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Geographical information systems applied in the field of renewable energy sources

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Abstract

This article presents a synthetic vision of geographical information systems (GIS) applications that are state of the art in the renewable energy field. The objective is to analyze the main qualities and problems of these applications, focusing on specific samples, and to carry out a methodological proposal in this genre.

From this point of view, the study synthesizes the analyzed applications in three big groups: Decisions Support Systems (DSS) based on GIS; renewable energy and distributed generation of electricity; and decentralized generation for the rural electrification. In addition, a synthetic table and bibliographical references is provided for each group.

Finally, several conclusions and a methodological outline are contributed for GIS application in the rural electrification with renewable energy.

Keywords: GIS; Renewable energy sources; Electric power; Rural electrification; Decentralized generation

1. Introduction

The main aim of this work is to expose the state of the knowledge in the application of the GIS in order to improve the renewable energy integration for electricity generation.

The renewable energy sources (RES) have some special "geographical qualities" for their treatment with GIS; the power of these tools is shown in their incorporation from the geographical analysis to the strategic planning of new facilities and in the simulation of supply–demand scenarios with different technological possibilities for satisfaction. Nevertheless, as we will see in the next study of GIS application to renewable energies, the approaches are carried out fundamentally from an energetic point of view, and rather than a territorial one. Because the object of this study is the use of renewable resources and demand satisfaction, rather than territory, the connections between energetic strategies and other possible land uses are not examined herein. This viewpoint involves, for example, the widespread use of variables such as facilities, slopes,

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resources, demand and, also, a certain environmental characterization without considering a deeper and integrated definition of the region (Domínguez, 2002).

Nowadays, there are several projects that utilize GIS from the field of renewable energy. Many of them have a sectoral character and apply GIS applications to localization problems resolution or to resources evaluation for specific sources. In this field, studies for wind farms siting, photovoltaic electrification, or biomass evaluation stand out. However, other studies are of a global nature. Often times, these projects aim to create a model of the territory from a perspective of different renewable source integration in the regional energetic system or, on the other hand, seek solutions to rural electrification problems.

2. State of the art

Next, the state of the knowledge in the GIS application is studied in the field of RES following a classification in one of three major groups: DSS predicated on GIS for renewable energy regional integration; GIS for the evaluation of renewable energy in the distributed electricity generation; and, finally, GIS for the evaluation of decentralized electricity generation systems.

2.1. Decision support systems

During the last decade, considerable effort has been expended to obtain DSS tools in order to facilitate renewable energy on a regional scale. Many of these projects have been implemented in the European Union within the APAS-RENA framework. The use of a geographical information system is common to all of these projects (see Table 1).

Inside the APAS-RENA framework, the first analyzed project was REGIS (FEDARENE, 1996), which was developed in two stages. The first stage was in the context of the initial referenced research framework and the second was in the ALTENER II Programme. In the first stage, a GIS was developed for renewable energy sources as an instrument of regional energy planning, with the participation of several regions integrated in the European Federation of Energy and Environment Regional Agencies (FEDARENE). The system was developed for technical users and economic decision-makers. It identified potential areas for renewable energy technologies, determining the socio-economic and environmental effects of this project. At the end of this first stage of the project, each region had the appropriate GIS equipment to integrate the available data on a regional scale. Local authorities also demonstrated great interest in regional energy planning using GIS. Finally, the operational component of the GIS was developed in the region of Nord-Pas de Calais in France as a pilot project. The second stage of REGIS was called "*Geographical Information System for Renewable Energy (REGIS) in Catalonia*." It was based on the previous pilot project and developed by the Catalan Institute of Energy (ICAEN).

The project EPURE (Voivontas, Assimacopoulos, Mourelatos, & Corominas, 1998) was also part of the APA-RENA Program. Its main objective was to move from the evaluation of potential renewable energy resources to the evaluation of the economic potential for investment. In this sense, the specific objective was to identify the regions that had economically competitive renewable resources with acceptable levels of financial risk. In order to achieve this goal, the project workers attempted to standardize the resource and demand data. Given this aim, a general method was established for an evaluation of resources that considered the area's potential economic, technical, and functional aspects.

Table 1
DSS based on GIS for renewable energy integration in European regions

GIS	Countries	First aspects	Software
REGIS	Spain, France, Portugal, and Greece	Socials, economic, and environmental	Arc View
EPURE	United Kingdom, Spain, France, Germany, Italy, and Greece	Economic	MAPINFO
EnTRACK	United Kingdom, Portugal, and Spain	Socials, economic, and environmental	
REPLAN	Greece	Demand, supply, technology, and scenarios	
REDES	Greece	Water management	

Another important project was EnTRACK (Clarke & Grant, 1996). For this project, renewable energies could be promoted in Europe via planning and management tools. These tools were required to include temporary and geographic variables of the demand and supply local models. The objective of EnTrack was a DSS for the evaluation of renewable energy integration alternatives.

The REPLAN project (Georgopoulou, Sarafidis, & Diakoulaki, 1998) sought to establish a large-scale integration methodology for renewable energy in Europe. In order to achieve this aim, a process based on specific software was created. This software was compound for four organized and interconnected modules: energy demand, supply, technology, and scenarios maker.

Finally, REDES (Muselli, Notton, Poggi, & Louche, 1999) was a methodological tool used to evaluate the profitability of renewable energy use in water desalinization facilities. It included a DSS based on a GIS. The project took place in Greece and followed these stages: water demand by use evaluation; renewable energy resources evaluation; and the availability of seawater resources, along with an evaluation of the desalinization methods and renewable energies possibilities.

2.2. Distributed electricity generation

The application of GIS with renewable energies in distributed electricity generation has been the focus of a number of projects, as well. These projects have usually been developed in order to evaluate renewable resources and the siting of grid-connected systems (see Table 2).

Frequently, the models for wind resource evaluations and siting integrate geographical analysis tools like Digital Elevation Models (DEM). DEM was one of the first tools used for the localization of wind farms (Wendell, Gower, Birn, & Castellano, 1993) due to the importance of topographical factors (elevation, slope, and morphology) in the application of this power source. Likewise, the usual tools for wind resource evaluation as the WAsP include analyses modules of topography and roughness. Sometimes, commercial GIS (IDRISI, MAPINFO, ARCINFO, etc.) have been incorporated in order to perform a global analysis of resources utilization. In some cases, the study is focused on resources evaluation, while mindful of the constraints involved with wind farm installation. The main objective of these samples is to make wind resource maps (Elliot, Aspliden, & Cherry, 1981).

Nevertheless, the most common examples are wind farm siting studies. One of the pioneer projects in this line was described by Petit (1995). The purpose of wind farm planning in the region of Nord-Pas-de-Calais in France was to inventory the best wind resources areas for wind power development. The project also considered natural and human constraints as factors.

Biomass is another popular field for GIS application. The influence of geographical factors is notable in potential resource distribution and the exploitation, transport, and siting of power stations. One of the most outstanding projects in this area was developed by Noon and Daly (1996) in Tennessee Valley (USA). There, a DSS denominated BRAVO (Biomass Resource Assessment Version One) was developed. BRAVO estimated the substitution cost and viability for the 12 thermoelectric power stations located at that site.

Table 2
GIS application to electricity distributed generation with renewable

Source	Issues		Author	Areas	First variables
Wind power	Resources		Elliot	Many countries	Wind resources, physiographics–thopographics, environment, natural and cultural assets, infrastructures and villages, and land uses
	Wind farm	Offshore	Matthies	EU	
			Voivontas	Greece	
		Onshore	Petit	France	
			Baban	UK	
Photovoltaic	Roofs		Marnay	USA	Solar radiation, prices, and population
Biomass	Resources		ALTENER	Spain	Administrative, cities, infrastructures, land use, pedology and topography
	Power plants		Voivontas	Greece	
			Graham	USA	

Table 3
GIS and electricity decentralized generation to rural electrification

Author/ project	Technology	Study area	First characteristics
SOLARGIS	Wind, PV, petrol, hybrid systems and electrical network	Mediterranean and developing countries	Geographic factors, LEC calculation, and demand estimation
Ariza	PV and electrical network	Córdoba	Territorial and economic competitiveness
Muselli	PV, petrol, hybrid systems, and electrical network	Córcega	Kina of load and LEC

2.3. Decentralized generation and rural electrification

Finally, there are many samples of GIS applications in the decentralized production of electricity and rural electrification with renewable energy (see Table 3). Most of them are related to the SOLARGIS project, whose aim was the "integration of renewable energies for decentralized electricity production in regions of European Union and developing countries" (Monteiro, Miranda, & Saraiva, 1998; Solargis-Team, 1996).

CIEMAT (Research Center for Energy, Environment, and Technology) and Public Organism for Research and Technological Development in Spain joined with the Electric Engineering Department of the University Polytechnic of Madrid (UPM) to develop the project "Geographical Information Systems in the Regional Integration of Renewable Energy for Decentralized Production of Electricity: Technical Parameters Analysis" (Amador, 2000). The aim of this collaboration was to determine the grade of uncertainty of the results provided by SOLARGIS and to develop a new application with high certainty in the results quality. In order to attain these objectives, the most outstanding technical and economic parameters in the regional integration of the RES for the decentralized production of electricity were analyzed.

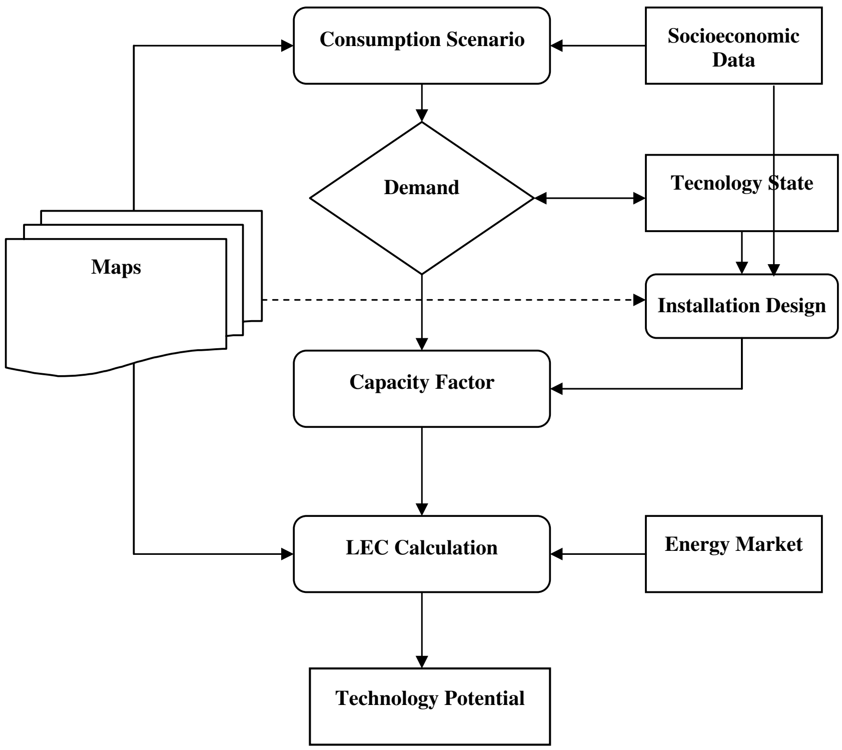

Fig. 1. GIS for rural electrification. Methodology proposal.

As a result of this study, a GIS application has been developed (Amador & Domínguez, 2005). This application is based on ArcInfo™ and it completes and improves upon the first version of SOLARGIS in several ways. First, it incorporates a demand scenario based on socioeconomic variables from experimental data of consumption. It also carries out the calculation of the capacity factor for conventional systems with professionally contrasted design criteria. It assigns new variables and eliminates other irrelevant or redundant factors. In addition, it notably improves the user program control. The flow diagram is shown in Fig. 1.

On the other hand, system evaluation was one of the most remarkable aspects of this project. In this sense, a spatial sensitivity analysis methodology has been developed. This methodology includes three stages: sensitivity analysis of the LEC, spatial sensitivity analysis, and results stability (Amador & Domínguez, 2006).

3. Conclusions

In conclusion, we would like to point out that the employment of GIS as a support tool for rural electrification plans and renewable energy integration presents many advantages, though we should not forget the need for results control. The main sources of uncertainty that generate results lacking control are deficient knowledge of demand, imprecision in the value of the different technologies' capacity factors, imprecision in the value of the economic parameters (especially the discount rate), and, lastly, the limitation of results to a previously defined context. Thus, the development of control methods for result stability and risk error is very important in the application of these systems by planners.

Finally, we would like to highlight the necessity of an integrated vision on a regional scale. This vision could be developed by a GIS that should include all of the energy system variables in an integrated model of decentralized electricity generation.

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