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Geographical Information System (GIS): A Critical Tool for Energy Science Analysis

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Abstract

This paper examined the critical role of GIS in energy science analysis with practical examples. It is established that GIS has the capability to identify the location of energy resources and it can also be used in mapping, analysis, exploration, monitoring, modelling and management of energy resources. In spite of these capabilities, GIS has not been properly exploited in energy science due to lack of awareness of what GIS can do especially in less developed countries. This is a challenge to GIS community. There is therefore a need for enlightenment of the public and stakeholders on the functionalities of GIS.

1. Introduction

Geographical Information System (GIS) is a computerised information system for gathering, organising, storage, management, analysis and display of geographically referenced data to provide useful information on the Earth's surface. Energy is one of the most essential resources of the Earth's surface. This is because it is vital for socioeconomic activities and technological development. Therefore, Energy science is an indispensable field of knowledge which requires special attention because of its relevance in human endeavours. Energy science involves the location, mapping, analysis, exploration, exploitation, monitoring, modelling and management of energy resources. GIS has the capability to contribute in all these areas of energy science. The role of GIS in the assessment and analysis of energy resources is presented in this paper.

2. Definition of GIS

GIS is "a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes" (Burrough and McDonnell, 1998). GIS consists of computer hardware and software that put in, store, preserve, manipulate, explore, and give out georeferenced data (Heimiller and Haymes, 2001).

The vital components of a GIS can be broadly divided into five classes: data acquisition; pre-processing; data management; manipulation and analysis; and product generation (Star and Estes, 1990). Data is acquired for GIS operations from secondary or primary sources such as global positioning system (GPS) and satellite remote sensing. The data is then georeferenced, enhanced and where necessary corrected geometrically and radiometrically. The objective of this is to refine and filter the data for organisation and storage in a database for subsequent analysis. This is followed by data manipulation and analysis with a view to synthesise, add value and derive useful geographic information for display as output.

GIS is a scientific tool for understanding Earth's surface features and making intelligent decisions (Environmental Systems Research Institute, 2010) about them. Therefore, GIS is a useful scientific tool for energy resource and critical resource geographies; which deal with scientific analysis in critical areas of energy resource location, exploitation and utilisation. GIS has the capability to integrate geographic data from multiple sources, organise them in form of layers, and select data required for a specific task, as it gives room to update geographic information (ESRI, 2010). This is useful in energy resource analysis because energy resources are dynamic, evolve from variety of sources, and their distributions vary spatially and temporally.

3. Application of GIS in Non-renewable Energy Assessment

Longley *et al.* (2005) outlined the uses of GIS to include mapping, measurement, monitoring, modelling and management of geographic information. These have important applications in energy science. Firstly, mapping is required to identify the location of energy resources for economic development. Measurement is vital to assess the potential of the resources for investment. Monitoring is necessary to ensure the viability of investment. Modelling is important to address the dynamism of resources in the future. Then, management is necessary to achieve efficiency of any functional energy system. Moreover, GIS has the capability to acquire spatial and non-spatial information on the resources, show distributions and variations of energy resources across a geographical area or region.

Furthermore, a critical area of energy system is the analysis of demand and supply. Isma'il (2012) utilised cartograms created in a GIS environment to visualise the global shift in production and consumption of fossil fuels. He discovered that cartograms provide informative and intuitive picture of the global shift in energy demand and supply.

4. Application of GIS in Renewable Energy Analysis

In order to harvest the potential of renewable energy resources, there is a need to assess the availability of the resources spatially as well as temporally (Ramachandra, 2007) to evolve better management plans for ensuring sustainability of the resources (Ramachandra and Shruthi, 2007). GIS is the ultimate tool which enables accurate estimation of available energy resources spatially and temporally. One approach to this is the spatial mapping of available renewable and non renewable energy resources in an area or region. The spatial mapping of availability and demand of energy resources is critical for integrated regional energy planning (Ramachandra and Shruthi, 2007).

Ramachandra and Shruthi (2007) applied GIS to assess spatially the availability of renewable energy resources and energy demand talukwise in Karnataka State of India. In this case, GIS was used for identifying and quantifying the effect of local constraints on the renewable energy potential. The study identified that coastal parts of Karnataka with the higher global solar radiation are ideally suited for exploiting solar energy. They also recommended six locations as the most suitable sites for construction of wind farms in the region. In addition, they discovered that the potential sources of small hydropower are at the base of existing irrigation dams, anicuts, canal drops and hill streams. The availability of bioresources in different taluks was found to depend on the agroclimatic zones. They found that GIS helps not only in spatiotemporal analyses of energy resources but also guides in implementing location-specific renewable energy technologies.

Domınguez and Amador (2007) synthesised the analysed applications of GIS in Decisions Support Systems (DSS); renewable energy and distributed generation of electricity; and decentralized generation for the rural electrification. They highlighted a number of renewable energy projects that have been implemented using GIS in different parts of the world. These include REGIS (Geographical Information System for Renewable Energy) in Catalonia; SOLARGIS (for wind, PV, petrol, hybrid systems and electrical network) in Mediterranean and developing countries; BRAVO (Biomass Resource Assessment Version One) developed in Tennessee Valley (USA).

GIS can not only enhance the way we produce and deliver energy, but can also change the way we analyse our earth's resources (ESRI, 2010). Matejicek and Pribil (2012) demonstrated how GIS is used for spatiotemporal analysis in order to estimate the potential energy sources in a selected region of the Czech Republic. In this case, GIS was employed to design decentralised energy systems using renewable energy resources such as solar, wind and biomass. The final GIS map illustrated the total utilisation of various energy systems in space and time, which can assist in decision-making processes on local and regional scales.

4.1. Solar Energy

Solar radiation data is required for harnessing and developing solar energy resources in any given geographical location. Conventionally, such information is obtained from a dense network of solar radiation or meteorological stations equipped with pyranometers and data acquisition systems covering an area of interest. Journée and Bertrand (2010) observed that solar radiation data has been spatially and temporally inadequate for many applications. This is due to the insufficiency and costly nature of installation and maintenance of networks of meteorological stations which provide the solar radiation data. An alternative and less expensive method to derive solar radiation data is the use of GIS techniques. This has been demonstrated by Rehman and Ghori (2000) who utilised a geostatistical technique (GIS + statistics) for the estimation of solar radiation in Saudi Arabia.

In addition, Photovoltaic Geographical Information System – PVGIS (Huld *et al.*, 2005) has been developed in the Joint Research Committee during the last 10 years and provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. PVGIS is a popular, widely employed and very efficient tool for further analysis on solar energy exploitation and development.

Similarly, Germany's SUN-AREA Research Project uses GIS: using ArcGIS Desktop tools, researchers identified all necessary rooftop data. In this case, ArcGIS tool was used to estimate the solar potential of all roof areas for solar energy deployment. In addition, the application gave the research team an intuitive interface for solar energy analysis (ESRI, 2010).

Also, a team of experts from The U.S. Department of Agriculture (2005) and the Department of Energy's National Renewable Energy Laboratory utilised GIS data to analyse and assess the potential for concentrating solar power (CSP), photovoltaics (PV), and wind resources and technologies on public lands. In addition, they identified using GIS the National Forest and Grasslands units that have the highest potential for development by industry of power production facilities based on solar and wind energy.

4.2. Wind Energy

Modelling the feasibility of wind power projects requires studying location, wind speed, proximity to transmission lines, landuse, landownership, environmental concerns, and other variables. GIS is capable of providing this information to developers. Wind energy development starts with a survey of the proposed location to collect location-based data which is compared with digital geographic information within the GIS environment. Then, the location-based data can be updated with GPS, other relevant data and analysed in GIS for facility layout (ESRI, 2010). Once a wind farm is up and functioning, operators continue to use GIS to manage it for proper functioning. Moreover, operators can use ArcGIS technology to model and predict how well the wind will perform and accurately match energy supply with demand (ESRI, 2010).

GIS analysis can combine data layers to identify areas with strong potential for wind resource exploitation using potential wind resource availability, electricity rate, and national electricity load information. In addition, a GIS is an exceptional tool for wind energy development because data can be readily updated and analysed to give digital geographic information as output. The output can be easily, quickly and efficiently distributed to the wind energy industry (Heimiller and Haymes, 2001) for wind energy development.

Moreover, an example of a pilot project is SWERA (2013) which is designed to collect solar and wind data in 13 developingcountries and to facilitate investments in solar and wind energy projects. SWERA is developing new GIS tools for energy planning and development. These tools include regional and national maps of solar and wind energy resources and a GIS that will allow easy access to the detailed information contained in these maps.

Furthermore, using ArcGIS Desktop software, the United States National Renewable Energy Laboratory team designed GIS which can determine the most favourable locations for wind farms based on the cost of transmission, locations of load centres and wind resources, and the layout of the electrical grid. GIS-based modelling allows analysis of terrain, which significantly impacts the quality of wind at a particular site. Also, ArcGIS was used to create a wind map book combining wind, transmission, parcel, and road data. GIS data helps investors and developers locate most appropriate wind power resource areas in Cascade County, Montana of USA. The county can visualise wind speeds and transmission lines with the functionality in ArcGIS (ESRI, 2010).

4.3. Hydropower

The Idaho National Engineering and Environmental Laboratory inconjunction with the United States Geological Survey employed GIS for the assessments ofall 20 hydrologic regions in the United States for hydropower development. The assessments provided not only estimates of the amount of low head/low power potential, but also estimates of power potential in several power classes defined by power level and hydraulic head, as well as estimate of the total power potential of water energy resources in individual states and hydrologic regions and nationionwide (Hall *et al.*, 2004).

Likewise, an integrated remote sensing and GIS based methodology was developed and tested by Bera and Bandyopadhyay (2012) for the evaluation of the groundwater resources of Dulung watershed, PaschimMedinipur District, West Bengal and a small part of the adjoining Jharkhand state in India. The researchers succeeded in delineating ground water potential zones for the entire Dulangnala watershed which has been categorised as very low, low, medium and high recharge potential zones.

4.4. Geothermal Energy

A team of experts from The U.S. Department of the Interior Bureau of Land Management (BLM) (2003) and National Renewable Energy Laboratory utilised GIS data to analyse and assess renewable resources (which include geothermal and hydropower) on public lands. They also identified using GIS the areas in the western United States with the highest potential for development of power production facilities based on renewable energy.

4.5. Biomass

For the purposes of assessing potentially available biomass, GIS can be a very essential tool for locating and planning the transportation and storage of the biomass. These are necessary steps for the development of biomass. This information will be used for the assessment of economic costs and benefits to both the buyers and sellers (Crocker, 2008).

Findings of the California Biomass Collaborative revealed that California has enormous and diverse biomass resource base that could potentially provide the state with alternative energy source. The Collaborative used ArcGIS software to examine the economic viability of biomass supply for different types of manufacturing facilities of future bioenergy, biofuel, and bio-based products.The GIS work of the California Biomass Collaborative may support state-wide efforts to attract developers and include biomass as a viable renewable resource to meet state energy demands (ESRI, 2010).

Stampfl *et al.* (2007) used GIS spatial analysis to predict *Miscanthus* biomass production on national and regional levels across Europe. They integrated data from various sources, and analysed them using GIS to produce energy statistics for the EU-25. They concluded that the GIS database can be easily updated in the future with new datasets or improved spatial resolution of data. Besides, the model offers greater flexibility and can be adjusted easily to changing policies, diverse climate and energy scenarios.

Furthermore, Samuta *et al.* (2012) estimated usable biomass potential and optimal locations of biomass power plants using GIS and an optimal method in Guangdong Province of China. They found that the linear programming analysis model which was prepared using GIS helped to obtain the optimal transportation process and the number of profitable conversion plants for the biomass resource.

5. Conclusion

The critical role of GIS in energy science has been examined with practical examples. It is established that GIS has the capability to identify the location of energy resources and it can also be used in mapping, exploration, monitoring, modelling and management of energy resources. In spite of these capabilities, GIS has not been properly exploited in energy science due to lack of awareness of what GIS can do especially in less developed countries. This is a challenge to GIS community.

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