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GIS FOR RENEWABLE AND SUSTAINABLE ENERGY "SITING WIND FARMS IN EGYPT"

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Abstract

Many countries including Egypt, are having difficulty in providing different sources of energy. Therefore, many countries are heading towards finding new clean and sustainable sources of energy instead of the current means of producing energy with its environmental and economic operational problems. New power generations are currently developed based on the utilization of renewable and sustainable energy depending on the availability of such resources in the country.
Protecting the country's natural resources and enhancing those resources, which have suffered from degradation stand as important features of the country's sustainable development goals. Presence of an effective system for managing the country's sustainable development goals becomes important and essential. Geographic Information Systems (GIS) proved to be one of the most important technological tools the country can employ in order to tackle this issue.
Many countries are already using GIS to plan and implement programs to promote sustainable socio-economic and environmental development. It is useful to sustain our resource using wind, solar, geothermal, and biomass energy. It is also important to search for cleaner, smarter, and more conscientious methods of energy production, transmission, and distribution. GIS is not only improving the way we produce and deliver energy, but it is also changing the way we view our earth's resources.
Renewable energy (RE) projects are too expensive to make random decisions related to site selection, therefore GIS is a powerful tool in querying and selecting the most suitable locations for constructing RE projects.
This paper aims to demonstrate the usefulness of GIS technology in locating the most suitable locations for constructing wind farms from urban planning point of view through determining a list of criteria, in order to generate new means of energy to preserve the natural resources to the coming generations.

1. INTRODUCTION

Through the Industrial Revolution, human activities started to produce new impacts on natural resources. Factories were built, producing new sources of pollution of air, water, and soil. Progress in science and technology reached unprecedented rates, raising enthusiastic optimism on development [1]. The unlimited growth of most developed countries would compromise seriously the terrestrial ecosystem, destroying limited natural resources, causing dangerous conditions for human health, and augmenting poverty in less developed countries, which were unable to contrast the exploitation of resources carried on for the sake of development at their expenses [1]. As a result, the awareness of the need for new sustainable development models arose.

The socio-economic development of any country is based on land and water resources. Due to increase in

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population, these resources are over stretched often leading to resource depletion. Therefore, there is a need to prudently manage these delicate resources [2]. Remote Sensing and GIS techniques can be utilized to generate data and information for sustainable development.

Egypt is facing many problems in different fields such as energy, water, agriculture, natural resources, urban, pollution and environmental degradation. Protecting the country's natural resources and regenerating those resources, which have suffered degradation stand as important features of the country's sustainable development goals [3].

Many countries are already using Geographic Information Systems (GIS) to plan and implement programs to promote sustainable socio-economic and environmental development. In Egypt, many of the technical requirements for successful GIS-based development programs already exist, and the incentives to use these tools, especially in the areas of water management, natural resource preservation and public participation, are very strong. [3]. Never the less, it still not institutionalized.

2- Sustainable Development

Sustainable development is the term commonly and broadly used to describe a complex range of objectives, activities, and mankind behaviors with respect to the environment which should be consistent with the aims of meeting "the needs and aspirations of the present without compromising the ability of future generations to meet their own" [4]. This concept implies that both technological and social settings should be organized so that human activities would not overload the capacity of the biosphere to absorb their impacts. [4]

Hence the concept of sustainable development which is defined by the International Commission of Environment and Development in 1987 as a development that meets the basic needs of the present generation without compromising the ability of future generations to meet their needs [5]. From this concept the development processes is dealt from a new and a comprehensive point of view, taking into account the other elements of development, especially the natural environment, which was suffering from the effects of this development on. The concept of sustainable development expanded to include social, economic and cultural aspects, and maintain the welfare of the citizens [5]. Despite the differences in the definition of the term sustainable development, but its main philosophy is to balance economic growth with preservation of the environment, through the careful use of limited resources over time [5].

It is essential for nations to learn how to use these resources in a sustainable manner to ensure that their benefits are enjoyed in the present as well as future generations. This is because, these resources can be depleted if they are not utilized in an effective and efficient manner.

3- Renewable Energy

Renewable energy comes from natural sources that are constantly and sustainably replenished. This technology will make our families life, more secure, and more prosperous by improving our air quality, reducing our reliance on fossil fuels, curbing global warming and protecting environmental values such as habitat and water quality.[6]

There are different forms of renewable energy, they depend in one way or another on sunlight. Solar energy is the direct conversion of sunlight using panels or collectors. Wind and hydroelectric power are the direct result of differential heating of the Earth's surface which leads to air moving about (wind) and precipitation forming as the air is lifted. Biomass energy is stored sunlight contained in plants. Other renewable energies that do not depend on sunlight are geothermal energy, which is a result of radioactive decay in the crust combined with the original heat of accreting the Earth, and tidal energy, which is a conversion of gravitational energy. [7]

3.1 Renewable Energy in Egypt

The concept of renewable energy is not new to Egypt. In 1986, Egypt's New & Renewable Energy Authority (NREA) was established to act as the national focal point for expanding efforts to develop and introduce renewable energy technologies on a commercial scale. Since then, a number of governmental organizations have been set up to help promote and develop policies to encourage the growth of the renewable energy industry. [8]

Renewable energy capacity in Egypt:

Hydro

Hydroelectricity has played a role in electricity generation in Egypt for decades. Projects such as the Aswan Dam produce 15,300GWh a year, or roughly five to ten per cent of Egypt's annual energy needs. As 85 per cent of Egypt's hydropower potential has already been developed, this is not regarded as a premier growth sector and the Government's focus has been directed more towards the wind and solar energy sectors.[8]

Solar

Due to its location, topography and climate, Egypt has an average level of solar radiation of between 2,000 to 3,200kWh per square meter a year, giving it significant potential for utilizing this form of renewable energy. To date, however, uptake of solar projects has been slow due to high capital costs. In 2010, Egypt's only major solar power project was commissioned in Kuraymat. The plant is a 140MW solar thermal combined cycle power plant of which 20MW is from solar energy. [8] These days there are several projects for Solar Projects some are under construction and others the final stages.

Wind Energy and Wind Farms

Egypt is recognized as having some of the world's best wind resources, especially in the Gulf of Suez area, with significant additional potential along the east and west banks of the Nile. According to the Egypt Wind Energy Association, 700 square kilometers have been set aside for new wind projects in the Gebel el-Zayt area which has wind speeds of 11 meters a second. [8] Therefore, it is realized that wind energy production is more cost effective than other alternatives.

The forecasted growth estimated the installed capacity needed by 2030 from renewable energies should be about 15000 MW including wind farms energy. The Government, therefore, assigned a huge area more of 1.5 million acres for more wind energy projects to come [9,10].

Egypt's best-developed wind region so far is the Zafarana district, with average wind speeds of around nine meters a second. The project (which is owned and operated by NREA) consists of a series of linked wind farms, the first of which started construction in 2000/2001. [11] The wind farm is erected in one of the windiest sites in this part of the world. The power project was set up, and includes the establishment of a large scale wind farm in Zafarana with a capacity of 600 MW by the end of the program. The project is built in successive phases, with each phase including 60 MW capacity. The New and Renewable Energy Authority (NREA) planned that 300 MW shall be financed through the State budget; while the private sector, local and foreign investors, are encouraged to finance the other 300 MW based on the Build, Own, Operate and Transfer (BOOT) system. [11]

In 2010, Zafarana wind farm's total installed capacity reached 550MW, making it one of the largest onshore wind farms in the world. [8]

4- GIS for Renewable Energy

Renewable Energy is becoming more and more important for supplying the increase in global energy demand, especially in conjunction with decisions to abandon nuclear energy in some countries. GIS can support the process of RE integration in many ways, such as finding potential areas for solar, biomass, and wind power plants; estimating the RE potential at macro- and micro scales integrating physical modeling; and analyzing the technical, economic, and social impact of RE projects [12].

A geographical information system is a powerful, quickly developing technology that is making a major impact on renewable energy industries. GIS integrates hardware, software and data for capturing, managing, analyzing and displaying all forms of geographically referenced information.

GIS is being extensively used to find and develop renewable energy resources. Renewable energy infrastructure projects are far too expensive to make random decisions on siting. For many reasons siting should be as exact as the science behind renewable energy itself [13]. Therefore GIS is very useful in searching the best locations for constructing RE projects and to find the best corridors for transmission and distribution of resources. [14]

GIS improves the way we produce and deliver energy. It is considered the go-to technology for making the best decisions about siting. GIS is capable of combing all different types of data such as information about local land use, population density, existing infrastructure, proximity to the grid, natural resource extraction, environmental assessments and more. It helps the stakeholders understand what is happening, plus what is expected to happen, in a specific geographical space. Fortunately, technological tools have been developed to help renewable energy providers decide the best locations for their wind turbines, solar panel fields, geothermal plants or biomass facilities.

Through each stage of a renewable energy project, GIS with the assistance of other Web-based tools is essential in each stage of the project, it enhance communication among teams, departments, professional fields, organizations and the public. Organizations of all sizes and in nearly every industry are realizing the benefits possible through GIS [13].

In siting wind farm and wind turbines the software performs a directed search and determines several siting solutions, numbering them in the order of the best fit. In this automated approach to siting, software-generates algorithms automatically search the solution space and efficiently provide project planners with a near optimal solution that can be statistically guaranteed.

4.1 GIS in Wind Energy

GIS is an outstanding tool for wind energy activities because data can be readily updated and the results of the GIS analyses can be expressed as charts, tables, and maps. These outputs are in digital formats that allow the results of GIS analyses to be quickly and efficiently distributed to the wind energy industry.

GIS is a valuable tool for wind resource assessment and development because it utilizes the significant spatial components found in both. Wind resource potential is strongly influenced by the exposure and the orientation of the terrain relative to the prevailing wind direction. The development of wind resources is significantly influenced by proximity to existing transmission lines, current land use, and potential energy demand. These relationships can be readily quantified with the spatial capabilities that are inherent in a GIS. [15]

In the last few years, the role of GIS in Wind Energy Program at NREL (Egypt's New & Renewable Energy Authority) has increased dramatically. It has evolved from a tool that provided professional graphic output with limited automated GIS capabilities, to a model for wind resource assessment, to a versatile tool researchers can use to examine and analyze data relationships to extract useful information. GIS has proven its value at NREL by presenting information that aids wind energy development decisions and will continue to play a vital and ever-expanding role at NREL based on its utility in the assessment and development of wind energy. [15]

5- Case Studies: GIS to Locate Suitable Locations for Wind Farms

The paper will present a number of case studies that demonstrate the use of GIS in selecting the most suitable locations for constructing wind farms. The cases were chosen from different countries, developed countries – USA (Minnesota City) and developing countries – Egypt (the whole country), India (Pollachi Taluk, Tamil Nadu) and Thailand.

Table 1: Datasets used for the wind farm site selection for the four case studies

	Minnesota, USA [19]	**Egypt** [20]	**Pollachi Taluk, India** [21]	**Thailand** [22]
Physical impacts	Wind speed	Wind speed	Wind speed	Wind speed
	Slope	Slope	Slope	
		Elevation		Elevation
				Roughness (mm)
Environmental impact		Protected areas		
	Vegetation area	Vegetation area		
	Water bodies	Water bodies	Water bodies	Water bodies
		Sand dunes		
	Wildlife conservation	Birds habitat		
				Scenic Areas
	Forest zones			
			Streams	
Human impacts	Main roads	Main roads	Main roads	Main roads
	Urban areas	Urban areas	Urban areas	Urban areas
		Ports		Airport Areas
		Railways	Railways	
	Electric grids	Electric grids	Electric grids	
	Recreational areas			
				Communities
				Important Places

5.3 Criteria for land selection

Table 2: Criteria used for the Physical Impacts in the four case studies

	Minnesota, USA [19]	**Egypt** [20]	**Pollachi Taluk, India** [21]	**Thailand** [22]
Physical criteria	*Wind speed at 80m* Poor (1) <6.03 m/s Good (2) 6.03-7.24 m/s Excellent (3) >7.24m/s	*Wind speed at 50m* > 5 m/s Suitable	*Wind speed at 80m* Least Suit. 1 < 7.0 m/s Moderately Suit. 2 ≥ 7.0 m/s - < 7.5 m/s Highly Suit. 3 ≥ 7.5 m/s - < 8.0 m/s	*Wind Power (W/m2)* 1 < 100 1 Less suitable 2 100-150 2 suitable 3 150 -200 3 Moderate suitable 4 200-250 4 High suitable 5 > 250 5 Extremely suitable
	Slope Unsuitable 0 >30° Poor 1 16-30° Good 2 7-16° Excellent 3 0-7°	*Slope* <15% Suitable	*Slope* Highly suitable 2 < 15% Moderately Suit. 1 ≤ 15% - < 30% Not Suitable 0 ≥ 30%	
		Elevation <300m Suitable		*Elevation (m)* 1 0-40 5 Extremely suitable 2 40-80 4 High suitable 3 80-120 3 Moderate suitable 4 120-150 2 Suitable 5 150-200 1 Less suitable 6 >200 0 Exclusion Zone
				Roughness (mm) 1 400 1 Less suitable 2 100 2 Suitable 3 50 3 Moderate suitable 4 10 4 High suitable 5 0.1 5 Extremely suitable

Table 3: Criteria used for the Environmental Impacts in the four case studies

	Minnesota, USA [19]	**Egypt** [20]	**Pollachi Taluk, India** [21]	**Thailand** [22]
Environmental criteria	*Vegetation & Forest area* High density forest 1 Poor Shrub Land & Grassland 2 Good Agricultural Vegetation 3 Excellent	*Vegetation area* Distance >= 1000 m Suitable Distance < 1000 m Unsuitable		
	Water bodies Areas > 400m Suitable areas =< 400m Unsuitable	*Water bodies* Distance >= 500 m Suitable Distance < 500 m Unsuitable	*Water bodies* Distance ≤ 400 m Unsuitable Distance > 400 m Suitable	*Water bodies (km)* 1 0.0-0.2 0 Exclusion Zone 1 0.2-0.4 1 Less suitable 2 0.4-0.6 2 suitable 3 0.6-0.8 3 Moderate suitable 4 0.8-1.0 4 High suitable 5 > 1.0 5 Extremely suitable
	Wildlife conservation areas > 500m Suitable areas =< 500m Unsuitable	*Birds habitat* Dist. >= 500 m Suitable Dist. < 500 m Unsuitable		
		Protected areas Dist. >= 1000 m Suitable Dist. < 1000 m Unsuitable		
		Sand dunes Dist. >= 1000 m Suitable Dist. < 1000 m Unsuitable		
			Streams Dist. ≤ 30 m Unsuitable Dist. > 30 m Suitable	
				Scene Areas (km) 1 0.0-1.0 0 Exclusion Zone 2 1.0-2.0 1 Less suitable 3 2.0-3.0 2 Suitable 4 3.0-4.0 3 Moderate suitable 5 4.0-5.0 4 High suitable 6 > 5.0 5 Extremely suitable

Table 4: Criteria used for the Human Impacts in the four case studies

	Minnesota, USA [19]	**Egypt** [20]	**Pollachi Taluk, India** [21]	**Thailand** [22]
Human Criteria	*Main roads* Distance <= 10 km Suit. Distance > 10 km Unsuit.	*Main roads* Distance from >= 500 m	*Main roads* Distance ≤ 150 m Not Suitable Distance > 150 m Highly Suit. Distance > 10000 m Not Suitable	*Main roads (km)* 1 0.0-0.5 0 Exclusion Zone 2 0.5-1.0 1 Less suitable 3 1.0-1.5 2 suitable 4 1.5-2.0 3 Moderate suitable 5 2.0-2.5 4 High suitable 6 > 2.5 5 Extremely suitable
	Urban areas Distance >500 m Suit. Distance <=500 m Unsuit.	*Urban areas* Distance >= 2000 m	*Urban areas* Distance ≤ 500 m Not Suitable Distance > 500 m Highly Suitable	*Urban areas (km)* 1 0.0-2.5 0 Exclusion Zone 2 2.5-3.5 1 Less suitable 3 3.5-4.5 2 Suitable 4 4.5-5.5 3 Moderate suitable 5 5.5-6.5 4 High suitable 6 > 6.5 5 Extremely suitable
		Ports (air and seas) Distance >= 2500 m		*Airport (km)* 1 0.0-3.0 0 Exclusion Zone 2 3.0-6.0 1 Less suitable 3 6.0-9.0 2 Suitable 4 9.0-12.0 3 Moderate suitable 5 12.0-15.0 4 High suitable 6 > 15.0 5 Extremely suitable
		Railways Distance >= 500 m	*Railways* Distance > 150 m Highly Suit.	
	Electric grids Distance <= 10 km Suit. Distance > 10 km Unsuit.	0 >50 km Non Suitable 1 20 – 50 km Poor 2 10 – 20 km Less suitable 3 5 – 10 km Suitable 4 1 – 5 km High suitable 5 < 1 km Extremely suit.	*Electric grids* Distance ≤ 200 m Not Suit. Dist. >200 ≤ 10000 m Highly Suitable	
	Recreational areas Distance > 1000 m Suit.			*Important Places (km)* 1 0.0-2.0 0 Exclusion Zone 2 2.0-2.5 1 Less suitable 3 2.5-3.0 2 Suitable 4 3.0-3.5 3 Moderate suitable 5 3.5-4.0 4 High suitable 6 > 4.0 5 Extremely suitable

5.1 Introduction

In the current century, energy became one of the most critical issues in human's life. Due to global warming, air pollution and the other problems caused by fossil fuels it became essential to find appropriate sources of renewable energy and wind energy is one of them.

Wind farm siting is an important stage in wind power development. Successful wind farm siting will help to realize the anticipated commercial and social benefits of the ongoing wind project, thus contributes to the sustainable development of wind industry.

Renewable energy projects are far too expensive to make random decisions on site selection. Suitability and siting of wind energy farm locations is a big challenge and not an easy task. It is a complex, and involves multiple criteria investigation for the proper selection to avoid any discourage to the investors. The complexity of siting is not only the wind potential or the technical issues [16,17], but in fact it is a sophisticated process with many other conflicting factors such as geographical, economic, social, environmental and political requirements.

5.2 Datasets

In order to locate the most suitable locations for wind farms it is essential to determine types of data and its criteria. Such siting criteria are related to topographical constraints, wind magnitude constraints, population, economic, accessibility, and ecological constraints [18].

Most of the case studies divided the type of data into three sets, first: physical impacts, second: environmental impacts and third: human impacts. From the case studies the following data sets were determined.

5.4 Data Analysis

The Egyptian and the Tai case study used the Analytical Hierarchy Process (AHP) for weighing and ranking the optimal wind farms site locations in the country. There were two types of data, vector and raster data. All vector data were converted to raster by the create distance tool. Each new raster layer was classified into 6 classes with common evaluation scale from 0 to 5, with (0) scale represents the unsuitable locations and (5) represents the extreme high. The raster data (wind speed, elevation and slope) were classified depending on the criteria mentioned above. Relative weight of importance was assigned to each layer. All layers were analyzed together to compute the overall ranking of the most suitable wind farms location in the case studies using the score and the relative weights of importance. Sites with score 5, 4 and 3 were the most suitable locations for constructing wind farms.

The USA and Indian case studies used the same procedures and process of analysis. The vector layers (environmental and human impacts) with the case of single-objective, a decision set contain two subsets: suitable and not suitable. For that, the vector layers were geo-processed by Boolean operators (AND, OR, NOR), in order to perform such functions as, Buffer, intersection, union, difference and clip within the QGIS software environment. Buffer zones were created and the distance scores (assigned '1' for suitable and '0' not suitable). The output vector layer was converted to raster layer with values of'1' for suitable and '0' not suitable. The raster layers (physical impacts) were classified into several classes depending on the criteria mentioned earlier. It was assumed that all the layers are of equal importance and therefore carry the same weight or Overall Average Weighting procedure. By using the analysis tools (map calculator) all output layers were merged together to get the suitability map for the wind farm locations.

5.5 Results

From studying and analyzing different case studies it was determined that almost all the case studies divided their datasets into 3 types of data: a) physical impacts, b) environmental impacts and c) human impacts. Almost the same data were used in each case study with some exceptions. These

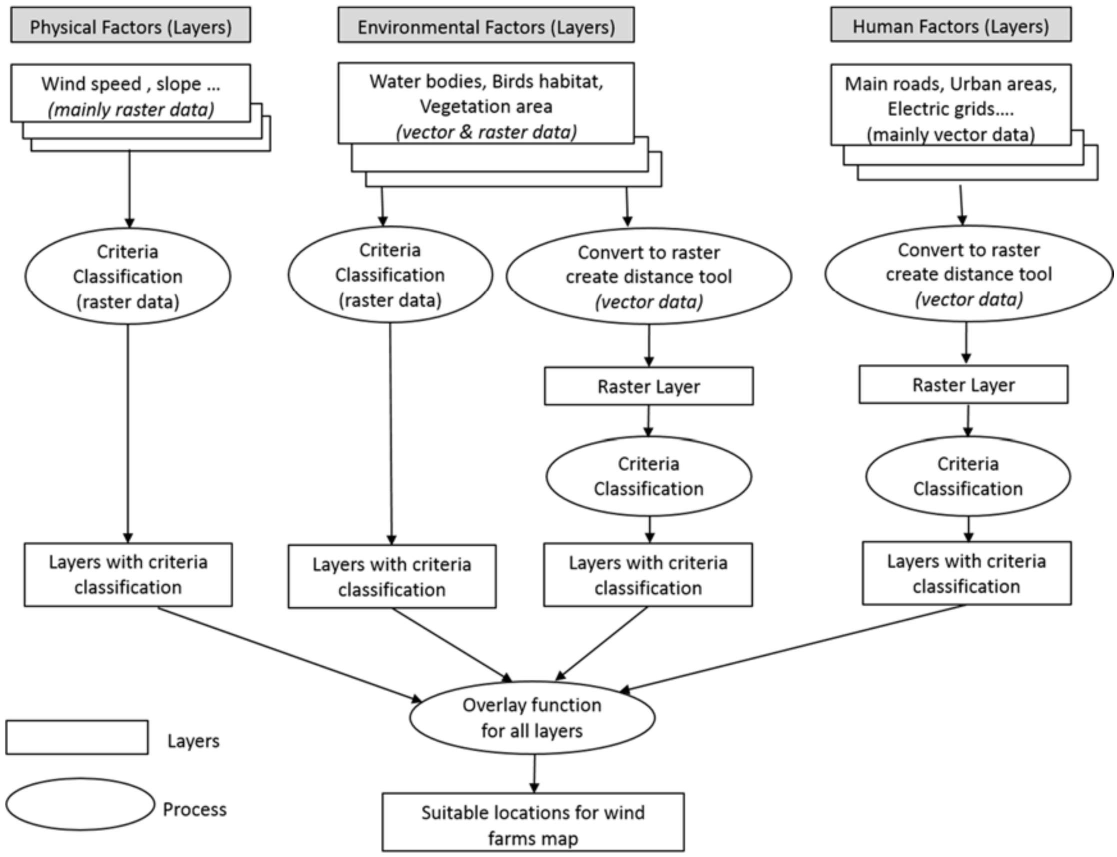

Figure 1: Conceptual Model for wind farms site selection

exceptions depends on the scale of the study area (city scale or the whole country), depends on features that can be presented in one place but not presented in another, e.g. railway, desert, forest. There were some differences in the criteria; some cases (Egypt, Thailand) the criteria were very detailed, all layers were divided into 6 classes. When the criteria are more detailed, the result will be more accurate and the number of suitable locations will be less.

Key Features for site selection of a wind farm are [23] :

- Superior wind speed
- Good road access to sites
- Suitable terrain and geology for onsite access
- Low population density
- Minimum risk of agro-forestry operations
- Close to suitable electrical grid
- Supportive land holders
- Privately owned free hold land
- Good industrial support for construction and ongoing operations
- Far from bird habitat
- Significant potential for revalidation.

In order to get accurate and precise results, it is important to check that the data collected is correct, accurate and up-to-date. It is better to get a suitability map with different scores to choose the high suitable locations when possible, and if not then choose the level after (suitable). This technique is better than getting locations with values 1 and 0 only (suitable and non-suitable).

Each country has its own characteristics and circumstances upon that they can decide the type of data and criteria they will apply, but with relation to international references. There cannot be fixed values for each criteria, these values depend on the size of the case study and availability of land.

There are many things that need to be considered when siting wind farms. The variables are enumerable and vary from region to region. Some common things to consider are the distribution of wind velocity, the impacts of turbines of migrating and local wildlife, infrastructure availability to transfer the energy from the unit to the grid, and the many, many potential use conflicts. GIS can incorporate these data into different layers and overlay them to create maps that show conflict uses and best fits. [24]

6- Conclusion

Many countries and Egypt is one of them, suffers from many problems and difficulties related to the inability of the government to supply energy and natural resources required to cover the needs of the population. Therefore, it is important to find alternative ways to provide the energy that will cover the population and investment needs. Almost all countries are going towards providing energy from renewable and clean energy. These alternative ways should be sustainable and compatible with the environment in order to preserve the natural resources for the coming generations.

Implementation of new energy sources from renewable power reduces the dependency on fossil fuels, which is the primary concern for many countries. Another important contribution of renewable energy is its high potential in reducing CO_2 emissions and thereby protecting the environment.

The wind farms siting developed by the GIS can give planners, utility, energy and private sectors, and environmental group a valuable tool for planning and assessing wind energy industry at any location in the country.

This paper studied a number of international and local case studies illustrating the process of finding the most suitable locations for wind farms industry depending on a set of data and criteria. The results of the analysis will be of great help and technical support to the investors and the government in making decisions. Such projects costs a lot of money, therefore it is important that the money will be spend in the correct place, and such analysis will encourage the investors to inject more capitals in wind energy industry and other types of renewable energy.

6.1 Advances Use of GIS Techniques for Setting Wind Farms

• GIS is capable of handling and simulating the physical, economic and environmental data and constraints.

• GIS offers reliable tools to support analysis, problem solving, planning, decision-making, and management of finding the most suitable locations for wind farms.

• GIS is a perfect tool for determining the availability of strong and continuous wind energy. Through the GIS, interpolation is used to establish wind contours around the points where data are known to produce a wind velocity map.

• GIS is capable of combing all different types of data such as information about local land use, population density, existing infrastructure, proximity to the grid, natural resource extraction, environmental assessments and more to produce one map with all possible wind farm locations.

• GIS is able to integrate a variety of criteria combined from different layers using the overlay function in GIS to produce a constraints map showing the most and least suitable areas for locating wind energy facilities.

• GIS can be integrated with multi-criteria analysis techniques, scoring how each alternative affects each criterion; weighting the impact and aggregating the score and weight of each alternative.

• GIS helps the stakeholders to understand what is happening, plus what is expected to happen, in a specific geographical space.

• GIS can be used; in combination with the internet, to provide interactive experiences for stakeholders.

• GIS is used to create 3D simulations of wind farms in their proposed locations. Using GIS, actual locations can be simulated with wind turbines on the horizon. Many who thought they may find the presence of the turbines disturbing on their horizon changed their mind after the seeing the elegant giants slowly turning in their backyard. [24]

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