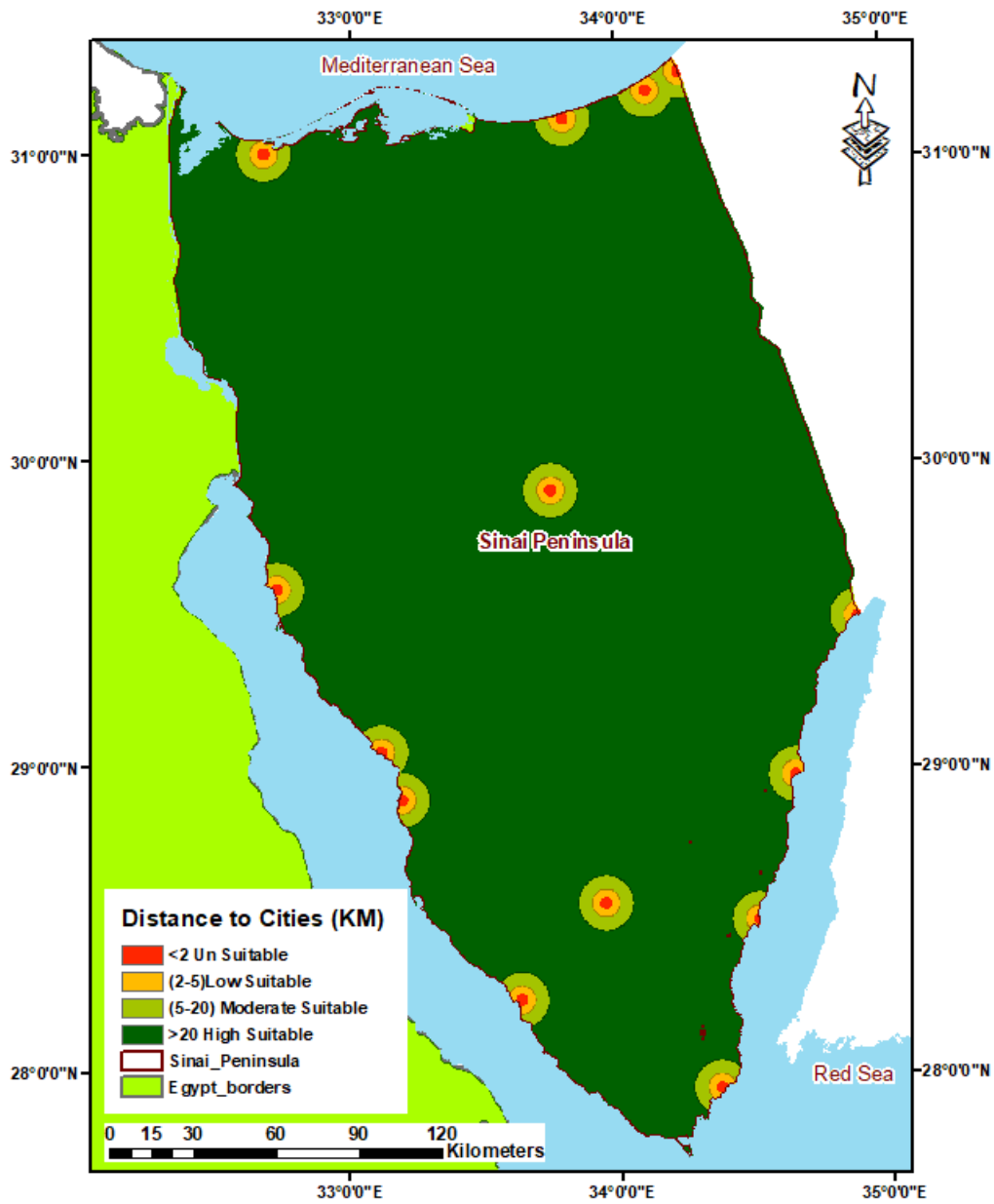
2.6.8 Distance to cities

In regards to the distance between the main cities and the potential sites. The city point layer buffer was reclassified to four categories with high suitable to > 5 km and unsuitable when the distance less than 2 km and marginally suitable, moderate for values in between (Dawod & Mandoer).

Table 8 Reclassification distances of Cities

Old values in meters	New values
0 - 2000	1
2000-5000	2
5000-20000	3
> 20000	4

Reclassified Distances to Cities Map



Coordinate System: WGS 1984 UTM Zone 36N
 Projection: Transverse Mercator

Prepared By: Mohamed Abozed
 Preparation Date: 30-11-2017

Map 13 Suitability Distances of cities

2.6.9 Weighted overlay analysis

In regards to the solar PV weight, overly analysis using the weight overlay tool in ArcGIS10.4.1. The final step of these processes was to aggregate all reclassified raster datasets that include the Horizontal global radiation, slope, and distance from transmission lines, distance from roads, city, shorelines and protected land use and land cover. The Weighted overlay tool works by aggregating all raster layers based on their weights. The final raster was reclassified manually to represent the data as clearly as possible as per below figure.

Finally, the map of suitable area been generated. After the creation of the exclusion area map as well as the rated area map (i.e. scoring and weighting) of the considered criteria, the suitable area is basically calculated by consolidating the exclusion area and the rated area in one map. By doing so, all excluded areas that received a value of zero or one keep that value, (exclusion) adopt the values calculated for the rated area.

As a result, the value score ranges between one and four. Therefore, the suitable areas for locating the solar PV farms values is four. The identified suitable areas were divided into four main classes, as shown in Table (N09)

Table 9 solar PV and wind suitability index

Suitability	Values scores
High suitable	4
Moderate suitable	3
Low suitable	2
excluded _unsuitable areas	1

Furthermore, the weight overlay analysis in finding the most suitable areas for establishing the wind renewable energy power plants, was the same method we have followed in finding the most suitable areas for the solar PV power plants expect in adding the reclassified airports raster layer as an important factor in selecting the wind power plants suitable locations.

The below table (No10) concludes the weights of all criteria in addition to all factors and its suitability. Furthermore, it concludes all values which have been assigned in the weight overlay tool.

Table 10 the Criteria used in Solar PV suitability analysis

Sn	Criteria	Weight%	factors	Suitability
1	Global Solar radiation(GHI)	0.25	<5(kwh/m ² d) 5-5.5 5.5-6 > 6	Unsuitable Low Suitable Moderate Suitable High suitable
2	Slope ,degree	0.15	>10% 5-10 3-5 0-3	Unsuitable Low Suitable Moderate Suitable High suitable
3	Dist. to Transmission lines	0.20	0-500 m 500-5000m 5000-20000m > 20000	Low suitable High suitable Moderate Suitable Unsuitable
4	Dist. to Roads	0.10	0-500 m 500-5000m 5000-20000m >20000	Low suitable High suitable Moderate Suitable Unsuitable
5	Dist. to Cities	0.10	< 2000 m 2000-5000m 5000-10000m > 25000 m	Unsuitable Low Suitable Moderate Suitable High suitable
6	Dist. to Protected areas	0.05	< 100 m 100-5000m 5000-10000m >10000 m	Unsuitable Low Suitable Moderate Suitable High suitable
7	Land Use &Land Cover	0.10	NA	Mainly the bare areas have been selected as most suitable areas
8	Dist. to Shorelines	0.05	< 500 m 500-5000m 5000-10000m >10000	Unsuitable Low Suitable Moderate Suitable High suitable

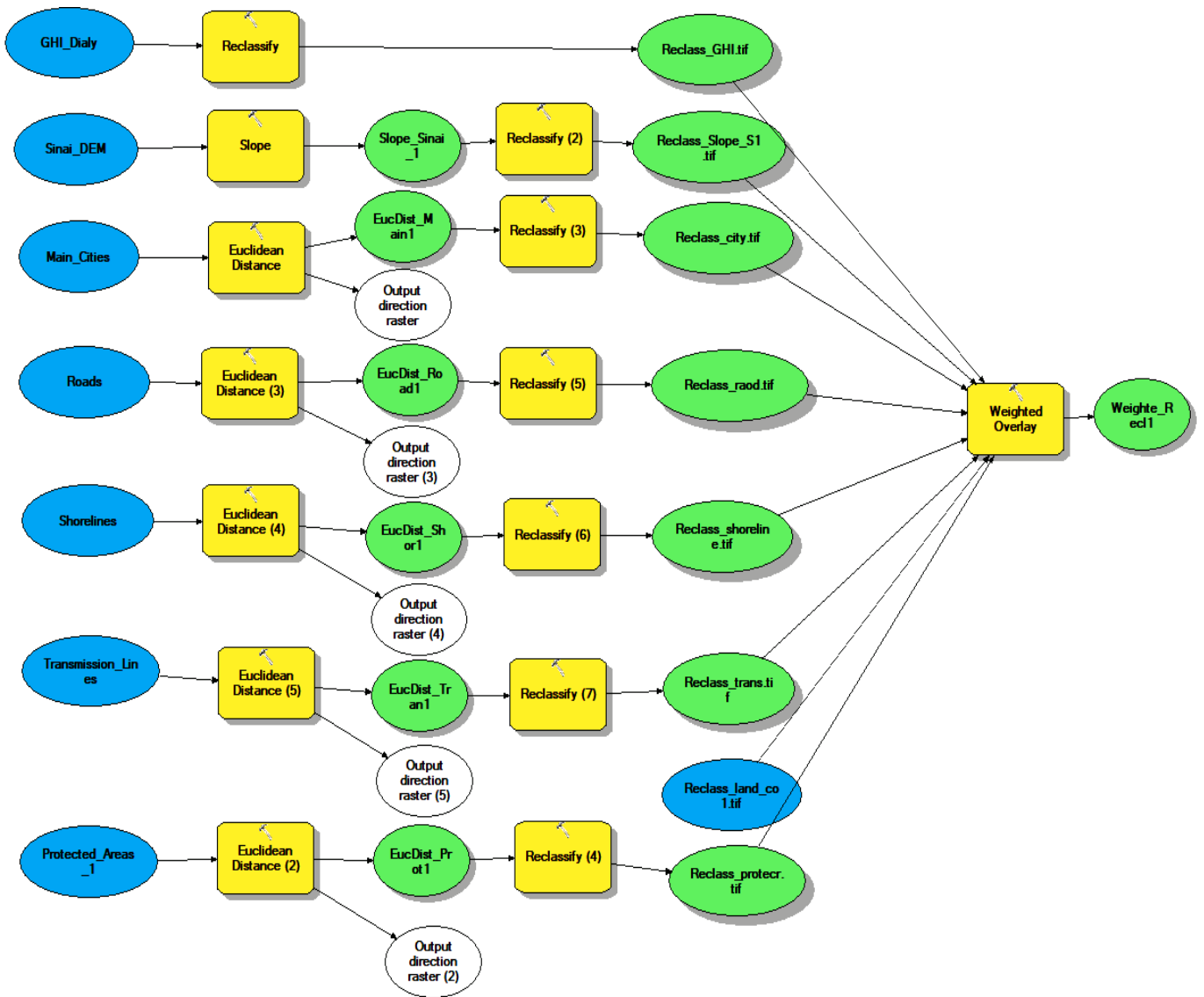


Figure 8 the model builder used in selecting solar PV suitable areas

2.7 Defining the wind power suitable areas

2.7.1 The Wind energy potential of Sinai

The existing wind-power resources are only partially used. Installed wind-power capacity accounted for 610 MW in 2014, which makes Egypt number 32 in the list of nations with wind-power installations.

Recently, the new and Renewable Energy Authority (NREA) built a wind farm of 60 MW closed to Sinai peninsula area in Zafarana region which located on the Gulf of Suez coast, therefore is considered the first large commercial wind farm of 60 MW is being developed across Egypt.

As we can see from the below bar chart, the generated power at the lowest wind speed of 5.4 M/S in January, while the generated production reached to the peak with 127 million KWH in August when the wind speed reached 8.8 M/S.⁴(Sayed Mansour, 2017)

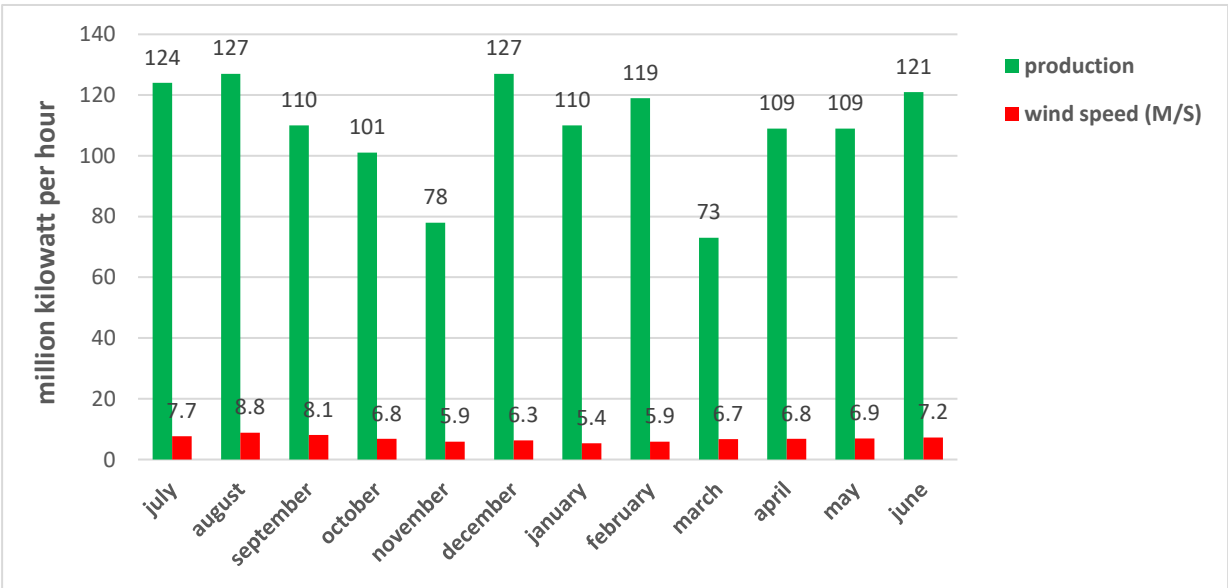


Figure 9 Zafaranah Wind farm production in comparizon to wind speed

⁴ Source: <http://nrea.gov.eg/beta/Technology/WindStations>

Due to Sinai unique location and the variety of the terrain areas. Sinai considered a perfect location in producing the most types of renewable energy resources especially the wind power, which has the needed capability in producing a competitive generated power as per the expected especially when wind speed reaching 10 m/sec in some area (Egypt's New and Renewable Energy Authority, 2017)

2.7.2 Defining the wind farm and the selected criteria

Similar to the previous assessment in finding the suitable locations for the PV solar power plants in other areas of the world, Site selection for large wind power plants requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use. We have applied and enhanced previously used methods and models to create a GIS model to find suitable sites for a wind energy farms. This model, based on various criteria, may provide data or even serve as a model for future researchers and studies. This model may be useful for the Egyptian researchers and developers to be able to visualize optimal sites for future solar & wind farm development.

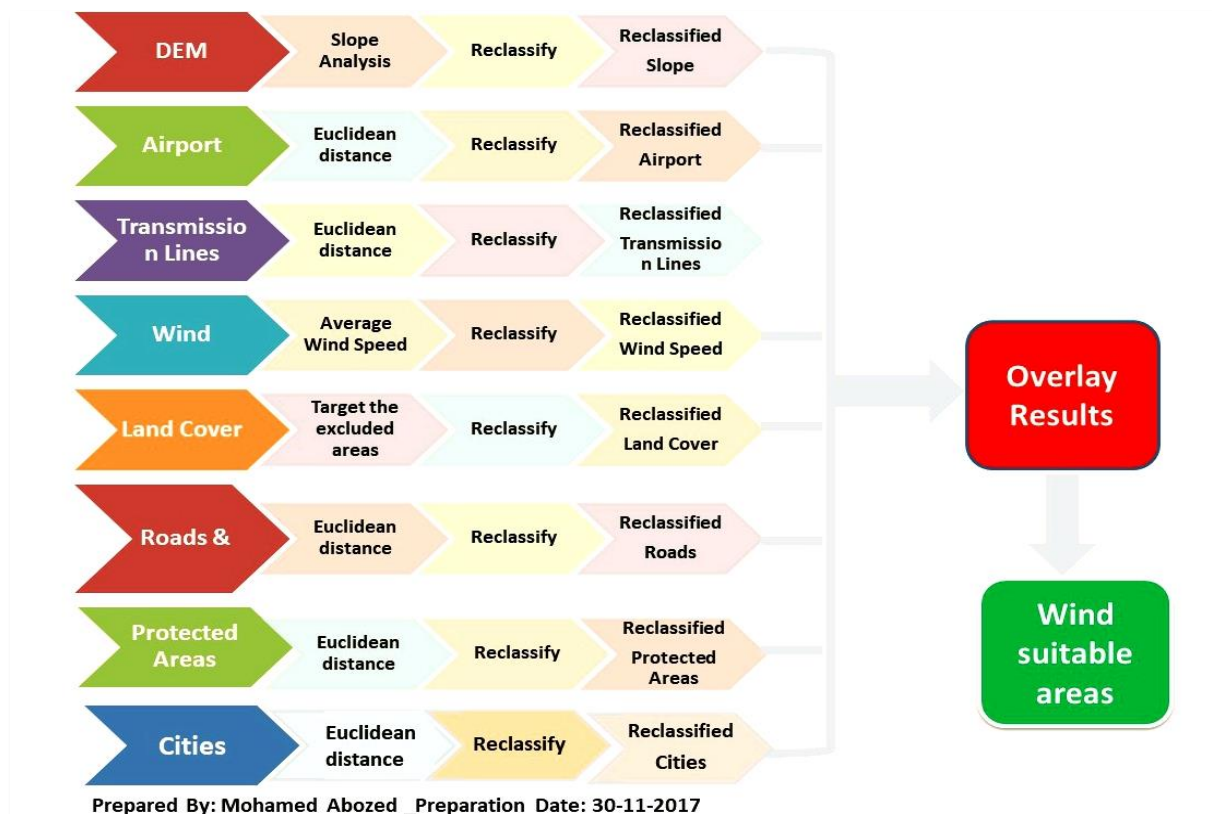


Figure 10 the overview of wind farms site suitability

The processes of the criteria selection are based on the comprehensive literature Review. These crucial criteria are to identify the suitable location for Wind farms to be installed in Sinai.

To sum up, the selected layers we considered many variables predominately including (wind speed, protecting areas, distance to cities, distance to roads, distance to transmission lines, distance to shoreline ,slope and distance to airports).

From one hand, these raster datasets mainly same as the raster layers used in defining the solar PV power plants optimal location. Even though, as per our research the technological advancements, There were many wind farms were located close to the shoreline and inside the open water areas especially across the European Union countries as per figure (No12) but rather, we considered the distance form shorelines in our study.

In addition to airports raster datasets that did not use in finding the suitable sites for solar PV power plants. We have used the shorelines data sets in order for considering all-important factors in our assessment. In the following paragraphs, we shall discuss our proposed criteria and then we have explained the criteria used in order for defining the suitable areas for wind power plants.



Figure 11 Norway wind farm in the North Sea

2.7.3 The average Wind speed of Sinai

Essentially, the Site selection for large wind turbine requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use (Bennui, Rattanamanee, Puetpaiboon, Phukpattaranont, & Chetpattananondh, 2007)

The Wind speed dataset was obtained from NREL and was particularly represents wind speeds measured at 50 m above the ground and are considered a True Wind solution that has been adjusted based on surface roughness and historical data (Janke, 2010).

Logically, the wind turbines performance depends on the wind speed. Therefore, the average wind speed considers a key criterion in determining the economic performance of a wind turbine. In addition, the wind energy potential criterion is incorporated in almost every study and is mainly considered the most important criteria (Bennui et al., 2007). One more opinion said, the wind energy potential criterion is incorporated in almost every study and is mainly considered one of the most important criteria. However, the annual average wind speed below 6 m/s been considered no longer economically feasible and, therefore, areas with a wind speed of less than 6 m/s were excluded from our area of study (Ma, Scott, DeGloria, & Lembo, 2005)

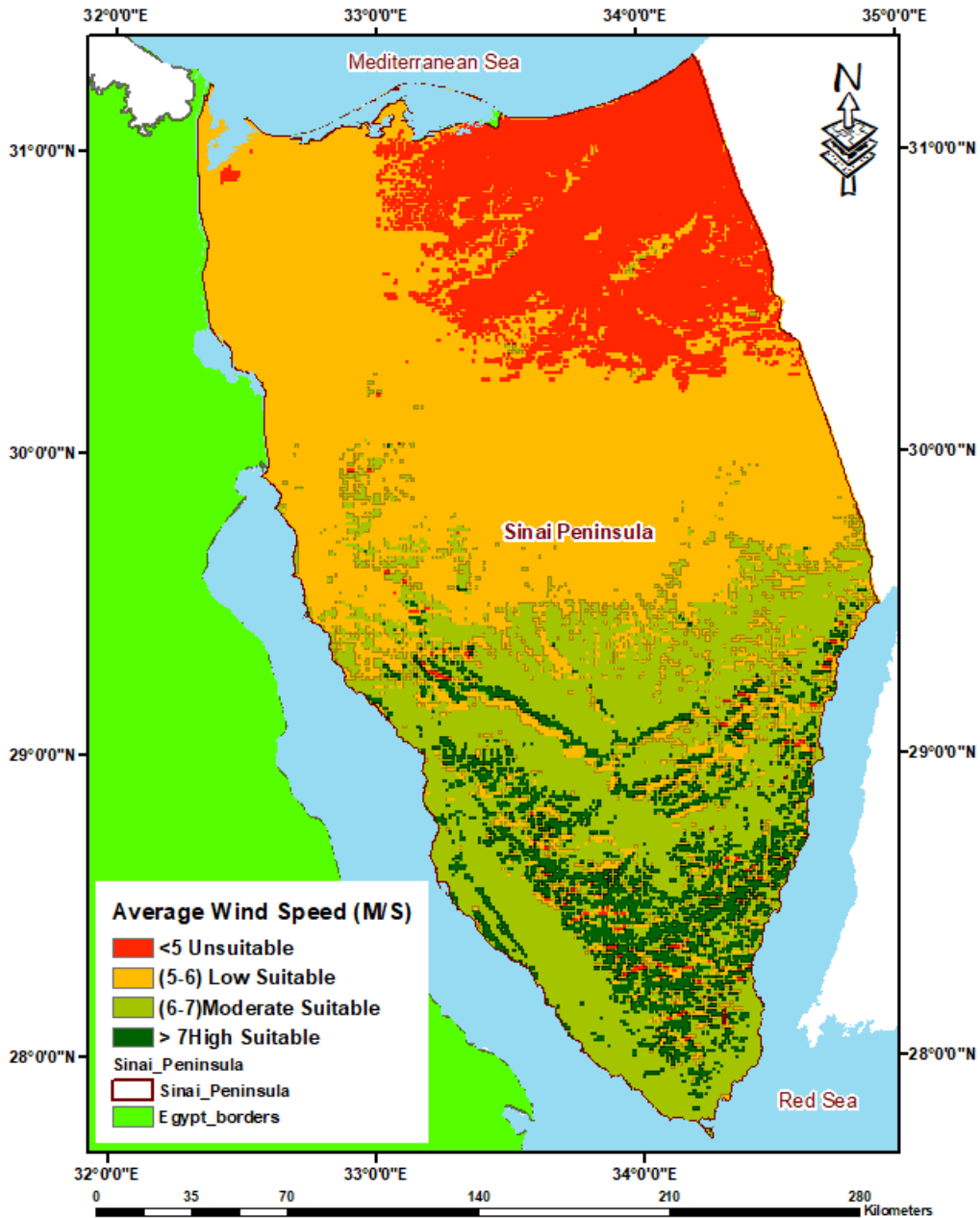
In addition to the above mentioned opinion, The average wind speed was reclassified as per the opinions of regional wind farm planners in addition to the old literature and as per the nature of the study area, we considered the average wind speed above 7 m/s at 50m height considered matches the high score value.

As long as the aim of this study is to use GIS in selecting the most suitable areas for the wind renewable energy. we have conducted the standard analysis using the ArcGIS 10.4.1. However, the average wind speed raster layer was reclassified to four categories with High suitable >7 m/s and unsuitable for wind speed less than 5 m/s and marginally suitable for values in between.

Table 11 reclassification of Sinai average wind speed

Old values	New values
3-5	1
5 -6	2
6 -7	3
7 -12.41	4

Average Wind Speed of Sinai



Coordinate System: WGS 1984 UTM Zone 36N
 Projection: Transverse Mercator

Prepared By: Mohamed Abozed
 Preparation Date: 30-11-2017

Map 14 The Average wind speed at 50 m above the ground

2.7.4 Slope suitability for wind power plants

As we previously mentioned, slope datasets was generated by using the Shuttle Radar Topography Mission (SRTM) elevation with a resolution of 90m in the ArcGIS 10.4.1. The purpose of using such layer in our study is to consider the areas, which its slope value within the range of (0-10) degrees. While the areas with slope value less than 10 degrees were considered suitable for wind energy power plants.

There were important researches conducted by (Effat, 2014; Luo, Banakar, Shen, & Ooi, 2007) revealed the importance of slope steep in moving the wind turbines. Moreover, explained why the summit of steep slopes wind may not hit the turbine rotor at a perpendicular angle. This will result in an increased level of fatigue for the turbine. Thus, the value of slope greater than 5 degrees will yield more turbulent wind patterns causing disruptions in turbine stability. On the other hand, Building on higher slopes also increases project costs. Ideally, the terrain should be rounded or flat because they will be exposed to higher more wind that is constant speeds. Moreover, reported the probability of the turbine failure is increasing when the slope is higher than 9 degrees as it is difficult for the wind to hit the rotor of the turbine perpendicularly at the summit of steep (Bartnicki & Williamson, 2012).

Last but not least, the slope was reclassified to four categories with high suitable for flat to 3 degrees and unsuitable for slopes greater than 10 degrees and marginally moderate and suitable for values in between (Dawod & Mandoer)

2.7.5 Distance from transmission lines

The distance between the transmission lines economically considered an important factor at the time of the cost increasing or decreasing the cost of production. Therefore, it should be taken first into account in selecting the suitable locations for building the renewable energy power plants. It is important to be in close to power stations and the existing transmission lines to minimize production costs (Bartnicki & Williamson, 2012)

The distance to transmission lines is a necessity in order to transport the energy created by the wind turbines and the Land that is connected to an electrical grid. Furthermore, we consider the distance between the proposed sites and the transmission lines depends on the topography of the study area and the distribution

network. The local distribution company may also allow direct power injections from the wind turbines into the medium voltage networks as per its distribution across the study area. However, the layer of the distance between the optimal sites and transmission lines was reclassified to four categories as high suitable between (500-5000)m, and unsuitable when the distance more than 20 km and marginally suitable, moderate for values in between (Dawod & Mandoer)

2.7.6 Distance from roads

There is no doubt that, road access is considered an important factor in regards to the renewable energy projects. In our study, we consider the Distance of 1km from the main roads is classified as highly not suitable. This definition is based on the fact the wind turbines cause visual disturbance to the enjoyment of the aesthetic beauty of landscapes. Distances 5 km from the road is also classified as moderately suitable. As per we previously conducted in defining the solar PV. Main roads raster layer of the distance between the optimal sites and the main roads was reclassified to four categories as a highly suitable to between (500-5000) m, and unsuitable when the distance more than 20 km. whereas marginally suitable, moderate for values in between (Dawod & Mandoer)

2.7.7 Distance from cities

Due to the various unfavourable environmental impacts on the populated centers and urban growth, in this research, distance from residential areas is considered as one of the important criteria in wind farms site selection. Therefore, wind farms are at a distance less than 2000m from the city considered not suitable. Moreover, regions at a distance more than 50 km from populated centers are considered as unsuitable areas (Noorollahi et al., 2016)

2.7.8 Distance from shorelines

(Moilola, 2009) suggested the distance for the wind farm is to be far away from the coast for about 4 km. the identical buffer zone was applied taking into consideration the paths for bird flight and future marine activities for tourism. In our current study, the Wind farms should be set apart from shorelines and wetlands. We set a buffer area less than 500 m for the unsuitable area. While we put the distances >500 m for the most suitable area since Sinai considering the wide area (Effat, 2014)

2.7.9 The distance to protected area

It is not deniable that, Sinai contains wide lands as protected areas. Logically, Wind farms sites should be set apart from the protected area like the inhabited areas, historical places or even birds sites & bird's immigration lines. Depending on the technical factors and the nature of the study area, the distances between the proposed sites and the protected areas, the used raster layer of the protected area was reclassified to four categories with high suitable to > 10 km and unsuitable when the distance less than 500 m and marginally suitable, moderate for values in between.

On a top of that, the other important geological / geomorphologic sites and natural reserves are protected by national legislation. Such lands were considered constraints as the development of a wind farm might have a significant impact on the environmental values of such areas.

2.7.10 The land cover & land use verification

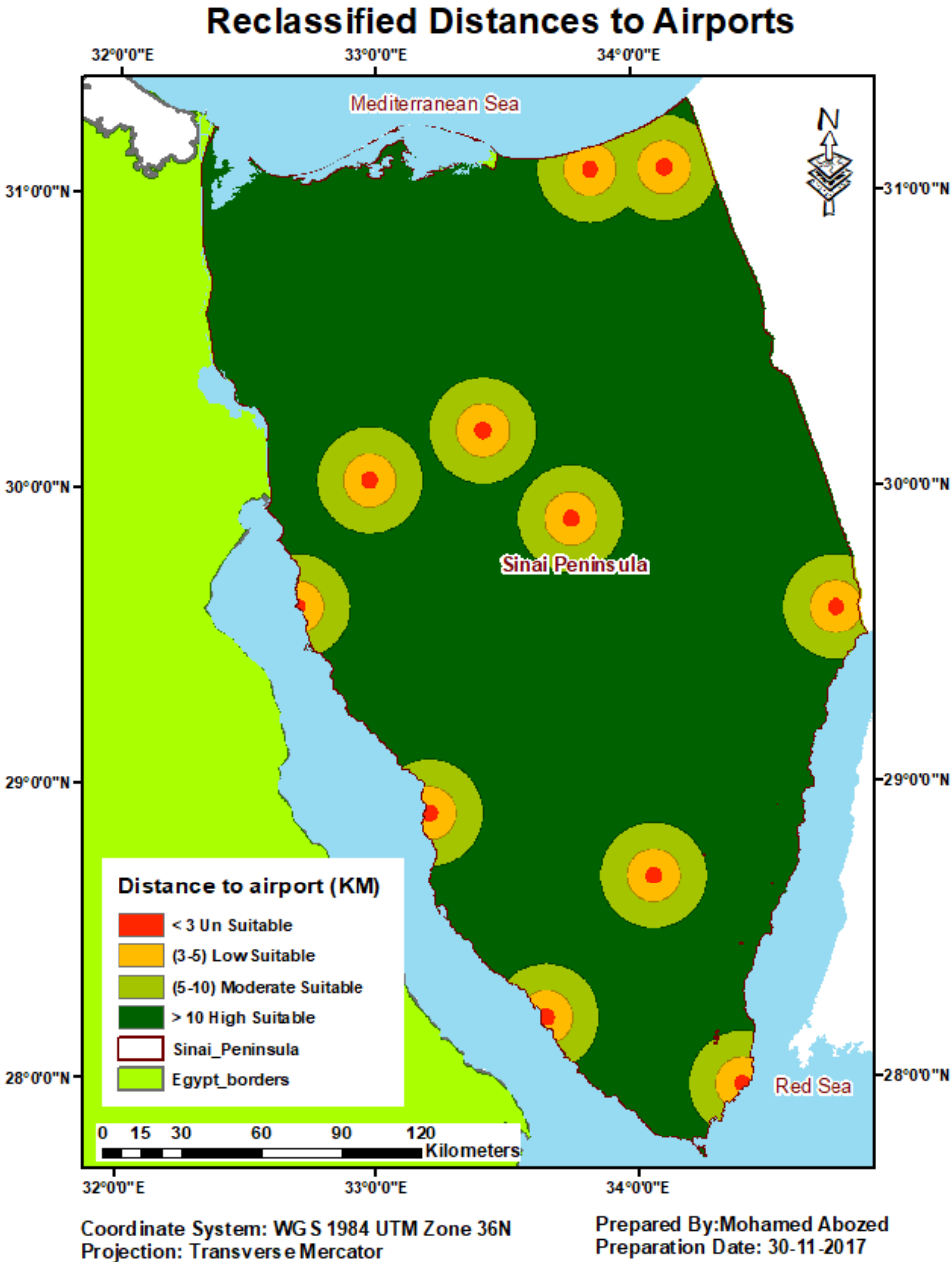
In fact, the nature of the study area fully considered an unoccupied area. Nevertheless, as a matter of affirmation, we have excluded the agriculture areas from our analysis depending on the classification of the raster layer of FAO land cover (Food and Agricultural Organization (FAO), 2002).

Obviously, the term of land use considered an important environmental factor for site selection. Thus , we considered the bare areas, soil and free areas as the best areas for wind activities. In addition, the mountains at the lowest as unsuitable areas. Moreover, the water bodies, built up, natural vegetation, agriculture areas and sand dunes considered unsuitable areas (Effat & Hegazy, 2013).

2.7.11 Distances to Airports

Airports are one the most important factor to be considered the processes of finding the wind power plants suitable sites due to the height of wind turbines as navigation can be affected by such operations. Electromagnetic interference caused by wind farms affects radar and flight paths to airfields close to the proposed sites. On a top of that, it is impossible to fly in the area closest to the wind turbines. Since Sinai has many military and civilian airports in addition to its facilities and runways.

There is an important study by (Dawod & Mandoer) considered the area more than 3 km and less than 3 km from the airports highly suitable and not suitable respectively. However, the spatial suitable analysis model for wind farms consider the airport buffer, which was not taken into consideration the solar farm site suitability analysis.



Map 15 Suitability of Airport Distances

Table 12 Reclassification distances of the Air Port

Old values in meters	New values
0 - 3000	1
3000-5000	2
5000-10000	3
10000-128237.7	4

In conclusion, as per the solar PV site suitability analysis, the same criteria and methods followed in wind farms site suitability analysis. However, the main difference in adding the airports into consideration as added criteria. The airports were considered due to the military nature of Sinai area. The airports' did not consider suitable when the distance less than three km. The below figure illustrates the site suitability analysis. It has been conducted in order for defining the most suitable areas for wind farms using the overlay tool. Table No13 contains all criteria used in the wind farm site suitability analysis

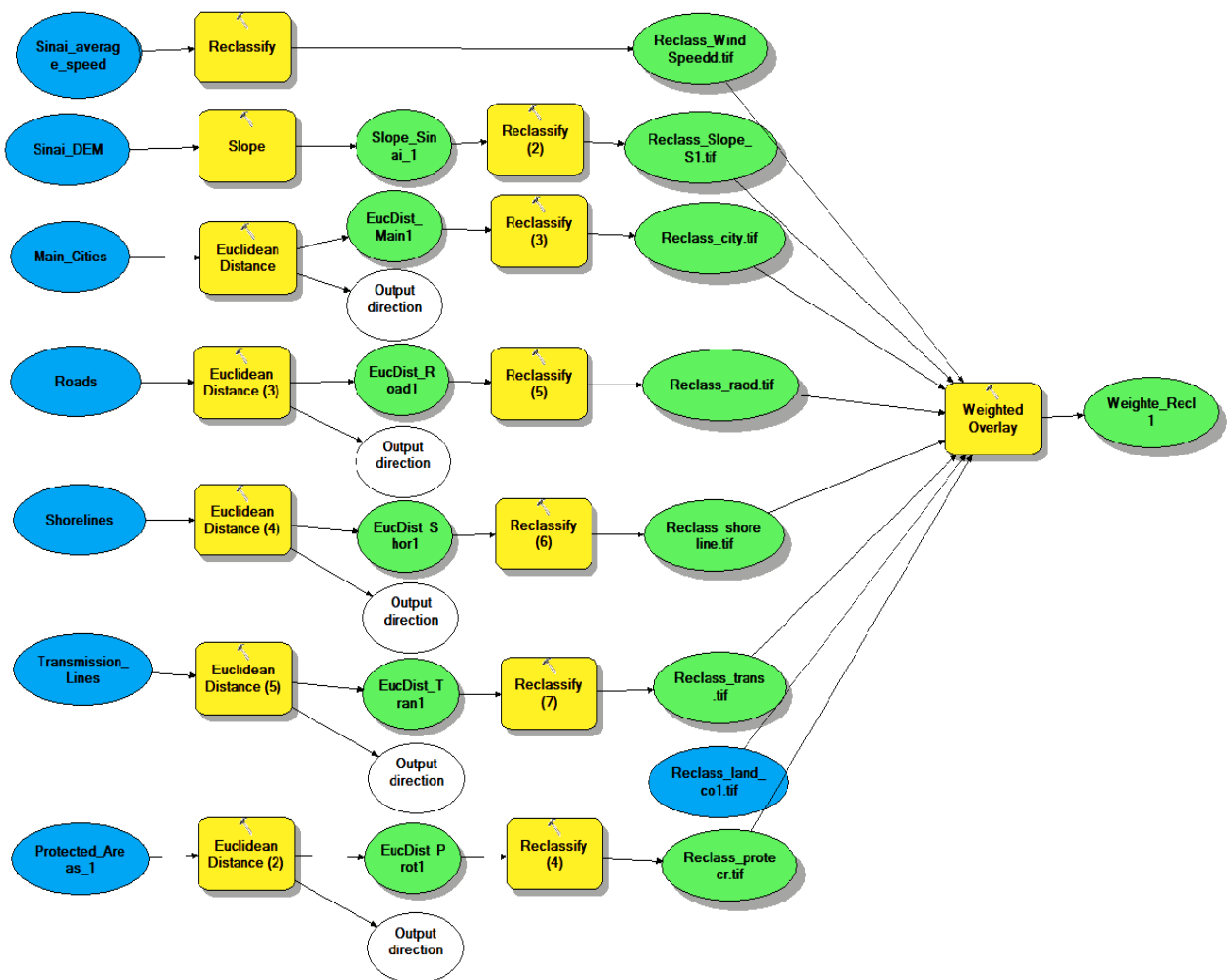


Figure 12 the model builder used in selecting the wind farms suitable areas

Table 13 the Criteria used in wind farms suitability analysis

Sn	Criteria	Weight%	factors	Suitability
1	Average wind speed(50m) high⁵	0.25	<5 (M/S) 5-6 6-7 >7	Unsuitable Low Suitable Moderate Suitable High suitable
2	Slope ,degree	0.15	>10% 5-10 3-5 0-3	Unsuitable Low Suitable Moderate Suitable High suitable
3	Dist. to Transmission lines	0.20	0-500 m 500-5000 5000-20000 >20000	Low suitable High suitable Moderate Suitable Unsuitable
4	Dist. to Roads	0.10	0-500 m 500-5000 5000-20000 >20000	Low suitable High suitable Moderate Suitable Unsuitable
5	Dist. to Cities	0.05	< 2000 m 2000-5000 5000-10000 > 10000 m	Unsuitable Low Suitable Moderate Suitable High suitable
6	Dist. to protected areas	0.05	< 500 m 500-5000 5000-10000 >10000 m	Unsuitable Low Suitable Moderate Suitable High suitable
7	Land Use &Land Cover	0.10	Not suitable	The bare areas have been selected as high suitable areas
8	Dist. to Shorelines	0.05	< 500 m 500-5000 5000-10000 >10000 m	Unsuitable Low Suitable Moderate Suitable High suitable
9	Dist. to Airport	0.05	< 3000 m 3000-1000 10000-20000 > 20000 m	Unsuitable Low Suitable Moderate Suitable High suitable

5 Average wind speed(50m) high in meter per second

Chapter-3

3. Processes and Results

Throughout our study, we have focused to pay the attention to the Sinai Peninsula as a promising region in the northeast area of Egypt, wherever due to its positive conditions; deployment of many renewable energy types like solar and wind power plants may be beneficial for its future development plans. Furthermore, GIS-based MCDA modelling for locating solar PV and wind energy power plant had been conducted based on a regional scale, considered the vast area to date.

The aim of this study was using the GIS tools to find the most suitable areas for two types of renewable energies the solar PV and the wind based on the principles developed by NREL and the old literature. If we look at the solar PV based on the NREL model, efficient solar PV systems require areas with intense sunshine with solar radiation exceeding 1300 kWhm²year to be economically feasible. However, GIS offered the needed level of functionality that was difficult to achieve with other software packages; they have powerful analytic capabilities, exceptional spatial data management storage, and retrieval functionality, and an array of visualization tools that make them an invaluable tool for site suitability analysis (Malczewski, 2006)

Based on the applied methodology, the main outcome of this study is a standard map for optimum locations for the wind, Solar PV farms. Obviously, identification of feasible locations for the Solar PV photovoltaic farms and wind systems is an important issue, particularly for the Egyptian government needs to overcome the stop production of power due to any reasons in addition to investing the needed money properly.

As we have previously mentioned, the final site suitability maps for both types of renewable energy was illustrated and divided into three different suitability categories in addition to the unsuitable areas. However, in order for to guarantee if the model offers reliable representations of the system, it represented Model validation (Carrion et al., 2008). The Validation was done by the Visual comparisons performed between the result of the most suitable areas and google earth image when these locations were overlaid on a google earth image to verify if the location has no constraints (Effat, 2013)

3.1 Result

In the following parts, we will discuss the key findings of our study. basically, the result depicted based on the reclassified raster datasets so that for each pixel, a score can be determined. all in all, raster datasets were integrated into the ArcGIS, and then the final suitability map was prepared. whereas, The raster datasets were overlaid whereas the final site suitability maps as shown on the map No (16,17) to represents the solar and wind farms respectively.

3.1.1 Solar PV suitable map

To come up with solar PV map, The data processing, classifying and weighting each of all used raster layers were considers the main steps in order for generating the map of the solar PV suitable areas. furthermore, Suitability rankings range from unsuitable areas, low suitability area, moderate suitability, and high suitability.

The ArcGIS 10.4.1 software was used to analyze extensive sets of data and consider all necessary factors in the data preparation, analysis, processing steps.

After rasterization, these classified raster maps were integrated using the weight overly tool of ArcGIS and multiplied by weights, and then the final suitability map was prepared. The final site suitability map revealed that the study area was divided into four main different suitability categories.

Whenever the used approach takes into consideration the proposed constraints in the processes of allocating the most suitable place to build the solar PV. All the datasets were integrated and overlaid in order to get the final site suitability map as shown in map No16. Basically, the final results have been calculated based on the raster format so that for each pixel, a score can be determined.

The final results shows that the central area of Sinai Peninsula werer considered more appropriate for solar PV power plants, mainly due to their favorite high solar irradiance, mild slope, and proximity to major roads, grid lines, and far from cities. It had also been noticed that wide areas of sites are suitable in the north and northwest in addition to the southwest areas of Sinai. Furthermore, there were some potential areas closed to the shorelines of the red see.

On the other side, the suitability map presented a few small of low suitable and moderate across the study area. Moreover, mostly unsuitable areas were located under the middle areas a facility due to its far from the main roads, power transmission lines, as well as its terrain

In conclusion, the solar PV suitability analysis, the result reveals that approximately 2906.3 km² of the study area is highly suitable and this is represented by nearly 4.8 % of the study area. The area moderate suitable is 36.2 % represented by 21190.18 km². In addition, approximately .05 % of the study area of low suitable and is represented by 402.7 km². Unsuitable areas for solar power plants consist approximately 3458.3 km² represented by 57.2 % of the study area.

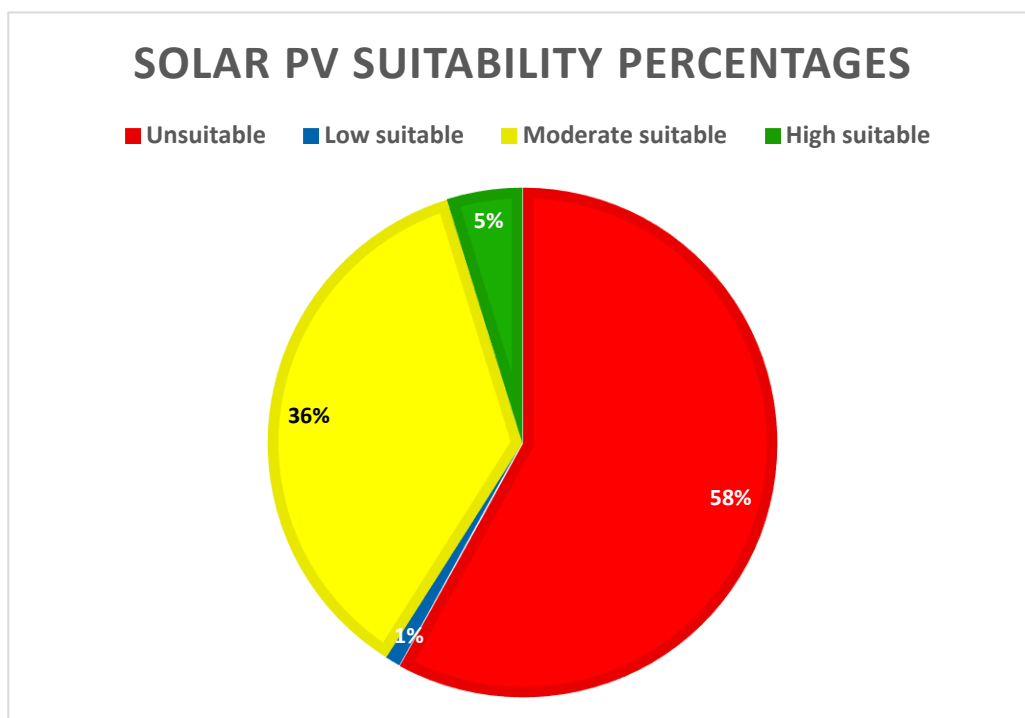
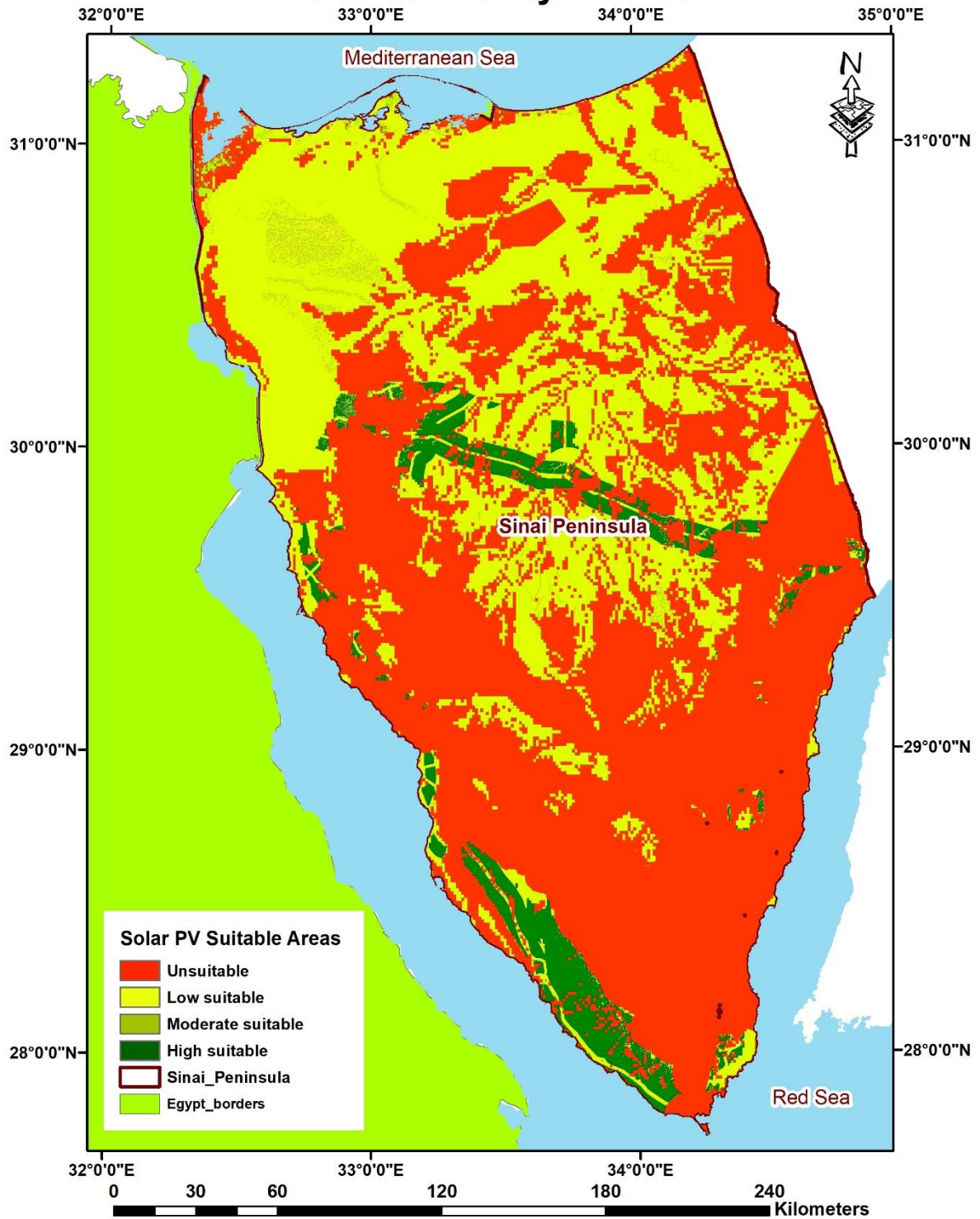


Figure 13 the percentages of suitable lands of the Solar PV

Solar PV Suitable areas Generated by Site Suitability Method



Coordinate System: WGS 1984 UTM Zone 36N
 Projection: Transverse Mercator

Prepared By: Mohamed Abozed
 Preparation Date: 30-11-2017

Map 16 Suitability map of the solar PV

3.1.2 Wind suitable map

As per our used methodology in selecting the optimal sites for the solar PV. All datasets were combined using the weighted overlay in ArcGIS. The main output was a map of suitable areas, were determined by reclassifying the scores derived from the weighted overlay tool. In addition to the solar PV suitability map, The final suitability map for the wind energy has same four categories of suitability: unsuitable, low suitable, low moderate suitable and high suitable.

To start with the suitability map of the wind areas shows that approximately 2.4 % of the land area in the study area fell into the high suitability category this area represented by 1485 km². The area moderate suitable is 38 % represented by 22834 km². in addition, approximately 1.5 % of the study area of low suitable and is represented by 892 km². Finally, the Unsuitable areas for wind power plants consist approximately 34583 km² represented by 57 % of the study area.

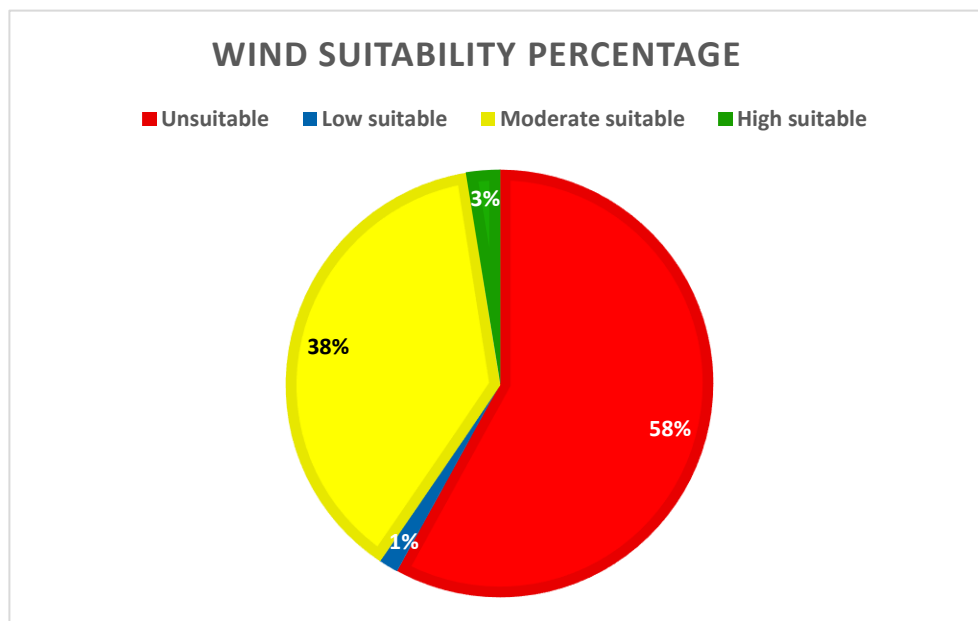
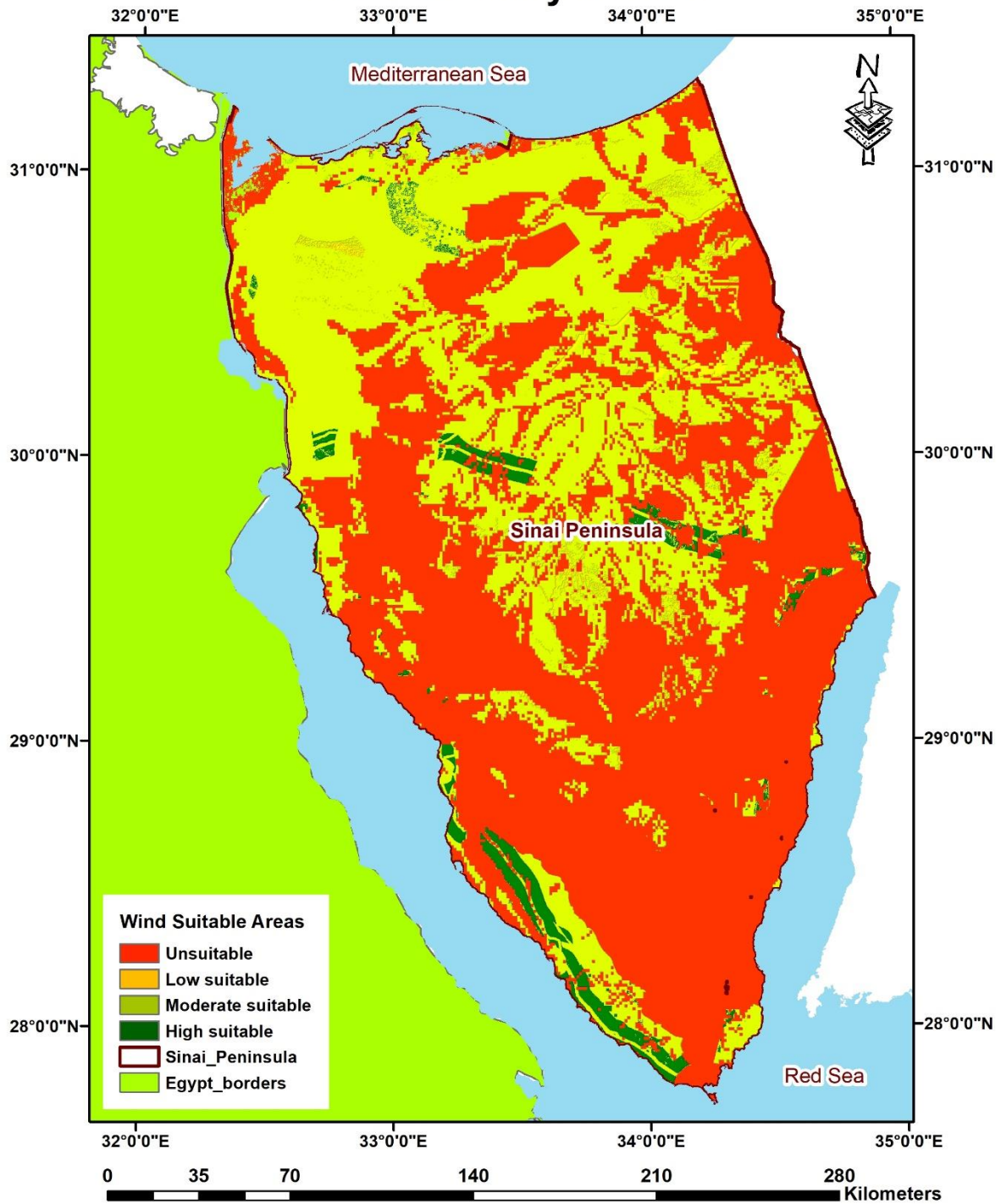


Figure 14 the percentages of suitable lands for wind farms

To come up with the below map, the suitable areas illustrated and located in the central areas of Sinai located closely to the transmission lines and the main. In addition to that, Since the wind speed considers the most important factor. It is clearly noticed that when the Wind speed decreases towards the northern areas of Sinai, the suitable areas gradually decreased.

Wind Suitable areas Generated by Site Suitability Method



Coordinate System: WGS 1984 UTM Zone 36N
Projection: Transverse Mercator

Prepared By: Mohamed Abozed
Preparation Date: 30-11-2017

Map 17 Suitability map of the wind farms

3.1.3 future work

Due to the data availability, it is recognized that a few limitations exist in this study. First, the datasets have been collected from many sources with different resolutions and scales especially the raster datasets.

Secondly, the criteria were weighted and combined in old models. The weighting and rating scheme is subjective to uncertainty, although it was mainly derived based on other studies.

The suitability map can be used as guidance to narrow down the search scope the suitable locations of the renewable energy power plants in a large-scale area. Furthermore, a survey work and sites visits should be incorporated into the final decision-making process before any large investment in construction. The application of the mapping results still needs to be validated with field measurements of solar irradiances as well as the wind speed and observation of any ecological variables, like sensitive habitats or migratory bird routes that may exist in any given location. in addition, the land cover verification.

In addition to the absence of birds immigration datasets, the collected data sets include neither the military sites nor the touristic areas and did not indicate accurately the suitable areas for the required types of activities. Therefore, further investigation will be more than worthy before taking the final decisions to select some area than select other depends on our findings.

The land cover and land use should be verified as per the site survey. In addition, distance to transmission lines was adopted as a simplified cost-related factor regardless of the capacity of transmission lines, the information of which was generally unavailable. on a top of that, it should also be mentioned that the modelled suitability should be interpreted as the “probability” of success in wind farm development.

Finally, due to the lack of touristic places datasets, the suitable sites should check out with site survey work or even by accurate satellite images in order for confirming the availability of these sites for the renewable energy activist.

Chapter-4

4. Conclusion

The Egyptian revolution of 25th, January, caused a terrible financial crisis for Egypt due to productions stop. However, the demands of energy increased gradually in parallel with the population increase. Furthermore, in the last 10 years, Egypt has the initial opportunity to bridge the gap between the demand for electricity and the supply, if Egypt starts to install the solar PV and wind power plants in order to generate the needed power as a green source of power. It is not deniable that the Renewable energy projects should increase rapidly in Egypt, due to concern about pollution and the increasing demands of the needed power.

As the main result of this study, the obtained two main results show that there is a very high potential of solar power generation in extensive areas of Sinai across the north-west, south-west and middle areas of Sinai respectively.

The first result was the optimal sites for solar PV power plants. However, geographical location of Sinai contains a large high altitude terrains, plays an important role. The spatial GIS model analyzed about 61000 km² area in total were selected as ideal locations for large-scale PV solar farms in Sinai peninsula taking into account various topographic, economic, social and environmental factors. The factors used in this study have more of an effect at eliminating non-suitable areas for large-scale solar farms.

The second result was the optimal sites for establishing the wind power plants across the study area. The selected sites were selected mainly based on the factor we used in selecting the solar farm areas except for the airport buffer zone.

Due to the large area of Sinai, which estimated approximately 61000 km², the result reveals many important numbers as we have previously mentioned.

In this study, spatial analysis techniques were applied to get the final maps for suitable areas for both types of renewable energies. These results indicated that the use of GIS and application of Multi-Criteria Evaluation could consider as a guide for the Egyptian government in developing Sinai area. Moreover, achieve better and sustainable urbanization over this large-scale area.

Finally, this study had identified significant gaps in research that need to be filled if large-scale renewable electricity projects are to succeed. Amongst others, the following areas of research should be developed further in future in-depth assessments: complementing previous research may entail detailed resource maps for different renewables generation technologies, both in terms of technical and economic potential. This may lead to a revision of the power pools' master plans to finally accounting for significant shares of renewable energy.

Finally, there is an immediate need for a detailed assessment of the capacity requirements of Sinai area and the cost of renewable generation deployment; and therefore, to design a planning system according to specific regional needs.

References

- Ahmed, N. A., Miyatake, M., & Al-Othman, A. K. (2008). Hybrid Solar Photovoltaic/Wind Turbine Energy Generation System with Voltage-based Maximum Power Point Tracking. *Electric Power Components and Systems*, 37(1), 43-60. doi:10.1080/15325000802322012
- Amer, M., & Daim, T. U. (2011). Selection of renewable energy technologies for a developing county: a case of Pakistan. *Energy for Sustainable Development*, 15(4), 420-435.
- Aydin, N. Y., Kentel, E., & Duzgun, H. S. (2013). GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. *Energy Conversion and Management*, 70, 90-106.
- Bartnicki, N., & Williamson, M. (2012). An Integrated GIS Approach to Wind Power Site Selection in Huron County, Ontario. *Department of Geography, University of Guelph, Guelph*.
- Bennui, A., Rattanamanee, P., Puetpaiboon, U., Phukpattaranont, P., & Chetpattananondh, K. (2007). *Site selection for large wind turbine using GIS*. Paper presented at the PSU-UNS International Conference on Engineering and Environment.
- Brower, M. (1992). *Cool energy: renewable solutions to environmental problems*: MIT press.
- Carrion, J. A., Estrella, A. E., Dols, F. A., Toro, M. Z., Rodríguez, M., & Ridao, A. R. (2008). Environmental decision-support systems for evaluating the carrying capacity of land areas: Optimal site selection for grid-connected photovoltaic power plants. *Renewable and Sustainable Energy Reviews*, 12(9), 2358-2380.
- Charabi, Y., & Gastli, A. (2011). PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renewable Energy*, 36(9), 2554-2561.
- Dawod, G. M., & Mandoer, M. S. Optimum Sites for Solar Energy Harvesting in Egypt Based on Multi-Criteria GIS.
- ED WARNER, C. D. O. (2015). GLOBAL WIND REPORT, ANNUAL MARKET UPDATE. *GLOBAL WIND ENERGY COUNCIL*, 76(2015), p.p38-39.
- Effat, H. A. (2013). Selection of Potential Sites for Solar Energy Farms in Ismailia Governorate, Egypt using SRTM and Multicriteria Analysis. *International Journal of Advanced Remote Sensing and GIS*, 2(1), pp. 205-220.
- Effat, H. A. (2014). Spatial modeling of optimum zones for wind farms using remote sensing and geographic information system, application in the Red Sea, Egypt. *Journal of Geographic Information System*, 6(04), 358.

- Effat, H. A. (2016). Mapping Solar Energy Potential Zones, using SRTM and Spatial Analysis, Application in Lake Nasser Region, Egypt. *International Journal of Sustainable Land Use and Urban Planning*, 3(1).
- Effat, H. A., & Hegazy, M. N. (2013). A multidisciplinary approach to mapping potential urban development zones in Sinai Peninsula, Egypt using remote sensing and GIS. *Journal of Geographic Information System*, 5(6), 567.
- Egypt's New and Renewable Energy Authority, N. (2017). Wind Power Statistics. Retrieved from <http://www.nrea.gov.eg/Technology/WindStations>
- El-Shimy, M. (2010). Optimal site matching of wind turbine generator: Case study of the Gulf of Suez region in Egypt. *Renewable Energy*, 35(8), 1870-1878.
- Elsheikh, R. F. A. Multi-Criteria Decision Making in Hotel Site Selection.
- ESRI. (2017). Overlay analysis approaches. <http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/overlay-analysis-approaches.htm>.
- ESRI Tutorial. (2017). Spatial Analyst toolbox,. *ArcGIS Desktop*. Retrieved from <http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/understanding-reclassification.htm>
- Figueira, J., Mousseau, V., & Roy, B. (2005). ELECTRE methods *Multiple criteria decision analysis: State of the art surveys* (pp. 133-153): Springer.
- Food and Agricultural Organization (FAO). (2002). Multipurpose Landcover Database for Egypt AFRICOVER Retrieved 31-8-2017 <http://www.fao.org/geonetwork/srv/en/metadata.show?id=38099&currTab=distribution>
- Foster, R., Ghassemi, M., & Cota, A. (2009). *Solar energy: renewable energy and the environment*: CRC Press.
- Georgiou, A., & Skarlatos, D. (2016). Optimal site selection for sitting a solar park using multi-criteria decision analysis and geographical information systems. *Geoscientific Instrumentation, Methods and Data Systems*, 5(2), 321-332.
- Global Solar Atlas. (2017). Global Horizontal Irradiance Retrieved from www.globalsolaratlas.info/downloads/egypt
- Hoogwijk, M., de Vries, B., & Turkenburg, W. (2004). Assessment of the global and regional geographical, technical and economic potential of onshore wind energy. *Energy Economics*, 26(5), 889-919.
- International Energy Agency. (2010). Technology Roadmap Solar Photovoltaic Energy. *INTERNATIONAL ENERGY AGENCY*.

- International Energy Agency. (2013). How will global energy markets evolve to 2035? *INTERNATIONAL ENERGY AGENCY*, 5.
- International Energy Agency. (2013). World Solar (PV and CSP). *INTERNATIONAL ENERGY AGENCY*. Retrieved from <http://www.iea.org/topics/solarpvandcsp/>
- Janke, J. R. (2010). Multicriteria GIS modeling of wind and solar farms in Colorado. *Renewable Energy*, 35(10), 2228-2234.
- Johansson, T. B., Patwardhan, A. P., Nakićenović, N., & Gomez-Echeverri, L. (2012). *Global energy assessment: toward a sustainable future*: Cambridge University Press.
- Kiatreungwattana, K., Mosey, G., Jones-Johnson, S., Dufficy, C., Bourg, J., Conroy, A., . . . Brown, K. (2013). *Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills*. Retrieved from
- Kihoro, J., Bosco, N. J., & Murage, H. (2013). Suitability analysis for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. *SpringerPlus*, 2, 265. doi:10.1186/2193-1801-2-265
- Klärle, M., Ludwig, D., & Lanig, S. (2013). Towards location-based analysis for solar panels by high resolution remote sensors (Lidar).
- Kucuksari, S., Khaleghi, A. M., Hamidi, M., Zhang, Y., Szidarovszky, F., Bayraksan, G., & Son, Y.-J. (2014). An Integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments. *Applied Energy*, 113, 1601-1613.
- Luo, C., Banakar, H., Shen, B., & Ooi, B.-T. (2007). Strategies to smooth wind power fluctuations of wind turbine generator. *IEEE Transactions on Energy Conversion*, 22(2), 341-349.
- Ma, J., Scott, N. R., DeGloria, S. D., & Lembo, A. J. (2005). Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS. *Biomass and Bioenergy*, 28(6), 591-600.
- Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science*, 20(7), 703-726. doi:10.1080/13658810600661508
- Melius, J., Margolis, R., & Ong, S. (2013). *Estimating rooftop suitability for PV: a review of methods, patents, and validation techniques*. Retrieved from
- Moilola, B. H. E. (2009). *Geographical information systems for strategic wind energy site selection*. Unpublished MSc Project Report, Vrije Universiteit Amsterdam, Amsterdam, Netherland.

- Mortensen, N. G., Hansen, J. C., Badger, J., Jørgensen, B. H., Hasager, C. B., Paulsen, U. S., . . . Said, U. S. (2006). Wind atlas for Egypt: measurements, micro-and mesoscale modelling. *2006 European Wind Energy Conference and Exhibition*, 13.
- New & Renewable Energy Authority. (2013). *Annual Report (2013)*. Retrieved from http://www.nrea.gov.eg/annual%20report/Annual_Report_2012_2013_eng.pdf
- New & Renewable Energy Authority. (2016). STRATEGIC ENVIRONMENTAL ,SOCIAL ASSESSMENT. *New & Renewable Energy Authority*.
- New and Renewable Energy Authority. (2013). *Annual report*. Retrieved from <http://www.nrea.gov.eg/Content/reports/AnnualReportAr2012-2013.pdf>
- Noorollahi, E., Fadai, D., Akbarpour Shirazi, M., & Ghodsipour, S. H. (2016). Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy Process (FAHP)—A Case Study of Iran. *Energies*, 9(8), 643.
- Ong, S., Campbell, C., Denholm, P., Margolis, R., & Heath, G. (2013). *Land-use requirements for solar power plants in the United States*. Retrieved from
- Pandey, C. K., & Katiyar, A. (2011). A comparative study of solar irradiation models on various inclined surfaces for India. *Applied energy*, 88(4), 1455-1459.
- Panwar, N., Kaushik, S., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: a review. *Renewable and Sustainable Energy Reviews*, 15(3), 1513-1524.
- Parida, B., Iniyar, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews*, 15(3), 1625-1636.
- Prasad, R. D., Bansal, R., & Raturi, A. (2014). Multi-faceted energy planning: A review. *Renewable and Sustainable Energy Reviews*, 38, 686-699.
- Quaschnig, V. (2004). Technical and economical system comparison of photovoltaic and concentrating solar thermal power systems depending on annual global irradiation. *Solar Energy*, 77(2), 171-178.
- Raji, S. (2017). *Modelling Potential Sites for Solar PV Plants in Northwest Nigeria Using Geoinformation Tools*. Paper presented at the Meeting the Energy Demands of Emerging Economies, 40th IAEE International Conference, June 18-21, 2017.
- Redweik, P., Catita, C., Brito, M., & Grande, C. (2011). *3D local scale solar radiation model based on urban LiDAR data*. Paper presented at the Proceedings of the ISPRS Workshop High-Resolution Earth Imaging for Geospatial Information, Hannover, Germany.

- Saleous, N., Issa, S., & Al Mazrouei, J. (2016). GIS-BASED WIND FARM SITE SELECTION MODEL OFFSHORE ABU DHABI EMIRATE, UAE. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, 41.
- Salim, M. G. (2012). Selection of groundwater sites in Egypt, using geographic information systems, for desalination by solar energy in order to reduce greenhouse gases. *Journal of Advanced Research*, 3(1), 11-19.
- Sánchez-Lozano, J., García-Cascales, M., & Lamata, M. (2016). GIS-based onshore wind farm site selection using Fuzzy Multi-Criteria Decision Making methods. Evaluating the case of Southeastern Spain. *Applied Energy*, 171, 86-102.
- Sayed Mansour, M. E. (2017). *Water and Renewable Energy Resources in the Red Sea Region*. Retrieved from https://www.uni-due.de/imperia/md/content/zwu/iwatec_winter_school_day_4_presentation_mansour_new.pdf
- Seng, S. M. (2011). *Location theory based wind energy system planning*. Universiti Tun Hussein Onn Malaysia.
- The Egyptian ministry of electricity and renewable energy. *Annual Report (2015-2016)*. Retrieved from http://www.moee.gov.eg/english_new/EEHC_Rep/2015-2016en.pdf
- Tsikalakakis, A., Tomtsi, T., Hatziargyriou, N., Poullikkas, A., Malamatenios, C., Giakoumelos, E., . . . Matar, T. (2011). Review of best practices of solar electricity resources applications in selected Middle East and North Africa (MENA) countries. *Renewable and Sustainable Energy Reviews*, 15(6), 2838-2849.
- U.S Energy Information Administration. (2018, Sep,27, 2013). What is renewable energy? Retrieved from http://www.eia.gov/energyexplained/index.cfm?page=renewable_home
- Uyan, M. (2013). GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. *Renewable and Sustainable Energy Reviews*, 28, 11-17.
- Wee, H.-M., Yang, W.-H., Chou, C.-W., & Padilan, M. V. (2012). Renewable energy supply chains, performance, application barriers, and strategies for further development. *Renewable and Sustainable Energy Reviews*, 16(8), 5451-5465.
- Wikipedia. (2017). *Renewable_energy Wikipedia*.
- Zell, E., Engel-Cox, J., Eckman, R., & Stackhouse Jr, P. (2008). Application of satellite sensor data and models for energy management. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 1(1), 5-17.