Utilization of GIS as a tool in exploring Renewable Energy Resources

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1. Introduction

1.1 Background

Greenhouse gas emissions, global warming and deterioration of the natural resource base have the cause for worldwide concern on energy. Thus, making the energy available in the form of electricity wherever and whenever needed is a growing challenge. According to the U.S. Energy Information Administration, the total energy consumption by end-use has increased since 1949 to 2010 in all the sectors: industrial transportation, residential and commercial [1]. As per the statistics of the Saudi Electric Company, the total produced energy from the company’s power stations was 176,566 GWh at the end of the year 2008. The growth in the energy production was found to be 7.7% as compared to the year 2007 [2]. The sold energy by the end of the year 2010 was found to be 212,263 GWh with an increase of 86% when compared to the year-end of 2000 [3]. Satisfying these demands using only the conventional source of energy is adding to the problem of environmental hazard. This made the world to move towards utilizing the non-conventional energy i.e., the renewable energy resources in order to reduce adverse effect on the environment. Mainstream renewable energy technologies available today are:

- Wind power (fig. 1)
- Solar Energy (fig. 2)
- Hydropower (fig. 3)
- Biomass (fig. 4)
- Biofuel (fig. 5)
- Geothermal energy (fig. 6)

Renewable energy has become a driving force in the effort to sustain the earth’s natural resources and to improve the users’ quality of life. Renewable energy systems are environmentally friendly compared to conventional energy systems. Renewable energy sources are the conventional option as they do not produce any physical pollution especially green-house gases. They do not exhaust any natural resource and the inputs they use are abundant in nature. The disadvantage of these sources is that the power from Renewable sources is intermittent; therefore, it would be difficult to provide a stable energy supply using only one renewable energy source. One more drawback of stand-alone renewable energy systems is their dependence on short and long-term weather and climatic conditions. By
combining two or more renewable energy sources into a hybrid system often helps to overcome this limitation and reduces reliance on conventional energy resources.

Figure 1: A Wind Farm located in Manjil, Iran.

Figure 2: 19 MW solar park in Germany

Figure 3: Hoover Dam in Nevada (USA)
Figure 4: A Cogeneration plant in Metz, France.

Figure 5: Brazil has BioEthanol made from sugarcane available throughout the country.

Figure 6: Steam rising from the Nesjavellir Geothermal Power Station in Iceland.
Recent eco-consciousness agendas in many countries have set goals for the development of renewable energy, specifically for its efficient generation and conversion to a consumable form of energy and its commercialization in the market. However, higher conversion costs, limited locations, environmental impacts, and other factors pose barriers to such development. To surmount these barriers, governments, researchers, and stakeholders should work together to enhance the conversion efficiency of renewable energy, develop advanced storage technologies, control distribution efficiency, and commercialize the use of renewable energy ultimately [4].

1.2 Introduction to GIS

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. GIS applications can be the foundation for many location-enabled services that rely on analysis, visualization and dissemination of results for collaborative decision making. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. Steiniger et al., (2009) identified seven major types of GIS software [5]:

(i) Desktop GIS,
(ii) Spatial Data Base Management Systems (SDBMS),
(iii) Web Map Server,
(iv) Server GIS,
(v) Web GIS clients,
(vi) Mobile GIS,
(vii) Libraries and Extensions.

The common tasks performed by these GIS software’s include the following [5]:

- Data visualization and exploration,
- Data creation,
- Data editing
- Data storage
- Data conflation
- Data queries
- Data analysis
- Data transformation
- The creation of maps
1.3 Problem statement

As stated above, the cost of conversion of renewable energy is very high and to make matter worse, the decision making for the suitable locations to install these technologies should be accurately done. Suitability mapping involves using a variety of data sources in which weights are assigned to geographical criteria. Data are often imported into a Geographic Information System (GIS), which combines potentially unrelated data in a meaningful manner. Weights that emphasize the relative importance of one criterion to another are often determined by managers, research specialists, stakeholders, or interest groups to enhance decision-making. A variety of environmental, transportation, planning, waste management, water resources, forestry, agriculture, housing, and natural hazard applications have been undertaken using GIS multi-criteria modeling techniques.

1.4 Objective

This study focuses on:

- The potential use of GIS in the field of renewable energy (solar, wind, bio-energy, hydro-energy, and hydrothermal energy) by review the available literature.
2. Literature review

The use of GIS in the field of renewable energy has seen a very sharp increase in the past decade. There are several projects that utilize GIS from the field of renewable energy. Many of them have a sectorial character and apply GIS applications to localization problems resolution or to resources evaluation for specific sources. G. Quinonez-Varela et al. (2007) has suggested a frame work to integrate GIS and Power Supply Simulation (PSS) and concluded by saying that the design of a novel integrated planning tool capable of automating the preliminary grid connection assessments for new renewable generators by combining the analytical capabilities of GIS and PSS platforms to assist the decision-making by utility planning engineers [6]. T.V. Ramachandra et al. (2007) have demonstrated the role of spatial and temporal analysis tools such as GIS in assessing the resource potential in a region. GIS provided them the means for identifying and quantifying the spatial and climatic factors affecting the availability of renewable energy potential. In addition to this, it also provided the flexibility to enrich the database, on which decisions are based, with spatial data and additional restriction on renewable resource availability [7]. Stefano Grassi et al. (2012) has used a GIS tool developed by Institute of Cartography and Geo-information, ETH, Zurich, to assess the Large scale technical and economical assessment of wind energy potentials and presented the conclusion that the developed tool can be very helpful to different users such as policy makers, wind project developers and investors. Policy makers can define different parameters (setbacks, exclusion zones, incentives, etc.) in order to analyze their impact on the power generation in the energy mix of a country or a region and thus estimating also the potential benefits and scenarios [8]. In summary, they have developed a tool that is not only capable of reducing the uncertainties in estimating the power generation over the identified areas, but also takes into account policy and financial framework to estimate their expected economic performances over their entire life cycle. Moreover, the designed tool enables to show the influence of different energy policy and economic factors on the integration of a renewable energy technology in the power mix in a given area.

Juan M. et al. (2013) combined a GIS and multi- criteria decision making (MCDM) methods in order to obtain the evaluation of the optimal placement of photovoltaic solar power plants in the area of Cartagena (Region of Murcia), in southeast Spain. Their study has not only served to assess the ability of the area of Cartagena, it has also demonstrated how it is possible to combine a Geographic Information System with Multi-criteria Decision Making Methods (GIS–MCDM) for use or application in the field of renewable energy. Using GIS–
MCDM tools, the difficult task of searching for sites is facilitated so the developer can choose those areas which, from an energy point of view, are optimal and serve the needs [9]. John Byrne et al. (2007) integrated lifecycle costing and geographic information system (GIS) methods in order to provide a comprehensive resource, economic, technological and livelihoods assessment for stand-alone, small-scale (less than 2 kW) renewable energy technologies for rural electrification using a representative sample of 531 rural households in three provinces of Western China. Their results helped China’s government remove major barriers requiring a multidimensional response, including policy and institutional reform, market development, new financing initiatives and a concreted outreach and training effort by indicating that a number of reliable and economical PV and wind applications exist to adequately address rural electricity needs where grid electricity is unavailable and biomass and micro-hydro options are not significant [10].

J. Van Hoesen et al. (2010) used GIS to suggest possible model for supporting rural community energy projects, which was used to develop an inventory of energy resource potential in a rural Vermont town for biomass, wind, and solar technologies. They concluded by saying that committees will be best informed through GIS-based analyses of local energy resource potential and will make the most democratic decisions by employing participatory GIS throughout the decision making process [11]. Amy Thomas et al. (2013) demonstrated the utility of a GIS-based approach to analyze spatial factors affecting potential generation from bioenergy, by relating supply to potential fixed location demand on a national scale. Using the example of England, they highlighted the significance of overlapping feedstock catchment zones, and the impact on total generation potential of end use allocation of this feedstock. Using the GIS approach they presented in their paper the clear differences in efficiencies relating directly to end use given the existing energy demand and supply context [12]. P. Zambelli et al. (2012) presented the results from the first FOSS4G software based methodology developed to estimate the amount of forest biomass available for energy production taking into account harvesting techniques in an Alpine area. They stated that the tremendous variety of geographic, topographic, and ecological conditions among nations encourages the creation and application of a diversity of recommended methods and approaches for developing inventories and obtaining forest biomass information [13].
3. Case studies

Case study I

J.R. Janke (2010) used GIS overlay techniques to examine the relationship between landcover classes and National Renewable Energy Laboratory (NREL)’s solar and wind potential data in Colorado. The Governor’s Energy Office in Colorado has shown interest in exploring clean, renewable energy by supporting outreach programs such as the Wind for Schools program for rural teachers and students. An anemometer loan program has recently been created to examine local wind potential. Financial incentives for investing in renewable energy are numerous. With the passing of the American Recovery and Reinvestment Act, Governor Ritter believes that Colorado’s New Energy Economy will be enhanced, providing new green jobs across the state. With renewed interest and financial support, geographic areas that are ideal for large-scale wind and solar farms must be located. Thus the objectives of his research were to [14]:

1. Explore which landcover classes have high wind or solar potential in Colorado based on existing National Renewable Energy Laboratory (NREL) data sets; and

2. Identify areas are suitable for wind or solar farm development using multicriteria GIS modeling techniques.

He reclassified Renewable energy potential (NREL wind speed measurements at 50 m above the ground and NREL annual insolation data), landcover, population density, federal lands, and distance to roads, transmission lines, and cities according to their suitability and assigned each with weights based on their relative importance to one another.

Table 1 GIS criteria used to model wind and solar farms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Ideal Conditions</th>
<th>Original Data Type</th>
<th>Final Data Type</th>
<th>Possible Values</th>
<th>Weight</th>
<th>Original Resolution</th>
<th>Final Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Potential</td>
<td>NREL Class 7 (superb)</td>
<td>Categorical</td>
<td>Categorical</td>
<td>[0.14, 0.20, 0.43, 0.57, 0.71, 0.85, 1.00]</td>
<td>3</td>
<td>200 m</td>
<td>1500 m</td>
</tr>
<tr>
<td>Solar Potential</td>
<td>Maximize W/m²/day</td>
<td>Continuous</td>
<td>Categorical</td>
<td>[0–1]</td>
<td>3</td>
<td>40 000 m</td>
<td>1500 m</td>
</tr>
<tr>
<td>Distance to Transmission Lines</td>
<td>Closer to Transmission</td>
<td>Discrete</td>
<td>Continuous</td>
<td>[0–1]</td>
<td>2</td>
<td>NA</td>
<td>1500 m</td>
</tr>
<tr>
<td>Distance to Cities</td>
<td>Far away from Cities</td>
<td>Discrete</td>
<td>Point</td>
<td>Discrete Values Ranging from [0–1]</td>
<td>1</td>
<td>NA</td>
<td>1500 m</td>
</tr>
<tr>
<td>Population Density</td>
<td>Low Population Density per Block Group</td>
<td>Categorical</td>
<td>Polygon</td>
<td>Categorical</td>
<td>1</td>
<td>NA</td>
<td>1500 m</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>Close to Roads</td>
<td>Discrete</td>
<td>Continuous</td>
<td>[0–1]</td>
<td>1</td>
<td>NA</td>
<td>1500 m</td>
</tr>
<tr>
<td>Landcover</td>
<td>Short Vegetation, Subdued, Stable Topography</td>
<td>Categorical</td>
<td>Polygon</td>
<td>[0.33, 0.67, 1.00]</td>
<td>1</td>
<td>NA</td>
<td>1500 m</td>
</tr>
<tr>
<td>Federal Lands</td>
<td>Not in Federal Lands</td>
<td>Categorical</td>
<td>Polygon</td>
<td>[0, 1]</td>
<td>1</td>
<td>NA</td>
<td>1500 m</td>
</tr>
</tbody>
</table>
The following variables were obtained from digital databases: NREL wind speed and solar potential classes, landcover, population density, federal lands, and location of roads, transmission lines, and cities (fig. 7). Landcover were categorized according to their suitability for development. Three classes were created. Ideal locations contained short vegetation, such as shrubs, prairie, grasses, scrub, steppe, agriculture, logged areas, or barren lands, which would not impede wind or reduce solar insolation. Areas that were not as suitable contained sparse, but taller vegetation (piñon, juniper, or ponderosa woodlands) or wetlands, which would be difficult to develop due to their ecologic importance. Non-ideal landcover contained pine, subalpine, and aspen forest or areas that would be difficult to develop based on their inaccessibility, instability, or degree of existing development.

Figure 7 Location of major roads, cities, and transmission lines in Colorado

Federal lands were used as a mask to filter areas where publicly or privately funded renewable energy projects may be difficult to implement. Areas such as National Parks, National Monuments, and Native American Reservations were assigned a value of 0 to remove them from the analysis, whereas the remaining areas were assigned a value of 1 (Table 1). Each of the data sets, categorized from poor to excellent (0e1), are provided in Fig. 8.
Figure 8 GIS variables used to model ideal locations for wind or solar farms
Results:

**Areas of high wind potential: GIS model**

According to the multicriteria GIS wind model, larger wind farms should be located in northeastern Colorado (Fig. 9). North of Fort Collins, a cluster of high scores exists. Model scores in the foothills of the Rockies between Estes Park and Boulder are also high (Fig. 9). These areas are located on the more densely populated eastern half of the state, so they could provide electricity to some major urban centers. Other isolated patches of high GIS model scores are located at remote sites in the Colorado Rockies. These may be ideal for ski resorts or sparsely populated communities to develop small-scale wind farms for powering ski lifts or other facilities.

![Ideal wind farm locations in Colorado according to GIS model criteria](image)

**Area of high solar potential: GIS model**

Ideal areas for solar farms are located in two distinct sections of Colorado: east of Denver and in the northwestern part of the state in Moffat County near Dinosaur National
Monument (Fig. 10). Although GIS model scores vary significantly, NREL solar potential data indicate that there is only a slight difference between model classes since most of the state receives sufficient insolation. The site in eastern Colorado should be explored in more detail for future development given its proximity to Denver. The site in northwestern Colorado is close to a transmission line; however, the potential to deliver solar power across the state may be limited.

![Ideal solar farm locations in Colorado according to GIS model criteria.](image)

This study has successfully used GIS overlay techniques to examine the relationship between landcover classes and NREL solar and wind potential data with the conclusion that the GIS model is better equipped at detecting regional renewable energy facilities that are capable of supporting large urban populations.

**Case study II**

Nazli Yonca Aydin et al. (2013) conducted a case study for western Turkey to determine suitable location for Solar–wind energy hybrid systems [21]. Many GIS applications have been developed for site selection problems in various research areas such as natural resources
management, environmental pollution and hazard control, regional planning, urban development, and utilities management. A GIS-based Multi-Criteria Decision-Making (MCDM) that provide a systematic tool for decision makers in site selection methodology for hybrid renewable energy systems was used together with Fuzzy Set Theory to model imprecise objectives in this research area. The objective of this study was:

- Identify economically and environmentally feasible locations for hybrid wind solar–PV systems in the western part of Turkey including Usak, Aydin, Denizli, Burdur, and Mugla provinces.

Economic feasibility objectives and environmental objectives are identified for the case study application through a comprehensive review of the literature, current Turkish laws and legislations, and interviews with the General Directorate of Electrical Power Resources Survey and Development Administration (EIEI) of Turkey. Tables 2, 3, 4 & 5 displays these objectives.

**Table 2 Environmental objective and associated criteria for wind energy**

<table>
<thead>
<tr>
<th>Environmental objectives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-1. Acceptable in terms of natural reserves</td>
<td>1000 m away from areas of ecological value</td>
</tr>
<tr>
<td></td>
<td>400 m away from water bodies</td>
</tr>
<tr>
<td></td>
<td>250 m away from ecologically sensitive areas</td>
</tr>
<tr>
<td>F-2. Acceptable in terms of safety and aesthetics for airports</td>
<td>2500 m away from airports</td>
</tr>
<tr>
<td></td>
<td>2500 m away from airports</td>
</tr>
<tr>
<td>F-3. Acceptable in terms of safety and aesthetics for town centers</td>
<td>Minimum 1000 m away from towns</td>
</tr>
<tr>
<td>F-4. Acceptable in terms of safety and aesthetics for large city centers</td>
<td>2000 m away from large settlements</td>
</tr>
<tr>
<td>F-5. Acceptable in terms of noise</td>
<td>500 m away from nearest habitat</td>
</tr>
<tr>
<td>F-6. Acceptable in terms of bird habitat</td>
<td>At least 500 m away from wildlife conservation areas</td>
</tr>
<tr>
<td></td>
<td>300 m from nature reserves to reduce risk to birds</td>
</tr>
</tbody>
</table>

**Table 3 Environmental objective and associated criteria for solar energy**

<table>
<thead>
<tr>
<th>Environmental objectives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1. Acceptable in terms of natural reserves</td>
<td>Only the constructions for public interest are allowed if activities are highly necessary to build on forest areas</td>
</tr>
<tr>
<td></td>
<td>Only the constructions that are compatible with the nature are allowed</td>
</tr>
<tr>
<td></td>
<td>The structures that have adverse impacts on habitat cannot be built</td>
</tr>
<tr>
<td>F-7. Acceptable in terms of agricultural areas</td>
<td>Agricultural area must be protected in order to sustain natural functions of the land</td>
</tr>
<tr>
<td></td>
<td>Cultivable land might be damaged by large scale installations thus must be protected</td>
</tr>
<tr>
<td>F-8. Acceptable in terms of flight security</td>
<td>Minimum distance to airports is 3000 m and maximum distance to airports is 5000 m</td>
</tr>
<tr>
<td>F-9. Acceptable in terms of lakes and wetlands</td>
<td>At least 2.5 km buffer zone to protect ecologic and topographic features</td>
</tr>
<tr>
<td>F-10. Acceptable in terms of coastline or river</td>
<td>Minimum distance is 100 m from the coastline</td>
</tr>
</tbody>
</table>
Table 4 Economic feasibility objectives for wind energy

<table>
<thead>
<tr>
<th>Economic feasibility objectives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-11. Acceptable slope</td>
<td>Slope up to 10%</td>
</tr>
<tr>
<td></td>
<td>Slope up to 30%</td>
</tr>
<tr>
<td></td>
<td>Slope up to 20%</td>
</tr>
<tr>
<td></td>
<td>Slope up to 30%</td>
</tr>
<tr>
<td>F-12. Acceptable proximity to transmission lines</td>
<td>At most 10 km from national grid</td>
</tr>
<tr>
<td></td>
<td>At most 2 km from national grid</td>
</tr>
<tr>
<td>F-13. Acceptable proximity to main roads</td>
<td>Minimum distance is required for operation and maintenance purpose</td>
</tr>
<tr>
<td></td>
<td>Maximum distance to major roads should be 10 km</td>
</tr>
<tr>
<td></td>
<td>Maximum distance to major roads should be 2.5 km</td>
</tr>
<tr>
<td></td>
<td>Maximum distance to major roads should be 240 m</td>
</tr>
<tr>
<td>F-14. Sufficient potential for wind energy generation</td>
<td>Economically feasible power values are between 300 W/m² and 400 W/m² in Turkey</td>
</tr>
<tr>
<td></td>
<td>Economically feasible power values starts from 200 W/m² in Europe</td>
</tr>
</tbody>
</table>

Table 5 Economic feasibility objectives for solar energy

<table>
<thead>
<tr>
<th>Economic feasibility objectives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-15. Sufficient Potential for Solar Energy Generation</td>
<td>Minimum solar radiation value is 4.5 kWh/m² day</td>
</tr>
<tr>
<td>F-16. Acceptable slope</td>
<td>Slope up to 3%, 1% most economic</td>
</tr>
<tr>
<td></td>
<td>Less than 3%</td>
</tr>
<tr>
<td>F-17. Acceptable proximity to transmission lines</td>
<td>For grid-connected systems, if the distance to transmission line is more than 0.5 miles, then additional costs associated with connecting the system to the nearest grid must be considered.</td>
</tr>
<tr>
<td>F-18. Acceptable proximity to urban areas</td>
<td>Minimum distance to urban areas should be 5 km. Maximum distance to urban areas should be 10 km</td>
</tr>
<tr>
<td></td>
<td>Electrical production plants need to be located near urban area to avoid transmission loss</td>
</tr>
<tr>
<td></td>
<td>Proper site selection and design of large PV installations due to the visual impact</td>
</tr>
</tbody>
</table>

Methodology:

In this study, suitable locations for Wind turbines and Solar–PV power plants are identified separately; then these priority sites are overlaid to obtain feasible locations for hybrid wind solar–PV energy systems. In order to perform site selection of hybrid wind solar–PV systems, environmental objectives need to be evaluated together with economic feasibility objectives. A selected location that has high environmental satisfaction degree may not be a priority site for wind and solar energy systems unless the energy potentials and other economic feasibility objectives are satisfied. Fuzzy membership functions of economic feasibility objectives related with wind and solar power plants are generated using the information summarized in Tables 4 & 5. Figure 11 displays the detailed methodology of their research.
Results:

Figures 12 & 13 display the total amount of wind energy and total amount solar energy available in Turkey respectively. Figure 14 shows the area of study. Individual satisfaction degrees for “Satisfaction of most of the economic criteria” for wind energy (figure 15) and “Satisfaction of the most of the environmental criteria” for wind energy (figure 16) are combined into an OPIWIND using the “and” operator. Then priority sites for wind energy are identified and given in Fig. 17. Individual satisfaction degrees for “Satisfaction of most of the economic criteria” for solar energy (figure 18) and “Satisfaction of the most of the environmental criteria” for solar energy (figure 19) are combined into an OPISOLAR using the “and” operator. Then priority sites for solar energy are identified and given in Figure 20. The authors have concluded by stating the following:

A map showing the priority sites for hybrid wind solar–PV systems is provided in Figure 21. Currently, within the study area there are six wind farms some of which are already constructed and the others have licenses to produce energy by using wind power. To increase the efficiency of energy generation on these locations, integration of solar–PV systems may be considered. Figure 22 shows the current wind turbine locations within the study area, and gives a detailed view of current wind farm locations and identified potential
areas for hybrid wind solar–PV systems. As can be seen from Figure 22, wind farm numbers 3 and 4, and wind farm number 6b are close to potential locations of hybrid wind solar–PV systems. Solar power plants can be planned at these locations so that solar–PV power plants can produce electricity when wind turbines fail due to weather conditions.

Figure 12 Wind energy potential atlas of Turkey

Figure 13 Solar energy potential atlas of Turkey
Figure 14 Study area

Figure 15 “Satisfaction of most of the environmental feasibility objectives” for wind energy
Figure 16 “Satisfaction of most of the economic feasibility objectives” for wind energy.

Figure 17 Priority sites for wind energy generation within the study area.
Figure 18 “Satisfaction of most of the environmental objectives” for solar energy.

Figure 19 “Satisfaction of most of the economic feasibility objectives” for solar energy.
Figure 20 Priority sites for solar power plants within the study area

Figure 21 Priority sites for hybrid wind solar–PV systems within the study area
4. Conclusion

GIS is used to create a map book combining Renewable energy resources (i.e., wind, solar, bio-mass, geothermal, bio-fuel, and hydropower), transmission, parcel, and road data. The countries can visualize Renewable energy resources and transmission lines with the functionality making nearly all facility layouts visual. Locating the right site can be done quickly and accurately with publicly available data and GIS technology. This helps investors and developers locate best renewable energy resource areas. This study have shown the potential role GIS plays in the field of renewable energy.
5. References


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