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Renewable Energy with the Help of GIS (Geographic Information System)

Distributed Generation with Renewable Energy System: Spatial Decision Support System

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List of Acronyms

DG	Distributed Generation
SDSS	Spatial Decision Support System
RES	Renewable Energy System
CHP	Combined Heat and Power
GHG	Greenhouse Gases
GIS	Geographic Information System
SQL	Structured Query Language
MCDA	Multi-Criteria Decision Aid
DM	Decision Maker

1- Introduction

The global requirement for sustainable energy provision will become increasingly important over the next years as the environmental effects of fossil fuels become apparent. Distributed Generation (**DG**) based on Renewable Energy Technologies (solar, wind, hydro and biomass) is becoming a more important energy option in the future generation system. Depending on the local conditions and energy potential, one or more of the widely used renewable energy sources can be exploited locally. Wind energy for electricity production, biogas from solid waste for heat and electricity production, solar for heat and electricity production, hydro for electricity production.

As other energy facilities, DG facilities require a sitting review process to acquire the permits and approval needs for construction and operation. Locating optimal sites for power generation facilities is a complex task involving many environmental, economic, and social constraints and factors associated with existing central power plants, substations, transmission and distributions lines, networks of power system, etc.

A Geographic Information System (GIS) is an appropriate tool to address this issue, since it efficiently stores, retrieves, analyses, and displays geographically referenced information (i.e., data identified regarding to their locations) according to user-defined specifications. Thus, once a GIS database is developed, it can provide an efficient and affordable means of analyzing potential DG facility site attributes.

This paper presents an outline of a Spatial Decision Support System (SDSS) to select optimal sites to install DG facilities. A variety of constraints and factors were identified that address environmental, energy, social, political and economic considerations. The results may help build a developmental vision for sustainable energy systems based on locally available natural resources, and facilitate a transition of national energy and environmental policies towards sustainability.

2- Description

The issue of climate change is becoming a great challenge which the international community must face in this century. Over the last decade, the EU has put significant effort into developing a common strategy in the energy sector. Substituting fossil fuels with Renewable Energy Sources (RES) is regarded as a significant measure for cutting global carbon emissions.

The environmental benefits that go along with the increased use of RES for electricity generation are widely acknowledged. Various life cycle assessment studies in particular point out the large potential of renewable energy technologies for reducing greenhouse gas emissions, as well as of emissions that contribute to regional environmental problems like acidification. As a consequence, quite ambitious targets for increasing the use of RES were specified by the EU, as well as by various national governments (Krewitt and Nitsch, 2003). The EU strategy is that 22.1% of the total electricity consumption in 2010 should stem from RES. Particularly Greece aims to increase the contribution of RES to an indicative 20.1% (European Directive 2001/77/EC).

Furthermore, a rapid growth for distributed electricity generation is foreseen (IEA, 2002). It is expected that the annual distributed electricity output will grow by 4.2% between 2000 and 2030 reaching 35 GWh by the year 2030 (Soderman and Pettersson, 2006). The use of renewable energy (solar, biogas, wind and hydro) and Combined Heat and Power (CHP) to limit Greenhouse Gases (GHG) emissions is one of the main drivers for Distributed Generation (DG) (Tagaris et al., 2004; Pecas Lopes et al., 2007).

In today's open energy market, distributed energy systems have an increasingly important role. Different definitions regarding Distributed Generation (DG) are used in the literature. DG is an electric power source connected directly to the distribution network or on the customer side of the meter, Ackerman et al. (2001). The distributed energy system is a complex system comprising of a number of energy suppliers and consumers, district heating pipelines, heat storage facilities and power transmission lines in a region, Soderman and Pettersson (2006)**.** DG should not be exclusively confused with renewable energy generation. Renewable can be exploited in DG and are very much encouraged by certain lobbying groups, though non-renewable technologies could also be considered in DG systems (Puttgen et al., 2003).

Traditionally, electricity is generated in large power stations, located near resources or at logistical optima; it is transported through a high-voltage transmission grid and is locally distributed through medium-voltage distribution grids. DG aims to add versatility of energy sources and reliability of supply and reduce emissions and dependence on fossil fuels (Figure 1). The goals of DG include the minimization of the environmental impacts of energy production and introduction of RES to the distribution network. In addition, DG can contribute to the reduction of transmission losses and help introduce new developments such as fuel cells and super-conducting devices (Hartikainen et al., 2007).

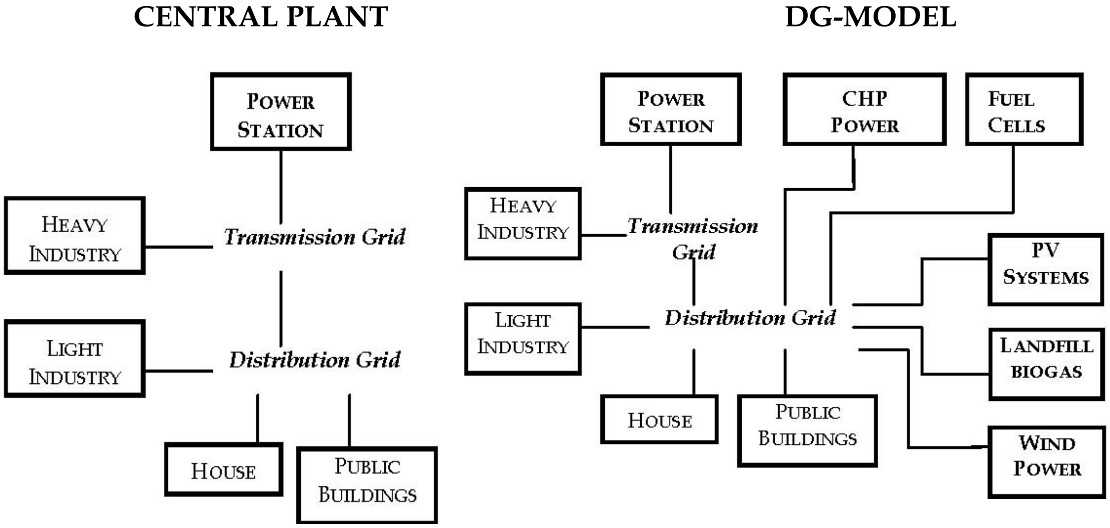

Figure 1: Schematic diagram of traditional central-plant model and DG-model

Certain DG technologies are not new (e.g., internal combustion engines, gas turbines, etc.). On the other hand, due to the changes in the utility industry, several new technologies are being developed or advanced toward commercialization (e.g., fuel cells, photovoltaic, etc.). Figure 2 presents the different distributed generation technologies (Poullikkas, 2007).

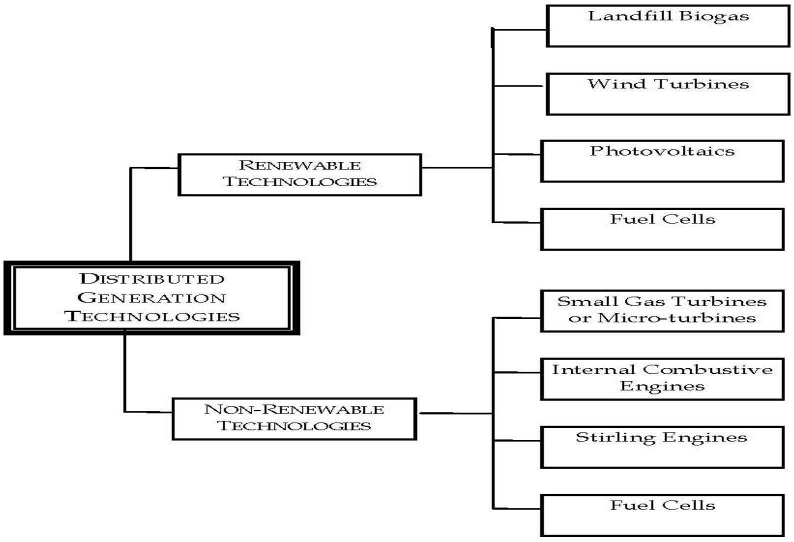

Figure 2: Distributed Generation technologies for power generation

3- General Analysis

3.1 Locating DG Facilities

Although enthusiasm for renewable energy has grown, locating major energy facilities has become increasingly difficult. DG facilities require, like other energy projects, a site locating process geographically constrained by laws or conditioned by the acceptability or unacceptability of the several entities involved in the process (Monteiro et al., 2001; Polatidis and Haralambopoulos, 2004).

Energy and electricity industry professionals and policy groups have developed a variety of studies and strategies for mitigating locating difficulty for a range of new facilities for new power plants (NCEP, 2006). However, locating DG facilities remains a broad and complex problem, affecting both conventional and alternative energy facilities, for which solutions are not obvious or well-understood (Vajjhala, 2006).

The most commonly identified causes of locating difficulty fall into three main categories: (a) public opposition, (b) regulatory roadblocks, and (c) environmental constraints (Vajjhala and Fischbeck, 2007). Together these categories encompass any combination of obstacles to the process of finding locations for new facilities. This includes factors such as public opposition; environmental, topographic, and geographic constraints; inter-agency coordination problems; local and federal regulatory barriers to permitting, investment, and/or construction. In addition to these constrains, financing of new facilities remains insecure and growing locating issues have only compounded investment uncertainty (Vajjhala, 2006).

Public opposition to site location is now so commonplace that it is usually the cause and the primary barrier to any new development. The term NIMBY (Not In My BackYard) has become part of the national vocabulary to the point where it has been replaced by the new term BANANA (Build Absolutely Nothing Anywhere Near Anything). The transition from NIMBY to BANANA marks a turning point in public influence on locating DG projects.

Public opposition to new power pants is perhaps the most well-known constraint on locating processes. However, the most fundamental and yet least discussed locating constraint is the physical or environmental characteristics of the site itself. Technical and engineering criteria provide the basic guidelines for the earliest stages of project decision-making as well as the identification of site alternatives.

In other words, in order to be economically viable, renewable facilities must be located close to RES potential. Furthermore, the specific physical conditions of a potential site (i.e. topography, local ecology, type of land cover, etc.) affect the overall project design, and related economic profitability. Particularly for the case of RES, these conditions include the availability and predictability of the resource itself. As a result, project planner's tradeoff between project attributes and site characteristics, since rarely one alternative can dominate others (Vajjhala, 2006).

Locating a facility in general is a difficult task, and renewable facilities face even greater challenges. Three of the most important obstacles for locating in particular RES facilities are as follows: (1) renewable resources are inflexible, (2) renewable energy facilities and transmission lines are tightly coupled systems, and (3) renewable resource sites have limited overlap. The first of these constraints is the most intuitive. Renewable resources are immobile: natural gas or coal can be readily stored and shipped to a wide range of locations, but the wind is blowing where and when it is blowing. In developing a renewable power plant, it is the site that chooses the project, not the reverse, Kahn (2000).

3.2 GIS in Environmental Planning

Because RES tend to be highly site-specific, it is important to know where they are available in addition to numerical assessment. A Geographic Information System (GIS), a computer system capable of assembling, storing, analyzing, and displaying geographically referenced information, is an appropriate tool to address this issue (Ma et al., 2005). Generally, a GIS is a computerized data base which allows one to integrate and to process information coming from different sources. As a toolbox, a GIS allows planners to perform spatial analysis by using its geo processing or cartographic modeling functions, such as map overlay, selection SQL (structured query language) and thematic analysis.

Among all the geo-processing functions, the map overlay is probably the most useful (Figure 3) where the different layers could represent real world features such as urban settlements, roads, land type terrain, water features, electric network, RES potential, etc. (Muselli et al., 1999; Quininez-Varela et al., 2007).

Some people refer to GIS as a spatial database used to collect, store and retrieve information about the location and shape of, and relationships among, geographic features. Indeed, GIS is a particular form of information system applied to geographical data. Geographical data include those which are spatially referenced (location-based data) and contain four integrated components: (1) location, (2) attribute, (3) spatial relationship, and (4) time (Zeng, 2002).

The application of GIS with renewable energies in distributed electricity generation has been the focus of a number of research projects (Domingues and Amador, 2007 in press). In this field, studies for wind farm location, photovoltaic electrification, or biomass evaluation stand out (Yapa, 1991; Voivontas et al., 1998; Gadsden et al., 2003; Ma et al., 2005; Masera et al., 2006; Yue and Wang, 2006; Ramirez-Rosado, 2007).

The appropriateness of a GIS for locating RES facilities is portrayed in Baban and Parry (2001):

1. It can manage and analyze the volumes of diverse multidisciplinary data.
2. It has the functionality to perform “what if” scenarios in order to evaluate the effects of different planning policies or to uncover the optimum RES (e.g., wind farm) site among a number of potential alternatives.
3. It is capable to be used for modeling the adverse impacts of proposed projects and suggest modifications to mitigate or minimized them.

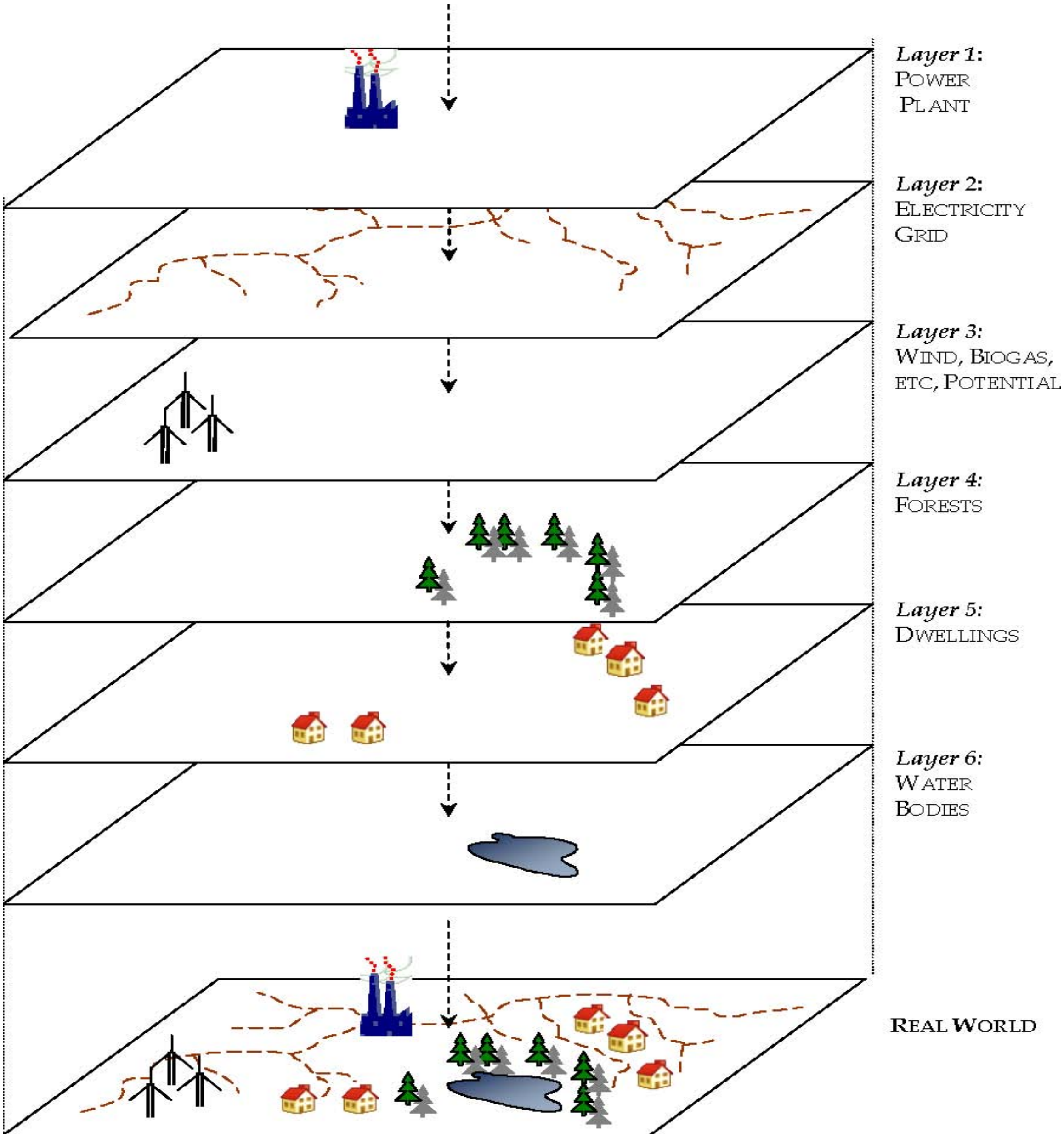

Figure 3: Map overlay function in GIS

3.3 Spatial Decision Support Systems - SDSS

The evaluation of a large number of possible site solutions for sitting DG facilities is facilitated by the use of a SDSS (Monteiro et al., 2001). SDSS is an interactive, computer-based system designed to support users in achieving effective decision making by solving semi-structured spatial problems, Malczewski (1999).

In recent years, there has been a rapid expansion of interest and research on spatial decision support systems. To varying degrees, these approaches attempt to:

A- Capture system dynamics;
B- Deliver outputs as spatial data that define biophysical, economic and social constraints;
C- Use new methods for translating factor layers into standardized inputs for problem criteria definition;
D- Use new methods for capturing uncertainty in ranking of alternatives;
E- Explore options for quantitative optimization with or without spatial component.

Spatial multi-criteria decision problems typically involve a set of geographically-defined alternatives from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski, 1995; Malczewski, 1999). Spatial multi-criteria analysis differs from conventional Multi-Criteria Decision Aid (MCDA) techniques due to the inclusion of an explicit geographic component. In contrast to conventional MCDA analysis, spatial multi-criteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the Decision Makers' (DMs) preferences with respect to a set of evaluation criteria. Therefore, two considerations are of paramount importance for spatial multi-criteria decision analysis (Ascough et al., 2002):

1. The GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability);
2. The MCDA analysis component (e.g., aggregation of spatial data and DMs' preferences into discrete decision alternatives).

It is common practice, in multi-criteria analysis, to distinguish criteria in two categories: factors and constraints. In a SDSS context, criteria are represented in separate map layers. The aggregation phase is eventually carried out to combine the information from the various factors and constraints (Jankowski, 1995).

The decision making process can be represented as a three-stage hierarchy of intelligence, design and choice (Figure 4) (Ascough et al., 2002). The three stages of decision making do not necessarily follow a linear path from intelligence to design and to choice (Malczewski, 1999).

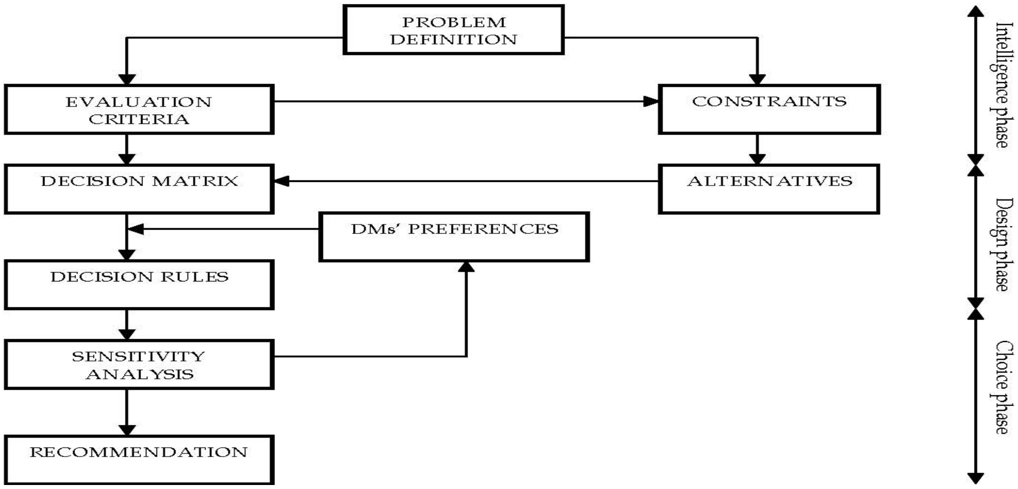

Figure 4: Decision flowchart for spatial multi-criteria analysis

4- Actualization - Case Study

4.1 Lesvos Island

Lesvos Island (Figure 6) is located to the northeast of Greece, in the Aegean Sea. Its total area is 1636 km^2, with 109,000 inhabitants. Tourism is the main economic activity in the island (apart from agriculture) and its seasonal characteristic, coupled with hot summers, are the main factors of the annual fluctuations in electricity demand (Eleftheriadou et al., 2004).

Figure 6: Map of Lesvos Island

Electricity production is based on an autonomous grid powered by a conventional diesel station, owned by the Public Power Corporation (PPC) and is located in the outskirt of Mytilene. It is fired by crude and diesel oil. Wind potential on the island is high (Figure 7) and PPC and other private and municipal investors have employed it for electricity generation, but these projects have so far managed to exploit only a small fraction of the island's full wind capacity. Other RES, geothermal and solar, have also been developed but on a very limited scale. Table 1 presents the installed electricity capacity in Lesvos in 2003.

Table 1: Installed electricity capacity in Lesvos in 2003

	Conventional power station capacity [MW]	**Wind capacity [MW]**
Lesvos	66.464	12.825

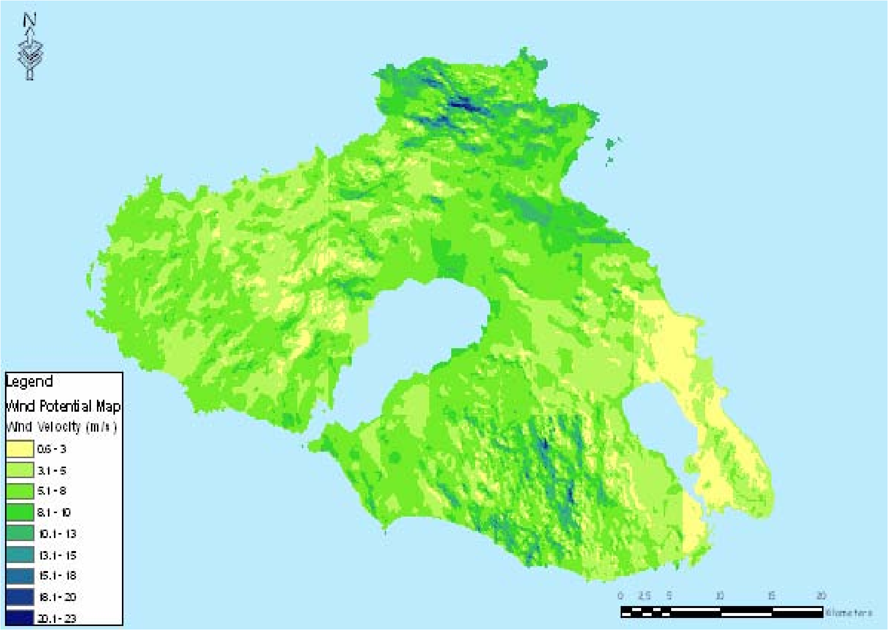

Figure 7: Wind Potential Map of Lesvos Island, Greece.

Due to the variable nature of RES, until recently, the Ministerial Decision prohibited licensing of a RES power station when the installed RES power exceeded 30% of the peak hourly demand of the previous year, to protect the stability of the electricity grid. Although this restriction has been currently abolished, it is still assumed to represent a technically feasible upper limit for the maximum RES penetration to the electricity production (Ntziachristos et al., 2005).

An assessment of suitable locations for wind power projects includes the examination of various geographic limitations and is considered essential for an effective process of energy planning. Targeting the most suitable sites will minimize controversy and improve public perception of wind power. Local, regional and national stakeholders participated in the decision-making process to identify suitable sites for placing wind turbines. Table 2 shows the relevant interest groups and Table 3 the selected criteria. Most criteria used in this case-study were based in regulations specified by central government (Hellenic Ministry of the Environment, Physical Planning and Public Works, 2007).

Table 2: Interest Groups Stakeholders)

Environmental Group – Naftilos (local non-governmental organization)
Wind farm investors – Hellenic Wind Energy Association
Regional Authorities of the North Aegean
Central Government – Representative of the Ministry of Development

Table 3: Criteria for siting wind farms in the island of Lesvos, Greece

CRITERIA Constraints	Units	Distance/ Direction	Type
Woodland	m	>500	Physical
Wind velocity	m/s	>5	Physical / Technical
Slope angles	%	<10	Physical / Technical
Archaeological sites	m	>1000	Cultural
Areas of special scientific interest (Petrified Forest)	m	>1000	Environmental
Areas of ecological value (NATURA 2000)	m	>1000	Environmental
Water bodies	m	>400	Environmental
Electricity grid	m	<10,000	Planning/Economic
Existing road infrastructure	m	<10,000	Planning/Economic

Factors			
Land owner’s income	€/year	Maximize	Economic
Return on investment	Year	Maximize	Economic
Number of jobs		Maximize	Social
Social acceptance (NIMBY phenomenon)		Maximize	Social
Visual impact	Km^2	Minimize	Social / Environmental
GHGs emissions reduce	tn CO$_2$(eq)/year	Maximize	Environmental
Noise annoyance	dB(A)	Minimize	Environmental
Installed capacity	MW	Maximize	Technical
Cohesion with local policies		Maximize	Political

Figure 8 presents the various thematic maps that represent the constraints to be taken into account to operate and locate wind farms in the island of Lesvos. This procedure results into the final constraint map that will be the primary input for the subsequent phase of the decision process, where each interest group selects a set of evaluation factors/criteria represented by GIS layers, and a multi-criteria analysis is employed.

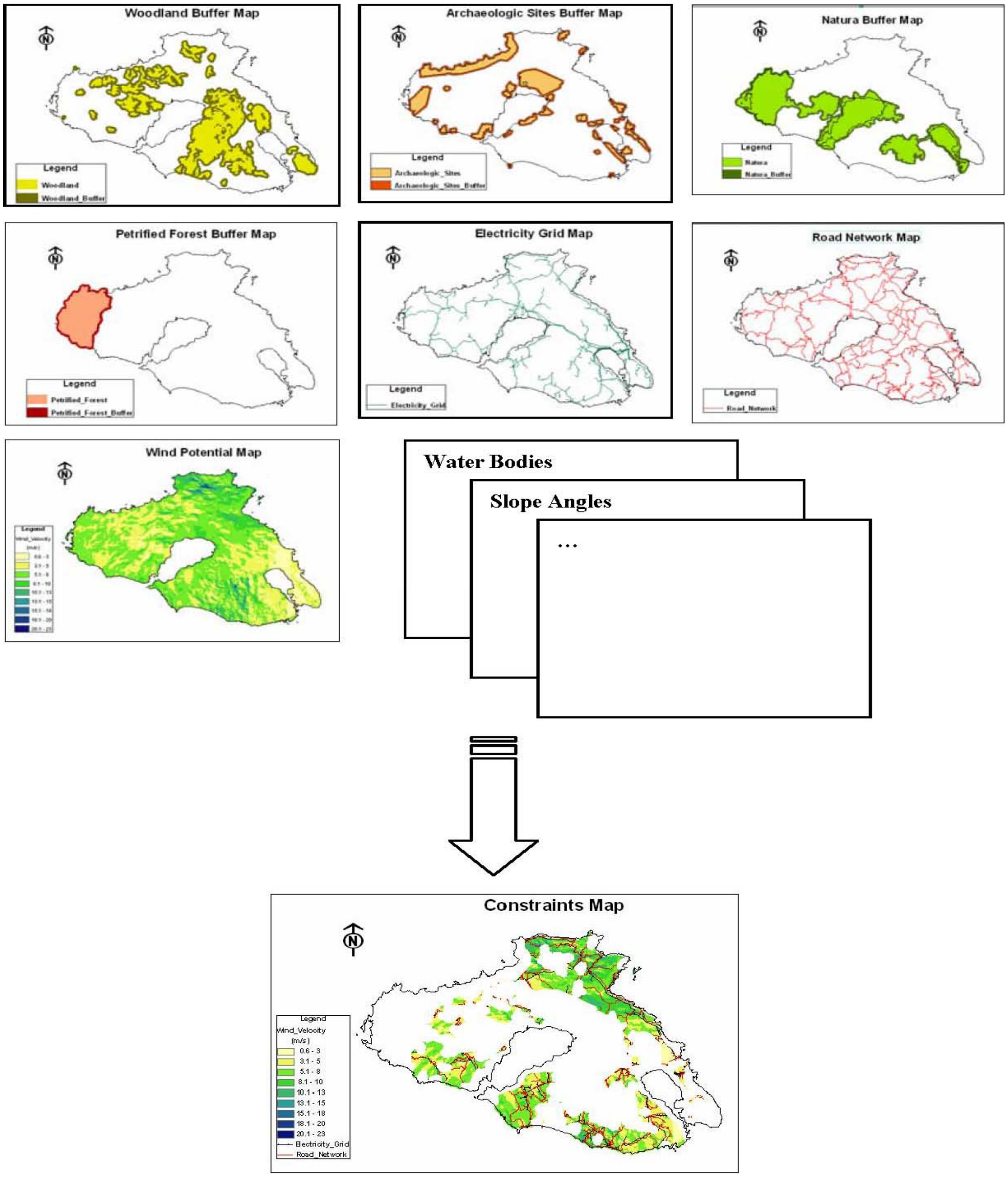

Figure 8: GIS-based assessment of the potential sites for locating wind turbines in the island of Lesvos under various constraints

In order to evaluate the importance of criteria it is necessary to assign a relative weight. This process of weighting the criteria is mainly the assessment of relative values for the importance of each criterion and usually formulates a ‘tolerance map’ for each interest group. These maps of tolerability should represent the relative ranking of preference sites for the wind turbines installations.

In the next evaluation stage the SDSS ranks potential sites according to their overall suitability for hostelling wind turbines; this process provides additional information to be utilized at the final negotiation phase.

5- Discussion

Locating optimal sites for power generation facilities is a complex task involving many environmental, economic, and social constraints and factors. With these restrictions and other considerations on land use, the problem is then to develop an appropriate Spatial Decision Support System (SDSS) to determine the most suitable sites for potential development.

Spatial decision support systems are widely used by planners in both commercial and public sector planning in order to evaluate policies and strategies, and to improve resource allocation. Flexible placement enables distributed energy generation, which allows individuals or communities to generate their own electricity, and provides a measure of protection from associated problems or threats targeting large, centralized power plants.

6- General Recommendation

As other energy facilities, DG facilities require a locating site review process to acquire the permits and approval needs for construction and operation. In this process different groups and individuals with different roles, interests and priorities are involved. SDSS is used to helps identify permissible areas to install DG facilities. Wind energy facilities are discussed to exemplify the use of the SDSS.

One of the most significant obstacles in exploiting wind power is land use restrictions. Development of wind power plants requires land with sufficient wind resources, proximity to the power grid, and compatibility with environmental and regulatory requirements.

Public resistance to wind farms is another challenge. Strong opposition to wind turbine placement is encountered in and around communities concerned with visual-, noise-, or environmental impacts. It is essential that these diverse factors should be examined so that site suitability is understood before construction, The locating site process is a multi-criteria decision problem requiring consideration of several criteria (Table 4) (Baban and Parry, 2001; Krewitt and Nitsch, 2003; Gamboa and Munda, 2007; Ma et al., 2005; Monteiro et al., 2001; Hansen, 2005; Ramachandra et al., 2005). These criteria involve bounding constraints that comprise of physical, planning, economic, environmental and cultural issues, and factors that represent a yardstick or means by which a particular option can be evaluated as more desirable than another. These constraints and factors influence the selection of potential sites. The constraints are based on the Boolean criteria (true/false), which limit the analyses to specific regions. The factors are criteria, which define some degree of suitability for all the geographic regions. They define areas or alternatives according to a continuous measure of suitability, enhancing or diminishing the importance of an alternative under consideration in the geographic space resulting after the exclusion of the areas defined by the restrictions (Hansen, 2005). Their type could be identified as (Monteiro et al., 2001):

A- Quantitative, where the attributes are a set of ranges of measurable values (e.g. distance to the electricity grid)
B- Qualitative, where the attributes are qualitative classes (e.g. types of land use)
C- Zonal, representing multiple geographical zones, each one influenced by specific local interest groups – actors (e.g. representation of local policies of the municipalities).

Table 4- Example of criteria for siting wind farms

CRITERIA Constraints	**Units**	**Distance/ Direction**	**Type**
Summits of large hills		Avoid	Physical
Woodland	m	>500	Physical
Slope angles	%	<10	Physical/Technical
Wind velocity	m/s	>5	Physical / Technical
Large settlements	m	>2000	Planning
Single dwellings	m	>500	Planning
Existing road infrastructures	m	<10,000	Planning/Economic
Electricity grid	m	<10,000	Planning/Economic
Water bodies	m	>400	Environmental
Areas of ecological value / special scientific interest	m	>1000	Environmental
Historic sites	m	>1000	Cultural

Factors			
Land owner’s income	€/year	Maximize	Economic
Return on investment	Years	Maximize	Economic
Number of jobs		Maximize	Social
Social acceptance (NIMBY phenomenon)		Maximize	Social

Visual impact	Km^2	Minimize	Social / Environmental
Forest lost	KM^2	Minimize	Environmental
GHGs emissions reduce	tn CO_2 (eq)/year	Maximize	Environmental
Noise annoyance	dB(A)	Minimize	Environmental
Installed capacity	MW	Maximize	Technical
Cohesion with local policies		Maximize	Political

Other aspects of the problem include the involvement of several actors in the decision process. Governments, utilities, private investors and local authorities become active participants in the energy planning procedure. Governments, as the major energy policy makers, are usually in favor of large scale integration of RES into local energy systems. Utilities, as the traditional energy administrators, put more interest on the reliability of the energy system and production cost. Investors are mainly interested in the profits that can be obtained by RES investments and local authorities focus on the harmonization of local needs with the proposed actions (Voivontas et al., 1998). Consequently, the objectives and interests of these actors could be in conflict. Examples of actors that could be involved on the process are:

1- DG technology developers and investors,
2- Local and national government and agencies,
3- Community groups and
4- Environmental organizations.

In the first stage of the methodology outlined here, the evaluation criteria are defined. A buffer zone in GIS software is usually required for every constraint to define the minimum distance of development sites to the selected geographic feature. The width of buffer zones varies in relation to the specific constraint. By aggregating all constraint layers, a final constraint map is calculated, which represent the areas that are restricted from development of (wind) power facilities. Furthermore, additional selective criteria are defined that are used to further explore the suitability of the remaining sites.

More specifically, under a MCDA approach, for each actor there is a set of criteria represented by geographic thematic maps. The thematic maps represent issues directly valuable by the actors. The alternative solutions, to be evaluated, are the possible locations. The aggregation phase is eventually carried out to combine the information from the various factors and constraints.

7- Conclusion

The inclusion of the RES potential of Lesvos (solar, wind, waste biomass, and geothermal) in the existing energy system is a step that will play a significant role in the overall sustainable development of the island. Even though the use of RES is costly at present, their use will minimize the emissions that the present conventional energy generation system releases to the environment.

This paper presented an outline of a Spatial Decision Support System (SDSS) to select optimal sites to install DG facilities on the island of Lesvos, Greece, where various renewable energy sources can be found. A variety of constraints and factors were identified that address environmental, energy, social, political and economic considerations. The results may help build a developmental vision for sustainable energy systems based on locally available natural resources, and facilitate a transition of national energy and environmental policies towards sustainability.

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